



PROCEEDINGS
DUNES & ESTUARIES 2005
*International conference on nature restoration
practices in European coastal habitats*

Koksijde, Belgium
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Edited by

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Preface

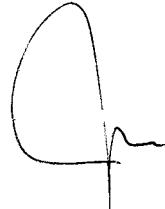
In 1993 the issuing of the decree on the protection of the coastal dunes by the Flemish Parliament meant the starting point of an intensified policy of the Flemish Regional Authority for the conservation of nature along Flanders coast.

Since then, nature conservation and restoration along the Flemish coast have known an unprecedented dynamic. This dynamic has for an important part been inspired by examples from other European countries. The Netherlands had its 'ecosystem perspective for the coastal dunes' before the concept of 'ecosystem perspective' was even known in Flanders and the wonderful work of the French Conservatoire du Littoral et des Rivages Lacustres was the edifying example for the Flemish purchase policy of coastal dunes. Ambitious Life nature-projects along the coasts of the United Kingdom and Denmark inspired similar initiatives of nature restoration in Flanders. Of course the input of Flemish scientists, volunteers in ngo's, political representatives, decision makers and civil servants of the environmental administration was and is still the main driving force behind the 'machine' that is trying to rescue the scarcely remaining natural areas along the strongly urbanised Flemish coast. But fact is that foreign examples have stimulated this Flemish enthusiasm and that the main forum in which stimulating information about nature restoration has been disseminated was provided by international conferences.

As during the last decade, the Flemish practice of planning, executing and monitoring natural restoration projects has significantly increased, the competent authority thought the time had come for the Flemish region to organise on its turn an international conference about nature restoration practices in European coastal habitats. Such an international conference was then included in the program of the Life nature-project 'FEYDRA', that was launched in 2002. The main aim of this conference, which in the meantime received the title 'Dunes & Estuaries 2005', is stimulating nature restoration along all European coasts by exchanging valuable knowledge and experience between managers and decision makers from all Atlantic European countries. The organisers chose deliberately to emphasise the practical aspects of land purchase, management and habitat restoration. The intention was to bring 'the people on the field' together and to let them learn from each other's achievements and failures.

For the practical organisation of this international conference the Coastal Union (EUCC) with its long tradition of networking and patronising international conferences and Flanders Marine Institute (VLIZ) with its vocation for collecting and disseminating data about the Flemish coast were obvious partners. The Municipality of Koksijde with its rich natural and cultural heritage offered the ideal location for the conference. The more so because the first large scale nature restoration work along our coast in 1995 (the demolition of the gigantic building of the Home Georges Theunis) as well as the largest part of the present Life nature-project 'FEYDRA', both took place on the territory of Koksijde.

We hope that the proceedings of 'Dunes & Estuaries 2005' will constitute a useful reference document that will further inspire many coastal nature managers to enhance the biodiversity and natural processes in their 'own stretch' of coast and so help to implement the European Habitat and Bird Directives. Finally we also hope that the Flemish experience will contribute to raise the awareness of other European regions and nations that it is better to preserve rather than to heal their coasts from an excessive urbanisation.



Jean-Pierre HEIRMAN

Director-general
Administration of the management of Environment,
Nature, Rural Areas and Water
Ministry of the Flemish Community

The symposium

The number of nature restoration- and development initiatives in dunes, estuaries and beaches along Europe's coasts is rising, ranging from small isolated projects to large-scale integrated programmes. The way the plans are conceived, scientifically underpinned, carried out and monitored varies enormously.

Planners, managers, scientists and the final users of these nature restoration projects all have every reason to learn from each other and exchange ideas and practical experience. To achieve this, the Nature Division of the Ministry of the Flemish Community (AMINAL-Nature Division) decided to organize a four-day international conference on the subject focussing on dunes, beaches and estuaries of the Atlantic coasts of Europe, in collaboration with the Flanders Marine Institute (VLIZ), the municipality of Koksijde and the Coastal Union (EUCC). The form and content of the programme allowing a maximal exchange of specific know-how and expertise among all those dealing with nature restoration in Atlantic, soft-substrate, coastal habitats.

This international conference fits in with the LIFE-nature project FEYDRA (Fossil Estuary of the Yzer Dunes Restoration Action) (*cf.* p.13-26, Herrier and Van Nieuwenhuyse, 2005).

Symposium sessions

- Coastal Conservation Policies
- Technical aspects of nature restoration activities and management planning
- Role of scientific research in the planning and the monitoring phase
- Tourism/recreation & nature development/restoration
- Nature restoration/development in harbours

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- Fred van der Vugte (EUCC, the Netherlands)

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Editing the proceedings of an international conference always remains a challenge and is only made possible through a joint effort of many persons. With the task completed, the Editors wish to acknowledge all those who contributed to the book, contentwise or technically. In the first place, we are indebted to the authors of the papers and reports for their efforts in providing high quality material. Secondly, we are grateful to all the referees who, on a voluntary basis took the effort to carefully examine the manuscripts submitted. Their names are listed in the former paragraph. Thirdly, the Editors acknowledge the following persons for their technical contribution: Kristin de Lichervelde, Roeland T'Jampens and Patrick De Moor.

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OPENING ADDRESSES

LIFE-Nature along European coasts

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Abstract

Since 1992, LIFE-Nature has been funding nature conservation projects across the European territory of the EC Member states. The current article briefly explains the rationale of the LIFE-Nature programme, its relationship to the implementation of the Birds and Habitats Directives and provides an overview of the types of actions funded. Given that LIFE-Nature is a limited fund compared to the needs of the Natura 2000 network, funding is only available for the most relevant actions at the European level.

Keywords: LIFE-Nature; Natura 2000; EU Birds Directive; EU Habitats Directive.

LIFE: an overview

LIFE stands for 'L'Instrument Financier pour l'Environnement', the environmental funding programme of the European Commission, DG Environment. The objective of LIFE, as defined in EC Regulation No. 1655/2000, is 'the implementation, updating and development of Community environment policy and of environmental legislation, in particular as regards the integration of the environment into other policies, and to sustainable development in the Community'.

LIFE III, the third LIFE programme covering the period 2000-2004 (Regulation (EC) No. 1655/2000), has recently been extended by two further years, until 31 December 2006 (Regulation (EC) No 1682/2004). LIFE III comprises three branches: LIFE-Nature, LIFE-Environment and LIFE-Third Countries. Between 1992 and 2004, the LIFE programme has provided co-funding of € 1.3 billion towards a total of almost 2500 projects worth € 3.6 billion.

Under LIFE III, 47% of the LIFE budget is for LIFE-Environment, 47% for LIFE-Nature and the remaining 6% to LIFE-Third Countries. For each of the three sub-programmes, separate calls for proposals, application guidelines, proposal form and selection criteria are published on an annual basis. Projects are selected on the basis of eligibility, selection and award criteria, the latter being coherence and quality, environmental benefit, socio-economic and operation context, as well as Community interest criteria. Projects are chosen purely on their quality and their potential

environmental value, and not according to national quotas. This ensures that only the very best proposals are selected for funding.

LIFE-projects are required (1) to be of Community interest by making a significant contribution to the above objectives, (2) to be carried out by technically and financially sound participants and (3) to be feasible in terms of technical proposals, timetable, budget and value for money. Priority is given to projects based on a multinational approach, when this was likely to have more effective results in terms of achievement of objectives taking into account feasibility and costs.

LIFE-Nature

Since 1992, the LIFE-Nature programme has been providing financial assistance to nature conservation projects throughout the European territory of the EU member states. The specific objective of LIFE-Nature is to contribute to the implementation of Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (the ‘Birds Directive’), Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (the ‘Habitats Directive’) and, in particular, the Natura 2000 European network established by the latter Directive.

Individual LIFE-Nature projects typically last 2-4 years. Applicants are primarily public nature conservation authorities (73%) and nature conservation NGOs (25%). Fewer projects are run by scientific institutions and other private bodies (2%).

LIFE-Nature funding is primarily used to finance actions maintaining or restoring the favourable conservation status of natural habitats and/or natural species populations. Financial assistance to projects is generally restricted to a 50% co-financing. Up to 75% of EC co-funding may however be granted to projects focussing on priority natural habitats or priority species within the meaning of Directive 92/43/EEC, or bird species considered as ‘priority for funding under LIFE-Nature’ by the ORNIS committee (of EU Member State delegates, set up pursuant to Article 16 of Directive 79/409/EEC).

The European Commission has further specified that LIFE-Nature projects should make a significant and tangible contribution to the conservation of habitats and species of European importance. Projects should focus on concrete conservation actions rather than desk studies, theoretical plans or research activities. Emergency actions, innovative actions, best-practice demonstration measures and actions based on sound scientific knowledge are considered a priority for funding. Projects should have a sustainable positive impact on the conservation status of the habitat types and species populations targeted. Obligatory compensation actions, related to the mitigation of negative impacts of plans and project on Natura 2000 sites, are not eligible for LIFE-Nature funding.

Prior information to and participation of the local populations and strategic stakeholders is centrally important for a successful project implementation. The promotion of partnership, experience-sharing and dissemination of best practices are thus often an integral part of each project. Lessons learned during the project implementation should

be disseminated through the best available means, including internet-based communication and publicly available layman's reports.

Preparing the Natura 2000 network

Since its start, LIFE-Nature has been designed as a support fund for the Birds and Habitats Directives (European Commission, 2003a).

In terms of providing assistance for the preparation of Natura 2000, LIFE-Nature has co-financed national or regional habitats and species inventories for Natura 2000 in Ireland, Spain, Italy, Greece and Portugal. Support has also been provided for the elaboration of legal and management planning guidelines, notably in Greece, France and the United Kingdom. A project in Germany developed guidelines for a national monitoring scheme.

In addition to the above direct support, LIFE-Nature has also indirectly fostered the set-up of Natura 2000: since 1996, while Member States have been under increasing pressure from the European Commission to set-up their Natura 2000 network, this was paralleled, under LIFE-Nature, by a strengthened conditionality for prior Natura 2000 site designation of the project area. Thus, in order to be eligible for LIFE-Nature funding, any site-related project after 1995 required a prior Natura 2000 designation. The condition for prior designation has been a strong incentive for the designation of additional Natura 2000 sites, particularly in those Member States and/or regions where designation has initially been limited to residual areas of the highest conservation value (which generally do not require any LIFE-Nature support).

Types of actions financed under LIFE-Nature

LIFE-Nature funding concentrates on those Natura 2000 sites that are not yet in an optimal state of conservation. Projects contribute, either directly or indirectly, to an improvement of the conservation status of the species and habitats of European importance. For all projects financed, detailed information is available in the electronic LIFE database: <http://europa.eu.int/comm/environment/life/project/Projects/index.cfm>

Rather than repeating what can be found in the detailed database information, I will only mention here those types of actions that have most often been financed on coastal sites:

Development of site management plans

Almost 60% of all site-related LIFE-Nature projects have involved a planning procedure that can be called a management plan in the widest sense. In addition to the detailed technical plans for site restoration and management prescriptions of the recurring site management, the preparation of management plans typically entails actions such as species and habitats inventories and mapping, preliminary socio-economic assessments and public consultation procedures.

However, management plan preparation actions are only eligible for LIFE-Nature funding, as long as they are part of a bigger project that is primarily focussing on concrete measures. The eligibility of management planning costs is also conditional to an appropriate approval of the plan by the relevant authority, at the latest by project end.

Land purchase and/or long-term appropriation of land use rights

Where land ownership structure and use rights on coastal Natura 2000 sites are contrary to the long-term conservation objectives of these sites, land purchase is an indispensable tool to dedicate the land use durably to habitats and species conservation. This is notably the case if intensive agricultural land uses are to be discontinued, in order to restore species-rich natural habitats, such as coastal salt marshes, heath lands, etc. More than 25% of the LIFE-Nature funding has been used for purchasing land.

Because of the political sensitivity that a transfer of land title using Community financial support entails, the Commission has defined a set of conditions, under which land purchase can be eligible. These include restrictions regarding the purchase of land outside Natura 2000 areas, the prohibition of the purchase of land already under public ownership, and the prohibition of the purchase of land not required for active restoration/management measures. Land purchase under LIFE-Nature must thus clearly be justified by the needs for an active and positive site management, which goes beyond the status quo of conservation status. Moreover, there are specific conditions regarding the purchase price and the final ownership of the land. For each land section purchased, a legal clause has to be inserted either in the legal act or in the public land register, specifying the exclusive nature conservation purpose of the purchase.

Hydrological engineering works

On coastal sites of the Member States bordering the Atlantic, the North and the Baltic Sea LIFE-Nature has often been used for the co-financing of large-scale hydrological restoration projects (together with land purchase). Typical actions include the removal or the relocation of man-made structures and dykes along shores and river mouths, the dredging of silted water bodies and the construction of dams and other hydrological infrastructure to increase the water table in dune wetlands, to restore salt marshes, etc. Project costs do not only cover the actual work, but may also include technical planning, permit procedures, and other preparatory steps.

Restoration and maintenance of open habitat types

The **restoration** of open habitat types is one of the most recurring themes in coastal LIFE-Nature projects targeting coastal dunes, meadows and heaths. A variety of techniques, both manual and mechanical, are used to restore open habitat types and prepare their future maintenance management. These include the clearance of overgrowth and scrubs, the removal of non-native forestry plantations and the initial mowing or flailing of abandoned grassland sites. In southern Europe, LIFE-Nature has frequently been financing the removal of invasive plant species on coastal sites (European Commission, 2004a).

Investments in maintenance equipment and infrastructure for the long-term management of open habitat types are also frequently funded under LIFE-Nature. Where mowing or turf cutting are prescribed, this may primarily involve the purchase of machinery. If the follow-up management is done through grazing, investment for the set-up of cattle fences, troughs, shelters, cattle stops and corrals are most often considered for LIFE-Nature funding. The purchase of grazing animals may also be considered eligible, provided that (1) the sites to be grazed are currently not eligible for Community funding under the Common Agricultural Policy, (2) the long-term maintenance of the animals is financially secured and (3) there is a long term guarantee for maintaining the grazing animals on the site after the project period.

Unless carried out on an experimental scale, and for demonstration purposes only, LIFE-Nature does not finance recurring **maintenance** actions such as grazing, mowing, burning etc., for two reasons. Firstly, the annual maintenance management of Natura 2000 sites often benefits from agri-environmental funding support under the Rural Development Regulation. LIFE-Nature is relatively limited in financial terms, and should not finance actions that could also be financed through other, better-endowed Community programmes. Secondly, LIFE-Nature projects have a limited duration, typically up to 4 or 5 years. It would be unsustainable to finance maintenance work during a limited period of time, if the follow-up financing for annual compensation-for-losses or active-management-payments after the project end would not be secured.

On the site demonstration level, LIFE-Nature has provided many good examples on how nature conservation can be usefully combined with recurring agricultural land uses, and has substantially contributed to the promotion and adaptation of existing agri-environmental schemes to the purposes of nature development (European Commission, 2003b).

Visitor control and guidance, public awareness for Natura 2000

Infrastructure cost for the guidance of visitors through Natura 2000 sites are eligible for LIFE-Nature funding, provided that the infrastructure is primarily aimed at mitigating the negative impact of an uncontrolled access to the site. This may include the financing of board-walks and paths through the Natura 2000 site, fences and barriers, information panels etc. Large-scale infrastructure aimed at recreational or tourism purposes, including the set-up of large visitor centres, are not eligible for LIFE-Nature funding.

LIFE-Nature projects are required to inform the public and relevant stakeholders about the objectives of the projects, and their role for the implementation of the Natura 2000 network. Good-practice guidelines on how to communicate Natura 2000 in LIFE projects have recently been published (European Commission, 2004b).

Monitoring and dissemination of project results

The monitoring of the impact of the concrete conservation measures is an obligatory duty for each LIFE-Nature project. Ideally, this entails an inventory of the situation before and after the work, and control sites to be monitored simultaneously with non-

intervention sites. The findings of the monitoring study should, as far as possible, be reported to the public in a layman's report, which is to be published at the end of the project on the internet. International networking and exchange of know-how amongst LIFE-nature projects is also strongly encouraged by the Commission.

Conclusions

On many coastal sites, LIFE-Nature has contributed to the set-up and implementation of Natura 2000, through preparatory inventories for site designation, management planning, land purchase, concrete site restoration, investment in the long-term management and dissemination of best-practice management measures. On the level of individual sites, the project based approach generates management capacity and know-how that remains available after the project. LIFE contributes to the creation of new partnership structures, both at the site level and through the exchange of knowledge at the supra-site level.

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EU biodiversity policy context for the conservation of estuaries and dunes

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Abstract

Europe's estuaries and sand dune systems have suffered serious losses and degradation over the past century due to land and water use changes and coastal development pressures. EU biodiversity policy aims to halt the loss of these and other habitats of European conservation concern by 2010. The main legal instrument to achieve this is Council Directive 92/43/EEC on the conservation of natural habitat and of wild fauna and flora, commonly known as the Habitats Directive. This identifies estuaries and different types of sand dunes as habitat types of Community importance. The designation and management of Special Areas of Conservation is the key mechanism under the directive to achieve the favourable conservation status of these habitat types. The focus of action has initially been on establishing this network of sites, using commonly agreed habitat definitions and site selection criteria, with a view to ensuring sufficient representation of estuaries and sand dunes in the NATURA 2000 network. This process is advanced and lists of sites for different Biogeographical Regions covered by the Habitats Directive are being established. Increasingly, the focus is on putting in place effective management and monitoring systems. There is already a considerable amount of experience on management and restoration of sand dunes and estuaries in the EU, especially from projects supported under the LIFE programme. The European Commission has proposed that EU rural and regional development funds be used to co-finance management measures for the NATURA 2000 network. New monitoring arrangements should also provide a unified source of information at the EU scale on estuaries and sand dunes. There will be a need to address other threats to these habitat types in Europe, especially the predicted negative effects of climate change, in the context of the wider debate on EU biodiversity policy.

Keywords: EU biodiversity policy; Habitats Directive; NATURA 2000; Site management and monitoring.

Pressures on sand dunes and estuaries in the EU

Sand dunes and estuaries have been under serious pressure within the European Union for many decades. It is estimated that the area of coastal dune habitats has declined by 40% since 1900, with one-third being lost since 1977 (EUCC, 1993). This loss and degradation can be largely attributed to a wide range of human impacts. Activities such as recreational developments, construction, agricultural development and afforestation (Doody, 1991) have had serious negative effects on dunes in different parts of Europe.

Not only have these activities resulted in the loss of the habitat but they have also disrupted the natural dune processes of surviving areas.

Likewise, there has been similar extensive loss and degradation of Europe's estuaries, concerning all of the coastal Member States that host this habitat type. For example it has been estimated that 85% of British estuaries have been affected resulting in the removal of 25% of the intertidal areas of estuaries through land claim (Davidson *et al.*, 1991), especially linked to urban and transport infrastructures. As many estuaries are important centres of urbanisation there have also been substantial pollution and eutrophication impacts as well as pressures from recreational and leisure developments.

This loss and degradation of sand dunes and estuaries in Europe not only has implications for biodiversity but also for the vital goods and services that these habitats provide to people. For example, sand dunes are part of the natural sea defence system of many coastlines and estuaries act as key nursery grounds for fish species.

The EU biodiversity policy context

There is increased recognition of the need to take action to halt the loss and degradation of biodiversity, including habitats of EU conservation concern such as dunes and estuaries. This is reflected in the declaration by EU Heads of State and Government at the Göteborg European Council of June 2001, which set the ambitious target to halt the decline of biodiversity by 2010.

This policy objective is fully reflected in the sixth environment action programme of the European Community, titled 'Environment 2010: Our future, our choice', which covers the period 2001-2010 (European Communities, 2002). Nature and biodiversity is highlighted as one of the four environmental fields for urgent action in this programme.

A variety of approaches, relevant to the conservation of dunes and estuaries, are identified as mechanisms to deliver this biodiversity policy goal. These include the implementation of integrated coastal zone management. The need for broader integration of nature biodiversity objectives into policy sectors such as agriculture, fisheries and transport, is highlighted. Legal tools such as those relating to strategic and project environmental impact assessment, environmental liability and the water framework directive, all of which are highly relevant to coastal conservation, also need to be fully utilized.

However, the cornerstone of the EU policy to protect habitats such as dunes and estuaries is the implementation of Council Directive 79/409/EEC on the conservation of wild birds (commonly referred to as the 'Birds Directive') and Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora ('the Habitats Directive'). These directives provide for targeted action to conserve these habitats, especially through the establishment and management of the Natura 2000 network.

The European Commission is at present reviewing the EC Biodiversity Strategy (European Communities, 1998) and is preparing a Communication on this subject which aims to clarify EU priorities for achievement of the 2010 commitments and towards the longer-term restoration of habitats and natural systems.

The central role of the Habitats Directive and Natura 2000

Whereas Special Protection Areas (SPAs) designated under the Birds Directive provide protection for dunes and estuaries, especially for sites that are wetlands of international importance for migratory waterbirds, the main targeted instrument for the conservation of these habitats is the Habitats Directive.

This sets out the overall objective of achieving favourable conservation status for the habitat type 'estuaries' and sand dune habitat types, listed in Annex I of the directive. Favourable conservation status means that the natural range and area of the habitat type is stable or increasing, that the specific structures and functions necessary for its long term maintenance are likely to continue to exist and that the conservation of its typical species is favourable.

The designation of Special Areas of Conservation (SACs) provides a legal mechanism for the maintenance, and where appropriate, restoration of these habitat types at a favourable conservation status. Together with SPAs under the Birds Directive, the SACs form the Natura 2000 network.

Different types of sand dunes are well represented in Annex I of the Habitats Directive (*cf.* Houston, 2005). Several dune habitat types such as fixed coastal dunes with herbaceous vegetation ('grey dunes'), have priority status under the directive which provides additional safeguards from potentially damaging development for SACs hosting these habitat types.

Establishing the NATURA 2000 network

Establishment of the network of sites to be protected under the Habitats Directive has proven to be a more difficult and longer task than originally envisaged by the timeframes set out in the directive. Since the adoption of the directive in 1992 the European Commission has worked closely with Member States to achieve this objective, especially within the framework of the Habitats Committee and its scientific working group. The European Topic Centre for Biodiversity of the European Environment Agency has also played a key role in the process. Experts from non governmental organisations, under the auspices of two umbrella structures called the 'European Habitats Forum' and the 'Habitats Users Forums' have also played an important role.

The need for Member States to ensure that the process of selecting and delimiting sites under the Habitats Directive is exclusively science based has been confirmed by jurisprudence of the EU Court of Justice in an important test case relating to the Severn Estuary in the United Kingdom (European Communities, 2001). This was in line with an

earlier similar ruling of the Court of Justice in a test case concerning the Lappel Bank in the Medway Estuary, the United Kingdom, which confirmed that economic requirements could not be taken into account when selecting the sites and defining the boundaries of SPAs under the Birds Directive (European Communities, 1996).

In order to ensure a common approach to the selection of sites for Annex I habitat types the Commission has prepared an interpretation manual of European Union habitats (European Commission, 2003). This provides a definition for each habitat type of Annex I, lists characteristic animal and plant species and takes account of the corresponding categories in other classification systems.

For the habitat type 'estuaries' there have been further discussions with the Habitats Committee in relation to the definition, with the European Commission providing additional guidance to aid selection of sites hosting this habitat type. This has emphasised the need for an inclusive approach in identifying estuarine sites because of the complex and dynamic nature of this habitat type. The selection process should take account not only of the constituent biotopes but also the relevant geomorphological features, dynamic ecological issues and hydrological processes. As shipping lanes and other sub-littoral channels play a role in the hydrological functioning of estuaries they should be included in the sites. The only justification for excluding part of a site is where irreversible changes to the nature of the estuary, such as land claims, have resulted in serious loss of ecological value of this component of the estuary.

The Habitat Directive requires each Member State to contribute to the creation of Natura 2000 in proportion to the representation within its territory of the dune and estuaries habitat types. In proposing the sites Member States have been required to apply the site selection criteria given in Annex III of the directive. These are elaborated in the Natura 2000 data format which also requires Member States to provide additional relevant information about the site (European Communities, 1997). Together with other scientific reference information this data has provided the basis for subsequent evaluations of the sufficiency of these proposals, carried out within the framework of seminars for each of the Biogeographical Regions covered by the directive. This exercise has involved the European Commission, Member States, the European topic Centre for Biodiversity, NGOs, and independent experts.

For the 15 countries that were EU Member States prior to May 2004 the process of selecting the sites is almost complete. By July 2005 lists of sites had been established for five of the six biographical regions concerned, with that for the Mediterranean Region in an advanced stage of finalisation. There are still a small number of gaps in the coverage of estuaries and dunes for different countries. For example, the Commission Decision on the list of sites of Community importance (SCIs) for the Atlantic Biogeographical Region of December 2004 indicates that the proposals of France, Germany, Portugal and the United Kingdom for 'estuaries' are still not complete. Details about each of the relevant Commission Decisions are available on the web site of the European Commission at <http://europa.eu.int/comm/environment/nature/home.htm>.

For the 10 new countries that acceded to the European Union in May 2004 the process of selecting Natura 2000 sites is already underway and substantial proposals have already been made with the first biogeographic seminar having taken place for Alpine Region in May 2004 and further seminars being planned for the coming months.

In total, about 260 sites contain ‘estuaries’, half of which are located in the Atlantic Biogeographical Region. There is very large variation in the area and proportion of this habitat type present in the different sites. Likewise, a large number of the sites contain dune habitat types. More than 800 sites contain at least one of the habitat types corresponding to ‘sea dunes of the Atlantic, North Sea and Baltic’ with half of these sites hosting the priority habitat type ‘grey dunes’. The majority of the areas are multiple dune habitat interest sites, which has implications for their future management.

Management of the Natura 2000 sites

As the process of selecting the Natura 2000 sites nears completion the focus is increasingly shifting to the protection, management and monitoring of the sites in the network. This is the responsibility of the Member States. The establishment of the lists of Sites of Community importance (SCIs) has already provided a high level of protection to safeguard sites hosting sand dunes and estuaries from potentially damaging developments. The preventative and procedural safeguards of Article 6 of the directive must be applied to any plan or project that may significantly affect the integrity of these sites. Member States now need to finalise the establishment of the network by designating the SCIs as SACs which gives legal effect to the proactive conservation measures outlined in Article 6(1) of the Habitats Directive.

The designation of Natura 2000 areas is not intended as a block on human activities in and around the sites. However, given that many of the sites occur in areas where there are potentially conflicting patterns of land and water uses there is a need for management planning to ensure that socio-economic activities are sustainable and not damaging to the conservation values for which the areas were selected. Although they may not always be necessary, management plans, which take into account the specific characteristics of the site and all foreseen activities, are identified in the Habitats Directive as a tool for the conservation or restoration of the sites. They also provide a vehicle for consultation and cooperation with economic groups present on the site. As such they have potential as a confidence building measure for those engaged in socio-economic activities in and around Natura 2000 areas.

There is already considerable experience through LIFE Nature projects in carrying out management and restoration actions for sand dunes (*cf.* Houston, 2005). There have also been strategically important projects involving the management of estuaries, such as the UK Marine SACs project (<http://www.ukmarinesac.org.uk>). This helped create broad partnerships and has provided valuable guidance on establishing management schemes for coastal Natura 2000 sites in the United Kingdom. It will be necessary to share this experience and expertise for the conservation of dunes and estuaries across the Natura 2000 network.

One particular challenge will be to work closely with the relevant authorities and users in the management and sustainable use of estuaries. As many of Europe's major ports are located in estuaries that now form part of the Natura 2000 network there will be a need to develop partnerships that work to ensure that activities and operations are carried out in ways that are not detrimental to the ecological integrity of these sites. There are already several important initiatives such as that under the auspices of the European Sea Ports Organisation (ESPO) and the Paralia Nature project, the latter co-ordinated by the Institute for Infrastructure, Environment and Innovation in Belgium (<http://www.imiparalianature.org/>). It will be necessary to build on these initiatives to strengthen dialogue, sharing of good practice and provision of relevant guidance for the management of estuaries in Natura 2000.

It has to be accepted that there will be particular circumstances where developments that are damaging to Natura 2000 sites hosting estuaries and dunes are allowed to take place once these have satisfied each of the substantive procedural steps for assessing plans and projects, defined in Article 6 (3) and (4) of the Habitats Directive. In such cases there will be a need for adequate compensatory measures to offset any loss of value of the affected site. This could involve restoration activities in the site or elsewhere. The European Commission has provided interpretative and methodological guidance on how to deal with proposed developments that affect Natura 2000 areas (European Commission, 2000; 2001). It plans to update this with additional guidance on the subject of compensatory measures.

There is also an ongoing debate on the future financing of the management of Natura 2000 sites. In this regard the European Commission has proposed that EU rural and regional development funds be used to co-finance management measures for the Natura 2000 network (European Communities, 2004).

Monitoring of sand dunes and estuaries

In order to meet the requirements of Articles 11 and 17 of the Habitats Directive Member States have to put in place a system of monitoring, assessment and reporting of the conservation status of estuaries and sand dunes habitat types listed of Annex I. For the next reporting period on implementation of the directive, covering 2001-2006, Member States will be required to carry out an assessment of the conservation status of these and other habitat types as well as species of EU conservation interest. Common approaches are being developed for these assessments. A framework for this has been agreed with the Habitats Committee in April 2005.

Much of the information will need to come from sites in the Natura 2000 network but the assessments of favourable conservation status will not be limited to the sites. A common matrix has been developed for assessing the conservation status which will have to be defined for different habitats on a case by case basis. Member States will need to use reference values and trends for the range and area of each habitat type. Other parameters to be considered will be the structure and functions of the habitat. The future prospects for its long term conservation will also require assessment. For Member States whose

territory includes more than one biogeographical region the assessments will need to be carried out for each region.

Member States will need to develop the necessary monitoring systems to enable these assessments to be carried out. As this is a highly technical matter experts, including those concerned with coastal habitats should have an important role to play in supporting the assessments made by the authorities in the different Member States. The information from the national assessments will then be compiled at EU level for the different habitat types and species within the framework of each biogeographical region.

Conclusion

Europe's sand dunes and estuaries have already significantly benefited from the legal protection of the Habitats Directive and Natura 2000, which has been the main driver for their conservation over the past 13 years. As the focus shifts from the selection of sites to their management, and where necessary restoration, there will be a need to put in place effective management and monitoring systems.

The sharing of experience and expertise among scientists, conservation managers and administrators will be essential to underpin this process with a view to ensuring the future success of the Natura 2000 network. Consideration will also increasingly have to be given to the implications of impending climate change on the conservation and management of sand dunes and estuaries with a view to developing appropriate mitigation and adaptive strategies in the future to ensure the overall integrity of the Natura 2000 network in dynamic and changing landscapes and seascapes.

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The Flemish coast: life is beautiful!

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Abstract

Along the quite short Belgian coastline (65km), six Natura 2000 sites have been delimited on land and one at sea. This probably explains why from the 20 Life nature projects that up to now have been or are being executed in the Flemish region no less than four are focused on coastal areas. This paper offers a review of those four coastal Life nature projects and their achievements. The Life nature project 'ICCI' (1997-2001) aimed at re-establishing ecological relations between sea and land, between sandy beaches, mudflats, salt marshes and coastal dunes and between coastal dunes and polders from De Panne to Nieuwpoort and stimulating the policy of purchase of coastal dunes by the Flemish region. Its successor, 'FEYDRA' (2002-2005), has as main goal, the restoration of annex 2 - habitats in several coastal dune sites in Koksijde and Nieuwpoort. 'Salt meadows at the Flemish coast' (1999-2003) and its sequel, 'The Uitkerkse Polder' (2003-2008), strive for the maintenance or restoration of polder meadows with a rich topography by land purchase and an appropriate nature management. The Life nature projects 'ICCI' and 'Salt meadows at the Flemish coast' have achieved complete realisation of their objectives. Both other Life projects that are mentioned above are still being executed, but the prospects look good. Essential elements in this success have been a thorough scientific preparation and a sustained action for public support. The Life nature projects in the coastal zone have not only accomplished their initial program, but also had a favourable influence on the conservation policy of the Flemish government for the coastal zone; prospected the possibilities for a federal conservation policy in the marine environment and stimulated dialogue between conservationists on the one hand, local authorities and drinking water supply companies on the other hand.

Keywords: Flemish coast; Sea; Land; LIFE-nature projects.

Natura 2000 at the Flemish or Belgian coast

In the federal state structure of Belgium the competence for environmental matters, including nature conservation, is bestowed to the Belgian federal authority in the territorial sea beneath the low water line and to the Flemish regional authority on land (including the tidal beaches) above the low water line. At the Belgian coast, several Natura 2000 sites have been delimited at sea as well as on land. In execution of the 'European Birds Directive' 49/709/EEC, three Special Protection Areas, 'the Western coast', 'the Poldercomplex' and 'the Zwin', have been designated by Order of the Flemish government of 17 October 1988, revised by the Orders of 20 September 1996, 23 June 1998 and 17 July 2000 (Fig. 1a).

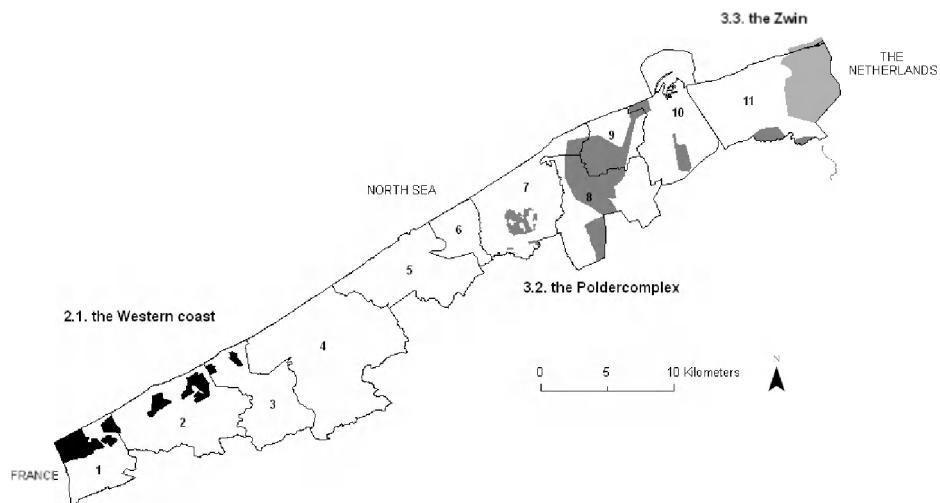


Fig. 1a. Situation map of the special protection areas SPA's on land (1=De Panne, 2=Koksijde, 3=Nieuwpoort, 4=Middelkerke, 5=Oostende, 6=Bredene, 7=De Haan, 8=Zuienkerke, 9=Blankenberge, 10=Zeebrugge, 11=Knokke-Heist).

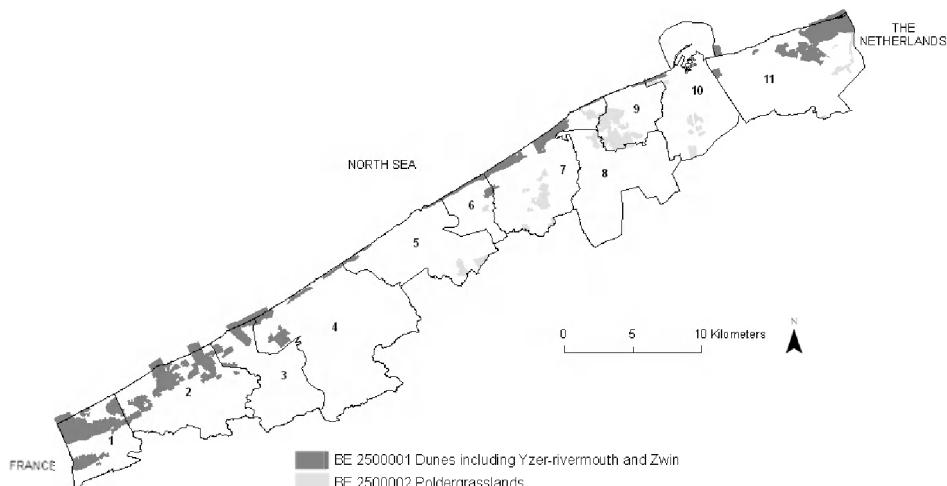


Fig. 1b. Situation map of sites of community importance SCI's on land (1=De Panne, 2=Koksijde, 3=Nieuwpoort, 4=Middelkerke, 5=Oostende, 6=Bredene, 7=De Haan, 8=Zuienkerke, 9=Blankenberge, 10=Zeebrugge, 11=Knokke-Heist).

By Order of the Flemish government of 4 February 2005 also part of the out-port of Zeebrugge and the Bay of Heist were temporarily designated as the Special Protection Area 'Breeding grounds of Coastal Birds in Zeebrugge and Heist'.

In the framework of the 'European Habitat Directive' 92/43/EEC, two Sites of Community Interest, 'BE2500001 - Dunes including Yzer-rivermouth and Zwin' and 'BE2500002 - Poldergrasslands', have been proposed by decision of the Flemish government of 14 February 1996, revised by the Order of the Flemish government of 24 May 2002 (Fig. 1b).

Also a part of the shallows in the Belgian territorial waters were proposed as Site of Community Importance in January 1996 under the name 'BEMNZ0001: Trapegeer – Stroombank' (Fig. 1c).

It is then obvious that 'L'Instrument Financier Européen pour l'Environnement', abbreviated as Life, more precisely Life nature, would play an important role as a tool for the practical implementation of the Natura 2000 – network at the Belgian coast.

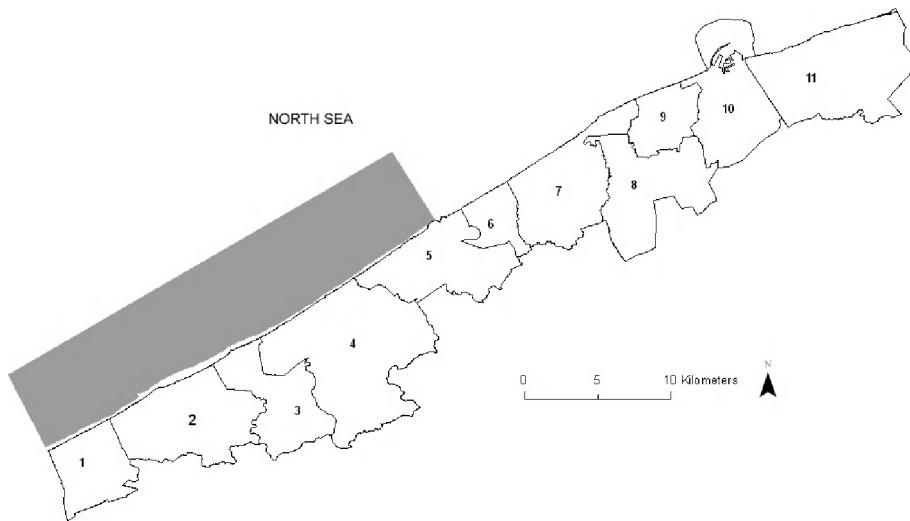


Fig. 1c. Situation map of sites of community importance SCI's at sea (1=De Panne, 2=Koksijde, 3=Nieuwpoort, 4=Middelkerke, 5=Oostende, 6=Bredene, 7=De Haan, 8=Zuienkerke, 9=Blankenberge, 10=Zeebrugge, 11=Knokke-Heist).

So far, four Life nature projects have been granted and have been or are being executed in the coastal region of Flanders:

- Integral Coastal Conservation Initiative, abbreviated as ICCI;
- Fossil Estuary of the Yzer Dunes Restoration Action, abbreviated as FEYDRA;
- Salt meadows at the Flemish coast;
- The Uitkerkse Polder.

This paper offers a review of these four projects, their concrete results and further achievements.

Integral Coastal Conservation Initiative (ICCI)

The ICCI – Life nature project (Fig. 2) was conceived in 1996 by the Nature Division of the Ministry of the Flemish Community, the federal government service Management Unit Mathematical Model of the North Sea and the Scheldt Estuary (abbreviated as MUMM) and the non-governmental organisations Belgian Nature and Birds Reserves (now Natuurpunt) and World Wide Fund for Nature. It was carried out from January 1997 to December 2001. Its theme was an integral approach for the conservation of the coastal ecosystem, involving its marine as well as its terrestrial component. Hence its name ‘Integral Coastal Conservation Initiative’ (not to be confounded with integrated coastal zone management). The Belgian coast features a quite remarkable sequence of sandbanks in the shallow sea, sandy beaches, mudflats, salt marshes, sand dunes, fossil sand dunes and polders. However, transitions between these different components are often artificially interrupted by dikes, buildings and other infrastructure. ICCI aimed at the restoration of natural transitions between sea and land, beaches or salt marshes and dunes, dunes and polders. The global budget of ICCI was € 2,499,172. The total budget that was invested by the European Union was € 1,124,628 (45%). The Nature Division of the Ministry of the Flemish Community invested € 901,899 (36.09%) the federal government service Management Unit Mathematical Model of the North Sea and the Scheldt Estuary (abbreviated as MUMM) invested € 239,502 (9.58%). The non-governmental organisation Belgian Nature and Birds Reserves (now Natuurpunt) invested € 177,244 (7.09%) and the non-governmental organisation World Wide Fund for Nature invested € 55,900 (2.24%).

Actions concerning the marine environment undertaken by the MUMM were:

- a quantification of the value and vulnerability of the marine environment as well as an assessment of the impact of human activities conflicting with nature conservation, as a basis for the limits to be imposed on such activities;
- an investigation of the possibilities of protecting a marine area by surveillance and an investigation of the technical, social and legal features of a marine surveillance scheme and carrying out a surveillance scheme on a trial basis;
- an effective wardening-scheme to reduce and prevent illegal fishing practices and oil-pollution;
- an inventory of shipwrecks in the Belgian territorial sea and
- a stranding manual for stranded marine mammals and birds and a vulgarising leaflet about the same subject.

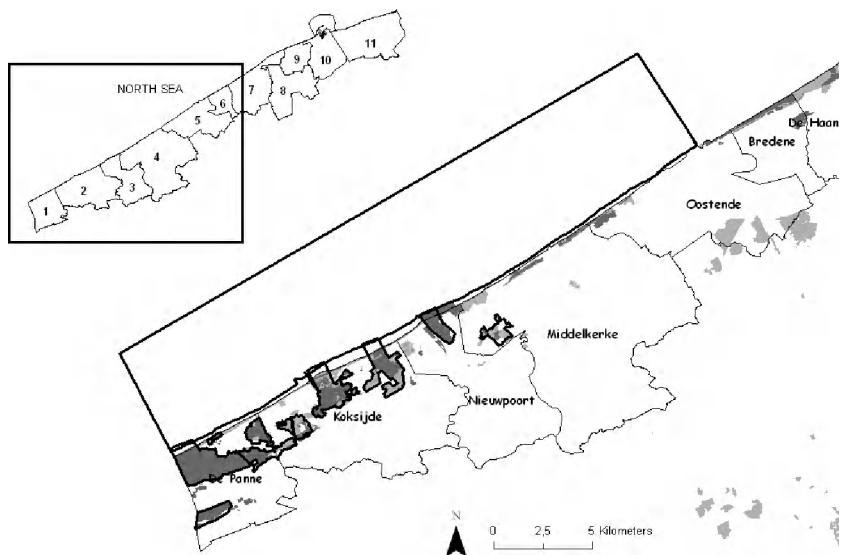


Fig. 2. Project site of the ICCI – Life nature project (dark grey: managed dune area; grey: nature site in the frame of the spatial planning legislation).

The scientific inspiration for ICCI's actions on land was provided by the practical guidelines from the Ecosystem Perspective for the Flemish coast, the management plans for the Flemish regional Nature Reserves of 'De Westhoek' and 'De Houtsaegerduinen' at De Panne and, last but not least, the Nature Restoration Plan for the 'Yzer-rivermouth' at Nieuwpoort. All these scientific documents were previously elaborated between 1994 and 1996 by the University of Ghent and the Institute of Nature Conservation, on commission from the Nature Division of the Ministry of the Flemish Community.

The main actions of ICCI on land were:

- the restoration of mudflats, salt marshes and sand dunes along the eastern bank of the 'Yzer-rivermouth' at Nieuwpoort by the complete demolition and removal of a derelict naval basis;
- the restoration of wet dune slacks and 'grey dunes' by the removal of 30ha of scrub and exotic tree-plantations, followed by the introduction of grazing by large herbivores in the Flemish Regional Nature Reserves 'De Westhoek', 'De Houtsaegerduinen' and 'Ter Yde';
- the excavations of pools and ponds in the above-mentioned nature reserves as reproduction habitat for amphibians, more precisely the Crested Newt (*Triturus cristatus*) and the Natterjack toad (*Bufo calamita*);
- the scientific monitoring of the response of flora, vegetation, fauna and physical environment to the above-mentioned restoration and management measures;

- the purchase of at least 20ha of land in the dunes or dune-polder-transition zone in order to be designated and managed as nature reserves;
- the elaboration of a scientifically based management plan for the Flemish regional Nature Reserve of 'Hannecartbos' at Oostduinkerke (municipality of Koksijde) in the framework of an area-perspective for the Ter Yde dunes;
- the redaction and publishing of a brochure to increase public awareness and support for nature conservation along the western part of the Flemish coast;
- a debate between drinking water production companies and conservationists about groundwater extraction and nature management in the coastal dunes and a political debate about the purchase of coastal dunes for conservation purposes.

All these actions were carried out with a success that surpassed the original expectations. However, the merit of ICCI is, even more than the remarkable material output of its actions, the significant impulse this European co-funded project has given to the policy of dune purchase and further nature restoration actions at the Flemish coast by the Flemish regional authority. We refer about that to the contributions in the present conference about the purchase of dunes (Herrier *et al.*, 2005), the removal of scrub and trees (Leten *et al.*, 2005) and the restoring of dunes and marshes by removing buildings and soils (Herrier *et al.*, 2005). The management plan for the nature reserve 'Hannecartbos' that has been drawn in the frame of ICCI also offered the basis for a following Life nature project: FEYDRA.

Fossil Estuary of the Yzer Dunes Restoration Action (FEYDRA)

To enhance the practical and financial feasibility of the execution of the very ambitious management plan for the Flemish regional Nature Reserve 'Hannecartbos', the Nature Division elaborated in 2001 a second Life nature project (Fig. 3).

As then the derelict water treatment plant of Nieuwpoort, that stood in a relict of the same fossil beach plain as the one in which 'Hannecartbos' is situated, was acquired by the Nature Division, also the planned removal of that plant was included in the project. The projects name, Fossil Estuary of the Yzer Dunes Restoration Action, refers to the estuarine origin of the three 'coastal dune' sites in which actions had to be undertaken: the neighbouring Flemish regional nature reserves 'Hannecartbos' and 'Ter Yde' at Oostduinkerke and the regional nature domain 'Groenendijk' at Nieuwpoort. Until late medieval time the area wherein the three sites mentioned above are situated constituted the western branch of the then estuary of the river Yzer. The European Commission gave its approval and FEYDRA started in 2002 and is supposed to be completed in December 2005. The global budget of FEYDRA is € 1,309,521. As the project site is completely included in the site of community importance 'BE2500001 - Dunes including the Yzer rivermouth and Zwin', the principal objective of FEYDRA is the restoration of threatened habitats and species of the annex 1, 2 and 4 of the European Habitat Directive that are typical for the coastal dunes.



Fig. 3. Project site of the FEYDRA – Life nature project (dark grey: managed dune area; grey: nature site in the frame of the spatial planning legislation).

Main actions of FEYDRA are:

- the drawing of a scientifically based management plan for the Flemish regional Nature Reserve of ‘Ter Yde’;
- the removal of 4ha of scrub to restore a wet dune slack, dune grasslands and shifting sand dunes in the nature reserve ‘Ter Yde’ in execution of the above-mentioned management plan;
- the removal of 6ha of artificial Elder- and Poplar- woodland from the Flemish regional Nature Reserve ‘Hannecartbos’ to restore calcareous marshland in a fossil beach plain;
- the dredging of nutrient-rich sludge from a dune-rivulet in the nature reserve ‘Hannecartbos’ to restore mesotrophic open water with Chara-vegetations;
- the placement of two dams on the rivulet in the nature reserve ‘Hannecartbos’ in order to disconnect the groundwater regime of the whole concerned dune area from the artificial drainage in the agricultural area of the polders;
- the demolition and removal of the derelict water treatment plant of Nieuwpoort in the regional nature domain of Groenendijk to restore calcareous marshland;
- the scientific monitoring of the response of flora, vegetation, fauna and physical environment (especially the groundwater and the soils) to the executed restoration and management measures.
- the improving of the experiential quality of the Flemish nature reserve Hannecart Wood by improving the walking paths and replacing the barbed wire fencing by a more attractive and functional enclosure.

The deforestation of 6ha in 'Hannecartbos' and the influencing of the groundwater regime by the placement of dams on the dune-rivulet needed a preliminary Environmental Effects Assessment. As cutting down trees and removing shrubs on a large scale as well as raising the groundwater level are often experienced as disturbing by the public, communication with the large public and local authorities received a lot of attention from FEYDRA. A colourful leaflet about the actions in 'Hannecartbos' was published and distributed on a large scale, a public information evening took place and was massively attended, press conferences were organised and an exhibition about FEYDRA was built in the Flemish regional nature visitor centre 'The Nightingale'. At the start of the different stages of the removal of scrub in the Flemish nature reserve Ter Yde, all the local residents received information leaflets in their letter boxes about how and why the works would be carried out and while the various work projects are being carried out in the three sites of the project, information boards are erected on the sites so that those who pass by are aware of what is being done. At the beginning of the project a website (www.mina.vlaanderen.be/feydra/) has been developed for more information about FEYDRA. At the end of the project a report about the results of FEYDRA will be published and distributed on a large scale.

The present international conference is intended as a forum for the exchange of experiences with nature restoration in coastal dune and estuarine habitats along the European coasts, in order to stimulate initiatives and improve methods and techniques of nature restoration projects.

An essential contribution of the Life projects ICCI and FEYDRA to nature restoration and management along the Flemish coast was that they allowed the Nature Division to create five new jobs that are vital for a good management of the Flemish coastal natural areas. These members of staff, whose tasks meanwhile have been recognised as recurrent by the Flemish government, have been taken into permanent service. FEYDRA has also revived the dialogue between the local drinking water Company IWVA and the Nature Division. This dialogue resulted in 2005 into an agreement by which the IWVA owned domains 'Cabour' (surface area: 88ha) at De Panne and 'Ter Yde' (surface area: 25ha) at Oostduinkerke were given into management to the Nature Division. Domain 'Cabour' is one of the most well preserved 4,500 years old, fossil beach-wall sites of north western Europe, containing the priority habitat '2150 Eu-Atlantic decalcified fixed dunes (Calluno – Ulicetiae)'. It is adjacent to the French fossil dune of Ghyselde. The IWVA – owned domain 'Ter Yde' is situated between the Flemish regional Nature Reserve 'Ter Yde' (surface area: 59ha) on the northern side and the Flemish regional Nature Reserve 'Hannecartbos' (surface area: 32ha) on the southern side. The incorporation of this IWVA owned domain into the Flemish regional Nature Reserve allowed to join 'Ter Yde' and 'Hannecartbos' into one enlarged nature reserve (surface area: 116ha) and to lift barriers for a coherent management of the whole area. The management-agreement about the IWVA owned Cabour domain allows the expansion of the Flemish regional Nature Reserve 'The Dunes and Woods of De Panne' from a surface area of 539ha to a surface area of 627ha.

Salt meadows at the Flemish coast (Versweyveld, 2003)

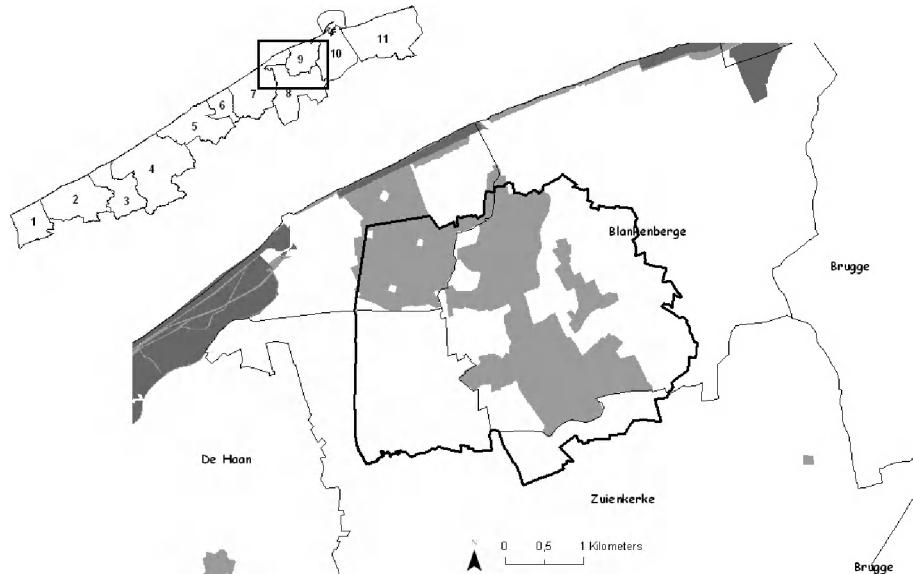


Fig 4. Project site of the Life nature project 'Salt Meadows at the Flemish coast' (dark grey: managed dune area; grey: nature site in the frame of the spatial planning legislation).

The Flemish coastal plain consists mainly of polders. The eldest parts of these polders are former peat bogs that have been inundated by the sea during the Middle Ages. These marine floods caused the bogs to become saline and left it covered with a fertile layer of clay. Peat and clay-extractions from the Middle Ages until quite recent time shaped the landscape into humid meadows with lots of ditches and pools. This historical landscape of humid meadows is not only important because of its non-tidal saline vegetation, but also attracts migrating birds in their thousands, especially the pink-footed goose (*Anser brachyrhynchus*), the lapwing (*Vanellus vanellus*) and the golden plover (*Pluvialis apricaria*). The 'Uitkerkse Polder' between Blankenberge, Zuienkerke and Wenduine is with its surface area of 1.230ha one of the most extended polder meadow sites of the Flemish coast. Although strongly reduced in size by the development of the inner-port of Zeebrugge, the 'Dudzeelse Polder' with its remaining surface area of about 180ha, offers the qualitatively richest salt meadows of the Flemish coastal plain (Herrier *et al.*, 2002). Since the 1960's the agricultural activity in the polders has strongly intensified, resulting in ploughing up half natural grasslands and heightening low wet meadows with their pools and ditches into arable land, especially maize fields. The 'Uitkerkse Polder' and the 'Dudzeelse Polder', together with other meadow-complexes between Ostend and the Dutch border, are part of the Special Protection Area 'BE2500002 - Poldercomplex' that was designated in the frame of the Bird Directive and of the site of community

importance ‘Poldergrasslands’. The non-governmental organisation (ngo) Belgian Nature and Birds Reserves, now Natuurpunt, who had already initiated the first conservation actions in the early 1990’s, conceived and applied for a Life nature project in favour of the maintenance and restoration of salt polder meadows, especially in the ‘Uitkerkse Polder’. The Life project ‘Salt Meadows at the Flemish coast’ was executed from 1999 to 2003 (Fig. 4). Its total budget amounted to € 1,490,000.

This Life nature project was designed to provide a major impetus for the pioneering work that had already been carried out in an extremely delicate social context. The two main components of this Life nature project were first the purchase of 60ha of degraded grassland followed by the restoration of its original micro-topography and secondly the broadening of the social and economic support for the conservation actions for the polders saline meadows. To this end, the possibilities for environment-friendly (soft) tourism were to be exploited to the full. Walking paths and bird observation huts were planned to be built in consultation with the tourist authorities. At the end of the project, all the actions had been successfully implemented. Again, at the end of the project more on-site conservation actions had taken place than originally foreseen. Not less than 95ha of land was bought and restored, instead of the 60ha that had been foreseen. More degraded grasslands than foreseen have been restored by re-opening ditches and ditch patterns and demolishing derelict buildings. A mobile exhibition was made to promote Natura 2000 through the Life restoration actions in the concerned site.

The attention for the polder-grasslands that was shown by the European Union through this Life nature project contributed to an impetus to the conservation policy of the Flemish regional authority for the concerned area. The Flemish government decided to increase the surface area of the proposed Site of Community importance ‘Poldergrasslands’ from 283ha to 545ha and to enlarge the surface area in the ‘Uitkerkse Polder’ being designated on the spatial zoning plans as ‘nature site’ from 245ha to 527ha. Immediate positive effects of this enlargement of the legally designated ‘nature site’ are an automatic prohibition to manure land and the right of first purchase in case land is offered for sale. Despite the opposition of some farmers to the conservation of the ‘Uitkerkse Polder’, Natuurpunt succeeded in concluding binding contracts with numerous local farmers to let their cattle graze the grasslands under strict conditions in this Acknowledged Nature Reserve.

Uitkerkse polder (Versweyveld, 2004)

In the continuation of the Life project ‘Salt Meadows at the Flemish coast’ the non-governmental organisation Natuurpunt conceived and applied a new Life nature project in favour of the maintenance and restoration of salt polder meadows in the ‘Uitkerkse Polder’. The Life project ‘Uitkerkse polder’ started in April 2003 and is supposed to be completed in March 2008 (Fig. 5: project site). Its total budget is € 4,205,003.

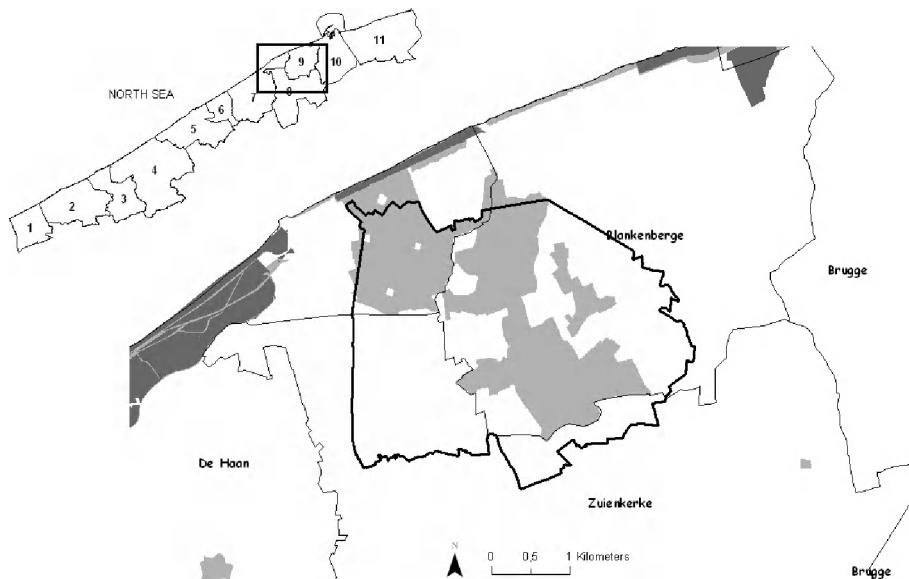


Fig. 5. Project site of the Life nature project 'Uitkerkse polder' (dark grey: managed dune area; grey: nature site in the frame of the spatial planning legislation).

The objectives of the project 'Uitkerkse polder' are:

- Large scale restoration of the unique salt meadows, concerning *Salicornia*-vegetations and *Glauco-Puccinellietalia* and their associated breeding species like Avocet, Common tern, Hen Harrier, Marsh Harrier, Spoonbill and Bluethroat.
- Restoring an inshore variety of 'Kreken' (large shallow inlets and bays), *Magnopotamion* habitats, grey dunes and *Calthion/Arrhentherion* meadows as well. All have almost or completely disappeared nowadays.
- Creating outstanding migrating, foraging and/or wintering conditions for species like Pinkfooted Goose, White-fronted Goose, Spoonbill, Short-eared Owl, Golden Plover, Ruff and Black-tailed Godwitt.
- Promoting and developing nature oriented tourism to ensure the social and economic embedment of Natura 2000.

The main actions are:

- the production of the necessary management schemes and a monitoring survey of the first results;
- the acquisition of approximately 120ha of land of which 30ha arable land in order to restore halophilous grasslands;
- large-scale restoration of salt meadows, extending of the existing 'core areas' and creation of new ones, with a total surface of app. 90ha;

- starting up recurring management (grazing management, hayfields) to obtain the optimal development and management of salt meadows and hay meadows and their associated species;
- the development and realisation of a broad program to develop the socio-economic potentials of the project area by means of the enlargement and re-styling of our visitor centre and the parking, the construction of new visitor facilities like a new bridge and footpath, an observation hide, new signposting and information panels, the drafting of a tourists walking brochure, the construction of a new permanent exposition at the visitor centre, the publication of articles, a layman's report and website for the general public;
- organisation of several activities in order to exchange experiences between other Life-projects and authorities, organisation of information meetings to inform local people.

Conclusions

The four Life nature – projects at the Flemish coast that until now have been or are being executed had effects that by far outreach their initial purposes. Of course they allowed large-scale nature restoration projects, such as the dismantling of the former naval basis of Lombardsijde and the partial deforestation of Hannecartbos, that without European support would have had much more difficulties to be realised. But as great a merit is the favourable influence these Life nature projects had on the dialogue between conservationists and other actors, not the least the water supply company IWVA and local authorities, and on the coastal conservation policy of the Flemish government, especially on its coastal dune purchase policy. In 1996 there were but three Flemish regional and two Acknowledged (private) Nature Reserves in the coastal dunes; in 2004 there were already 12 Flemish regional and four Acknowledged Nature Reserves here. This expansion of the number and surface area of nature reserves along the coast is for a good deal the result of the impetus given by the Life nature projects to the purchase and active management of coastal dunes and polders. The first Life nature project, ICCI, also led the fundaments for the further marine conservation policy of the Belgian federal government.

Life nature has been a blessing for nature conservation along the Flemish coast, as it has generated a dynamic that had never been seen before 1997.

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COASTAL CONSERVATION POLICIES

Plenary session 1 – chair: Roland Paskoff

The conservation of sand dunes in the Atlantic Biogeographical Region: the contribution of the LIFE programme

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Abstract

Since 1992 the EU LIFE programme has supported a series of dune conservation projects within the Atlantic Biogeographical Region. LIFE co-financing has been used to safeguard threatened sites through land purchase, to support the development of the Natura 2000 network, to undertake practical management and to interpret the functions and values of dunes to a wide audience. The additional resources from LIFE have been targeted at specific sites, at national programmes and, through wider networking initiatives, at the community of practitioners. LIFE projects have contributed to the development of European and National policies by acting as case studies and milestones. Dissemination of information is aided by practitioners networks such as the European Union for Coastal Conservation and through the series of conferences and workshops held within the framework of the projects. A further step may be to use the completion of the Natura 2000 network as a catalyst for encouraging a more coordinated approach to networking and for raising some of the key issues affecting dune systems at the European level.

Keywords: Dunes; LIFE programme; Atlantic Biogeographical Region; Project results; Networking.

Introduction

Sand dune habitats of the Atlantic Biogeographical Region

An inventory of the sand dunes of Europe was compiled in 1991 on behalf of the European Union for Coastal Conservation (Doody, 1991). This important piece of work is now updated (*cf.* Doody, 2005). The Atlantic Biogeographical Region with its large dune systems along the Aquitaine Coast of the Bay of Biscay, the Dutch mainland, the Wadden Islands, the machair of Ireland and Scotland and the Danish west coast is the major European region in terms of the scale and number of its dune systems.

Sand dunes are well represented in the EU Habitats Directive (Table I) with 10 habitats listed under 'Sea Dunes of the Atlantic, North Sea and Baltic coasts'. Other dune habitats can be added including coastal dunes with *Juniperus* spp. (found only in UK and Denmark in the Atlantic Region) and there is a considerable range of habitats (Table II)

and associated Annex II and Annex IV species (Table III) associated with European coastal dunes.

Table I. Sea dunes of the Atlantic, North Sea and Baltic coasts

Code	Description	BE	DE	DK	ES	FR	IE	NL	PT	UK
2110	Embryonic shifting dunes	X	X	X	X	X	X	X	X	X
2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> (white dunes)	X	X	X	X	X	X	X	X	X
2130*	Fixed coastal dunes with herbaceous vegetation (grey dunes)	X	X	X	X	X	X	X	X	X
2140*	Decalcified fixed dunes with <i>Empetrum nigrum</i>		X	X			X	X		X
2150*	Atlantic decalcified fixed dunes (<i>Calluno-Ulicetae</i>)	X	X			X	X	X	X	X
2160	Dunes with <i>Hippophae rhamnoides</i>	X	X	X		X	X	X		X
2170	Dunes with <i>Salix repens</i> ssp. <i>argentea</i> (<i>Salicion arenariae</i>)	X	X	X		X	X	X	X	X
2180	Wooded dunes of the Atlantic, Continental and Boreal Region	X	X	X		X		X		
2190	Humid dune slacks	X	X	X		X	X	X	X	X
21A0 *	Machairs (*in Ireland)						X			X

Six sub-types are identified under the priority habitat 2130 fixed coastal dunes, representing a series of types from the Straits of Gibraltar to the Baltic Sea.

Table II. Additional habitats associated with dune coasts

Code	Description	BE	DE	DK	ES	FR	IE	NL	PT	UK
1110	Sandbanks which are slightly covered by sea water all the time	X	X	X	X	X	X	X	X	X
1140	Mudflats and sandflats not covered by seawater at low tide	X	X	X	X	X	X	X	X	X
1150*	Coastal lagoons		X	X	X	X	X			X
1210	Annual vegetation of drift lines		X	X	X	X	X		X	X
1220	Perennial vegetation of stony banks		X	X		X	X			X
1330	Atlantic salt meadows (<i>Glauco-Puccinellietalia maritimae</i>)—also some 1310 and 1320	X	X	X	X	X	X	X	X	X
2250*	Coastal dunes with <i>Juniperus</i> spp.			X						X
2260	<i>Cisto-Lavenduletalia</i> dune sclerophyllous scrubs				X	X				
2270*	Wooded dunes with <i>Pinus pinea</i> and/or <i>Pinus pinaster</i>					X			X	
2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	X	X	X				X		
2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>		X	X				X		
2330	Inland dunes with open <i>Corynephorus</i> and <i>Agrostis</i> grasslands	X	X	X		X		X		X
3110	Oligotrophic waters containing very few minerals of sandy plains (<i>Littorellietalia uniflorae</i>)	X	X	X	X	X	X	X		X
4030	European dry heaths	X	X	X	X	X	X	X	X	X
7230	Alkaline fens	X	X	X	X	X	X	X		X

Table III. Some Annex II and Annex IV species associated with sand dunes in the UK

Great crested newt	<i>Triturus cristatus</i>
Narrow-mouthed whorl snail	<i>Vertigo angustior</i>
Slender Naiad	<i>Najas flexilis</i>
Fen Orchid	<i>Liparis loeselii</i>
Shore Dock	<i>Rumex rupestris</i>
Petalwort	<i>Petalophyllum ralfsii</i>
Natterjack Toad	<i>Bufo calamita</i>
Sand Lizard	<i>Lacerta agilis</i>

Current uses and threats to European dune systems

Coastal communities have generally utilised the sandy soils in association with the sea and seashore and the backlands (polders, peatlands, etc). However, historical records throughout north-west Europe show that large scale destabilisation and sand drift (the so-called wandering dunes) also occurred. Whole communities could be driven out by advancing waves of mobile dunes. Factors triggering dune de-stabilisation probably included climatic deterioration, increasing populations and over-use, de-forestation, and general lack of management, often despite local and national laws. Powerful natural cycles may also be at work as dune coasts adjust to a changing coastline.

By the early twentieth century the stabilisation of sandy ‘wastelands’ was advocated by coastal authorities and as technology improved large scale projects, such as the dune building programmes along the Aquitaine coast, could be completed.

Most dune systems are subject to ongoing low intensity management. The open areas of fixed dunes and dune heaths are often, but not always, plagio-climax communities kept open by grazing, cultivation, scrub cutting and fires.

The present day use and management of dune systems also varies from the local community-based approaches on the machairs of Ireland and Scotland to more centralised control through Forestry Services and nature agencies throughout much of northern Europe.

Uses of dunes fall into a number of broad categories and generally several types of land use are to be found within one ‘system’:

- The continuation of low-intensity agricultural activities including grazing, cultivation and rabbit-cropping. There are no easy-to-hand figures of the extent of dune area which is being maintained through such traditional and re-introduced practices. In a healthy situation a dune system will tolerate some marram cutting, sand extraction for agricultural use (especially within the same system), cultivation and trampling by livestock. Most traditional activities will be able to continue within Natura 2000 sites and may even be promoted. The machair coasts are essentially agricultural zones.

- The use of the dune area primarily as a recreational site where the needs of tourism infrastructure impacts on the naturalness of the site. Such uses are often linked also to beach-based recreation and the beach and dunes must be treated as one unit for overall management planning.
- The use of the dune area primarily as a nature reserve where access and management are tailored to the needs of species and habitats. Keeping the open landscape is often a priority with a focus on scrub control and the conservation of grazing management.
- The use of the dune area as a sea defence.
- The use of the dune area for land uses such as forestry, water abstraction, sand extraction, military use, golf courses and other leisure activities. In all these uses nature can still survive well although natural processes (e.g. blowouts) are often restricted.

Current threats to dune systems include the catastrophic damage caused by development, and the more insidious cumulative damage caused by fragmentation, over-stabilisation, afforestation, the edge effects of development, uncontrolled recreational uses, water loss, nutrient deposition, lack of ecological understanding and general lack of awareness and respect by local communities and tourists.

Projects funded under LIFE

LIFE projects (through the strands of LIFE-Environment and LIFE-Nature) have helped to support conservation by translating new ideas about dune management into practice and demonstration. The two elements of the LIFE programme have proved complementary in helping to link broad management issues (forestry, beach management, erosion etc) to the specific nature conservation priorities of Natura 2000. Ecological knowledge and experience has also been exchanged through a LIFE-Nature Co-op project.

Some of the actions undertaken by these projects include:

- Working with local communities to raise awareness of the need for sustainable management
- Reducing the impact of recreation pressure through the introduction of visitor management
- Stabilisation of sand-drift where infrastructure and development is at risk whilst also supporting less-intensive techniques where time and space allow (the dynamic approach)
- The re-building of shifting dunes damaged by tourist pressure
- Changing attitudes within well-established sectors such as forestry to allow a new balance with nature to be achieved
- Taking nature conservation messages to new partners such as golf courses and military sites
- The purchase of sites at risk and the development of land acquisition policies
- The restoration of dune areas following the removal of development infrastructure
- The establishment of management and monitoring systems at the Natura 2000 site level

- Investigations into the difficulties of monitoring habitat quality in such naturally dynamic areas
- Long-term predictions of habitat losses and gains as a result of sea-level rise and climatic change
- Studies into insidious threats such as nutrient deposition
- Production of brochures and publications at local, national and international level
- Encouraging the development of European networks through workshops, conferences and publications.
- Working in parallel with other EU funding sources (e.g. INTERREG) and national funding opportunities to develop long-term management programmes.

A concurrent theme within LIFE projects is the motivation of the people involved in assembling and running the projects. Often they are breaking out from 'institutional' working practices to develop new ideas and engage new stakeholders.

An analysis of the work of several LIFE projects

A search of the LIFE database for the keywords 'dunes' or 'sand dunes' gives nearly 100 projects. Not all of these are directly associated with dune management and the range of projects in the Mediterranean and Baltic Seas are not included in this review. For the Atlantic Biogeographical Region 16 projects have been selected as particularly relevant for dune conservation (Table IV). Whilst no projects have been funded to date in Germany and the Netherlands the contribution to knowledge and networking from these countries has helped with the understanding of dune habitats and conservation concerns. Dutch interest in wider networking led to the establishment of the European Union for Dune Conservation (now EUCC) in 1987.

The contribution of the LIFE fund to the 16 projects selected is about 11.4 million Euro with a total project expenditure of 22. million Euro (an average of 50%).

Projects in France

The Office National de Forêts has co-ordinated two LIFE-Environment projects on coastal dunes. The first 'Biodiversity and dune protection' marked a turning point in the forestry sector's understanding of their responsibilities towards forest production, coastal defence, recreation management and nature conservation. The aim was to find management solutions which conserved the biodiversity of the dunes at six sites. The results were drawn together through the publication of 'Biodiversité et protection dunaire' (Favennec and Barrière, 1997).

Project actions included the development of a restoration plan to reduce recreation damage and repair dunes (Mimizan and Messanges), dune stabilisation to protect property whilst maintaining the landscape value of the dunes (Cap-Ferret), gaining understanding of coastal processes through the production of eco-dynamic maps (La Coubre and Oléron), preparation of a management plan to conserve the biodiversity of a complex dune system (Merlimont), restoration and diversification of a dying dune woodland (Vendée) and conservation management of forests (Landes de Lessay).

Table IV. Selected LIFE projects

Project reference	Project title	Total €	EU €	Beneficiary
92ENV/F/000021	Protecting dunes from erosion	1,600,000	600,000	Conservatoire de l'Espace Littoral et des Rivages Lacustres
92ENV/F/000024	Biodiversity and dune protection	2,865,000	1,386,946	Office National des Forêts
94NAT/DK/000492	Re-establishing lichen and coastal heaths in the Anholt desert, Denmark	490,000	245,000	Aarhus County
95ENV/P/000119	Recovery, conservation and management of species and natural habitats in the coastal area of central Portugal	695,306	281,558	University of Coimbra
95ENV/P/000254	Campaign for the dunes' preservation in Vila Nova de Gaia	607,124	290,849	Câmara Municipal de Vila Nova de Gaia
95ENV/F/000676	Rehabilitation and sustainable management of four French dunes	913,134	456,567	Office National des Forêts
95NAT/UK/000818	A conservation strategy for the sand dunes of the Sefton Coast, North West England	1,013,400	506,700	Sefton Metropolitan Borough Council
95NAT/UK/000821	Integrating monitoring with management planning	786,000	393,000	Countryside Council for Wales
96ENV/UK/000404	Implementing alternative strategies in Irish beach and dune management	1,312,007	630,403	University of Ulster
96NAT/B/003032	Integral Coastal Conservation Initiative	2,551,854	1,137,106	AMINAL
96NAT/DK/003000	Protection of grey dunes and other habitats on Hulsig Hede	1,004,575	502,287	Nordjyllands Amt/County
99NAT/UK/006081	Living with the Sea	2,234,433	1,117,217	English Nature
02NAT/B/008591	Fossil Estuary of the Yzer Dunes restoration area	1,309,522	654,761	Ministerie Vlaamse Gemeenschap AMINAL
02NAT/DK/008584	Restoration of dune habitats along the Danish West Coast	4,675,796	2,805,478	Danish Forest and Nature Agency

Project reference	Project title	Total €	EU €	Beneficiary
03NAT/CP/NL/000006	Dissemination of ecological knowledge and practical experiences for sound planning and management in raised bogs and sea dunes	152,000	98,000	University of Nijmegen
04NAT/ES/000031	Dune regeneration on Laida beach (Urdaibai)	522,568	261,284	Patronato de la Reserva de la Biosfera de Urdaibai
TOTAL		22,732,719	11,367,156	

Concurrent with this project was a project led by the Conservatoire du Littoral to protect the dunes at Sangatte in the Nord-Pas-de-Calais region through dune restoration and the control of public access.

The second ONF LIFE-Environment project ‘The rehabilitation and sustainable management of four French dunes’ continued to develop management which considered the principles of dynamic coastal geomorphology (and beach-dune interaction) and biodiversity (by focusing on four Natura 2000 sites). The second project was important in taking the ideas from being revolutionary to normal practice within ONF. The key actions were a plan for the conservation of priority grey dune habitat at the Quiberon-Plouharnel dunes in Brittany, enhancement of the biodiversity of the maritime pine and oak woods at the Combots d’Ansoine dunes at the mouth of the Gironde Estuary, an overall management plan for the dunes at Seignosse-le-Penon and recreation management to reduce damage to the dunes at Tarnos and to protect the habitat of rare plants.

Project results are presented in a special volume of ‘Les Dossiers Forestiers’ (Knowledge and sustainable management of Atlantic coast dunes) (ONF 1996) and so has become formalised within ONF. The project recommendations aim to combine conservation with rational tourist use of the ONF forests and dunes. The projects have also had other spin-offs such as recognition of the importance of lichens, fungi and insects in the dune ecosystem and more understanding of the value of grey dunes.

Projects in Portugal

The first ONF project developed links between the situation on the Atlantic coast of France and the Portuguese coast. These links were explicitly developed in the second ONF project and a joint video produced.

A specific LIFE-Environment project in Portugal (‘campaign for the dunes’ preservation in Vila Nova de Gaia’) was focused on raising public awareness of the value and fragility of the narrow dune systems along the Portuguese coast. The project carried out actions based on an 18km section of coast around Gaia but also targeted the population along 200km of coastline. The awareness-raising actions were aimed at decision-makers, travel agents, students, residents and visitors. The project pump-priming has helped to encourage other restoration projects along the Portuguese coast.

A similar project in 1995 involved the recovery, conservation and management of species and natural habitats in the coastal area of central Portugal. The actions were aimed at protecting dunes through access control, the recovery of dune scrub, the restoration of woodlands following fires and interpretive and educational activities.

Projects in Spain

In 2004 a restoration project was approved for dune regeneration on Laida beach at the mouth of the rivers Guernika and Mundaka. Here, intensive recreational pressure has damaged the natural shifting dune habitat making natural recovery impossible. The project will rebuild the dune formations using sand trapping fencing and will replant the area with natural vegetation. Public awareness and control of recreation pressures will assist recovery.

Projects in Belgium

Two LIFE-Nature projects run by the Ministry of the Flemish Community have made a major impact on the protection, management and understanding of the dune systems of the Belgian coast and represent a policy-shift away from almost total exploitation for tourism development. The first of these, the Integral Coastal Conservation Initiative (ICCI) helped to secure the conservation of dune sites as a component of the Belgian coast. The remaining dunes sites are fragmented and isolated but nevertheless contain valuable habitats and species.

The project concerned legal protection for the dunes and coastal zone, land purchase, habitat management and restoration, management planning and scientific monitoring. The link between policy, science and management has been particularly well developed and sets the scene for future management work. Project actions included the restoration of dune heath, scrub removal, introduction of grazing, the re-flooding of inland meadows and the removal of military infrastructure.

The second project is entitled Fossil Estuary of the Yzer Dunes Restoration Action. This continues the work of the first project on this site and aims to restore the natural dynamics of the priority fixed dune habitat so that wind, water and grazing activities can maintain a healthy habitat. Actions include the restoration of a dune stream (a rare feature), scrub and tree clearance and the demolition of infrastructure. The project will also use the Westhoek dune system as an example of good dune management.

Projects in the United Kingdom

The sand dunes of the Sefton Coast in north-west England is one of the largest dune systems in the UK. The area is under numerous ownerships and has been fragmented by past development, road and rail infrastructure and afforestation. The opportunity was taken through a LIFE-Nature project to develop an overall management strategy for the Sefton Coast candidate Special Area of Conservation. This helped to strengthen the existing level of conservation management, to engage new partners, to purchase private

land, to develop habitat and species strategies and to disseminate information to local people about the conservation value of the site.

The additional support through the LIFE fund allowed the development of a GIS database for the cSAC. The project encouraged a whole site approach to management rather than a system based solely on land ownership and this has encouraged the more extensive application of conservation techniques and the sharing of resources.

Large sand systems are usually a complex matrix of habitat types where the boundaries are often indistinct and this leads to challenges for monitoring. The monitoring of cSACs in Wales was addressed by the LIFE-Nature project ‘Integrating monitoring with management planning: a demonstration of good practice on Natura 2000 sites in Wales’. The detailed work concluded that since it was so difficult to establish accurate and repeatable monitoring programmes for dune sites the best option was to revert to more simplistic measures, e.g. height of vegetation as an indicator of ‘quality’. The study looked at five dune types (2110, 2120, 2130, 2170 and 2190) and made recommendations for sampling techniques and for the setting of conservation objectives for maintenance and restoration management.

The Living with the Sea project was established with the support of the UK Government to consider the issue of conserving dynamic coastal habitats, and especially Natura 2000 sites, in the face of coastal change. The project developed the concept of Coastal Habitat Management Plans (CHaMPs) to predict the ‘gains and losses’ of habitats on a given section of coast over a 50-100 year period. Although the predicted losses of dune coasts was considerably less than the predicted loss of saltmarsh there is nevertheless general concern that dune coasts are subject to greater erosion than accretion. The CHaMPs approach helps to set dune systems in a wider coastal context and to habitats such as sand and mud flats, saltmarshes and lagoons.

A fourth UK beach and dune project was led by the University of Coleraine in Northern Ireland and, as a cross-boundary project, is considered with Ireland below.

Projects in Ireland

The Republic of Ireland benefited from the support of the LIFE-Nature fund to assist with the preparation of a national inventory of Natura 2000 sites including information on the current distribution and condition of the Irish dune systems.

A LIFE-Environment project was launched in 1997 to work with a number of local communities in Northern Ireland (UK) and the Republic of Ireland to develop management strategies for beach and dune systems. Beaches traditionally provided both sand and sea-weed to improve the fertility of the cultivated machair. But lack of understanding can lead to exploitation and the loss of beaches. Dunes can be damaged by the burning and harvesting of marram grass (*Ammophila arenaria*) and the collection of sand can lead to erosion. As with many LIFE projects the processes of consensus building and participation were integral to success. Final dissemination was through the publication of a good practice guide to rural beach management (McKenna *et al.*, 2000).

Projects in Denmark

A number of LIFE-Nature projects have been undertaken in Denmark, beginning with site specific projects on Anholt and Hulsig Hede and leading to the extensive project ‘Restoration of dune habitats along the Danish west coast’ covering 11 coastal Natura 2000 sites.

The project on Anholt aimed to re-establish the lichen and coastal heaths on the island. The actions involved the clearance of mountain pine *Pinus mugo* across some 400 ha of the 1200 ha site. The project was also an opportunity to develop techniques to be used on other restoration projects and to establish monitoring schemes.

A second project aimed at the protection of grey dunes and other habitats on Hulsig Hede (Hulsig Heath) in north Jutland. The mobile nature of the dune systems in north Jutland with remaining examples of the wandering dunes has made for a rich environment which also supports significant numbers of Annex I bird species. The project focused on the large scale removal of conifers from a 1680 ha site and the preparation of a long term strategy.

Following the lead from these local authority-led projects a larger and more ambitious project was drawn together by the Danish Forest and Nature Agency in 2001. The project focuses on the conservation of 11 Natura 2000 sites covering over 24,000ha, selected mainly for the priority habitats fixed grey dunes and decalcified dunes with *Empetrum nigrum*. In this project some 4000ha will be cleared of non-native conifers and a further 2000ha will be restored through burning, grazing and cutting.

Restoration actions and dune management

Dune repair/restoration techniques – learning to live a bit more with nature

In the ONF projects a number of techniques for dune restoration were developed and implemented. Such techniques include the re-profiling of dune faces, the planting of dune grasses and sowing of other species (e.g. *Helichrysum stoechas*) and fencing to restrict access and allow recovery. Pathways and information boards were erected to explain the work to the visitors. Similar work has been completed by the Portuguese project in Vila Nova de Gaia and will be the main action in the Spanish project at Urdaibai. Such actions are necessary where the damage to the dunes has reached a state where increased mobility threatens infrastructure and becomes a nuisance. A purist approach could argue that nature can be left to reform the dune landscape but with continued recreational use and nearby development the constraints to nature are already imposed. The situation along the narrow dunes at Vila Nova de Gaia gives a stark choice; no dunes or managed dunes. Total naturalness is no longer an option along many developed coasts.

One of the challenges for the stabilisation work on some of the French sites was how to maintain biodiversity value. Studies were undertaken to assess the changes in the vegetation communities as a result of stabilisation work. In much of the widespread

historical sand stabilisation work undertaken throughout north-west Europe preservation of biodiversity value was never an aim; today the need to respect and conserve natural values and landscapes is a key concern in such works.

An important feature of almost all LIFE projects is that the additional resources allow more time for communication and networking. Thus LIFE projects can help to progress conservation thinking on a wide front. The natural interest in sharing experience between sectors has been enhanced through practical projects such as those in France which have developed new approaches to dune management.

In England the national approach to develop Shoreline Management Plans did not, at first, give adequate attention to the requirements of the Habitats Directive. This weakness has been addressed through the Living with the Sea project which has targeted coastal engineers and conservation managers and encouraged new and long-term (50-100 year) thinking about the direction of coastal change and the appropriate responses for environmental, economic and social needs.

In the 1980s the idea of a ‘dynamic approach’ to soft coast management was being championed. The idea has now been widely applied and the LIFE projects, with their focus on communication and dissemination, have made a significant contribution to awareness raising.

Dune forestry – a new balance

Plantations of conifers are associated with sand dunes in all countries within the Atlantic Biogeographical Region, with the largest areas in France and Denmark. The underlying reasons for these plantations differ from region to region and include stabilisation as a priority (the sandy ‘wastes’ of Denmark being stabilised with *Pinus mugo*), commercial forestry and by-products (e.g. resin from *Pinus pinaster* in Les Landes), shelter for game (e.g. some of the plantings in the Netherlands) and attempts at commercial forestry (UK and Ireland). Whilst forestry was the single purpose land use in many areas there was little consideration given for the natural values of the dunes. This unbalanced view is now changing throughout north-west Europe and whilst good arguments can be put forward for the removal of trees the plans do not always go down well with local opinion which often now values the recreation and shelter functions of the woodlands. Also, the woodlands themselves often support an interesting wildlife including, in the United Kingdom, the endangered Red Squirrel (*Sciurus vulgaris*).

In all countries where forestry plays a major role in the coastal zone (France and Denmark especially) there is a sector-wide recognition that a more appropriate balance must be found between forestry (for timber and amenity) and natural habitats. Most at risk have been the fixed dune habitats (grey dunes and heaths) and several thousand hectares have now been restored.

LIFE projects have been able to put into practice restoration on a large scale and continually help to improve techniques and knowledge. Costs and effort are carefully recorded and this information can assist with estimating the cost of national restoration

programmes. It is important, however, that networking between projects and national agencies continues so that the collective knowledge is available.

Habitat management: mowing, grazing and turf cutting

Until the 1980s the control of sand movement in dunes was generally managed in a 'traditional' manner according to national legislation or policy. Generally this meant stabilisation of areas of mobile sand, marram planting, scrub and tree planting and access restrictions. In the 1980s, however, ecologists began to argue against such fixed management views and promoted the need to control vegetation growth through mowing, grazing and rejuvenation of soils through turf-stripping and other techniques.

Initially such techniques were confined to the nature reserves but as the 'dynamic approach' became more widely accepted there were more opportunities given for the creation of blowouts and destabilisation to encourage natural processes. Again LIFE projects, for example on the Sefton Coast, have helped to develop these approaches and go beyond the nature reserves to private land, military sites and golf courses. On some sites it was possible to introduce grazing to control scrub and to keep the habitat open, on others scrub cutting programmes have been developed to ensure that scrub does not exceed a fixed percentage (e.g. 10%) of the site and on others bare sand areas have been created to encourage early stages of dune succession. Some of the most extensive schemes of this nature have been carried out in the Netherlands in recent years.

LIFE projects have helped to consolidate management practice and disseminate practical information to professional networks. Some projects, such as the ICCI project in Belgium have combined applied scientific study to establish monitoring systems and assess the impact of management actions. Seminars, such as the European Dune Symposium, held by the Sefton Coast LIFE Project, have combined science and management to promote best practice (Houston *et al.*, 2001).

Managing for species

It is often difficult to achieve the correct balance between management at the whole site, habitat and species level. Inevitably through rarity interest, also supported by the Habitats Directive and national legislation, some management will be carried out for individual species. Dune habitats are a good example of this dilemma where the conservation of charismatic rarities such as the Annex IV species, sand lizard (*Lacerta agilis*) and natterjack toad (*Bufo calamita*) often lead to the development of local and national strategies. Although such strategies focus and coordinate effort it is important that action for species is integrated within a more holistic overview of the dune site. Knowledge of the requirements of species, however, can often help to support the rationale for site management. An example would be the Annex II bryophyte *Petalophyllum ralfsii* which is an indicator of young dune slacks. A decline in this species may be associated with over-stabilisation and a loss of dynamic dune forming processes. A similar message is given by the Annex II species *Liparis loeselii*, the fen orchid.

The importance of dunes for Annex I bird species requires some further study. In Denmark the link between dune management and species conservation is integral to the restoration projects but, to date, there has been no European overview of the link between dune management practice and population trends.

Working with private landowners

The Natura 2000 network is not a network of nature reserves and much of the land is in, and will remain in, private ownership. The same rule applies in many areas to the dunes and comprehensive management strategies must embrace the issue of private ownership. Much of the duneland in the Netherlands, for example, is owned by a series of private water companies, but the potential damage through water abstraction has been recognised and these sites are now models of sustainable multiple-use management. In Belgium only 1400ha of the total of 3600ha are in the ownership of public bodies; the remaining areas have been protected but due to land speculation and the hope of future development land prices have risen. Nevertheless it is important that funds such as LIFE-Nature can be used to ensure that sites can be acquired in perpetuity.

The Integral Coastal Conservation Initiative and the Sefton Coast project have worked with private golf course owners to encourage conservation management actions. In the Sefton example, the golf courses (seven in total) occupy an area of some 500ha within the 2000ha dune system (25%) and their management is integral to the management of the whole Natura 2000 site. In the Belgian case the better long term solution would be to relocate two courses (120ha) to the polderland for total restoration of the current sites.

Military sites are a common feature on many dune coasts and a number of these have been established for a considerable length of time. The disturbance on such sites from vehicle movements, exercises and explosives has often helped to conserve early stages of dune succession and the general lack of fertilizers and pesticides makes such sites rich in wildlife. Projects in the UK (Sefton Coast), Belgium and Denmark have worked closely with military site managers to introduce conservation practices of benefit to dune habitats and species.

When working with private landowners the additional resources provided through LIFE funding help to develop working partnerships, prepare plans and often to carry out the initial works. But the spin-off is that these areas, whether a military site or a golf course, become examples of best practice in their sector.

Monitoring

Several projects have attempted to establish monitoring protocols for dune condition, habitats and species. The French approach has been through the development of eco-dynamic maps and monitoring a number of parameters. The Welsh monitoring project included dunes and a detailed evaluation of the monitoring problems associated with four habitat types (strandline, embryo dunes, humid dune slacks and grey dunes) was carried out. Because of the potentially high complexity of monitoring in dune systems there is a view that simplified systems may be all that can be realistic.

Monitoring is a key element of the Danish dune projects and a comprehensive programme has been established.

Access, public awareness and communication

Whilst the present day pattern of land-use on many dune systems was set by the end of the nineteenth century (forestry plantations, etc.) the twentieth century saw the rise in coastal tourism, first centred around coastal resorts and then further afield as camping grounds and access routes developed. Few of these visitors have an understanding of the potential damage that trampling pressures can do to dunes or of the unique natural values of the habitats.

Projects in France (at Seignosse-le-Penon and Tarnos dunes), in Portugal and in the UK (Sefton Coast) have focused efforts on nature trails, information and educational activities. The Portuguese projects have made a special effort to develop broad educational materials aimed at changing attitudes and perceptions to dunes in general.

Even where dune areas are better protected and total destruction is not the main threat there can be very different views expressed by local people on how the sites should be managed. A particular issue arises when large scale woodland removal is proposed. Even where the woodlands are relatively young and obviously an alien feature there can be strong opposition to clearance.

LIFE projects have spent a considerable effort in setting out the case for dune conservation by introducing local people and visitors to the natural values of sites through guided walks, specific nature trails, leaflets, booklets and videos. Through such understanding the conservation dilemmas can be more reasonably discussed and, generally, consensus can be reached. This may mean, for some sites, accepting some form of compromise between ecological best practice and local opinion but, across a number of sites, or a region, the conservation objectives can usually be met.

Networking

LIFE projects represent only a small part of the conservation effort on sand dunes and in terms of total management effort are no more than contributions to an ongoing process. But, importantly, LIFE projects are seen as ‘milestones’ in the development of techniques and networking. The additional funding given to LIFE projects brings with it a responsibility to disseminate information to other interested bodies. The main LIFE projects in France, UK, Belgium and Denmark have thus been able to achieve results on sites, have an impact at the national level (e.g. a link to Habitat Action Plans in the UK, or development of ONF policy in France) and have also support from the European and international dune management community through conferences and publications.

LIFE funding is therefore already indirectly supporting networking, not just for dunes, but for other habitats and species across Europe. A more direct funding opportunity comes through the LIFE-Nature co-op programme and, through a project led by the

University of Nijmegen, dune managers will come together to share experience and prepare guidelines for decision making.

Conclusion: towards a Natura 2000 network

In 2004 the initial list of sites for the Atlantic Biogeographical Region was approved, marking the end of the first phase of the establishment of the Natura 2000 network. Although there is still much to be resolved in terms of the funding of the network the publication of sites presents an ideal opportunity for stimulating habitat networks. After all, Natura 2000 depends on the collective effort of Member States and site owners and managers to achieve the goal of ‘favourable conservation status’. The current loose European dune network, supported as it has been by a series of LIFE projects, could perhaps use the opportunities presented by Natura 2000 to establish more formal networking.

But it must be remembered that Natura 2000 sites are only one element of a network. The experience of dune management in Europe over recent decades would advocate that every dune site, no matter how small, is important for biodiversity and for acting as a link in a chain of sites.

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Sand dune inventory of Europe

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Abstract

In November 1991 an inventory of sand dunes in Europe was published (Doody, 1991). This included a general review of the habitat and its conservation and summary descriptions of the status of the sand dunes in most of the countries in Europe. This paper sets out to provide an update of the sand dune resource in Europe as a basis for revising the inventory, which will be published at a later date if support (financial and information) can be obtained.

Keywords: Sand dune; Survey; Inventory; Europe.

Introduction

Almost the first European dune conference was held in Leiden, The Netherlands, in 1987. Following this conference one of the first tasks suggested by the newly established European Union for Dune Conservation [EUDC] was to produce an inventory of coastal dunes throughout Europe (Fig. 1). This was published by the UK Joint Nature Conservation Committee and the European Union for Coastal Conservation (EUCC an expanded EUDC) with funding from the Department of Nature Conservation, Environmental Protection and Wildlife Management in the Dutch Ministry. It was presented at the European Coastal Conservation Conference organized by the Dutch Ministry of Agriculture, Nature Management and Fisheries held in Holland in November 1991.

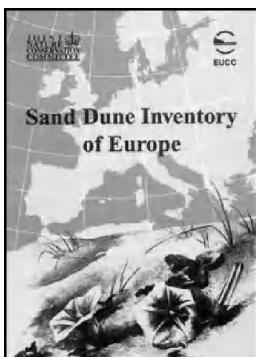


Fig. 1. The original inventory.

The wide ranging nature of the dune landscapes of Europe and the sometimes different perceptions within individual countries of what constituted a sand dune required a very broad definition of the type of dune encompassed within the survey. As a first stage it was decided to adopt the definitions given by Ranwell and Boar (1986) (Fig. 2), which are largely based on a geomorphological classification of dune systems. In addition in order to get some idea of the extent of change, which had taken place, dunes modified by human activities such as

afforestation were included. Wherever possible the dune distribution given for each country represented the maximum extent of blown sand.

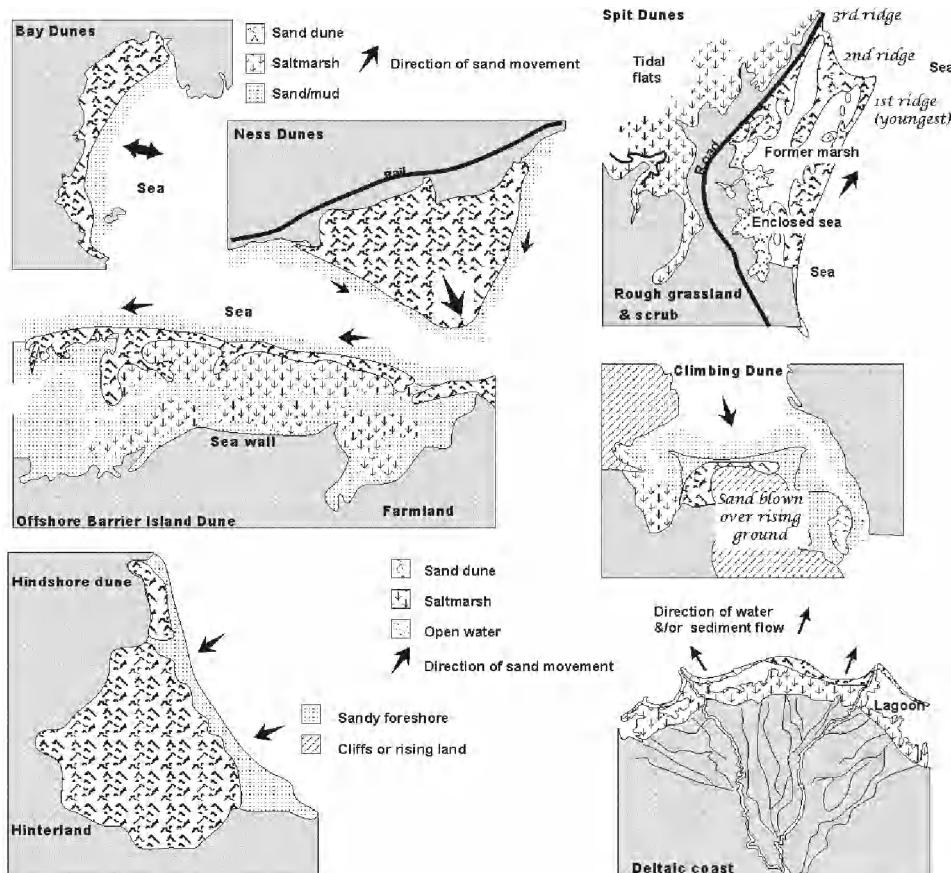


Fig. 2. Seven sand dune types recognized in the inventory. Note: a map of the sand dunes associated with deltaic coasts was not included in the original figure.

The scope of the inventory required the cooperation of a wide variety of people involved in dune conservation throughout Europe. In the event it proved difficult to obtain detailed information suitable for the inventory for some countries and the best available published information was used. The inventory provided a brief description of the type of dune formation, vegetation, important sites, a comment on conservation issues and a short list of references.

In the 12 years or so since then there has been a considerable amount of activity in the field of sand dune conservation. This paper summarizes some of the areas where more detailed information has been collected. No attempt is made to provide a comprehensive update. The examples are chosen to illustrate developments since 1991.

Country and regional reports

Iceland

An introduction to the sand dunes in Iceland is given in the original inventory but there was no distribution map. A considerable amount of information has been collected on the sand dunes of Iceland since then. The map below is taken from Gneipsson and El-Mayas (1994) (Fig. 3). Key features of sand dunes in Iceland are their volcanic origins, the need for a continuous programme of sand stabilisation and the impact of river dams on sediment delivery to the coast.

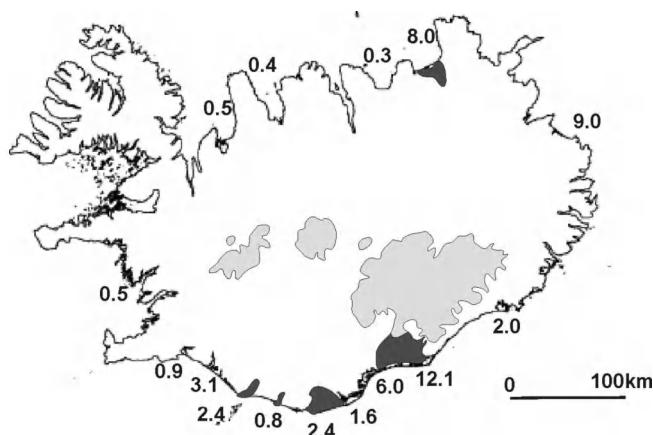


Fig. 3. Distribution of the main sand dune areas of Iceland (black). The main glaciers providing the melt-water to deliver sediment to the sea are shown in grey. The annual amount of sediment in kg is given for each site (after Gneipsson and El-Mayas, 1994).

Great Britain

Surveys of the sand dunes in Great Britain were undertaken in the late 1980s early 1990s. They were based on standard methods of mapping and classification [in accordance with the National Vegetation Classification (Rodwell, 2000)] of the vegetation. The results will be published in three reports: Vol. II Scotland (Dargie, 1993); Vol. I England (Radley, 1994) and Vol. III Wales (Dargie, 1995).

The surveys were designed to facilitate the selection of sites for conservation designation including Natura 2000, identify 'Ecological Zones' and as a basis for monitoring future change. The results highlighted the enormous diversity of coastal sand dune vegetation, with more than 120 distinct types recorded from right across the spectrum of the National Vegetation Classification. They also illustrated the considerable range of variation that exists between different geographical areas.

The close relationship between dune vegetation and physical processes was a recurring theme in the reports, as was the influence of changing patterns of land use. The report identified four main issues in coastal dune management for nature conservation. These are:

- the importance of understanding the role of instability in dune conservation;
- the need for the management of recreational use;
- the methods for managing successional change;
- and the importance of naturalness.

The Scottish survey, which only covered approximately 30% of the resource has been extended and a complete review of all the sand dunes was completed in 1999/2000.

Spain

In the 10 years up to 1993 a survey of natural sites, land use, conservation instruments, problems and options in Spanish coastal dunes and wetlands was undertaken. Regional reports on Huelva, Valencia and Santander were also completed and published in a students report (Joven, 1993).

Turkey

The dunes of Turkey are extensive and in 1990 in many areas relatively unaffected by human activities other than grazing pressures. Since then the situation has changed considerably with the drive for tourist developments continuing apace. Chronicling the dune areas that survive is being undertaken by Turhan Uslu who helped prepare the original report for Turkey. Information as it becomes available is published on his web site <http://www.turhanuslu.net/anasayfa1.htm> (Screen shot shown below Fig. 4.)

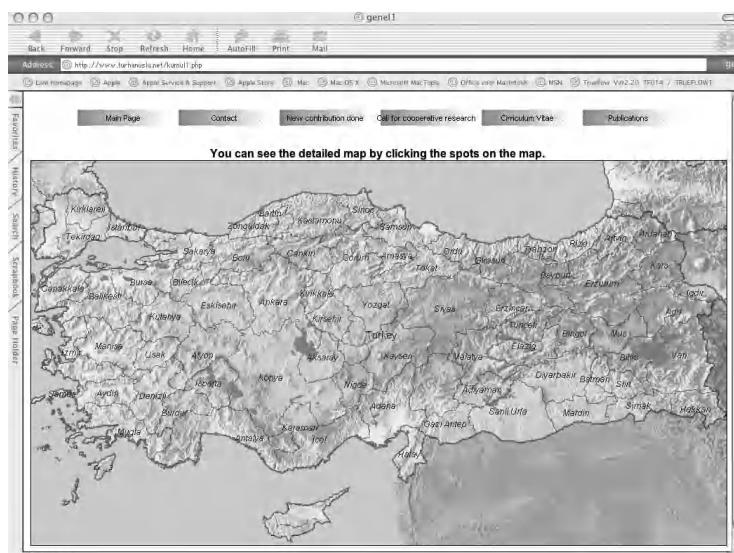


Fig. 4. Distribution of sand dunes in Turkey.

Other surveys

Taken together with detailed surveys of sand dunes in Finland (Hellemaa 1998), Denmark (Brandt and Christensen, 1994), Ireland (Curtis, 1991), and the Atlantic coast of France (Favennec, 1998) there is a wealth of information for many European countries.

Additional sources of information on the sand dunes of Europe (and the rest of the world) can be found in two other publications:

- The World's Coasts: Online edited by Eric Bird
<http://reference.kluweronline.com/?xmlid=2222222222> ;
- Dry Coastal Ecosystems, specifically the volume on polar regions and Europe (van der Maarel E. (Ed.), 1993).

The World's Coast Online is based on The World's Coastline hardbound book (Bird and Schwarz, 1985). It includes detailed information for some countries less for others. The Dry Coastal Ecosystems volume also covers coastlines generally but has a wealth of information on sand dunes embedded within it. Other surveys almost certainly exist but are not known to the author.

Conferences and case studies

Conferences

The first two conferences organised by the EUCC The Coastal Union (as it is now called) were largely concerned with sand dunes. The reader is referred to the conference proceedings for further information (van der Meulen *et al.*, 1989; Carter *et al.*, 1992). Subsequent EUCC conferences covered coastlines more generally but relevant information is still to be found on sand dunes in the following volumes resulting from meetings in Greece (Salman and Bonazountas, 1995/6) and Wales (Healy and Doody 1995; Jones *et al.*, 1996).

In addition to the general conferences there have also been several specialist meetings. Tourism and its effects on dune conservation was a major concern and a meeting was held in Holland in 1995 to consider recreation and planning (Drees, 1997). A further meeting was held to consider the special case of the extensive dune landscapes of Denmark (Ovesen, 1998). These meetings further extended our knowledge and understanding of sand dunes and their management.

Case studies

Three case studies serve to illustrate some significant changes to the way sand dunes have been viewed over the last decade or so. Generally there has been a move away from considering eroding sand dunes as a problem, to one where this is seen as a natural and healing force. Two of these examples are LIFE Nature funded projects, dealt with in more detail by Houston (2005).

The Råbjerg Mile, Denmark

For centuries the exploitation of vegetation in the dune areas of Denmark had helped to create massive movements of sand. In many areas these had become a social catastrophe as the sand covered farmland, farms, houses, roads and churches. In 1792, the country adopted its first Sand Drift Act. in an attempt to prevent the massive movement of sand. This and other laws, together with large plantations in dune areas up to and including the 1950's helped bring sand drift under control. Today there is much more focus on the protection of the natural environment.

Even when the Danish dune area was being afforested the big mobile dune of Råbjerg Mile situated to the north of the country was left unplanted. Today it serves as an example of a natural phenomenon and as an aid to understanding sand drift. The dune front moves at a speed of about 15m per year depending on climate conditions and is drifting out of the governmentally owned area. Discussions are underway with the aim of allowing the natural sand movement to continue with compensation being made to private properties, which will be inundated by the sand. The public has free access to the area by foot, which is actively encouraged and helps maintain the moving dune front (Fig. 5).



Fig. 5. Children enjoying the mobile dune of the Råbjerg Mile. The dune is advancing towards the farmstead visible in the middle distance.

Sefton Coast, north west England

In 1978 in response to a growing awareness of erosion and other management problems on the Sefton Coast dunes a voluntary 'management scheme' was agreed as a partnership between the local authorities and other statutory and voluntary organisations. This evolved into the 'Sefton Coast Partnership'. During the 20 years since its inception

the area has become a key site for the development of management practice in coastal dunes.

A research seminar in 1991 helped lay the foundation for understanding the importance of dune dynamics for habitat sustainability (Atkinson and Houston, 1993). In the early stages of the management scheme control of erosion and recreational use was seen as a key conservation requirement. In 1998 a European seminar provided the culmination of an EU LIFE Nature project (Houston *et al.*, 2001). By this time the message from the conference was clear "dunes are dynamic and the sediment budget is a key to their natural functioning".

The "Sands of Time" web site <http://www.sandsoftime.hope.ac.uk/index.htm> and the web site for the "Sefton Coast Partnership" <http://www.seftoncoast.org.uk/> provide valuable information on current thinking about sand dunes, their conservation and management.

Atlantic coast

The dunes of France, especially along the Atlantic coast, have been subject to intensive and extensive stabilisation over many years. Between 1996 and 2001 an EU LIFE Environment project "The Rehabilitation and Sustainable Management of Four French Dunes" was carried out. This sought to provide management solutions for the sites, which had been incorporated into the Natura 2000 network. It was anticipated these would also have relevance for other "mobile" coastal features in Europe. The final report concluded that:

"Beach and dune coasts are mobile by nature. To continue to benefit from the services they provide, we must accept fluctuations, all too often considered as threats. This option does not exclude rational economic use."

It went on to give a number of general recommendations:

- local management must be placed in a wider context (space and time);
- need for multi-disciplinary networks commensurate with the complexity of the systems;
- use flexible techniques, interfering as little as possible with natural processes;
- management should be cost effective;
- leave space so dunes can provide "complimentary functions";
- transfer knowledge;
- have cross-border cooperation (Favennec, 2002).

Further information can be found on the Office National des Forêts website at <http://www.onf.fr/foret/dossier/littoral/li05.htm> (in French).

Conclusions

Dune landscapes have provided places to study ecological succession, areas of considerable nature conservation significance and in some areas protection from storms.

They have clearly been abused in the past to such an extent that in many areas they have either been completely destroyed or no longer fulfil their landscape, wildlife or sea defence function. They have also helped us understand the importance of dynamic management. As Prof. Bill Carter said at one of the early conferences dedicated to dune conservation “these habitats are not sensitive but robust and designed to accommodate the changes in tides, tidal energy and sediment availability”. It is our desire to prevent them from moving that has caused so much damage.

The projects described above have helped reinforce our understanding of the importance of mobility to the functioning and long term sustainability of dune systems. In so doing they have also laid the foundation for a more proactive approach to sand dune conservation. In this context the value of a dynamic dune, not only for nature conservation, but also in relation to sea defence has been recognised. Encompassed within this is the importance that mobile dunes play in dune restoration.

In recent years a new European view has emerged that respects the value of dune systems to society as natural sea defences, wildlife refuges and recreational areas. This has been further enhanced by other studies such as the recommendations from the EURosion study [Niesing (2005) and <http://euroSION.com>]. This has shown the importance of the interrelations between sand dunes and other sedimentary features. Not least amongst these, is the role of the catchment and factors affecting the sediment delivery and coastal dynamics.

Much has happened to change our understanding of sand dune conservation and management since the publication of the first dune inventory. We now have a much better knowledge of the location of the sand dunes, their vegetation and important sites. A quick trawl through the internet and contact with several of the original contributors to the inventory suggest that much more could be achieved by collating studies carried out over the last 10 years or so. This would help bring the inventory up to date, at least as a baseline for further work. There are also many sites with management and restoration information [see for example <http://members.lycos.co.uk/WoodyPlantEcology/sanddune/> for Sand dune ecology, Copyright © 1999 Pierre Binggeli. All rights reserved]. Adding the additional information on sediments such as that available from Iceland and other sources such as the sand dune section of the Habitat Restoration Guide (Doody and Pamplin, 2003) could form the basis for a major revision of the original inventory.

This paper is as much a plea for offers of help to undertake such a revision, as it is a review of sand dune resource information. If finance, information and collaboration are forthcoming then a revised and expanded inventory is possible. Please contact the author if you can help.

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Purchase of dunes: the first step towards nature restoration along the Flemish coast

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Abstract

In 1997 only 1022ha of the remaining 3800ha of coastal dunes was owned by the Flemish Region. The other 2778ha were mostly private property of real estate development firms, large landowners, individuals and, to a lesser degree, public owned by water collection companies, the Ministry of Defence and a couple of municipalities. The then public owned dunes of the Flemish Region were divided as follows among the different administrations of the Ministry of the Flemish Community: 522ha under competence of the Nature Division, 350ha under that of the Waterways and Coast Division and 150ha under that of the Forestry Division. Most of the areas owned by the Nature Division were already purchased between 1956 and 1990. Lack of personnel, funds and strategic perspective prevented the Flemish Region to pursue an active policy of land purchase along the coast. In 1996 an 'Acquisition Plan for the Coastal Dunes' was drawn up by the Group for Applied Ecology of the University of Antwerp under the supervision of the Nature Division. Parliamentary initiatives, following a political debate organised in the frame of the Life nature project 'ICCI', led to the creation of an 'instrument for the acquisition of coastal dunes' by decision of the Flemish government of 3 February 1998. Since 1998 the 'Instrument for the acquisition of coastal dunes' consists of two members of staff, that were added to the Nature Division, and a special article on the budget of the Flemish government. This budgetary article received an initial annual endowment of EUR 1,735,255 in 1998, EUR 3,222,616 in 1999 and EUR 4,462,083 for each year between 2000 and 2004. That initial endowment has been reduced to EUR 2,546,000 in 2005. A weakness in this financing system is that the possibly annually remaining budget cannot be transferred to the budget of the next year, so that no strategic fund can be built up. The active prospecting by the staff of the Acquisition Instrument has allowed the Nature Division to purchase 480ha of dunes between 1998 and 2004. Nearly all these acquisitions were realised with agreement of the former owner. In execution of the Decree of 21 October 1997 concerning Nature Conservation and the Natural Environment, the right of pre-emption of the Flemish Region has been introduced in most of the legally protected areas of Flanders. In the coastal zone however this right of pre-emption has not led to spectacular results, because of a very strongly fragmented property structure and high ground prices due to land speculation. Although the Acquisition Instrument has obtained very good results, a long way still has to be gone before the goal of public ownership of all remaining coastal dunes will be achieved. Essential improvements of the financial and legal instruments for the purchase of dunes should be the creation of a strategic financial fund, an actualisation of the since long outdated expropriation act and improvement of the right of pre-emption for conservation purposes to be able to fend off land speculation.

Keywords: Dune purchase; Budget; Nature Reserves; Property structure; Legal arsenal.

Context

Flanders has the most urbanised coastline of Europe, north of the Pyrenees and the Alps. In 1870 the total Belgian coastal dune and salt marsh area had a surface area of 6000ha of which today but 3800ha remain. Of this remaining dune surface area 2700ha are designated as 'green areas' in the framework of the spatial planning legislation and 1100ha, previously designated as urban, recreational, military or agricultural area, are protected within the framework of the decree on the protection of the coastal dunes of 14 July 1993. This remaining surface area of coastal dunes is spatially strongly fragmented into an archipelago of relatively small not-built-upon areas in an urban and suburban sea of buildings and roads. Nevertheless, the coastal dunes still possess a very important scientific value, due to the occurrence of coast-related gradients in their physical environment and a specific biological diversity that does not occur elsewhere in Flanders. In spite of the above mentioned legal protection of the remaining coastal dune areas, their littoral-related high biological diversity is still under great threat from:

- the further nibbling off of the remaining dune surface area by the expansion of the surrounding suburban gardens;
- the disturbing border effects on the too small remaining dune sites;
- the extinction of the traditional pastoral use of the coastal dunes;
- the lowering of the groundwater level by the extraction of groundwater for the supply of drinking water and by city sewers that have a draining effect;
- the increase of fall-down of pollutants and
- a too high recreational pressure.

The largest part of the remaining surface area of the dunes and salt marshes along the Flemish coast was designated as Special Protection Area (SPA) in execution of the 'European Bird Directive' 79/409/EEC and as Special Area of Conservation (SAC) in execution of the 'European Habitat Directive' 92/43/EEC. Thus, the maintenance and restoration of the biological diversity of the coastal natural areas by an appropriate management are an international responsibility for the Flemish regional authority.

The purchase and subsequently the designation and management as nature reserves of the remaining coastal natural areas is the most appropriate way for the Flemish Region to implement this international responsibility, because of:

- the poor agricultural quality of dune soils;
- the very high scientific value and the fragility of the natural habitats that are typical for the natural environment of the coast, amongst which two priority habitats of the annex 1 of the European Habitat – Directive, more precisely 'Fixed coastal dunes with herbaceous vegetation' ("grey dunes") and 'Eu-Atlantic decalcified fixed dunes (Calluno-Ulicetea)';
- the rather radical character of the management measures that have to be taken to maintain or restore coastal habitats (removal of scrub and exotic tree-plantations, year-round grazing without additional nourishment, cutting off sods, removal of vegetation and soil-layers to restore sand-drift, demolition of abandoned buildings and roads etc.);
- the need of educational and recreational facilities in the coastal dunes that are visited by high numbers of tourists as well as by local inhabitants;

- the rather limited surface area of the remaining coastal dunes or the scarcity of the coastal dune – environment (3800ha is a smaller surface area than this of the Zonië forest near to the city of Brussels).

Review of the acquisition of dunes for nature conservation purposes between 1956 and 1997

The first series of acquisitions of coastal dunes for nature conservation aims by the national authority (at that time: the Belgian State) took place in the years 1956-1965. These land purchases concerned the area that was designated by royal decree in 1957 as the State Nature Reserve ‘De Westhoek,’ at De Panne, and the following expansions, with a total surface area of 346ha. Between 1965 and 1997 the Belgian State and its legal successor after the institutional reform, the Flemish Region, purchased ‘de Hoge Blekker’ at Koksijde (18ha, several acquisitions between 1980 and 1984), ‘Hannecartbos’ at Oostduinkerke (32ha in 1981), ‘de Karthuizerduinen’ at Oostduinkerke (6ha in 1983), ‘de Houtsaeegerduinen’ at De Panne and Koksijde (80ha, several acquisitions between 1988 and 1990), the domain of the ‘Children’s home Georges Theunis’ at Oostduinkerke (16ha in 1994), ‘de IJzermonding’ at Nieuwpoort (7ha, acquisitions between 1985 and 1989) and ‘D’Heye’ at Bredene (13ha, in 1997), all adding up to a total of 172ha. In the same period several smaller parcels with a total surface area of 4ha that are situated in different dune sites were also bought. In 1997 the property situation of the remaining coastal dune area (with a total superficy of 3800ha) consisted of:

- 522ha owned by the Flemish Region and managed by the Nature Division;
- 150ha owned by the Flemish Region, managed by the Forestry Division;
- 350ha owned by the Flemish Region, managed by the Waterways-Coast Division, competent for coastal defence;
- 2778ha that were property of essentially private owners and real estate firms, and to a lesser degree, also of other public owners such as the Ministry of Defence, water supply companies, municipalities etc.

To achieve that, within a term of about twenty years from 1997 on, the totality of the 2778ha remaining area of coastal dunes and salt marshes would be public property of the Flemish Region, annually a surface area of 139ha should be purchased. Since between 1965 and 1997 only 176ha of dunes have been acquired, the annual rate of dune acquisitions in this period was 5.5ha (= 176ha/32 years). As the enumeration of historical acquisitions given above shows, we see that in reality the purchase-rate then had a much more erratic character, because of the fact that some years a ‘large’ piece of land could be bought when the opportunity offered itself and other years there were no acquisitions at all. The very slow progression of the acquisition of coastal dunes by successively the Belgian State and the Flemish Region during the period 1965-1997 had several causes:

- the lack of active prospecting by the competent services of the public authority towards landowners who were prepared to sell their property;
- the lack of financial means of the competent services of the public authority;
- the strong real estate speculation by a lot of landowners and developers, resulting in a general lesser readiness to sell land for reasonable prices.

Acquisition Instrument for the Coastal Dunes

The need for a more determined policy of purchase of coastal dunes was the subject of a symposium that was organised in April 1997 in the context of the Life Nature project 'Integral Coastal Conservation Initiative' (ICCI). A comparison between the slow progress in dune purchase by the Flemish Region in Flanders (at that time) with the impressive achievements of the French state-institution 'Conservatoire de l'Espace Littoral et des Rivages Lacustres' in France was then the object of a debate between representatives of different political parties. This symposium led members of the Flemish Parliament of different political parties to introduce a legal proposal to create an acquisition instrument for the maritime dune region. This parliamentary initiative had as a consequence that the Flemish government decided on 3 February 1998 to reserve a special article on its annual budget on behalf of the purchase of land in the maritime dune region. The financial endowments of that 'dune acquisition'-article amounted to:

in 1998: 70.000.000 Belgian francs, equivalent of EUR 1,735,254.67;

in 1999: 70.000.000 Belgian francs, equivalent of EUR 1,735,254.67;
after budget control BEF 130,000,000, equivalent of EUR 3,222,615.82;

in 2000: BEF 180,000,000, equivalent of EUR 4,462,083.45
after budget control BEF 110,500,000, equivalent of EUR 2,739,223.45;

in 2001: BEF 180,000,000, equivalent of EUR 4,462,083.45
after budget control BEF 86,000,000, equivalent of EUR 2,131,884.31;

in 2002: EUR 4,462,000.00
after budget control EUR 6,747,000

in 2003: EUR 4,462,000.00
after budget control EUR 1,428,000

in 2004: EUR 4,529,000.00
after budget control EUR 2,600,000

in 2005: EUR 2,546,000.00

The effectively allocated amounts are:

in 1998: BEF 70,000,000, equivalent of EUR 1,735,254.67;
in 1999: BEF 119,193,683, equivalent of EUR 2,954,734.22;
in 2000: BEF 86,200,000, equivalent of EUR 2,136,842.18;
in 2001: BEF 83,700,000, equivalent of EUR 2,074,868.80;
in 2002: EUR 6,715,267.00;
in 2003: EUR 1,192,034.12;
in 2004: EUR 2,598,760.07;

As the opportunities for voluntary acquisition are quite variable from year to year, some years the financial endowment can by far not be completely used, while other years it is far from sufficient to financially cover especially 'large' (and expensive) acquisitions, such as, for example, the purchase in 2002 of 'the Zwindunes and polders', with a total surface area of 222ha. The decision of the Flemish government of 3 February 1998 postulated that a regulation had to be worked out to permit the transfer of the annual balance between the endowment and the effectively allocated amount from one budget year to the following one. Such a regulation would have allowed to build up a strategic financial fund. However this part of the above-mentioned decision of the Flemish government was never executed.

The acquisition instrument for the coastal dunes consists, besides of an article on the budget of the Flemish government, also of an administrative entity, counting two members of staff, within the Coastal Conservation Unit of the Nature Division of the Ministry of the Flemish Community. These two members of staff are charged with:

- prospecting towards as well as negotiating with the sale-willing landowners;
- giving instructions to the acquisition committee of the Ministry of Finance that is competent for the appraisal of land value and the drawing up of the deeds of sale;
- the preparation and follow up of the administrative files for the provision of the financial funds that are necessary for the purchases;
- the preparation and follow up of the ministerial orders to designate the purchased grounds as Flemish Regional Nature Reserve and the ministerial orders for the approval of the management plans of these new nature reserves;
- the preparation and follow up of the files concerning the indemnity claims of landowners whose former building land is no longer suitable for building because of the construction ban in the frame of the decree on the protection of the coastal dunes of 14 July 1993.

To help establish the priority for purchase of the remaining dune sites, the Acquisition Instrument has two scientific reference works at its disposal:

- the 'Ecosystem Perspective for the Flemish Coast' (Provoost *et al.*, 1996) that gives orientations for possible nature development and
- the 'Acquisition Plan for the Coastal Dunes and Adjacent Areas along the Flemish Coast' (De Loose *et al.*, 1996) that contains a priority classification of the dune areas, based on scientific criteria.

Achievements of the Acquisition Instrument for the Coastal Dunes

Thanks to the reserved endowments and specialised staff of the Acquisition Instrument for the Coastal Dunes, the Nature Division of the Flemish Regional Authority acquired 480ha of dunes during the period 1998-2004. This means that the rate of dune acquisition has increased from an annual average purchased surface area of 5.5ha during the period 1965-1997 to about 69ha during the period 1998-2004 (Fig. 1. Coastal dunes purchased by the Ministry of the Flemish community and managed by the nature division, from 1956 up to 2004 inclusive; map 1a-c, cf. end of paper).

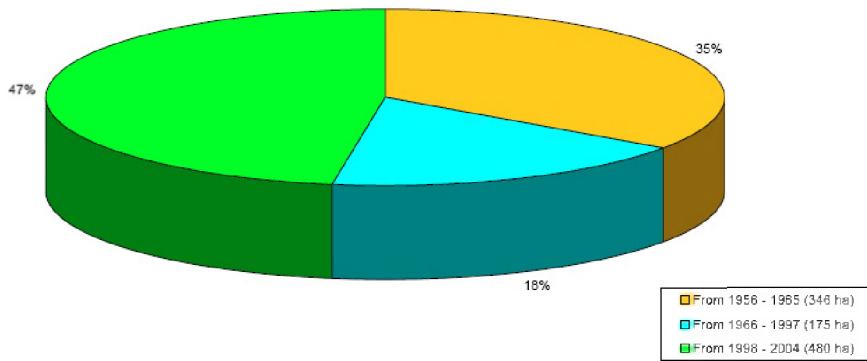


Fig. 1. Coastal dunes purchased by the Ministry of the Flemish community and managed by the nature division, from 1956 up to 2004 inclusive (situation 01/01/2005).

From a patrimonial and managerial point of view essential land acquisitions that were finalised in the period 1998-2004 are (in order of their geographical location, from west to east, rounded off figures of superficies):

- expansion of the domain 'De Westhoek', at De Panne: 22ha;
- acquisition and expansion of 'Het Garzebekeveld', at De Panne: 15ha;
- acquisition of 'De Duinzoom Oosthoek', at De Panne: 20ha;
- expansion of the domain 'De Houtsaeerduinen' with 'Kerkepannebos', at De Panne en Koksijde: 7ha;
- acquisition of 'De Fluithoek', at Koksijde: 13ha;
- acquisition of 'De Noordduinen', at Koksijde: 45ha;
- acquisitions in 'De Doornpanne', at Koksijde: 12ha;
- acquisitions in 'Het Schipgat', at Koksijde: 14ha;
- expansion of the domain 'Ter Yde', at Koksijde, Oostduinkerke: 40ha;
- acquisition in 'Labeurhoek', at Koksijde, Oostduinkerke: 8ha;
- acquisition of the domain Groenendijk (former wastewater treatment plant), at Nieuwpoort: 5ha;
- expansion of the domain 'De Ijzermonding' by acquisition of the former military harbour of Lombardsijde, at Nieuwpoort: 29ha;
- expansion of the domain 'D'Heye', at Bredene: 8ha;
- acquisition of 'De Zwinduinen en -polders', at Knokke: 222ha.

The conclusion about the results of the Acquisition Instrument for the Coastal Dunes is that since its creation in 1998 a huge progress has been made in the purchase policy of

the Flemish Region and the expansion of her public domain along the coast. (Situation on 01/01/2005: Fig. 2. Property structure of the coastal dunes; map 2a-c, cf. end op paper).

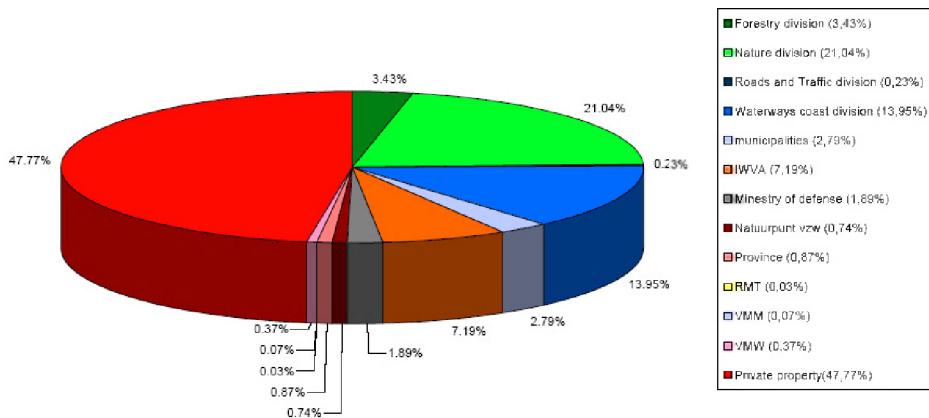


Fig. 2. Property structure of the coastal dunes (situation 01/01/2005).

First step towards management

The Coastal Conservation Unit of the Nature Division of the Flemish regional authority is competent not only for the purchase of natural areas, but also for the legal designation of public owned land as Flemish Regional Nature Reserve and the planning as well as the execution of the management of these nature reserves. From the moment that the purchased parcels of land constitute a large enough and coherent area of several hectares, the Nature Division starts to draw up a management plan. After having been the object of discussion in the management committee of the nature reserve and having received the legally obligatory advise of the Flemish High Council for Nature Conservation, these management plans have to be approved by order of the Flemish minister competent for nature conservation.

Table I. Review of the domains in the maritime dune region that stand under the care of the Nature Division, whether or not they (already) have the legal status of Flemish Regional Nature Reserve (FNR) (cf. map 3a-c, end of paper) – phase of planning and execution of management (situation 01/01/2005)

Name of the domain and municipality	Management Plan	Phase of execution of management plan
De Westhoek at De Panne 340ha 27a 31ca FNR: Yes - MO of designation: 08/29/1957 MO of extension: 12/14/2001	Yes approved by MO of 05/09/1996	Completely executed (partially co-funded by Life-project ICCI)
De Houtsaeerduinen at De Panne and Koksijde 86ha 18a 42ca FNR: Yes - MO of designation: 12/27/1989 MO of extension: 12/14/2001	Yes approved by MO of 05/09/1996	Completely executed (partially co-funded by Life-project ICCI)
Duinzoom Oosthoek at De Panne 19ha 10a 21ca FNR: Yes - MO of designation: 07/23/2001	In elaboration	A nature arrangement project was executed on the field
The three above mentioned Nature reserves were consolidated into a new one known as De Duinen en Bossen van De Panne at De Panne and Koksijde and subsequently extended 539ha 03a 40ca MO of consolidation : 05/24/2004 MO of extension: 07/13/2004	In elaboration	-
Several domains at De Panne managed by the Nature Division: 21ha 43a 10ca FNR: Not yet	Not yet	Urgency measures taken
Belvédère at Koksijde 6ha 94a 06ca FNR: Yes - MO of designation: 05/21/1999	Yes approved by MO of 09/04/2000	Completely executed
De Noordduinen at Koksijde (59ha 21a 73ca) 13ha 63a 13ca FNR: Yes - MO of designation: 11/12/2002 45 ha 58 a 60 ca FNR: Not yet (purchased in 2004)	Not yet	A Nature Arrangement Project is in execution

Name of the domain and municipality	Management Plan	Phase of execution of management plan
Het Schipgat, De Doornpanne en De Hoge Blekker at Koksijde (46ha 59a 59ca) 43ha 53a 16ca FNR: Yes - MO of designation: 05/21/1999 MO of extension: 04/03/2000 MO of extension: 12/14/2001 3ha 06a 41ca FNR: Not yet (purchased after 2001)	Yes approved by MO of 12/27/2001	In execution
Ter Yde at Koksijde (65 ha 65 a 63 ca) 59ha 07a 91ca FNR: Yes - MO of designation: 10/29/1998 MO of extension: 09/27/2001 6ha 57a 72ca FNR: Not yet (purchased after 2001)	Yes approved by MO of 06/25/2003	In execution (co-funded by the Life-projects ICCI and FEYDRA)
Hannecartbos at Kokijde 31ha 88a 35ca FNR: Yes - MO of designation: 02/01/1989 25 a FNR: No	Yes Approved by MO of 06/10/1999 (co-funded by the Life-project ICCI)	In execution (co-funded by the Life-project FEYDRA)
De Labeurhoek at Koksijde 8ha 06a 20ca FNR: Not yet (purchased in 2004)	Not yet	-
Several dune parcels at Koksijde: 92a 35ca FNR: Not yet	Not yet	-
De Simliduinen at Nieuwpoort 49a 67ca FNR: Not yet	Not yet	-
Groenendijk at Nieuwpoort 4ha 96a 55ca FNR: Not yet (purchased in 2002)	Not yet	Nature restoration works in execution (Co-funded by Life-project FEYDRA)
De IJzermonding at Nieuwpoort 127ha 88a 16ca FNR: Yes - MO of designation: 03/03/1999	In elaboration	Nature restoration works completely execution (Co-funded by Life-project ICCI)

Name of the domain and municipality	Management Plan	Phase of execution of management plan
Dunes of the military domain 'Kamp Kwartier Lombardsijde' at Nieuwpoort 30ha FNR: No	Yes	In execution
De Schuddebeurze at Middelkerke 4a 48ca FNR: No	Not yet	Urgency measures taken
D'Heye at Bredene and De Haan (21ha 12a 16a) 13ha 16a 38ca FNR: Yes - MO of designation: 07/08/1998 7ha 95a 78ca FNR: Not yet (recently purchased)	Yes approved by MO of 04/03/2000	In execution
De Baai van Heist at Knokke Heist 57ha FNR: Yes - MO of designation: 10/22/1997	Yes approved by MO of 07/13/2000	Completely executed
De Sashul en de Vuurtorenweiden at Knokke-Heist 17ha 12a 06ca FNR: No	Nature development plan was elaborated (1998)	The development plan was completely executed
De Zwinduinen en -polders at Knokke-Heist (222ha 11a 46ca) 221ha 68a 49ca FNR: Yes - MO of indication: 12/02/2003 42a 97ca	In elaboration	Urgency measures taken

This table shows clearly that since the creation of a special staff unit in 1998 the planning and execution of the management of the Flemish Regional Nature Reserves along the coast keeps pace with the purchase of land. In 2004 the municipality of De Panne entrusted the management of the nature domain 'Oosthoekduinen' that she owns (about 60ha) to the care of the Nature Division of the Flemish regional authority. As the management plans for the regional nature reserves 'De Westhoek' and 'De Houtsaegerduinen' have already been completely executed, the above mentioned municipal domain, as well as both given nature reserves and other nature domains owned by the Flemish Region on the territory of De Panne were legally united by ministerial order of 24 May 2004 in the Flemish Regional Nature Reserve 'De Duinen en Bossen'

van De Panne' (meaning 'The Dunes and Woods of De Panne'), with a total surface area of 539ha. For a technical description of the management of the regional nature reserves we refer to Herrier *et al.*, 2005 and Leten *et al.*, 2005).

Difficulties concerning the acquisition of the coastal dunes along the Flemish coast

Highly fragmented property structure

During the years 1930-1950 several important dune areas, especially on the territory of the municipalities Oostduinkerke and Nieuwpoort, were divided by real estate developers into numerous small lots, that subsequently were sold as housing estates to private individuals. Many of these private allocations never got a regular grant from the competent authorities and became totally obsolete after the Law of 29 March 1962 on the Town and Country Planning came into effect. These dune sites, that only had been allocated on paper, were afterwards designated as 'nature areas' on the zoning plans. They often also received international protection statuses in the frame of the European Bird- and Habitat-directives. Of course the highly fragmented property structure of the concerned dune sites makes their acquisition by the Flemish Region very difficult, given the fact that every single parcel has to be purchased separately so that negotiations with hundreds of different private owners are necessary. To give an idea of this difficulty, the example can be mentioned of one site with a surface area of only 32ha that is divided into 244 lots owned by 334 different individuals.

Persistence of real estate speculation

The coast is also from a tourist point of view the most important region of Flanders and this fact has its consequences on the real estate market. Although all remaining coastal dune areas are now legally protected, speculations about possibilities for real estate development persist among some private dune owners. These speculations involve that the readiness of dune owners to sell their dunes to public authorities for reasonable prices is limited. Real estate speculations have even been wrongly encouraged by the recent general liberalisation of the restrictions on building possibilities in rural areas, though the regulations on this point in 'spatially fragile areas', such as 'nature areas', 'protected dune areas' and 'agricultural areas of importance for the dunes', remained unchanged and very restrictive. Nevertheless some people are willing to pay high prices for small dune farmhouses or to enlarge their back-gardens with a parcel of dunes. Luckily the legislation prohibits the alteration of dune vegetation and those who have purchased one (or more) dune parcel(s) to enlarge their back-gardens should be aware of all the legal obligations as a result of the different protection statuses. Nevertheless speculation has a bad influence on the prices of land so that the average price for protected coastal dunes often amounts to the double of this for woodland or even agricultural land in the interior of the country.

Shortcomings in the legal arsenal for purchase of coastal dunes

Weakness of the right of pre-emption

Since the delimitation of on the one hand the expansion zones of several existing Flemish Regional Nature Reserves in 1999 and on the other hand the Flemish Ecological Network (Dutch abbreviation: VEN) in 2003, most of the legally protected coastal dune areas are subjected to the right of pre-emption of the Flemish Region by virtue of the Decree of 21 October 1997 on Nature Conservation and the Natural Environment. The right of pre-emption of the Flemish Region is exercised by the Flemish Land Agency (Dutch abbreviation: VLM) after advice of the Nature Division. Although the largest part of the dunes between the French border and Westende falls under the field of application of the right of pre-emption, in a period of five years since 1999, no more than seven parcels scattered over four separate dune sites with a total surface area of only 2.7ha have been acquired by means of the mentioned legal instrument. The main cause of this limited success of the right of pre-emption is the fact that most of the dune parcels that are the object of transactions concern rather small lots containing (former farm-) houses or other buildings or otherwise lots adjacent to buildings. Therefore the offered prices are often speculatively high. It is also to be regretted that the areas that have been designated as 'agricultural area of importance for the dunes' in the frame of the decrees on the protection of the dunes, are not subjected to the right of pre-emption of the Flemish Region. These areas concern the part of the Maritime Dune Region where the land prices are still relatively low and where the right of pre-emption would have had the highest chance of success. The agricultural importance of the poor sandy soils of these areas is in most cases marginal and still further declining or even extinct, so that the desirability of a change of the spatial destination from 'agricultural' to 'nature area' seems quite obvious. At present the area of application of the right of pre-emption for nature conservation purposes is restricted to 'green areas' and 'protected dune areas' that are situated within the Flemish Ecological Network. Nevertheless it is necessary to widen that field of application to all areas that are protected in execution of the decrees on the protection of the dunes, also those situated outside the Flemish Ecological Network.

Obsolete legal frame for expropriation procedures

The article 41 §1 of the decree of 21 October 1997 on Nature Conservation and the Natural Environment gives the legal opportunity to the Flemish Region and the Municipalities to expropriate real estate for nature conservation purposes. Since the fragmentation of the property structure and a lack of sell-readiness of the dune owners are two main obstacles for the rapid acquisition of some dune areas that have a high priority of acquisition, it is then often asked why the Flemish Region does not utilise that expropriation instrument more to facilitate her dune purchase policy. The main reason for the restraint of the Flemish Region to use the expropriation instrument on behalf of nature conservation is the absence of an appropriate legal frame for expropriation procedures. The procedure laid down in the original Law of 17 April 1835 (sic) on the expropriation in the public interest is so intricate that she has fallen in general disuse. Furthermore, this procedure is not much use for nature conservation purposes as she

implies a concrete plan of the works that has to be subjected to a preliminary public inquiry, while the acquisition of a nature site in the short term not always aims at the execution of works. The more recent Law of 26 July 1962 concerning expropriations in the public interest and concessions for the building of motorways (sic) requires great urgency as a condition for application. This 'great urgency' of expropriations on behalf of nature conservation has often been successfully contested by the lawyers of expropriated landowners before court. Besides nature conservation also other matters of public interest (social housing, public works,...) have the need of a more appropriate legal frame for expropriation procedures. To solve this problem, an initiative on the level of the federal legislator has to be taken.

Conclusions

The creation in 1998 of the Acquisition Instrument for the Coastal Dunes within the Nature Division of the Ministry of the Flemish Community has resulted in the expansion of the Flemish regional public domain along the coast with 480ha in seven years. This means that an enormous increase of the rate of dune acquisition has occurred from an annual average of 5.5ha during the period 1965-1997 or 13ha during the period 1956-1997, to an annual average of 69ha during the period 1998-2004. In spite of this large increase in surface area that has to be managed by the Coastal Conservation Unit of the Nature Division, the planning and execution of the management of the Flemish Regional Nature Reserves along the coast keeps pace with that increase. Hopefully these encouraging results will lead the Flemish government to continue its coastal dune purchase policy by maintaining the necessary financial means and staff. However there is still a long way to go before all the coastal dunes and salt marshes that today still are private property or military training ground will be definitively set safe as public domain. In this respect, improvements of the expropriation legislation and the right of pre-emption for nature conservation purposes could prove useful.

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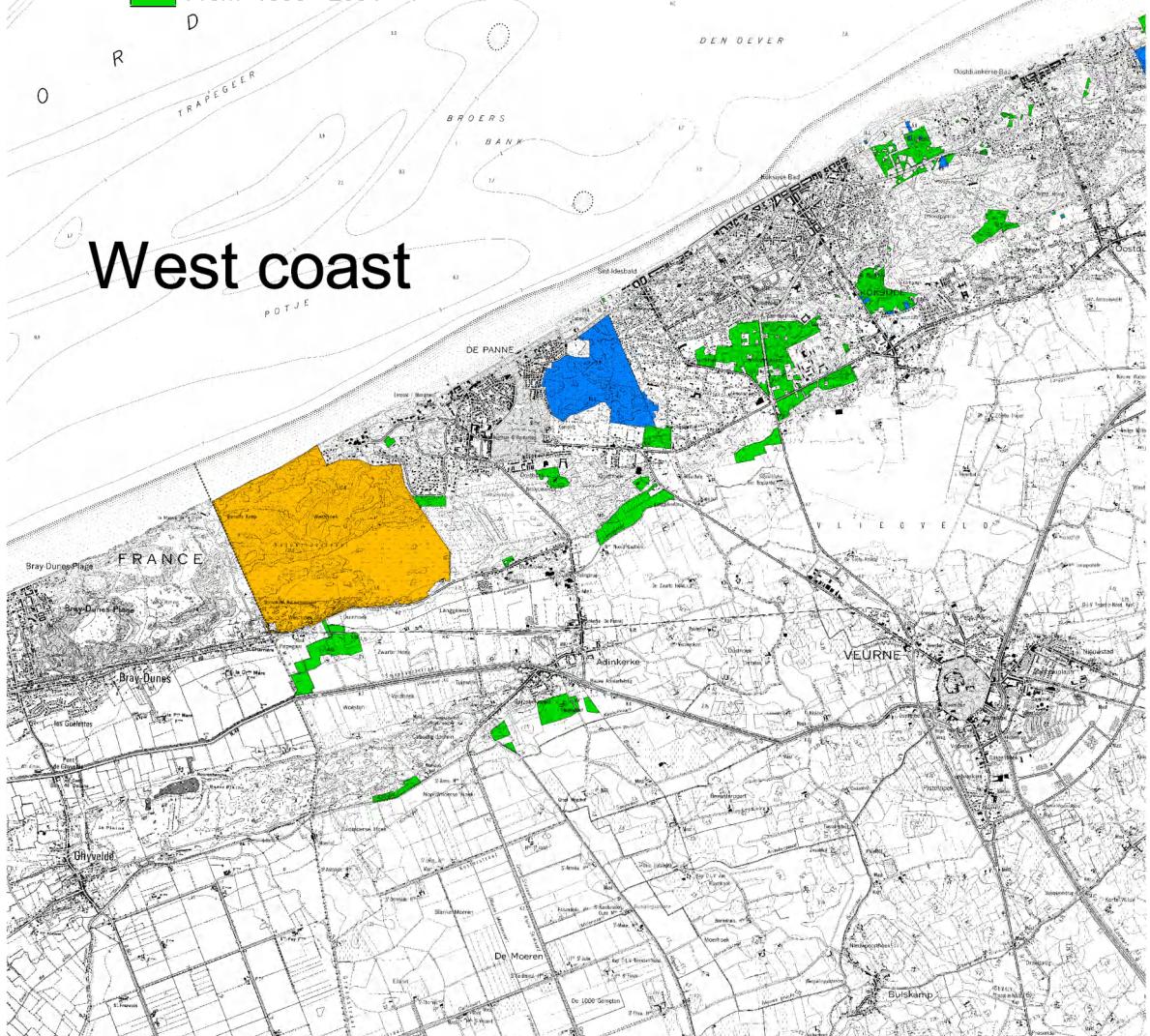
MAPS

Map 1a
Coastal dunes purchased by the Ministry of the
Flemish community and managed by the nature
division, from 1956 up to 2004 inclusive
(situation 01/01/2005)

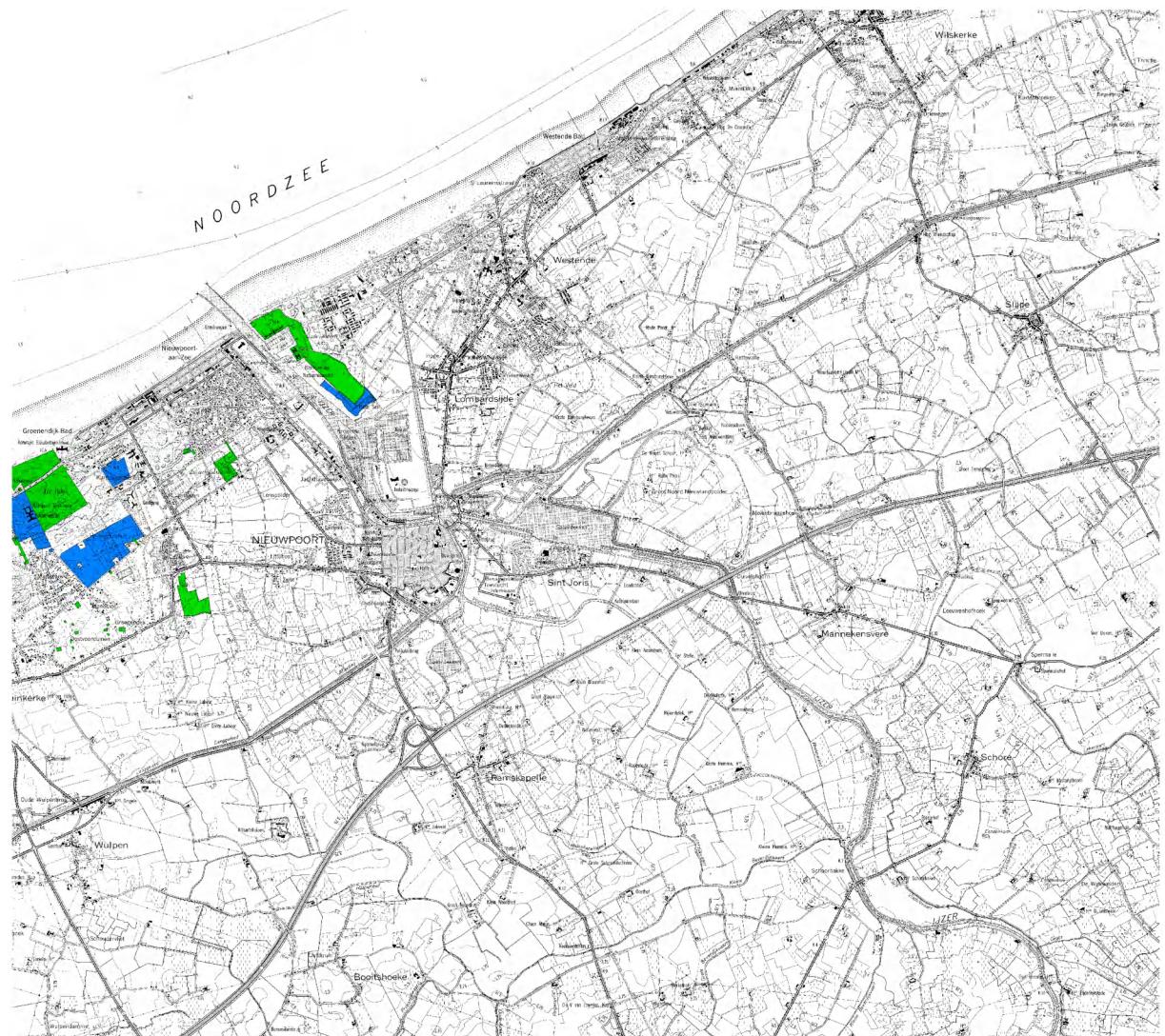
Legend:

- █ From 1956 - 1965
- █ From 1966 - 1997
- █ From 1998 - 2004

West coast



1 0 1 2 Kilometers



Map 1b

Coastal dunes purchased by the Ministry of the Flemish community and managed by the nature division, from 1956 up to 2004 inclusive
(situation 01/01/2005)

Legend:

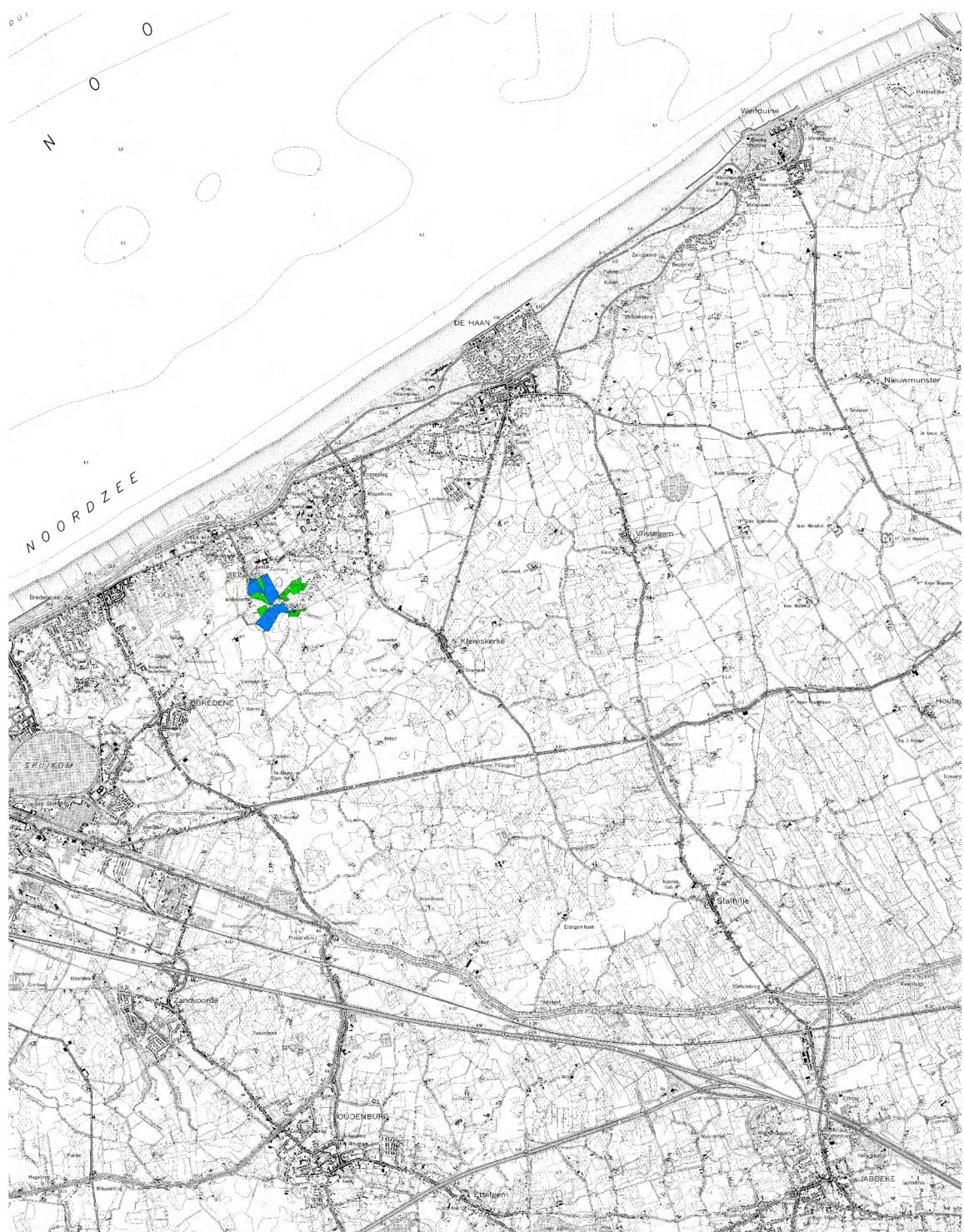
- █ From 1956 -1965
- █ From 1966 - 1997
- █ From 1998 - 2004

Central coast



1 0 1 2 Kilometers





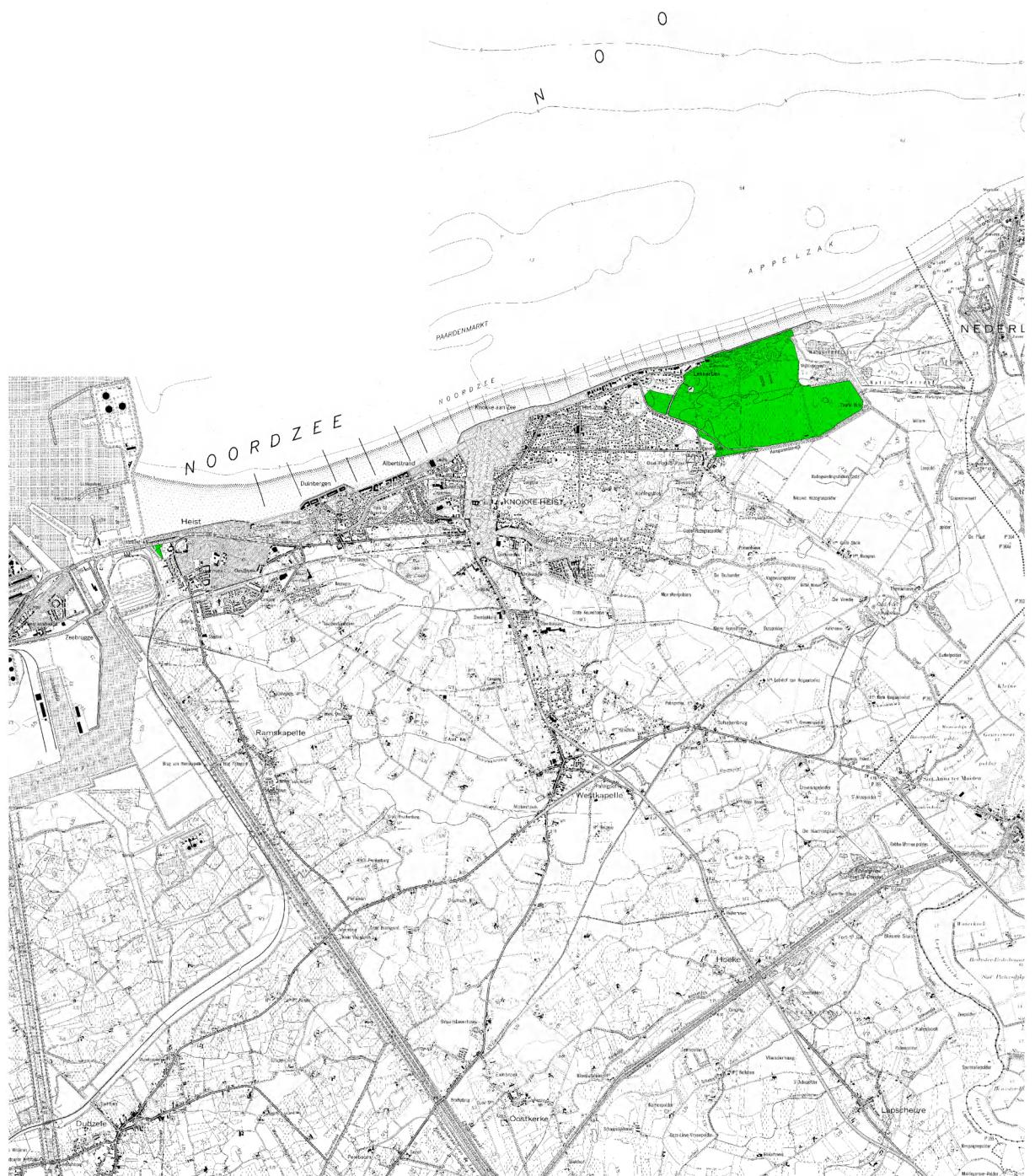
Map 1c
Coastal dunes purchased by the Ministry of the
Flemish community and managed by the nature
division, from 1956 up to 2004 inclusive
(situation 01/01/2005)

Legend:

- █ From 1956 -1965
- █ From 1966 - 1997
- █ From 1998 - 2004



1 0 1 2 Kilometers



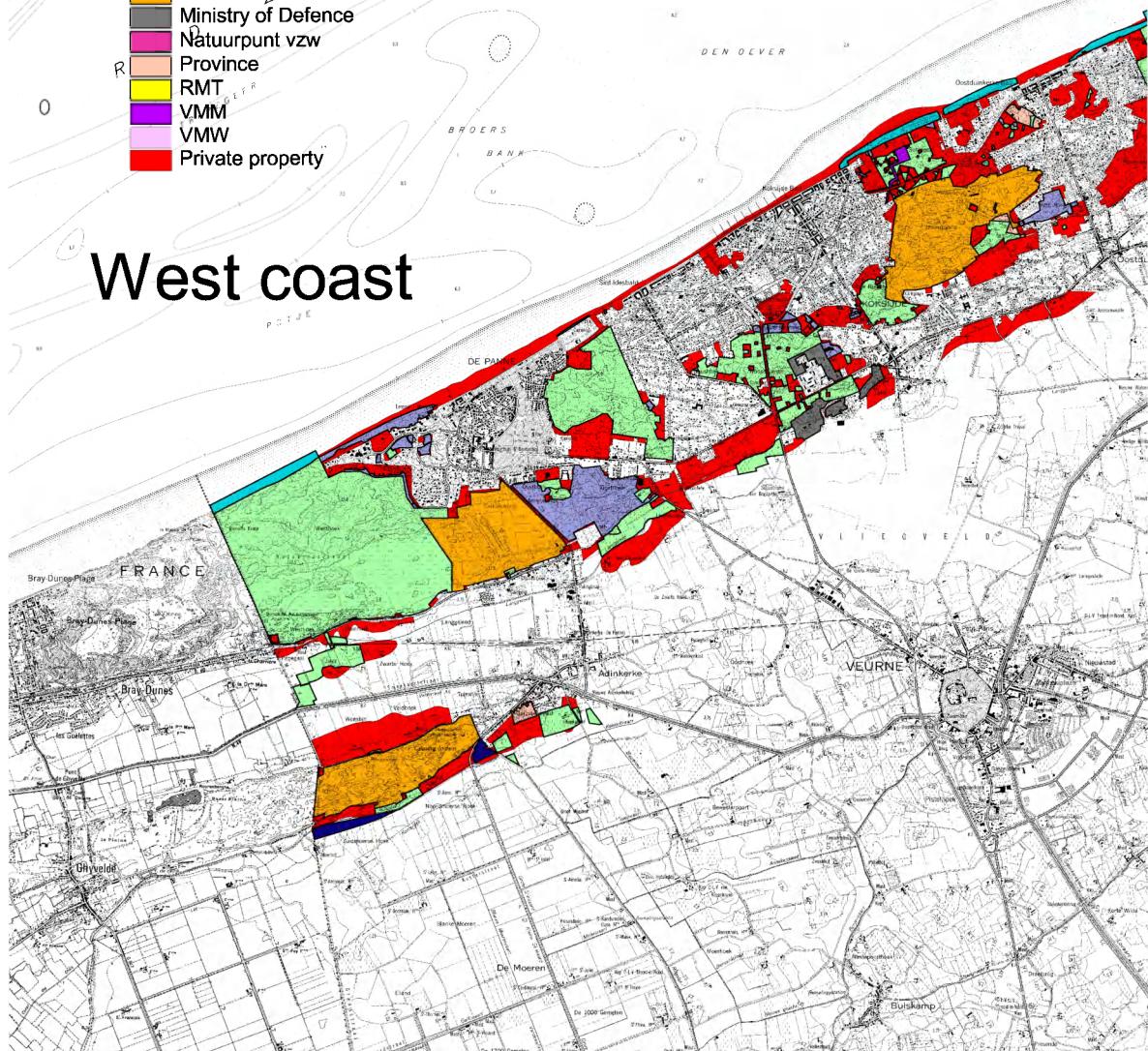
Map 2a

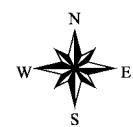
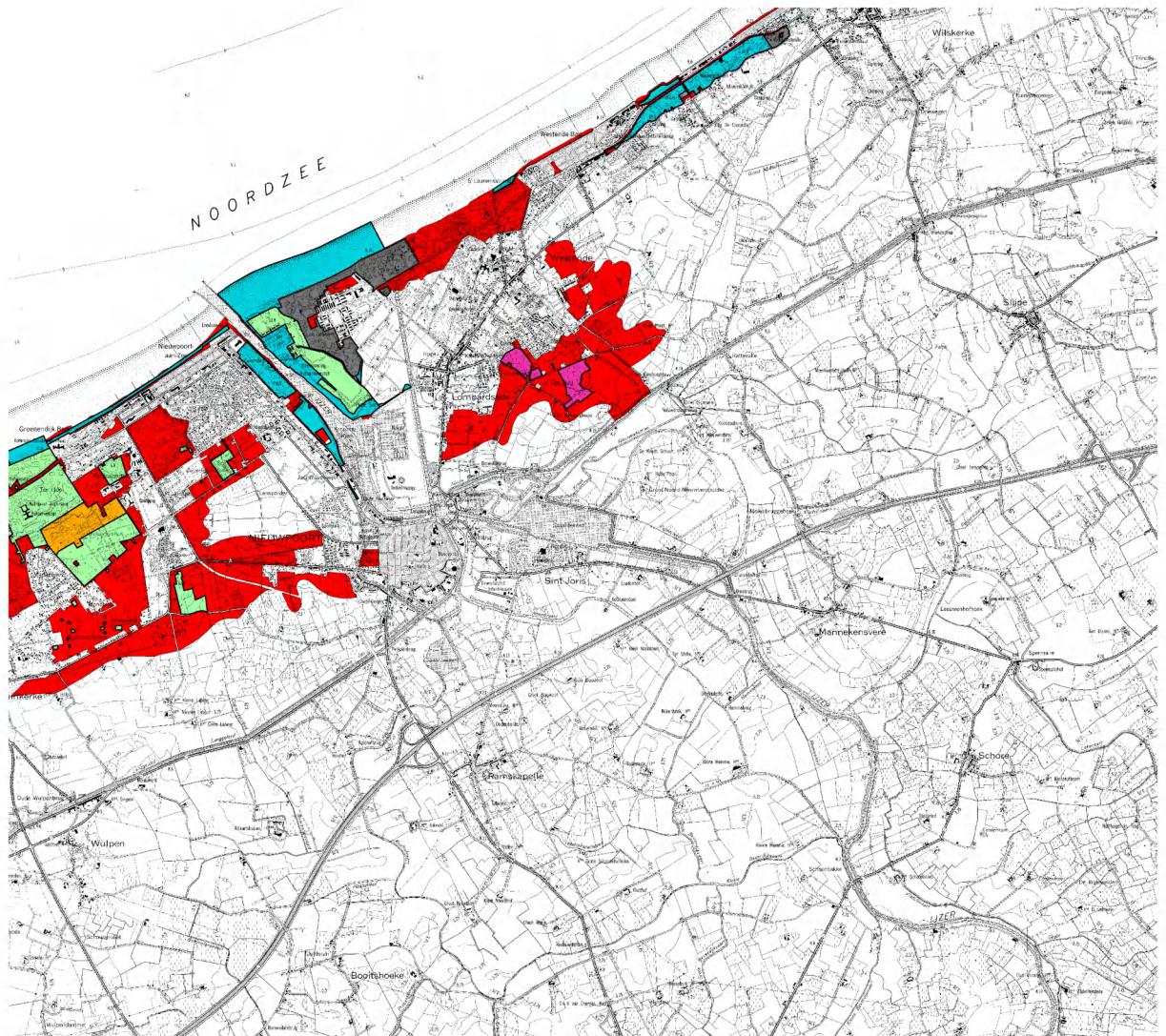
Property structure of the coastal dunes (situation 01/01/2005)

Legend:

- Forestry Division
- Nature Division
- Roads and Traffic Division
- Waterways-coast Division
- municipalities
- IWVA
- Ministry of Defence
- Natuurpunt vzw
- Province
- RMT
- VMM
- VMW
- Private property

West coast





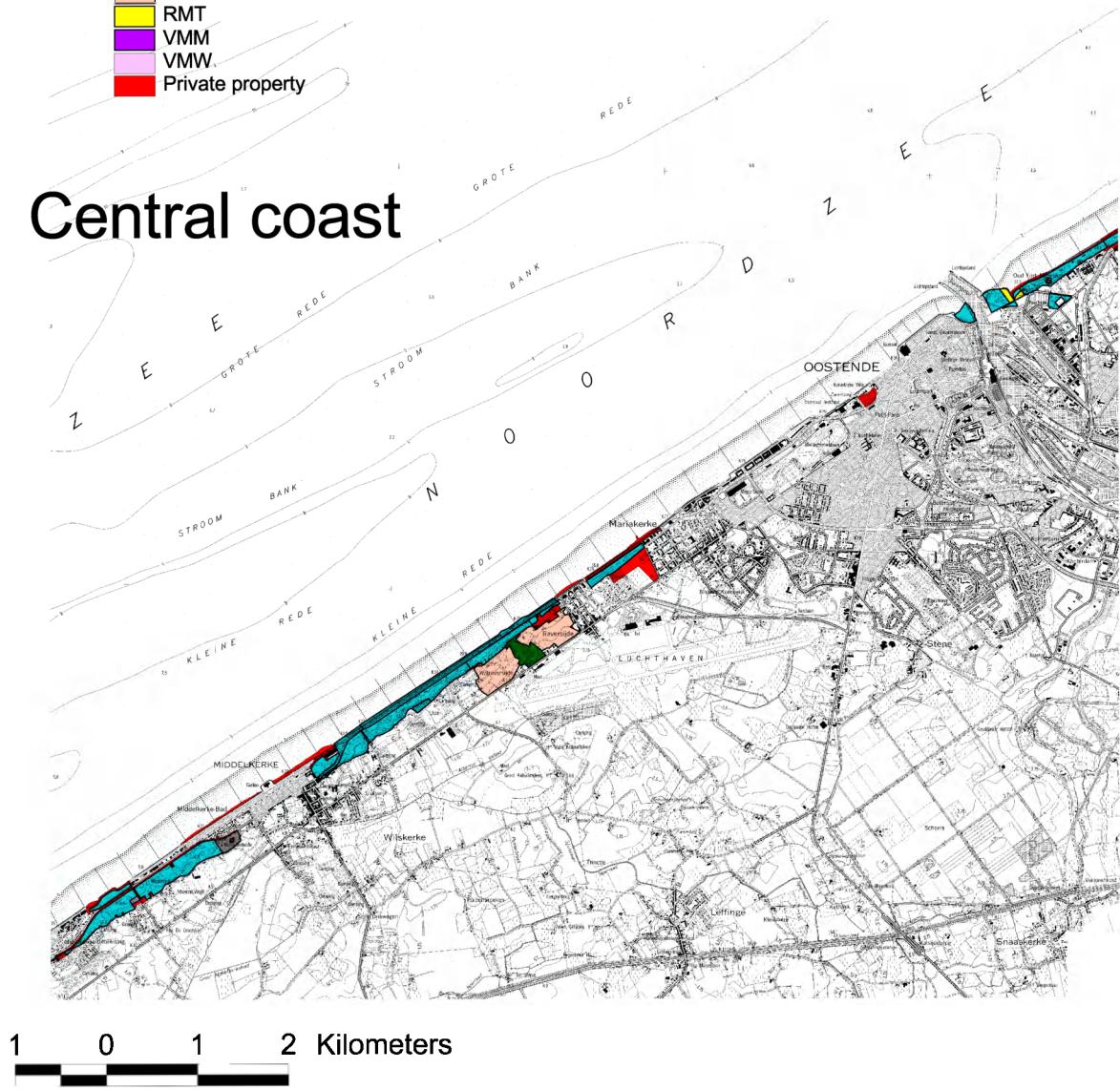
Map 2b

Property structure of the coastal dunes (situation 01/01/2005)

Legend:

- [Green square] Forestry Division
- [Light green square] Nature Division
- [Dark blue square] Roads and Traffic Division
- [Cyan square] Waterways-coast Division
- [Purple square] municipalities
- [Orange square] IWVA
- [Grey square] Ministry of Defence
- [Pink square] Natuurpunt vzw
- [Light orange square] Province
- [Yellow square] RMT
- [Magenta square] VMM
- [Light pink square] VMW
- [Red square] Private property

Central coast



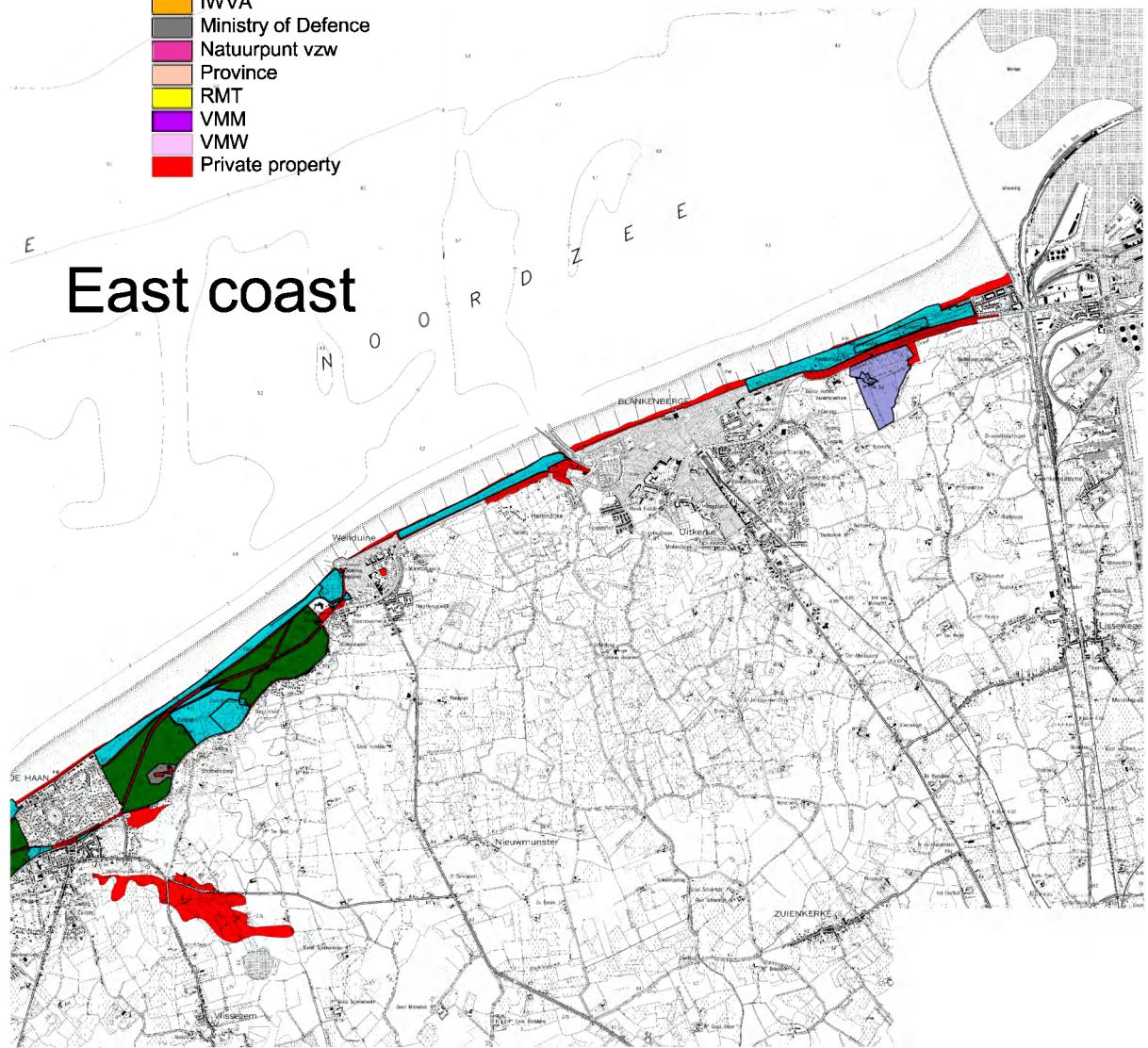


Map 2c

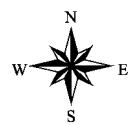
Property structure of the coastal dunes (situation 01/01/2005)

Legend:

- [Green square] Forestry Division
- [Light green square] Nature Division
- [Dark blue square] Roads and Traffic Division
- [Cyan square] Waterways-coast Division
- [Purple square] municipalities
- [Orange square] IWVA
- [Grey square] Ministry of Defence
- [Pink square] Natuurpunt vzw
- [Light pink square] Province
- [Yellow square] RMT
- [Magenta square] VMM
- [Light red square] VMW
- [Red square] Private property



1 0 1 2 Kilometers

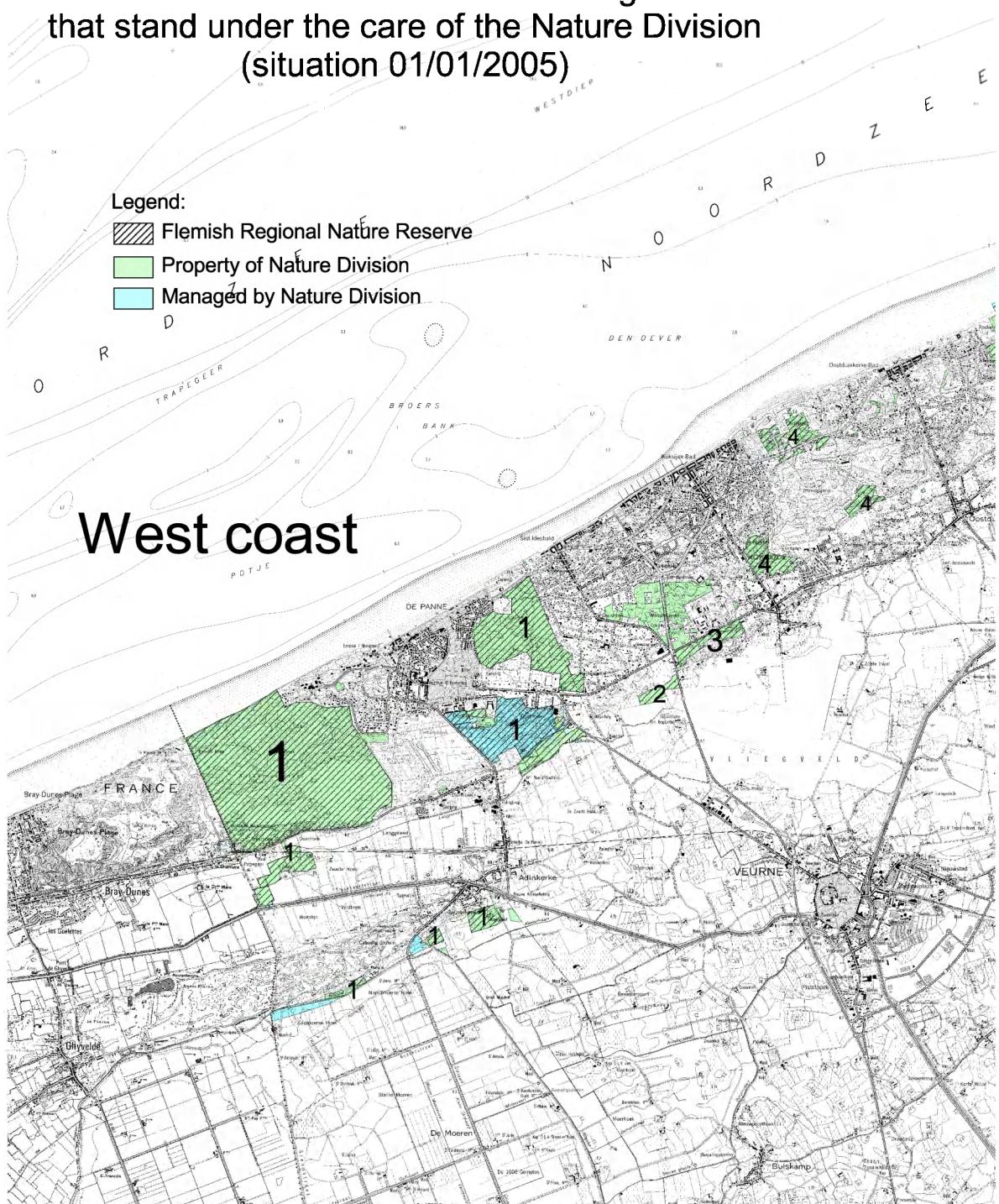


Map 3a
Domains in the maritime dune region
that stand under the care of the Nature Division
(situation 01/01/2005)

Legend:

-  Flemish Regional Nature Reserve
-  Property of Nature Division
-  Managed by Nature Division

West coast



1 0 1 2 Kilometers



- 1 De Duinen en Bossen van De Panne**
- 2 Belvédère**
- 3 De Noordduinen**
- 4 Het Schipgat, De Doornpanne en De Hoge Blekker**
- 5 Ter Yde**
- 6 Hannecartbos**
- 7 De Ijzermonding**



Map 3b

Domains in the maritime dune region that stand under the care of the Nature Division (situation 01/01/2005)

Legend:

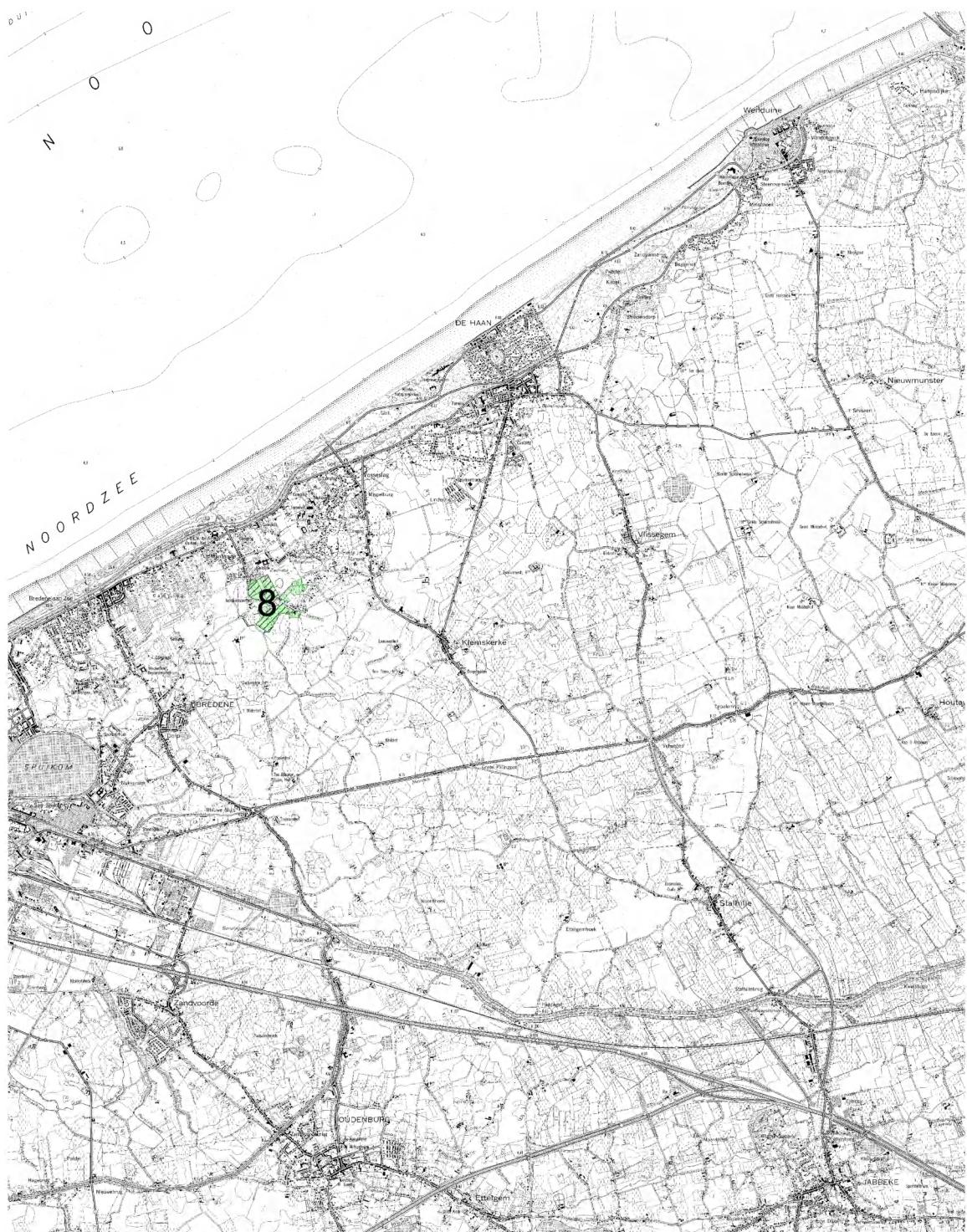
-  Flemish Regional Nature Reserve
-  Property of Nature Division
-  Managed by Nature Division

Central coast



1 0 1 2 Kilometers





8 D'heye



Map 3c

Domains in the maritime dune region
that stand under the care of the Nature Division
(situation 01/01/2005)

Legend:

 Flemish Regional Nature Reserve

 Property of Nature Division

 Managed by Nature Division





9 De Baai van Heist

10 De Zwintuin en -polders



The French policy experience of purchasing coastal areas

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Abstract

Created in 1975 by the French Government, the Conservatoire du Littoral is responsible for:

- the acquisition and the protection in perpetuity of the most sensitive and endangered coastal land:
 - along the coast of metropolitan France and overseas territories
 - around lakes larger than 1,000ha
- the management by local government of the lands acquired in order to open them to public access and to ensure the protection of natural values.

Over the years, the Conservatoire has defined three main criterias for selecting land for acquisition:

- the site is threatened by urbanisation, being divided up or being made artificial (for example, the infilling of wetlands);
- the site is deteriorated and needs rapid restoration;
- the site is closed to the public whereas it should be open to everyone.

Since 1975 the Conservatoire du littoral owned 70,500ha in France (3,200ha in Nord-Pas-de-Calais), protected more than 860km of coast (37km in Nord-Pas-de-Calais), *i.e.* 10% of the metropolitan coast (25% in Nord-Pas-de-Calais). With the application of a new legal act (27/02/02) the Conservatoire du Littoral became one of the French government tools for ICZM with new competences on maritime properties.

Keywords: Coastal protection; Land acquisition; French public body; ICZM.

Introduction

The coastline and the shores of our main lakes undoubtedly make up some of the most beautiful, rich and varied parts of France. The coastline is also one of the most densely populated areas and as a consequence is fragile and endangered (Tables I and II).

Table I. Populated areas density (1999)

Coastal communes (overseas)	in France	277 hab.km ⁻²
	in Nord-Pas-de-Calais	657 hab.km ⁻²
Coastal cantons (districts)		186 hab.km ⁻²
Coastal departments		129 hab.km ⁻²
France		108 hab.km ⁻²

Table II. Population increase (1990-1999)

Coastal communes (overseas)	+ 5.7%
Coastal cantons (districts)	+ 7.0%
France	+ 3.6%

For this reason, the public authorities have been taking the necessary measures to protect and organize these areas. Numerous surveys have been carried out, legislation reinforced and procedures made more explicit. In 1975, the French parliament decided to enlarge these measures by creating a public organization: the 'Conservatoire de l'Espace littoral et des Rivages lacustres'.

In charge of purchasing natural sites, which are endangered (degradation and sites which may disappear in the long term), the Conservatoire is a public government agency. It has the responsibility of developing appropriate land-use policies for the protection of threatened natural areas. Its mission and types of intervention are defined in the Environment Code (articles L.322, art. R. 243). Its activities cover 22 regions, 46 departments and 1,140 coastal and lacustrine local authorities.

Competence areas

- Metropolitan France and French overseas departments
- 5,200,000ha of land
- 10,000km of coastline (8,000km and 1,200km of coastal dunes on the metropolitan area)

At the end of 2003, the Conservatoire owned 70,500ha of endangered or fragile natural beauty spots covering over 300 localities. In 2004, more than 8,000ha of coastal dunes are protected by the Conservatoire du Littoral. In this way, it guarantees the protection of 775km of coastline and inland lake shores made up of dune, marshland, mudflats, islands, woods, moors and heathland.

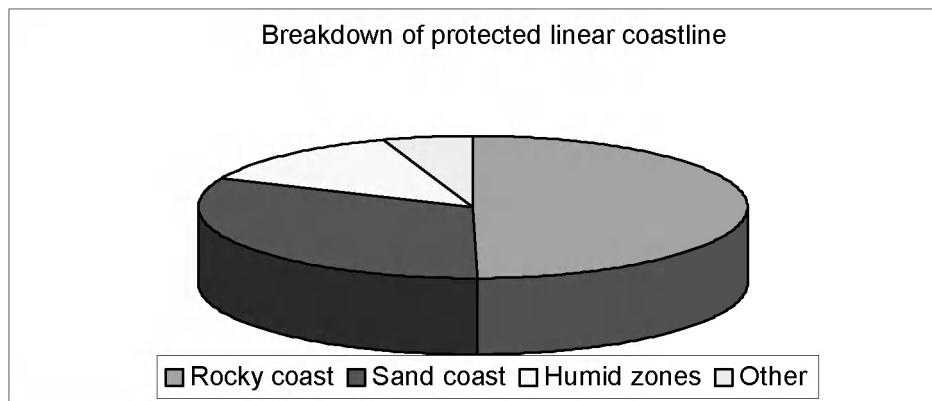


Fig. 1. Breakdown of the protected linear coastline.

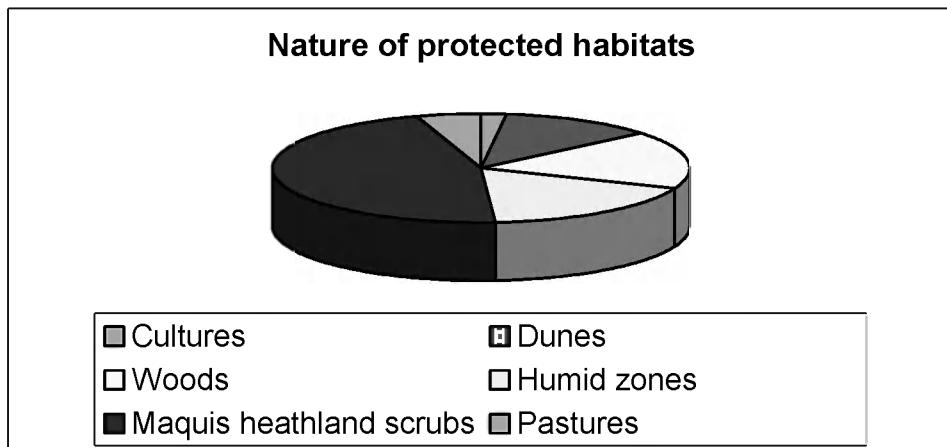


Fig. 2. Nature protected habitats.

The one objective is to 'conduct a land acquisition policy to safeguard coastal zones, respect natural sites and maintain their ecological equilibrium'.

In this geographical area, the Conservatoire's mission is twofold, quantitative and qualitative. Its main priority is to acquire endangered natural sites; but it is also the safeguard for the quality of these areas as well as their ecological equilibrium. For this reason the Conservatoire can make recommendations concerning its mission to the relevant authorities.

Another important public agency for dunes management is the Office national des Forêts. It is a public national organization under the supervision of the government (Ministries of Agriculture and Environment). It manages large coastal and wooded (pine

forest) dunes on the Atlantic seacoast, especially in Aquitaine (SW France). Some parts of them are dedicated to biodiversity as biological reserves.

A selective and reasoned intervention

Within its zone of competence, the Conservatoire does not decide alone which areas should be left in their natural state. It should take into account (article R.243-2) the regulations existing as well as the Development and Urbanization Masterplans (SCOT) and Local Plans (PLU). It is up to the authorities responsible for town planning to determine which zones should be assigned to urbanization or development; the Conservatoire does not normally buy these areas, but can argue that an area should be classified as a natural zone. These considerations and the concern to use its budget as efficiently as possible, have driven the Conservatoire to define more precise selection criteria, using past experience and the general framework of the legal texts, for those situations where a policy of acquisition to reinforce the statutory intervention of the government and communes is justified.

Legal framework in France to protect dunes

Forestat code

- (L431-2) Special governmental authorization for sandy vegetation extraction and wooded destruction
- (L431-1) Forestry ministry can enforce dune fixations
- (L432-1) in the Department of Pas-de-Calais:
 - land extraction is forbidden in dunes from the coast up to a distance of 200m inland
 - prohibition of destruction and extraction of sandy vegetation on dunes except for the landers after special authorisation.

Urbanism codes

- (L146-6) On the coastline, the urbanisation is forbidden in the special scientific interest areas like salt marshes, dunes, estuaries,...

Environment code

- (L341 and so on) Areas of outstanding beauty can be protected by the law (1930' legal Act): all new constructions are forbidden and each management is authorized by the environment administration.

Broad possibilities of intervention

The parliament has given the Conservatoire a whole panoply of means to acquire ownership of the land it wishes to protect, whether it concerns donations and legacies, negotiated acquisitions, the right of pre-emption (substituting pre-emption by the

department) or expropriation. A public body prefers to negotiate amicably and only rarely resorts to legal proceedings.

With the application of a new legal Act (27/02/2002) the government can assign maritime properties to the Conservatoire (marshes, meadows in estuary, intertidal zonation, beach along coastline,...).

Land acquired by the Conservatoire receives a specific status – it becomes ‘public property of the Conservatoire’, the lands become inalienable. The Conservatoire’s public property can only be transferred by decree issued by the ‘High Court’ (Conseil d’Etat), following a recommendation by a majority of $\frac{3}{4}$ of the board of directors.

An active partner for the local authorities

The Conservatoire’s action is part of the government’s involvement in the effort undertaken by the local communities and Departments to preserve natural sites. The Conservatoire is compelled by parliament to closely involve the local authorities in the preparation of its acquisition program.

The organization of the Conservatoire is based on the essential role played by the Conseils de Rivage (Coastal and Lakeside Councils). These councils are composed of county and regional members of the local parliament. They discuss the acquisition proposals to be submitted to the Conservatoire’s board of directors – with an equal representation of politicians and administration – which decides on the acquisition program. These councils are also consulted for each contract or partnership between the Conservatoire and local, county or regional authorities.

The Conservatoire consults the communes prior to any acquisition. It also coordinates its work with the departments, which buy land with the departmental tax for environmentally sensitive areas (TDENS). The departments set up the pre-emption zones which become the framework for the Conservatoire’s interventions.

With the decentralization of government, the Conservatoire is a particularly active partner of the local authorities. Its role is to collaborate with local elected people in order to develop a concerted policy of the sharing of acquisitions, financial participation and the management of the acquired sites. This overall strategy also takes into account European cooperation concerning the protection of coastal and lakeside zones.

Many properties of the Conservatoire du Littoral in France participate in the application of the Habitats Directive and Birds Directive (in Nord-Pas-de-Calais 95% of the properties are incorporated in the Natura 2000 Network).

Management agreements

The Conservatoire does not manage the land that it owns. It signs management agreements with the local authorities whenever they are willing, either with the relevant NGOs, or with farmers. Experience has shown that the size of the sites and the expense usually lead to a partnership between the commune and the Department as far as the management of these zones is concerned.

No matter which authority is given to the management of the Conservatoire's properties, the latter retains the right to participate in the definition and the implementation of the choice of management development. Depending on the state of the natural environment, the intervention is more or less significant, and ranges from simple conservation to restoration. To justify an intervention, the Conservatoire makes every effort to establish an ecological evaluation and a management plan for each site.

The conditions of public visiting of the site, the limits of which are fixed by the ecological evaluation, are based on two principles: prohibition of all motorized traffic and camping, and the control of the numbers of people. With this in mind, the Conservatoire develops new methods of conservation, environmental restoration, landscape planning and visitors facilities.

As for the existing buildings situated on the Conservatoire's property, they are – as a rule decided by the board of directors – destroyed when they are of no real use in relation to the objectives set out and if they represent no real architectural interest.

With respect to financial investments in the sites, the Conservatoire has adopted the principle that the owner is responsible for all investments essential to the protection of the natural environment, *i.e.* all interventions having an effect on the very nature and state of the land; however, in return, the yearly management expenses such as maintenance of infrastructure or the supervision of the area will be financed by the manager. The Conservatoire also offers technical assistance to the local authorities, a.o. in the training of the wardens.

The job of these wardens is to maintain, clean and ensure the protection of the sites. They also play an educational role and provide information to the visitors.

Private donations and legacies

Every year, hundreds of donors send money to the Conservatoire du Littoral which assigns it to acquisitions. On several occasions, it has fund-raising campaigns to finance the acquisition and conservation of certain areas of outstanding natural beauty.

This was the case in 1991 with the purchase of the Pointe du Raz. In 1992, a similar operation was launched in order to safeguard Cap Gris Nez, in the department of Pas-de-Calais.

In addition since October 96 it benefits from donations acquired by inheritance or capital taxes.

Development of sponsorship

More and more companies wish to contribute to environmental protection. Procter & Gamble France created a business foundation in June 1992 for the protection of the coastline whose sole aim is to promote the work of the Conservatoire: survey, research

on the natural environment, information campaigns, rehabilitation operations, publications. As part of this program, it financed the publishing of 'l'Atlas des Espaces naturels du Littoral' (Atlas of Natural Coastal Zones), produced by the Conservatoire and some general studies:

- Climate change and land strategy
- Public access, tourist pressure and management plans
- Forestall fire in the Mediterranean area

Promoting a dynamic idea of coastal protection

The Conservatoire bases its interventions on strong convictions:

- Only natural zones maintain a certain diversity of animal and plant communities and landscapes, which areas used for the very specific needs of human activity no longer have. The verb 'to protect' must not be taken as a synonym for 'freezing' or 'blocking progress'.
- A large part of the economic production, on land or at sea, is linked to the existence of rich and varied natural surroundings, therefore the prospects for development depend on the quality of the surroundings and environment. Nature has been a constant source of inspiration for man's development, they are complementary, not rivals.

In some rare cases, however, where an unavoidable incompatibility between protection and development becomes obvious – which would have an important negative impact on the natural heritage – it is the conservation imperative which prevails.

The deterioration of the landscape and natural surroundings should not be considered irreversible. What has been degraded can be repaired, even if this task is difficult, long, always expensive and often incomplete.

With the help of the local authorities concerned, and thanks to public donations or company sponsorship, the Conservatoire has undertaken this policy of reconstruction and restoration of prestigious sites such as the Pointe du Raz or the Pinède de Palombaggia and tomorrow Cap Gris Nez and Cap Blanc Nez in Nord-Pas-de-Calais and Bay of Somme in Picardy which had been seriously spoiled by unsightly buildings and uncontrolled visiting. This action is significant. It is part of the development of a new type of tourism, which pays more attention to environmental quality. More than 20 million visitors come to the Conservatoire's sites each year.

Co-ordinating the interventions of the various partners

The protection of the remaining natural beauty spots requires an overall policy conducted at all levels, European, national, regional, departmental and communal, accepted by all social categories, politicians, technicians, NGOs, citizens, and provided with all the necessary legal, technical and financial means: town and country planning, regulation, classification of sites, control of conveyance and acquisitions. The Conservatoire's work, as it is decisive, must be exemplary for all the other partners involved in conservation.

The necessity of creating a national heritage of natural zones protected definitively and open to all, must lead local authorities and all individuals to take more care of protecting their natural areas. In this way, nature conservation should gradually be prescribed throughout the whole country. The conservation of nature cannot be limited because it is its diversity that we must protect.

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TECHNICAL ASPECTS OF NATURE RESTORATION ACTIVITIES AND MANAGEMENT PLANNING

Plenary session 2 – chair: Fred van der Vegte

Sledgehammers, cranes and bulldozers: restoring dunes and marshes by removing buildings and soil

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Abstract

Flanders has the most urbanised coastline of Europe, north of the Pyrenees and the Alps. During the 20th century seaside resorts grew to one another to finally form one urban agglomeration from the Dutch to the French border, only locally interrupted by some rather small not built up areas of dunes. However even the remaining and legally protected 'natural areas' often include buildings, roads or even dredging sludge dumps. In this situation of an extremely damaged and fragmented natural environment, management by mowing and grazing is not sufficient to restore it to a satisfactory level. Open space and physical conditions have to be restored in order to create chances for the redevelopment of natural habitats and wild species. In this paper an overview is given of the most important nature restoration works that have been or are currently being carried out by the Nature Division along the Flemish coast since the year 1995. These projects include: (1) the demolition of the buildings of the former children-home 'Georges Theunis' - to reactivate large scale sand drift (1995) and the removal of a soil dump - to recreate a wet dune slack (1997) in the Flemish Nature Reserve 'Ter Yde' at Oostduinkerke; (2) the digging off of soil dumps and the excavation of a former raceway - to restore decalcified fossil dunes (1997-2000) in the Flemish Nature Reserve 'D'Heye' at Bredene; (3) the complete demolition of the former military harbour and the digging off of the dredging spoil-dumps - to restore mud flats, salt marshes and sand dunes (1999-2003) in the Flemish Nature Reserve 'The Yzer-rivermouth' at Nieuwpoort; (4) the demolition of the former 'Swimming Pool' - to create a pond, a wet dune-slack and grey and white dunes (2004) in the Flemish Nature Reserve 'Zwin-dunes and polders' at Knokke; (5) the demolition of the former sewage treatment plant of Nieuwpoort - to restore calcareous marshland and humid dune slack areas (2004-2005) in the fossil beach-plain of the regional nature domain 'Groenendijk'. The paper describes how these projects have been conceived, planned, prepared and finally executed and, if the necessary data are already available, it compares their results with their initial objectives concerning stimulating natural processes and increasing biodiversity. All the concerned sites are included in the proposed Special Area for Conservation 'Dunes including Yzer-rivermouth and Zwin' which has been proposed under the European Habitat-directive 92/43/EEC. All the above mentioned projects aim at an active implementation of this directive. Although it is more economic to demolish constructions than to restore them, such large scale demolition- and ground-works are relatively expensive in proportion to the rather limited budgets which are available for nature conservation. EU financial contribution was obtained under the LIFE nature - projects 'Integral Coastal Conservation Initiative' (ICCI) and 'Fossil Estuary of the Yzer-Dunes Restoration Action' (FEYDRA).

It has been of significant importance to facilitate the dismantlement of the military harbour and the demolition of the sewage treatment plant, both of which were situated at Nieuwpoort.

Keywords: Nature restoration; Demolition of buildings; Earthworks; Flemish coast. LIFE.

Introduction

Common measures of nature management include mowing hayfields, cutting down shrubs and trees and grazing by stock, cattle or horses. Along the Flemish coast these methods, based on traditional agrarian activity are generally applied in nature reserves. Nevertheless, the urbanisation of the Flemish coast has reached such a high degree that restoring the natural environment to a satisfactory level in the remaining coastal dune areas requires more drastic measures. Of the 38 remaining legally protected coastal areas, consisting mainly of dunes and sometimes including adjacent salt marshes and polder areas, only two areas have a surface area exceeding 500 ha, while 23 areas have a surface area of less than 50ha (De Loose *et al.*, 1996). Most of these protected areas are still cut through by roads and contain isolated buildings or clusters of buildings. On some sites the ground level has been raised, on others the natural relief has been levelled off. In certain cases demolition of buildings, roads and earthworks is necessary to restore natural processes and habitats. Since 1996 the scientific inspiration for such nature development and restoration projects along the Flemish coast is provided by the Ecosystem Perspective for the Flemish Coast (Provoost *et al.*, 1996) which includes orientations for nature development in the remaining natural areas. This paper reviews the most important projects that have been or are being carried out since 1995 for conservation purposes along the Flemish coast (Fig. 1).

The projects are described according to the chronology of their execution. All the described projects are situated within the limits of the special area for conservation 'BE 2500001 Dunes including the Yzer-Rivermouth and the Zwin' which, on the basis of the 'European Habitat Directive', is included in the list of areas of Community importance.

Review of the major nature restoration works along the Flemish coast

(1) Ter Yde at Oostduinkerke (municipality of Koksijde)

With its surface area of 261ha, Ter Yde is one of the three largest remaining dune-areas of the Flemish coast and one of the very few places where sand drift on a quite large scale is still possible. This site has a very varied landscape consisting of fore-dunes, high parabolic dunes formed in the wake of a large drifting dune-front, a largely afforested fossil beach plain (the 'Hannecartbos') and medieval low 'hedgehog-dunes'. Until the early 1990's a 16ha large part of Ter Yde was owned by a children's' care organisation. On this private estate a gigantic building, the Home Georges Theunis, was erected in the 1930's, on top of a high dune (Fig. 2a). This building was four storeys high, with a base-area of 1ha and foundations to a depth of 8m below ground level. After a fierce public discussion about a new usage for the huge building, which lasted from 1989 to 1994, the

ownership of the estate was transferred to the Nature Development Service of the Flemish Region in 1994. In April 1995 the Flemish minister of the Environment ordered its demolition to restore the original, once drifting sand dunes which it was built upon.

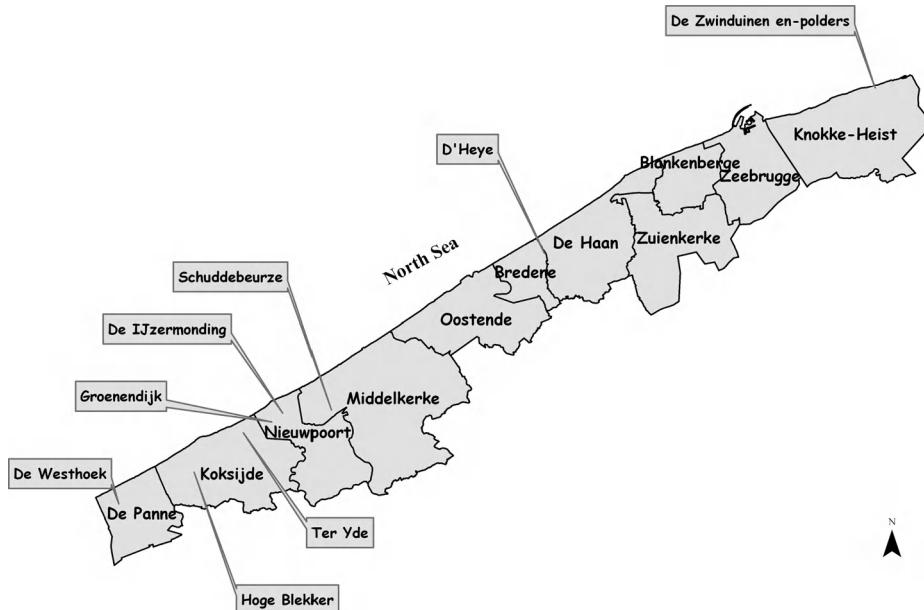


Fig. 1. Location of the most important demolitions and earthworks for conservation purposes along the Flemish coast.

This decision is considered to be a historical turning point in the coastal conservation policy of the Flemish government. After the demolition, the 2m thick upper layer of soil on the demolition site was sifted through a sieve with a mesh of 10mm x 10mm to get rid of stone fragments. After a couple of years, an armoured soil surface formed itself by the accumulation of stone fragments that were too small to have been removed by the sifting. The reactivated sand drift that had been one of the purposes of the removal of the building stopped. The rather flat surface of the former demolition site was since then gradually being colonised by Biting Stonecrop (*Sedum acre*), *Erodium glutinosum*, Sand Cat's-tail (*Phleum arenarium*) and other pioneer species of arid sandy and rocky soils (Fig. 2c). Two of the main potentialities of the Ter Yde site that are mentioned by the Ecosystem Perspective (Provoost *et al.*, 1996) are the occurrence of a quite large sand drift and actually humid dune slacks. The management - plan of the Flemish Nature Reserve Ter Yde (Van Nieuwenhuyse, 2003), that was approved by ministerial order in 2003, sets out that the dune-hill of the former Home Georges Theunis - building should be excavated into a bowl-like shape in order to reactivate large scale sand drift again. These earthworks will now soon be carried out. Also to stimulate the pursued sand drift, in 2004 Sea buckthorn (*Hippophae rhamnoides*) scrubs have been mechanically

removed from the opposite slope of the same dune over a surface area of 2.8ha. The litter and the upper soil-layer that was enriched with organic material were also mechanically removed to denude the mineral sand. The removal of scrub here is a part of the Life nature - project 'FEYDRA' (abbreviation of 'Fossil Estuary of the Yzer Dunes Restoration Action').



Fig. 2. Ter Yde at Oostduinkerke: a. The Home George Theunis; b. The demolition of the Home George Theunis in 1995; c. The site of the Home Georges Theunis in 2004.

The main target habitat of these works on the dune of the former Home Georges Theunis building is '2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)'.

The estate also included a 50 years old Pine- and White poplar- plantation on the site of a former dune slack which was artificially raised with superfluous soil from the construction of the adjacent road. In 1997, in agreement with the Life nature - project 'ICCI' (abbreviation of 'Integral Coastal Conservation Initiative'), the exotic trees were removed and the heightened ground on which they had been planted was excavated to the average height of rise of the groundwater level, in order to restore the original humid dune slack (code 2190) over a surface of 0.5ha. Within three years after the excavation a wet dune slack vegetation with amongst others Grass-of-Parnassus (*Parnassia palustris*) and Marsh Helleborine (*Epipactis palustris*) had developed.

(2) D' Heye at Bredene

The rather small Flemish Nature Reserve D' Heye (20ha) is situated on the relic of a fossil, decalcified dune-tongue that penetrates 2.5km into the polder area. The Flemish Region acquired the land in 1996. The Ecosystem Perspective for the Flemish Coast (Provoost *et al.*, 1996) mentions the following potentialities for nature development in the fossil dunes of Bredene:

- strongly dried up (by the water extraction, which should end in 2005), but potentially humid dune site;
- grasslands of decalcified dunes;
- possibility for nature development by cutting sods or excavations and restoration of relief after the restoration of the hydrology.

A management plan was ordered by the Nature Division of the Ministry of the Flemish Community and drawn up in 1997 (Econnection, 1997). The plan gives a further interpretation of the Ecosystem Perspective.

According to the management plan the following works were carried out:

- The former horse raceway, which was levelled off in the 1920's, and had been heavily fertilised, was dug away up to the mineral substrate in 1997. A volume of 1,450m³ of soil that was enriched with organic material was removed from the site.
- Between September 1999 and January 2000 (Fig. 3):
 - a former depression that had been filled up with sand, was dug out again over a surface area of 8,400m²; also two ponds were excavated.
 - a levelled off and too strongly fertilised area was excavated at the same time over a surface area of 9,200m².



Fig. 3. 1999: The excavating of a fertilised area in D'Heye at Bredene to restore '2190 humid dune slacks' and '2150 EU-Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)'.

The dug out soil from both locations was spread out over a zone containing the stony remnants of a tramway and demolition material from bunkers with a total surface area of 2.2ha. The displaced earth was spread in such a way that a slightly undulating relief was created. About 8,200m³ of soil was displaced within the framework of these nature restoration works. Target-habitats of this project were '2190 Humid dune slacks' and '2150 EU-Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)'. The results obtained are satisfactory and include the appearance in the excavated areas of Three-nerved Sedge (*Carex trinervis*), Glaucous Sedge (*Carex flacca*) and Lesser Centaury (*Centaurium pulchellum*) on lime rich soils and Heath-grass (*Danthonia decumbens*), Tormentil (*Potentilla anglica*), Oval Sedge (*Carex ovalis*) and *Montia minor* on decalcified soils. Even the vegetation of the area that was heightened with the excavated soil includes plant species that are typical for decalcified fossil dunes, such as Broom (*Cytisus scoparius*) and Gorse (*Ulex europaeus*).

(3) The Yzer - rivermouth at Nieuwpoort (Deboeuf et al., 2002)

The Yzer is the only river that flows into the North Sea along the Belgian coast. The map published by "Le Dépôt de la Guerre", edition of 1876 shows that in 1860 the eastern bank of the Yzer-rivermouth was still pristine and consisted of a sandy beach, mudflats, salt marshland and dunes. The western-bank was already consolidated since medieval time and bordered on a large dune area which was not yet built-up. During the 20th century the dunes on the western bank of the Yzer-rivermouth got completely urbanised by the development of the seaside resort of 'Nieuwpoort-Bad'. In the years 1950-1970, a military harbour was established on the eastern bank (Fig. 4) and the remaining salt marshes and dunes were covered with 300,000m³ of dredging sludge.



Fig. 4. Aerial photograph of the Yzer-rivermouth in 1957 and 2004.

In 1993 the Ministry of Defence announced that the Naval Basis of Nieuwpoort would be sold off. To prevent real estate speculation, the former Naval Basis was designated as a 'protected dune site' within the framework of the Decree on the Protection of the Coastal Dunes by Order of the Flemish Government of November 16, 1994. In 1995 its status on the Town and Country Planning Map was changed into "natural area with scientific value". To implement the several protection-statuses of the Yzer-rivermouth area, a plan for the restoration of its natural habitats was commissioned by the Nature Division of the Ministry of the Flemish Community to the University of Ghent. This 'Nature Restoration Plan for the Yzer-rivermouth' was finalised in 1996. The former Naval Basis was transferred from the federal Ministry of Defence to the Flemish Region in December 1998. Finally the area of the 'Yzer-rivermouth' was designated as a 'Flemish Nature Reserve' by the Ministerial Order of March 3, 1999. The specifications for the demolition of the former military harbour were deduced from the 'Nature Restoration Plan for the Yzer-Rivermouth' by a contracted civil engineering consultant. The Ecosystem Perspective for the Flemish coast (Provoost et al., 1996) identified transitions between salt-marshes and dunes and the possibility of restoring mud flats and

salt marshes by excavation as main potentialities for nature development at the 'Yzer-Rivermouth'. Target habitats of the project are: '1130 Estuaries', '1140 Mudflats and sandflats not covered by seawater at low tide', '1310 Salicornia and other annuals colonizing mud and sand', '1320 Spartina swards (*Spartinion*)', '1330 Atlantic salt meadows (*Glauco-Puccinellietalia*)', '2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)' and '2150 Fixed dunes with herbaceous vegetation (grey dunes)'.

The execution of the Nature Restoration Plan was split up in four phases:

Phase 1: the 'dry works' or demolition of the buildings and roads of the former Naval Basis. These works started on September 13, 1999 and ended on January 28, 2000. They consisted of the removal of: asbestos; a total volume of 50.000m³ of buildings; a total surface of 14.000m² of concrete roads; a total length of 3,600m of pipes.

Phase 2: the 'wet works' or the removal of the jetties and quays of the former Military harbour (Fig. 5). Those works started on 18 September 2000 and ended on 18 March 2001. The 'wet works' consisted of the removal of:

- eight jetties consisting of wooden and concrete stakes and gangways;
- 1.3km of bank revetment in blue stone and sheet piles (with a surface of 20,200m²);
- a slipway for 500 ton ships;
- a surface of 4,500m² of concrete roads.

Also a volume of 178.000m³ of soil was dug out, of which 35.000m³ was transported to destinations outside the nature reserve. The remaining volume of sand that was excavated from the quays around the slipway was used for creating dunes above the pits left by the removal of the buildings ('dry works').



Fig. 5. Phase 2: the 'wet works' or the removal of the jetties and quays of the former Military harbour.

Phases 3 and 4: the digging away of 333,000m³ soil from the dredging sludge dump, of which 275,000m³ were transported to destinations outside the nature reserve. The remaining volume of soil was used to reinforce the coastal defence around the restored tidal area. The works started on January 14, 2002 and ended on March 2, 2004.

The first two phases were realised with the financial support of the European Community in the framework of the LIFE Nature – project 'ICCI'. The removal of the former military harbour and dredging sludge dump allowed the restoration of about 50ha of tidal habitats and coastal dunes (Fig. 4). The first summer after the dismantlement of the military harbour and after the excavation of the dredging soil dumps, Glasswort (*Salicornia spp.*) and Annual Sea-blite (*Suaeda maritima*) already quite massively appeared on the soil-substrate which once more had come under tidal influence after the excavation of previously raised areas. The restoration of mud and sand flats have also resulted in a significant increase in the numbers of foraging Dunlin (*Calidris alpina*), Great Ringed Plover (*Charadrius hiaticula*) and Redshank (*Tringa totanus*) (Devos *et al.*, 2004) and also of resting Sandwich Terns (*Sterna sandivicensis*) and Common Terns (*Sterna hirundo*). The natural development of the site after the works has been monitored by a multidisciplinary scientific project, called MONAY (abbreviation of MOnitoring NAture - restoration at the Yzer-rivermouth).

(4) The Zwindunes and -polders at Knokke-Heist

The Flemish Nature Reserve 'The Zwindunes and -polders' has a surface area of 222ha and is situated within one of the two largest remaining natural areas of the Flemish coast. 'The Zwindunes and -polders' consist mainly of rather low coastal dunes and a large fossil beach plain that were cut off from marine influence in the second half of the 19th Century. The Flemish Region acquired the land in 2002. In the north-western corner of the site a vast Swimming Pool - complex (Fig. 6a) with a surface area of 3.5ha was derelict since 1980. The Swimming Pool - complex was built in the years 1950-1960 and was, at its time, made to Olympic standards. It included the large building of an indoor swimming pool and an open-air swimming pool, and also lots of bitumen pathways and asbestos pipes. The Ecosystem Perspective for the Flemish Coast (Provoost *et al.*, 1996) mentions the removal of infrastructure as a possibility for nature development at the former Swimming Pool-site.



Fig. 6a. The Swimming Pool – complex.

Having learnt from previous experiences, especially the poorly prepared demolition of the Home Georges Theunis building, the preparation of the demolition and earthworks for the former Swimming Pool was contracted out to an engineering consultant. Of course the target habitats were determined by the Nature Division on the basis of the potentialities offered by the area itself:

- the open-air swimming pool, which reached a depth of 5m below ground level, was taken out and replaced by a permanently inundated pond that corresponds with '3140 Hard oligo - mesotrophic waters with benthic vegetation of Chara formations' (Fig. 6b);
- fountains and the soil underneath them were removed to create humid dune-slacks (code 2190);
- the pathways and indoor swimming pool were demolished and the original sandy soil underneath was planted with Marram grass (habitat '2,120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)') or covered with sods of dry dune-grassland that had previously been removed over a surface of 4,450m² and put apart [habitat '2,130 Fixed dunes with herbaceous vegetation (grey dunes)'].



Fig. 6b. The demolition of the Swimming Pool-complex.

Just to give an idea of the extent of the project, it included the removal of:

- 18,000m³ of construction-material of the indoor-swimming pool:, of which 4,000m³ below the ground level;
- 3,125m³ of construction-material of the open-air swimming pool;
- 150m³ of construction material of the outbuildings;
- surface of bitumen pathways: 850m²;
- surface of concrete hardening: 2,050m²;
- length of underground pipes: 1,350m.

The landscaping of the demolition site into more natural looking dunes also required the felling of 500 Pine- and Poplar-trees, the removal of Sea-Buckthorn thickets over a surface of 6,800m², the displacement of 12,000m³ of soil and the plantation of 2,500 indigenous trees and shrubs.

The works were executed between January 10, 2004 and April 1, 2004. The first results during the vegetation season 2004 were encouraging (Fig. 6c). Pioneer water plants such as Lesser Pond-weed (*Potamogeton pusillus*) and Common Water-crowfoot (*Ranunculus aquatilis*) quickly colonised the pond. On its shore Sea-Milkwort (*Glaux maritima*) and Saltmarsh Rush (*Juncus gerardii*) appeared, probably as a result of a local persistent seedbank. The newly dug out dune-slack was rapidly colonised by, among others, Lesser Centaury (*Centaureum pulchellum*), Seaside Centaury (*C. littorale*) and Knotted Pearlwort (*Sagina nodosa*). On the higher and dryer grounds upon which sods had been spread out, a mostly rough vegetation of plants developed that are typical for wastelands on lime-rich soils such as Perennial Wall-rocket (*Diplotaxis tenuifolia*), Evening-primroses (*Oenothera div. spp.*), Great Mullein (*Verbascum thapsus*) and Common Stork's-bill (*Erodium cicutarium*). A further change towards dry dune-grasslands is expected in the area where sods were spread.



Fig. 6c. On the former location of the open-air swimming pool a permanently inundated pond was built. This habitat corresponds with '3140 Hard oligo-mesotrophic waters with benthic vegetation of Chara formations' (situation in September 2004).

(5) Groenendijk at Nieuwpoort

'Groenendijk' is the name of a fossil beach plain that in the 14th Century still was a part of the estuary of the river Yzer. Probably around the 16th Century this beach plain was definitively cut off from the sea by the formation of high dunes. Originally the now largely afforested plain, the so-called 'Hannecartbos', in 'Ter Yde' and the cultivated plain of 'Groenendijk' were both parts of the same beach plain, but got spatially separated from each other by the development of holiday-villages and camping grounds in the second half of the 20th Century. In the 1950's a water treatment plant was built here (Fig. 7a). The water treatment plant was closed down in 1996. The lands of the derelict water treatment plant, with a surface area of 5ha, were purchased by the Flemish Region in 2002.



Fig. 7a. A part of the derelict water treatment plant at Groenendijk.

The humid hayfields that remained were heavily fertilised for many years in the past. Nevertheless after a couple of years of management by mowing and grazing without fertilizing, the biologically valuable humid dune-slack vegetation has already been able to restore itself to such a degree that species like Tubular Water-dropwort (*Oenanthe fistulosa*), Ragged-Robin (*Lychnis flos-cuculi*) and Western Marsh-orchid (*Dactylorhiza majalis*) have reappeared.. An old record of Creeping Marsh-wort (*Apium repens*) on the site or in the immediate surroundings underlines the potentialities of the area. The Ecosystem-perspective for the Flemish Coast (Provoost *et al.*, 1996) mentions the following potentialities for nature development:

- site with estuarine origin;
- actually humid dune site and presence of seepage;
- 'old' dune slack vegetation;
- possibility to restore open space and nature development by cutting sods or excavations and restoration of relief.

The rare geomorphologic formation of a fossil estuarine beach plain and the potentialities of its lime-rich soil and typical hydrology for the restoration of a calcareous marshland, led to the decision to demolish and remove the buildings and infrastructure of the water treatment plant. Within the framework of the LIFE nature - project 'FEYDRA', the elaboration of the specifications of the works was again entrusted to an engineering consultant. These specifications were based on the target habitats and species that are determined by the Nature Division in accordance with the 'European Habitat Directive': '3140 Hard oligo-mesotrophic waters with benthic vegetation of Chara formations', '2190 Humid dune slacks', '2170 dunes with *Salix arenaria*', Creeping Marsh-wort (*Apium repens*) and Crested Newt (*Triturus cristatus*).



Fig. 7b. The demolition of the derelict water treatment plant at Groenendijk.

The works started on the 11 January 2005. These works involve the removal of 810m³ of polluted sludge, 2,042m² of uild-up area, 5,100m² of concrete surface, 620m of pipes, and a displacement of soil of 30,910m³ (Fig. 7b). As part of the LIFE nature-project 'FEYDRA' a multidisciplinary scientific monitoring-project is carried out to study the natural development of the demolition site.

(6) Smaller works

Besides the 'large scale' works that have been reviewed above, a number of 'smaller' demolition works were carried out in order to rid coastal dunes of disturbing buildings: the villa 'La Cigogne' on top of Flanders' highest dune, the 'Hoge Blekker' in Koksijde (2000), two small 'twin dwellings' on the fossil dunes of Westende (2005), the derelict 'Halewyck' -farmhouse on the fossil dunes of Bredene (2005) and the derelict villa 'Mosselkot' on a dike of the nature reserve 'Yzer-Rivermouth' (2005).

Conclusion

Although in most cases it is not possible to restore the original habitat in its entirety, the removal of buildings, roads and (alien) soil allows for improvement of abiotic conditions, and for the development of biologically valuable natural habitats. Demolition

and excavations have become quite common and are well accepted, even indispensable tools for nature restoration along the Flemish coast. A thorough investigation of the potentialities and the precise inventory of the actual fragile nature values of the sites to be restored, form an essential part of the elaboration of the specifications for the works which are to be carried out. The European co-funding by LIFE - nature of two projects has given an important impulse for the nature restoration policy of the Flemish Region and is gratefully acknowledged.

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Eelgrass (*Zostera marina* L.) in the western Wadden Sea: monitoring, habitat suitability model, transplantations and communication

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Abstract

Eelgrass almost completely disappeared in the course of the previous century. Because of this, the Dutch authorities funded a four-year (2002-2005) project "Reintroduction of eelgrass (*Zostera marina* L.) in the western Wadden Sea". The objective of this project was to create a stable eelgrass population which would grow into a source for further recovery and expansion. Transplantations were carried out using the expertise from previous research on habitat requirements, donor suitability and transplantation techniques. Furthermore, actual eelgrass beds in the Wadden Sea were monitored, a communication strategy was implemented and a seagrass map (for both *Z. marina* and *Z. noltii*) was developed with a Habitat Suitability Model in order to select optimal locations for transplantation and protection. This paper gives an overview of these activities and their results. Transplantation depth, size and density of planting units were varied to optimize the transplantation technique. Some transplantations were carried out in proximity of a mussel bed to test facilitative effects. A chain of unfortunate events caused the transplantation in the year 2002 to fail. The transplantation in 2003 became very successful: high survival rates with abundant development of reproductive shoots, though few seeds were observed. In spring 2004 few seedlings were found, which may have been due to the low seed production observed in 2003 and/or abundant macro-algal development. The transplantations in 2004 resulted in equally high survival rates as in 2003. Fortunately, abundant seed production was measured in September 2004.

From the experimental pilot in transplanting we learned that higher density (14 vs. 5 plants·m⁻²) has a favourable effect on survival, except at the most sheltered locations where density had no effect. Variation in planting unit size (37 vs. 61 plants) had no effect, while variation in depth (+2 vs. +8cm MSL) only had marginal effects. Planting in open spaces within a mussel bed had a positive effect on eelgrass survival during the first growing season, indicating facilitation. At present, natural seagrass beds in the Wadden Sea cover approximately 270ha, but this figure varies from year to year. Habitat suitability was found to be 20-50% in an area of 9,490ha in the Dutch Wadden Sea and 50-80% in an area of 1,747ha. Another 200ha was highly suitable (80-100%) for seagrass growth. This, together with the small scale transplantation successes and the persistence of (dynamic) natural beds, gives hope for future seagrass recovery in the Wadden Sea.

Keywords: Facilitation; GIS-model; Seagrass; Transplantation; Wadden Sea.

Introduction

The cosmopolitan eelgrass (*Zostera marina* L.) suffered worldwide from the ‘wasting’ disease in the 1930s (Rasmussen, 1977; Giesen *et al.*, 1990ab; de Jonge *et al.*, 2000), which wiped out hundreds of hectares. Natural recovery of eelgrass in the Wadden Sea was poor, probably due to intensive engineering activities (e.g. Nienhuis and de Bree, 1977; Nienhuis, 1983; Reise, 1985), poor visibility in the water column and fishery activities (Giesen, 1990ab; de Jonge *et al.*, 2000) and increased nutrient loads in the 1970s and 1980s (van Katwijk *et al.*, 1997, 1999, 2000). By that time, the abundance of eelgrass in the Wadden Sea had been reduced by more than 99% since the 1930s (de Jonge *et al.*, 2000). In the 1990s water quality improved and the visibility of the water column increased again (de Jonge *et al.*, 1996, 2000), but eelgrass did not recover in the western Wadden Sea. The seeds or seed bearing shoots of the remnant eelgrass locations in the eastern part of the Dutch Wadden Sea may not have reached the western part due to predominantly westerly winds and currents.

In 1987, the Dutch government started to support studies into options for seagrass restoration in the western Wadden Sea, in order to restore natural values. These studies were carried out by the Radboud University Nijmegen in cooperation with the National Institute for Coastal and Marine Management. Habitat suitability in the Wadden Sea was tested, suitable donor populations were identified, selection criteria for optimal habitats were defined and transplantations techniques were evaluated (van Katwijk, 2003; van Katwijk and Wijgergangs, 2004). In 2002, the Dutch government decided to put effort into the recovery of eelgrass in the Wadden Sea on a larger scale. This project was funded by the Dutch Directorate-General for Public Works and Water Management and carried out by the two above-mentioned institutes in cooperation with the research institute Alterra. The purpose of this paper is to give managers, politicians and scientists an overview of the different aspects of a reintroduction project.

Status of legal protection and policy regulations on eelgrass

The elaboration of the EU Habitats Directive (1992) was a step forward in the protection of European terrestrial and marine habitats and species. Several marine habitats were identified as targets for conservation and restoration, such as sandy shore, mud flats, coastal sub-tidal sandy sediments, large shallow inlets and bays. Mudflats, shallow inlets

and bays are habitats where eelgrass could be a dominant natural inhabitant. Eelgrass, as species, was not considered to be endangered and has not been protected under this instrument. In addition to the Habitats Directive, the Oslo-Paris Commission (OSPAR - 1992) for the protection of the marine environment of the North East Atlantic recently prepared an initial list of threatened and/or declining species and habitats. The inclusion of *Zostera* beds on this list reflects the necessity of protection of these habitats and species. Some additional protection for eelgrass may also be provided by the Ramsar Convention and the EU Birds Directive.

Eelgrass (*Zostera marina*) was, together with Dwarf Eelgrass (*Zostera noltii*), incorporated in the Dutch Red List of threatened plants in March 2002. This list proceeded from the implementation of the Convention of Bern (1982), in which protection for endangered and vulnerable species was demanded. Eelgrass and its habitat have been protected by the Dutch Flora and Fauna Act since 2002. Furthermore, *Zostera* beds were chosen as a classification tool for several Dutch water bodies including the Wadden Sea under the European Water Framework Directive. In 2005 the Dutch government will decide about species and habitat protection under the *Planologische Kernbeslissing* (PKB). Results of the present project were used to support an increase of no-activity zones around eelgrass plants from 40 to 500m.

In spite the fact that eelgrass habitats are protected under the above-mentioned instruments, they are still highly endangered. It remains important to give global consideration to eelgrass habitats on a wide scale and it remains necessary to define specific conservation regulations at the level of the species or genus.

Transplantations

Location selection

Location selection has been considered the most important phase in restoration practices (Fonseca *et al.* 2002) and therefore considerable attention was given to these activities. Areas considered for planting were selected according to the following criteria (van Katwijk 2003):

- eelgrass used to grow naturally in the selected area in the past;
- the area should have natural protection against prevailing wind directions;
- the area should have some freshwater input;
- no fishing activities or bait digging should be allowed in or in the proximity of the area.

As a result of the selection process Balgzand, a tidal area in the western Wadden Sea of approximately 6,000ha, was chosen to be the main area for the project as it fits all selection criteria (Fig. 1). The habitat suitability map (explained below) supported the selection of Balgzand.

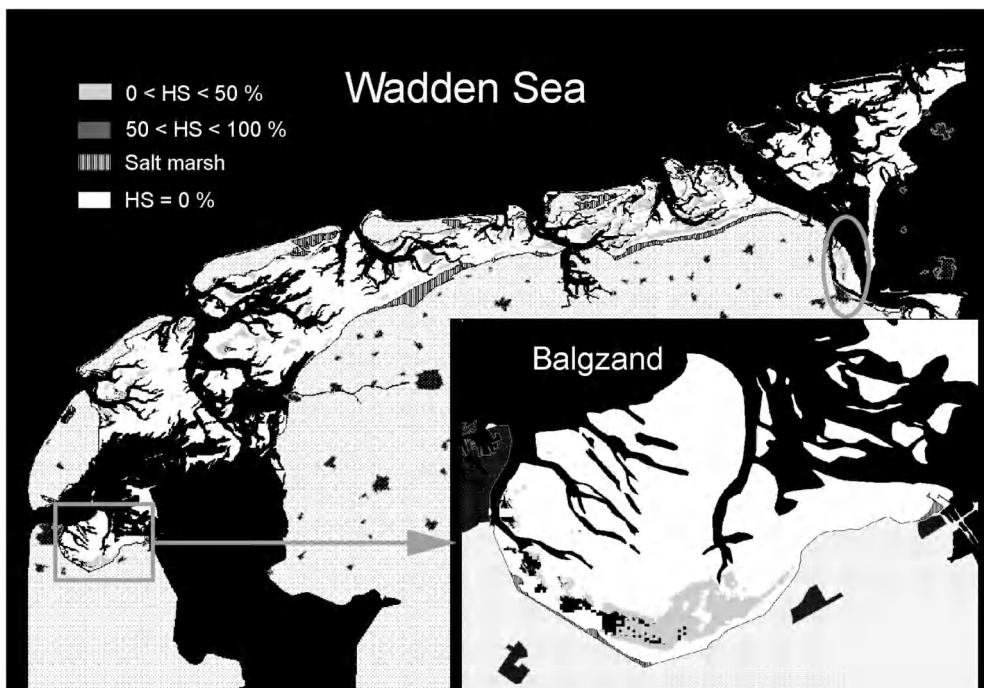


Fig. 1. Map of the Wadden Sea as a result of the Habitat Suitability Model. Habitat Suitability (HS) for seagrass is presented in three categories (%): HS = 0, 0 < HS ≤ 50 and 50 < HS ≤ 100. The grey square is enlarged and represents the Balgzand area. The grey oval encircles the donor population in the Ems Estuary.

The following criteria were used to select transplantation areas on a local scale (van Katwijk and Wijgergangs, 2004):

- sediment should be stable and not too coarse;
- depth of the location should be between +15 and -20cm MSL;
- wave exposure should be slight;
- a thin layer of water should remain during low tide.

Additionally, it was considered of vital importance to spread risks in space and in time, consistent with the apparent strategy of natural beds. Natural beds (www.zeegras.nl, see also below), as well as transplantations (*e.g.* Bos *et al.*, 2004), show large fluctuations in cover and density.

Seedlings that were to be used for transplantation were collected at the tidal area Hond/Paap in the Ems Estuary in the eastern Dutch Wadden Sea (Fig. 1). Seedlings were dug up by hand (only one seedling per 9m² to guarantee genetic diversity) and carefully rinsed and transported to the new locations at temperature of collection.

A planting unit (PU) consisted of 37 (or 61) seedlings transplanted in a hexagon bed (Fig. 2). The mutual distance between two neighboring shoots was constant (in six

directions) by the nature of this hexagon shape. Shoot density was set at mutual distance of 30cm (high density = 14 seedlings·m⁻²) or 50cm (low density = 5 seedlings·m⁻²). High density (HD) and low density (LD) PUs were always transplanted in pairs. The imaginary line between the two center points of all pairs of PUs was fixed at 50°N to assure similar exposure to the tidal currents.

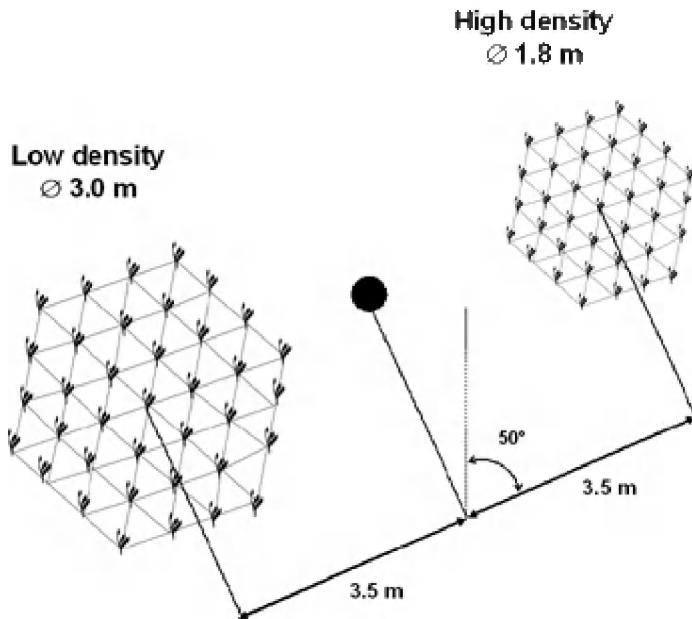


Fig. 2. Planting units (PU) with eelgrass seedlings at low density ($LD = 5 \text{ seedlings} \cdot \text{m}^{-2}$) and high density ($HD = 14 \text{ seedlings} \cdot \text{m}^{-2}$). Size of PU diameter is indicated. PU-pair axis was positioned at 50°N to guarantee similar exposure to the prevailing currents.

Habitat Suitability Model

A habitat suitability map was developed for the seagrasses in the Dutch Wadden Sea (de Jong *et al.*, 2005). This map shows locations which are potentially suitable for the growth of seagrasses (Fig. 1) and is applicable to both *Zostera marina* and *Zostera noltii*: two species that often co-occur and have highly similar habitat preferences. The map is based on a GIS-model using five environmental factors: duration of exposure to dehydration, current velocity, wave exposure, salinity and ammonium load. The relationship between seagrass habitat suitability (HS) and these factors was based on own monitoring data and available literature (see below). The habitat suitability map could be used to support policy measures on protection or to determine suitable eelgrass locations for transplantation. This makes it an important policy instrument.

Duration of exposure to dehydration

Upper and lower limits of seagrass zonation are determined by duration of exposure to dehydration during each tidal cycle. If the duration is too long the plants desiccate, and if the submersion period is too long exposure to waves causes continuous and harmful flip-flapping of the leaves (van Katwijk and Hermus, 2000; van Katwijk *et al.*, 2000). The relationship between duration of exposure to dehydration and HS is based on monitoring, field experiments and literature studies (Harmsen 1936; van Katwijk and Hermus, 2000; van Katwijk *et al.*, 2000; Groeneweg, 2004; Bos *et al.*, subm.; www.zeegras.nl) and was defined as follows: duration of exposure to dehydration $\geq 65\%$: HS 0%; 60% and 50%: HS 100%; 45%: HS 50%; $\leq 40\%$: HS 0%. Values in between were interpolated.

The habitat suitability map based on duration of exposure to dehydration was composed of a bathymetric chart of the Wadden Sea (2002, Ministry of Transport, Water Management and Public works [TWPI]) and data on average, neap and spring tidal cycles.

Current velocity

When current velocities are too high, drag forces on the leaves increase, productivity and biomass development decrease, and ultimately the leaves tear off (Conover, 1968; Fonseca and Kenworthy, 1987; Fonseca *et al.*, 1998; Schanz and Asmus, 2003; Bouma *et al.*, subm.). These effects occur in the range between 0.1 and $1.2\text{m}\cdot\text{s}^{-1}$. In the model we used the following relationship: current velocity $0\text{-}0.5\text{m}\cdot\text{s}^{-1}$: HS 100%; $0.7\text{m}\cdot\text{s}^{-1}$: HS 50%; $\geq 0.9\text{m}\cdot\text{s}^{-1}$: HS 0%. Values in between were interpolated.

The habitat suitability map based on current velocity was composed of the coastal zone model for currents SWAN, for dominant wind directions and moderate storm velocities, namely: SW $20\text{-}22\text{m}\cdot\text{s}^{-1}$; W $21\text{-}22\text{m}\cdot\text{s}^{-1}$; NW $18\text{-}21\text{m}\cdot\text{s}^{-1}$; NE $15\text{m}\cdot\text{s}^{-1}$.

Wave exposure

Waves have more severe effects on seagrasses than currents. Wave action causes a continuously varying drag force on the leaves; a flip-flapping that may best be compared with metal tiredness. A relationship between eelgrass growth and duration of exposure to wave dynamics was corroborated in field experiments (van Katwijk and Hermus, 2000; Bos *et al.*, subm.). There is little information on critical values though. In the Wadden Sea, negative effects were detected at 0.4 and $0.6\text{m}\cdot\text{s}^{-1}$ orbital velocity (van Katwijk and Hermus, 2000). In the model, the following relationship was used: orbital velocity $0\text{-}0.2\text{m}\cdot\text{s}^{-1}$: HS 100%; $0.3\text{m}\cdot\text{s}^{-1}$: HS 50%; $\geq 0.4\text{m}\cdot\text{s}^{-1}$: HS 0%. Values in between were interpolated. The habitat suitability map based on orbital velocities was similarly composed as the current velocity map (see above).

Salinity and ammonium loads

It is generally known that seagrass productivity and vitality decrease at high salinity (*e.g.* Kamermans *et al.*, 1999; Wijgergangs and de Jong, 1999; van Katwijk *et al.*, 1999;

www.zeengras.nl). It is also known that high nitrogen loads, particularly ammonium-N, have a negative effect on seagrass and could even become toxic (van Katwijk *et al.*, 1997, 1999). Moreover, salinity and nitrogen loads interact and cause a synergistic effect on seagrass vitality. At a relatively low salinity, nitrogen stimulates growth, whereas at a high salinity growth is impaired. Nitrogen compounds cannot be used for growth by eelgrass and thus accumulate, negatively affecting the plant (van Katwijk *et al.*, 1999). On the basis of these studies the relationship between salinity, ammonium and seagrass habitat suitability was estimated (Table I).

Table I. Habitat suitability (%) for *Zostera marina* and *Zostera noltii* as function of ammonium flux and salinity (PSU, Practical Salinity Unit). Habitat suitability was optimistically estimated as to compensate for overestimation of ammonium loads by the EcoWasp model (described below)

Salinity, median period July-September (PSU)	Ammonium flux ($\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$)			
	0-50	50-100	100-150	>150
>31	100 ¹	0	0	0
28-30	100	80	60	40
23-27	100	100	100	80
16-22	100	100	100	100
<16	0	0	0	0

¹) A positive effect of low ammonium loads is expected, resulting in habitat suitability of 100%.

The habitat suitability map on salinity was composed of a 2D model based on water movements, water quality and local freshwater sources (Jager and Bartels, 2002). We used the calculations of spring 1988 which was a relatively wet period in a relatively wet year.

The habitat suitability map based on ammonium load was composed of ammonium fluxes from the sediment. Ammonium fluxes were calculated by the ecological model EcoWasp (Brinkman, 1993). Data from the Ministry of TWP comprising the monitoring results of abiotic parameters were all based on channel samples, and were not considered suitable to estimate tidal flat nitrogen loads. EcoWasp calculates ammonium fluxes on the basis of temperature and organic matter content. The model includes several biological processes: benthic and pelagic algae, filter feeders and mineralisation processes in the sediment (Brinkman, 1993).

Organic matter content was calculated from silt maps (fraction <16µm) according to Zwarts (1988). Silt maps were based on the SWAN wave and current model mentioned above. Values for waves and currents were calculated using a dataset of 7,000 sediment samples of 0-10cm depth (Zwarts, 1988; Zwarts, 2003; de Jong *et al.*, 2005) and correlated to sediment silt content.

A shortcoming of the ammonium prediction was that the benthic diatom activity (ammonium consumption) was underestimated, as it was based on an average light

climate. The area of interest, with an exposure period of about 50%, has a higher light availability. Ammonium tolerances were optimistically estimated to compensate for this (Table I).

Results and discussion of the habitat suitability map

The habitat suitability map correctly predicted the currently existing eelgrass locations (Fig. 1). However, some locations were considered to be too large, especially in the eastern Dutch Wadden Sea. Wave energy was estimated using a wave energy model and this may have resulted in an underestimation for particular areas. Wave energy predictions in shallow areas have a relatively large uncertainty and the SWAN model cannot be tested due to the unavailability of wave measurements on tidal flats. The habitat suitability model has its drawbacks, but can be considered to be a policy instrument, using the best available scientific, technological and monitoring information. In the Dutch Wadden Sea, the model predicts high habitat suitability (80-100%) for seagrasses in about 200ha, whereas another 1,800ha are moderately suitable (50-80%). The model confirms that the Balgzand area is a suitable location for reintroduction of seagrass.

Transplantation results

Field activities started in June 2002 with the transplantation of about 1,500 eelgrass seedlings. Survival was low and soon it was discovered that incorrect depth data had been provided. The eelgrass seedlings had been transplanted at -20cm MSL and deeper, rather than between depths of -10 and +10cm MSL, as was planned (Jager *et al.* 2002). Previous studies had shown that transplanted eelgrass hardly survived at these depths (van Katwijk and Hermus, 2000).

In June 2003 about 1,800 eelgrass seedlings were transplanted to three new locations in the Balgzand area. About 50% of the originally transplanted shoots had grown into eelgrass plants by the end of the growing season at one location (Fig. 3A). The plants developed reproductive shoots but no seeds were observed. Moreover, no seedlings were found to develop in spring 2004, probably due to the low seed production (pers. obs.).

The locations, where survival of transplants had been high in 2003 were selected to be enhanced with 1,400 seedlings in June 2004. Again about 40% had survived by the end of the growing season (Fig. 3A) and produced reproductive shoots. An intensive study into seed production proved that seeds were present, which supported expectations that developing seedlings were to be found in spring 2005.

Seedling density, depth and quantity

The success of transplantation could be affected negatively by local disturbances and therefore it was considered important to simultaneously work in different microhabitats during the eelgrass transplantations. Apart from transplanting at different locations, transplant density, transplant depth and number of shoots per planting unit were varied.

High density PUs supported survival of transplants at those locations exposed to waves and currents, whereas planting density had no effect on survival of transplants in sheltered habitats (Bos *et al.*, submitted).

Shoots were transplanted at different depths in the safe range (see above). However, none to locally small differences in survival of transplants were observed between depths of +2 and +8cm MSL (Bos *et al.*, 2004; Bos *et al.*, 2005).

As mutual protection was expected to affect survival of transplants, the size of PUs was varied (37 or 61 plants). No significant differences were observed though.

Interaction between eelgrass and the blue mussel

Eelgrass and blue mussels have been observed to occur together in tidal habitats (reviewed in van Katwijk, 2003). Eelgrass grows at greater depth if the blue mussel is present. This possible facilitation may be based on the capacity of the blue mussel to reduce the velocity of the current (Bouma *et al.*, submitted). A natural mussel bed located in relatively shallow water in the Balgzand area was selected to study this interaction. 444 seedlings were transplanted within the mussel bed, whereas 111 seedlings were transplanted to an open mudflat adjacent to the mussel bed at similar depth of -50cm MSL.

Although transplants disappeared before the end of the growing season (Fig. 3B), it was observed that plants growing in the mussel bed survived significantly longer (Kaplan-Meier, $P<0.01$) than those growing on the exposed mud flat (Bos *et al.*, submitted).

Long-term successes

Experiments with eelgrass seeds and reproductive shoots carried out in the Balgzand area in the year 1999 resulted in fluctuating numbers of between 26 (2002) and 800 plants (2003) distributed over circa 5ha (Bos *et al.*, 2004). In 2004, only 50 plants were found. The number of eelgrass plants seems to be inversely related to macro-algal development in the preceding year. Massive decay of macro-algae that drift ashore is an often observed threat to eelgrass (Hauxwell *et al.*, 2001, Cardoso *et al.*, 2004). A longer period of monitoring is required to support evidence for this relationship.

Communication

In 2002, a communication plan was developed in which the Ministry of TWP formulated the following objectives:

- creation of public support for the reintroduction project;
- visualization of the project;
- information of interested persons;
- transferring of knowledge.

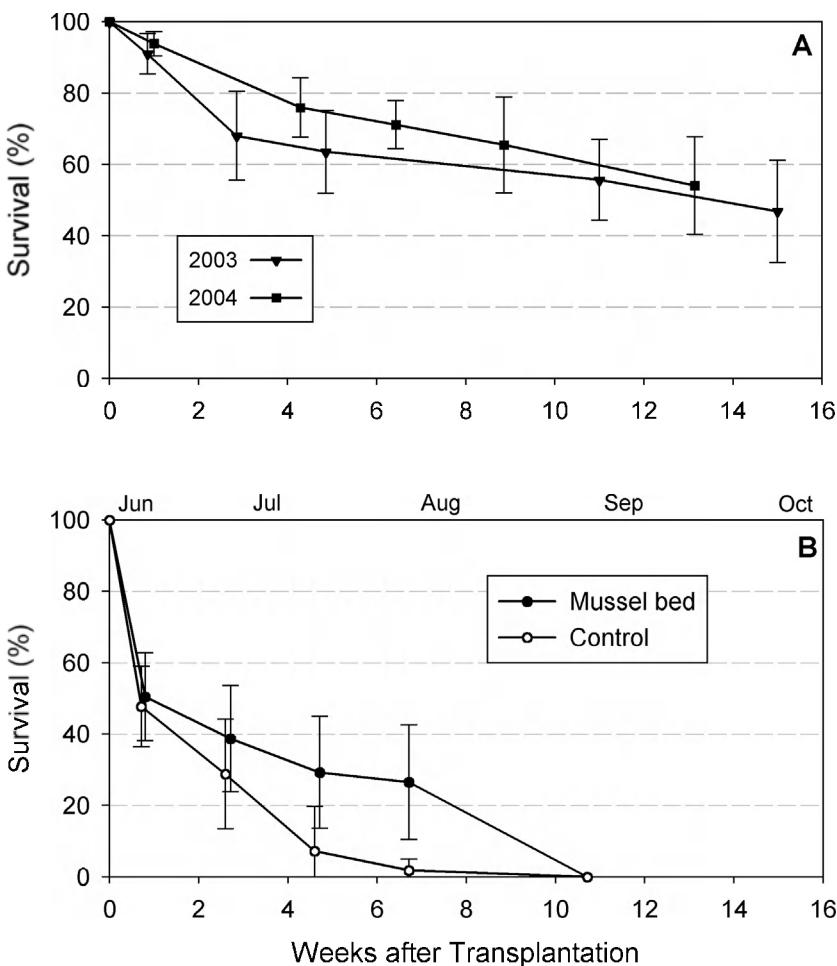


Fig. 3. Survival of eelgrass transplants at two locations in the Balgzand area. A: Relatively high survival at a location in two successive years 2003 and 2004. B: Survival of eelgrass transplants in a mussel bed and at a control location at a relative deep site.

Target groups are all the stakeholders of the Wadden Sea area, including politicians, civil servants, managers, interested citizens, NGO's and the press. Employees of museums and local tourist centers (Zuiderzeemuseum Enkhuizen, Ecomare Texel, Center for Nature and Landscape Terschelling, Information Center 'Noordwester'

Vlieland and Visiting Center ‘t Kuitje’ Den Helder) were interviewed to elaborate the type of information needed for the different stakeholders. Furthermore, employees of the Ministry of TWP advised on the level and type of information required for professional target groups.

The museums and tourist centers unanimously advised that information for interested citizens should not contain any explanations about policy decisions. The representatives of the Ministry suggested that professionals however should be informed about the policy decisions. Next, it was decided to develop a brochure for interested citizens. The information presented did not go into unnecessary detail and the text/figure ratio was set at about 50%. The brochure presented information about the ecology of eelgrass, the importance of the restoration of viable populations, the results of restoration so far, the aims for future restoration and also referred to the project website www.zeegras.nl. This website was primarily set up as a communication tool for monitoring data and general knowledge of the species to both interested citizens and professionals. Later it was supplemented with information about the transplantations, policy backgrounds, technical information as well as with actual developments. Photographs with explanatory captions, as suggested by the museums and tourist centers, illustrate the restoration activities. Through hyperlinks the professional and interested visitor is able to find background information and information on related subjects. The website is set up in the Dutch and English languages and provides the option to order a brochure in either language.

Discussion and conclusions

The area covered by eelgrass in the Dutch Wadden Sea roughly measured about 270ha in 2003 (Table II). However, the yearly fluctuations of eelgrass coverage are relatively high. Therefore, it is extremely important to have an estimation of the total area of potential eelgrass habitat. This shows the importance of the habitat suitability map. By protecting the potentially suitable eelgrass habitats, this species may recover at a higher rate than when only currently existing eelgrass habitats are protected.

Table II. Eelgrass area presented for three locations in the Dutch Wadden Sea in the year 1995, 1999 and 2003. The average area and standard deviation are calculated with data from 1988-2004. All values are in ha. “0” represents only a few plants whereas “–” represents no data available (www.zeegras.nl, Groeneweg 2004)

Location	Year			Average	STD
	2003	1999	1995		
Hond/Paap	256.2	92.3	63.6	117.3	86.5
Terschelling	0	5.8	19.2	6.4	6.5
Voolhok	6.3	-	-	7.8	2.1

The high dynamics in natural beds and the variations in transplantation survival (e.g. Bos *et al.*, 2004) stress the importance of spreading risks when transplanting eelgrass. Changes in local environmental conditions may cause transplants to be wiped out. This can probably be avoided by simultaneously planting at different locations. An important

observation during the present study was that it may be useful to spread risks in more than one dimension. Optimal survival of transplants depends on several factors. Therefore, the risks should be spread in space (location), and also in e.g. depth or density of transplants. The results of such activities could additionally help to adjust the methodology and optimize the transplantation strategy.

Transplantation of seagrasses has been carried out and studied for decades all over the world (e.g. Phillips, 1980; Worm and Reusch, 2000; Short *et al.*, 2002; van Katwijk, 2003). It is a common phenomenon in transplantation experiments that the total number of plants in a PU logarithmically decreases towards a stable number. Survival of transplants was calculated to fluctuate around a median of 35% in 53 North American seagrass transplantation studies (Fonseca *et al.*, 1998). During the present study, survival ranged from 28 to 68% seven weeks after transplantation. Although these surviving plants produced reproductive shoots, winter survival and seedling growth were low. Seed maturation may have been poor during these observations. Nevertheless, an intensive study on seed maturation in 2004 showed the existence of relatively high numbers of ripe seeds (Bos *et al.*, 2005). Hopefully this will result in the development of seedlings in 2005.

Co-occurrence of blue mussels (*Mytilus edulis*) and eelgrass has often been described with special emphasis to the protective function of the blue mussel (e.g. van Katwijk and Hermus, 2000). Experiments by Bouma *et al.* (subm.) showed that the blue mussel facilitates eelgrass by reducing the drag force on eelgrass shoots when exposed to currents. We tested this relationship at a relatively exposed location and found that transplanted eelgrass shoots had a significantly higher survival in mussel beds than without mussel bed protection (Fig. 3B; Bos *et al.*, submitted). However, all plants disappeared towards the end of the growing season. This suggested that a protective mechanism of the mussel bed was present, but not strong enough to support long-term survival. Similar observations were done by Reusch and Chapman (1995), who found that mussel beds protect eelgrass during moderate storms, but not during strong storms. For future transplantations, it might be useful to plant adjacent to or within mussel beds or other naturally present objects that provide shelter.

Although locations were carefully selected, local environmental conditions may vary and highly influence the results of transplantation activities. Therefore, an ample period of time should be reserved for location selection and the fine-tuning of the methodology. Loss of transplants is unavoidable, but may result in knowledge that helps to develop the methodology and to increase survival in the years to follow.

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Invasive scrub and trees in the coastal dunes of Flanders (Belgium): an overview of management goals, actions and results

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Abstract

Even in nature reserves and under the European Habitat Directive protected dunes of the Flemish coast, species and habitats of the open dune landscape (especially Habitat-types 2130, 2170 and 2190) have become seriously endangered. On the other hand, natural dune scrub and pioneer woodland (Habitat-types 2160 and 2180), together with alien species and manmade habitats (plantations,...), strongly increased. Since the Nature Division became responsible for nature management in Flanders (1995) and with the aid of European funding (Life-projects ICCI and FEYDRA), action was undertaken to stop and reverse this trend. The management dilemma (species rich open dune vs. natural scrub and woodland) is tackled on the basis of an Ecosystem Perspective for the Flemish Coast and by drawing up scientifically based management plans. This paper gives, from a nature managers point of view, an overview of the history and nature of these changes, the problems and dilemmas for nature conservationists, the extent and management techniques of scrub and alien tree removal and of open dune restoration, and a first evaluation of results.

Keywords: Flemish coast; Scrub encroachment; Biodiversity loss; Removal of scrub; Alien trees.

Introduction

Written and photographic descriptions (Massart, 1908a, 1908b, 1912) and botanical data (De Raeve *et al.*, 1983) picture the historic Flemish dunes as a very open landscape, mostly poor in shrubs and even completely lacking spontaneous trees and woodland. It was predominantly made up of (semi-)mobile dunes and low vegetation and was rich in typical open dune plant species and populations of what we now consider to be Red List or Target species (Biesbrouck *et al.*, 2001; Provoost and Bonte, 2004) of various dune valley habitats. The actual landscape of the protected dune areas looks very different: large areas of wet to humid dune valley systems and even dry dunes are covered with various thickets. Locally, even extensive plantations and scattered (sub)spontaneous pioneer woodlands have become established. Alien species form a growing part of the dune flora, even in protected nature areas. Parallel with landscape and vegetation change, important changes in species composition of the dune area occurred. A great number of highly specialised (plant) species of the open dune habitats has disappeared or

has become very rare, while widely dispersed and less typical taxa are spreading. Alien species make up a growing part of the dune flora, even in protected nature areas. The direct impact of urbanisation and lowering of the water table on dune landscape, flora and fauna has of course been even more drastic than that of vegetation change, but is not the subject of this paper. As an evaluation tool, this overview mostly uses botanical criteria, but results and conclusions probably also hold when other organisms are concerned.

20th century scrub expansion in the Flemish dunes

The nature reserve De Westhoek (De Panne, Belgium; Fig. 1) is one of the best studied dune areas of the Flemish coast and may be used as a good example for the description of landscape and botanical evolution over the past century. Despite protection as Belgium's first public nature reserve (est. in 1957) and the presence of large-scale dynamic geomorphological processes with continuous formation of new wet dune slacks up to this day, a series of Red List species had become locally extinct or very rare by the 1980's (D'Hondt, 1981). Two groups of species and their habitats (Romao, 1999) seemed to be especially affected: 'Humid dune slacks' (Natura 2000-code 2190), often intermingled with 'Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*)' (code 2170) and 'Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.' (code 3140), and dune grasslands belonging to the 'Fixed dunes with herbaceous vegetation ('grey dunes')' (code 2130). Although the area of 'Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes')' (code 2120) and moss dunes (code 2130) also decreased (De Vlieger, 1989), this did not (yet) lead to the complete loss or endangerment of valuable plant species. Animals, especially invertebrates and birds, of the open dynamic dune landscape may however be much more influenced! On the other hand, dune scrub ('Dunes with *Hippophae rhamnoides*'; code 2160), mostly dominated by *Hippophae* and/or *Ligustrum vulgare*, and to a lesser degree 'Wooded dunes of the Atlantic, Continental and Boreal region' (code 2180) increased. These phenomena were not restricted to De Westhoek, but were observed by scientists and managers in most of the coastal dune areas in Belgium and adjacent France (De Vlieger, 1989; De Raeve *et al.*, 1983; Provoost and Hoffmann, 1996).

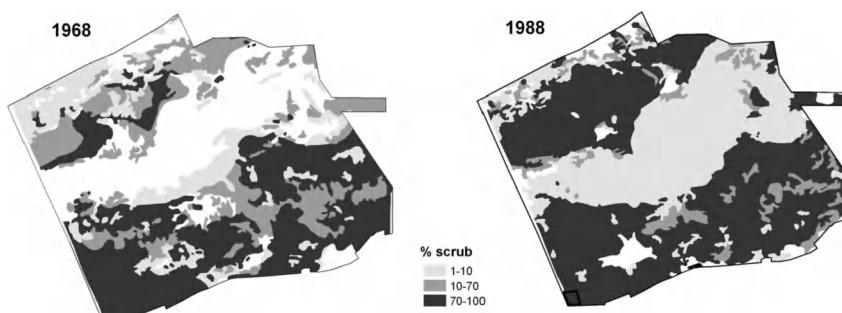


Fig. 1. Scrub extension in De Westhoek nature reserve (De Panne, Belgium) between 1968 and 1988 (Van Nieuwenhuyse, 2002, based on De Vlieger, 1989).

The decrease of wet dune slack species probably started in the 1950's or even earlier, for a large part due to the exponential expansion of *Hippophae*-scrub. At the beginning of the 1980's dense *Hippophae*-thickets had already colonised the open pioneer stage of all unmanaged Westhoek dune slacks some 15 (max. 20) years after their formation (Fig. 1). By that time several typical Red List-species were extinct (*Liparis loeselii*, *Orchis morio*, *Teucrium scordium*,...) or had become very rare (*Schoenus nigricans*, *Equisetum variegatum*, *Herminium monorchis*, *Gentianella uliginosa*,...). Only species adapted to rapid spreading into the most recently formed dune slacks (such as *Centaurium littorale*, *Parnassia palustris*, *Sagina nodosa*,...) and/or commonly present in the local persistent seed bank (*Anagallis tenella*, *Carex trinervis*, *C. viridula*,...) were able to survive this evolution. Nevertheless, by 1984, the population of *Parnassia palustris*, symbol species of the nature reserve, was almost restricted to a central complex of young dune slacks, including some of the first actively managed (mown) parts (Fig. 6c: with scores of 'occasional' and 'frequent' predominantly in the managed sites). This decline in species and quality was even (much) greater in the more isolated and/or less dynamic dune ecosystems, such as the nature reserve 'Dunes Marchand' at Zuydcoote (France) or the 'Zwinduinen en -polders' at Knokke (Belgium).

Even though populations of humid and dry grassland species may also have been diminishing since World War II, it was only from the 1970's onward that a threatening decline really became obvious. Key species in this encroachment process was mostly *Ligustrum*, together with *Hippophae* and dominant grass species as *Calamagrostis epigeios*. Few species (e.g. *Anthyllis vulneraria*) disappeared completely from the reserve, but a high number became very rare (*Thesium humifusum*, *Asperula cynanchica*, *Briza media*,...) or survived only locally. For instance, by the beginning of the 1980's, *Helianthemum nummularium* had probably already suffered great losses, but was locally still widespread in scattered small open patches between the *Ligustrum*-scrub of late-medieval dune valleys and low dunes in the southern part of De Westhoek (Fig. 6a). Twenty years later, almost none of these populations survive (Fig. 6b). This also seems a general feature, even in areas where dune grasslands once dominated the landscape.

If scrub invasion of the open dune ecosystems caused the loss of important and vulnerable species and populations, it also raised the general number of species in the dune area. A considerable part of the present dune flora in fact consists of 'new' species, often species from disturbed sites or garden escapes, but also indigenous species related to scrubs and woods. The losses in biodiversity of the open dune landscape are partly outweighed by the gain of rare species such as *Polygonatum odoratum*, *Rhamnus catharticus*, *Rosa stylosa* and others. Just as in some dune areas the nightly concerts of Natterjack toads have been replaced by the singing of Nightingales. Also epiphytic mosses, lichens and fungi have often profited from this evolution (Provoost and Bonte, 2004). Most of these species, however, are generally increasing in the whole of Flanders. Of some of them (e.g. *Berberis vulgaris*, *Lonicera xylosteum*, *Narcissus pseudonarcissus*,...) the indigenous status is even dubious.

External factors, e.g. lowering of the water table (due to water abstraction, nearby urbanisation, etc.) or increasing N-deposition (due to air pollution), and the loss of geomorphological dynamics (sometimes called 'fossilisation' of the dunes; Van der Hagen, 2002) are often cited as the main causes for this expansion. Field-experience and

historical data indicate however another important cause. Rapid and massive colonisation of the younger stages of secondary dune valley development by pioneering *Hippophae*-scrub may well be the normal natural process in lime-rich dunes, in Flanders and elsewhere in NW-Europe. In any case, pollen analysis reveals high amounts of *Hippophae*-pollen in dynamic medieval stages of landscape development (De Ceuninck, 1987). Also De Bruyne (1906) describes the presence (and extensive cutting!) of *Hippophae* in young dune valleys of the very dynamic historical dunes of De Panne. On the other hand there are no indications that the species-rich mixed thickets that are actually replacing grey dunes and older dune valley grasslands have ever existed in the medieval dune landscape.

The historical open dune landscape was probably the product of the introduction and breeding for hunting purposes of rabbits since late medieval times, the use as grazing ground for livestock (cattle, donkeys, sheep,...) up to 1940, the cutting of shrubs for firewood or dune stabilisation, etc. All these oppressing factors gradually came to an end by the middle the 20th century, at the time scrub expansion started. So, the almost completely open dune landscape of Massart (1908ab) must at least to some degree be considered as semi-natural. And the invasion of indigenous shrubs probably was the natural process of primary (*Hippophae*) or secondary (*Ligustrum* and mixed scrub) succession once the stressing and disturbing influences of agropastoral use had stopped.

Parallel to the increase of natural dune thickets, a new phenomenon came into view by the 1990's: the invasion of alien species, both woody and herbaceous. This tendency occurred in the already endangered open dune slack habitats, dry dune grasslands and moss dunes, but even more in the natural scrub communities and pioneer woods. It was essentially a somewhat postponed effect of the unrestrained urbanisation and fragmentation of the natural Flemish dune belt during the 20th century. Provoost and Bonte (2004) point out that, with the end of the 19th century as a reference, more than half of all plant species are 'new' to the actual coastal area and that no less than 20% are real aliens. Not all of those species act as aggressive threats ('pest species') to indigenous ecosystems. However, seedlings and shoots of some species derived from local plantations (*Populus xcanescens*, *P. xjackii*, *Acer pseudoplatanus*, *Salix* spp,...) or derelict brushwood used for the stabilisation of drifting sand (*Populus* spp.), garden escapes (*Mahonia aquifolia*, *Rosa rugosa*, *Claytonia perfoliata*,...) or accidentally introduced species (*Senecio inaequidens*,...) can thoroughly influence (semi-)natural dune ecosystems and lead to an additional loss in biodiversity. Speaking of 'alien species' in this context may be somewhat ambiguous, as almost all trees in the actual dune vegetation descend from cultivated ancestors and some authors even regard species as *Populus (x)canescens* and *Acer pseudoplatanus* as indigenous in Flanders, albeit not necessarily autochthonous in the coastal dunes. Therefore, the emphasis is mostly on the 'invasive' character and the threat to historical biodiversity, rather than on the 'alien' character of the species.

Management planning

The evident decline in quality of the open dune habitats (especially wet dune slack vegetation and dune grasslands) caused by an, at least partially natural, extension of

Hippophae- and *Ligustrum*-scrub creates a management dilemma for nature conservationists. International criteria are not very helpful either, as the EU-Habitat Directive Annex I obliges the protection of *all* (semi-)natural dune habitats, albeit that humid to dry dune grasslands and moss dunes (= 'grey dunes', Habitat-code 2130) enjoy a priority status. Do we thus accept the losses in historical and internationally valuable biodiversity connected to the actual, more or less autonomous (= 'natural') processes in vegetation development? Or do we interfere for the preservation of, in the actual situation, mostly semi-natural habitats with high biodiversity value, resulting in a loss in autonomy of the dune ecosystem as a whole? Or should we search for some compromise?

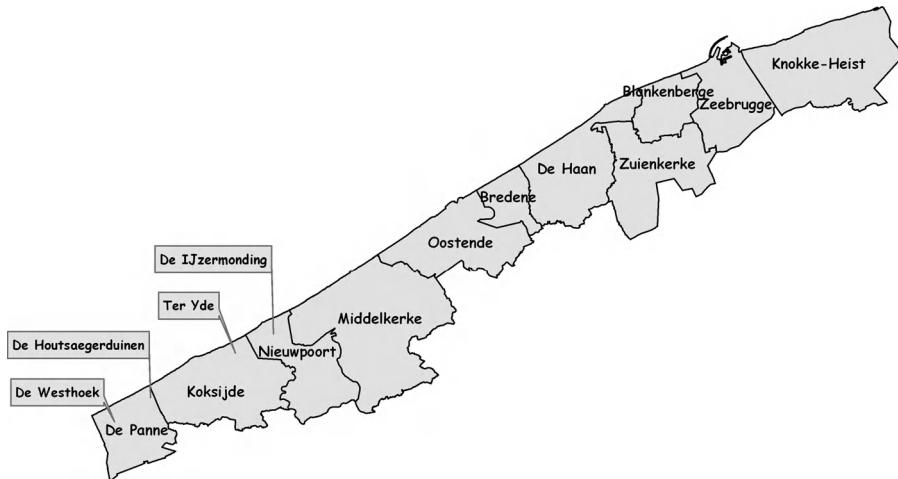


Fig. 2. Location of the concerned nature reserves and managed sites.

Due to the lack of a scientific and integrated approach of coastal conservation and the lack of sufficient means, the management policy remained ambiguous for a long time (Herrier and Killemaes, 1998). When the Nature Division of the Ministry of the Flemish Community became responsible for nature management in 1995, a general Ecosystem Perspective for the Flemish Coast (Provoost and Hoffmann, 1996; Herrier, 1998) and a number of specific management plans were drawn up, creating the necessary solid base for nature management. With Provoost and Hoffmann (1996) as a beacon, each management plan could emphasize its own specific aspects (location of concerned sites in Fig. 2). On the military base of Lombartsijde/IJzermonding (30ha, Nieuwpoort), partly managed by the Nature Division, for example, a radical policy of preserving the completely open, '19th century' dune landscape with dune grasslands, moss dunes and dune slack vegetation was agreed upon (Degezelle and Hoffmann, 2002). *Hippophae*-scrub and *Populus*-plantations are systematically removed here. In De Westhoek (345ha; Hoys *et al.*, 1996a) a compromise-scenario was chosen, based on the (virtual) division of the reserve in a western part with emphasis on biodiversity and a variety of vulnerable habitats ('pattern-oriented management'), and an eastern part with emphasis on undisturbed natural vegetation development ('process-oriented management'). Extensive grazing by large herbivores and geomorphological dynamics act as unifying landscape

processes. A comparable policy was developed for the nature reserve of Ter Yde (62ha, Oostduinkerke; Van Nieuwenhuyse, 2003). In the nearby Hannecartbos (32ha), the remnant of a marshy medieval beach plain now largely covered by not very vital plantations, the restoration of wet dune slack grasslands, historical ditches and dry 'hedgehog-dunes' goes hand in hand with the conversion of the plantation towards a more natural dune woodland. Special attention is given to the connection with adjacent open dune ecosystems and the maintenance of tall-herb fringes (habitat of e.g. Annex II-species *Vertigo mouliniana*) (Hoffmann *et al.*, 1999). On the other hand, the management plan for the Houtsaeerduinen (80ha; De Panne), an isolated reserve enclosed by urban area, aims especially at the development of natural scrub and woodland and the suppression of aggressive alien species (Hoys *et al.*, 1996b). Grazing should maintain species and landscape diversity during this process. Here only some small patches of relict dune slack and grassland are temporary mown to prevent scrub encroachment.

Where preservation or restoration of open dune ecosystems is the primary goal, management plans generally aim at the creation of as large and little fragmented entities as possible. The creation or preservation of a diversified vegetation structure with extensive transitional zones is also a constant point of attention. Another basic principle, at least when reactivation of mobile dunes is not the main aim of the action, is a respectful approach towards conservation of the soil, seed bank, micro-topography, relict populations, etc., in other words: of the site's ecological history. It is, for instance, known that a too drastic removal of the topsoil is harmful for *Vertigo angustior*, an Annex II-species of lime-rich dune slacks (Janssen and Schaminée, 2004).

Management practice (Table I)

General features

Starting in the 1970's, active vegetation management in the Westhoek nature reserve remained restricted to the yearly mowing of a former farm meadow (<2ha) and of some small patches of wet dune slack vegetation ('maintenance management'). Regrettably, most of these initial management sites were situated in unfavourable parts of the reserve, as they were influenced by a gradual lowering of the water table due to adjacent drinking water exploitation, and some were later abandoned. Following the recommendations of D'Hondt (1981), the first more adequate measures were undertaken. Those early actions concerned the conservation of the often very small relict populations of vulnerable species like *Herminium monorchis* (<10 individuals), *Schoenus nigricans* (2 individuals), *Gentianella uliginosa* (<50 individuals) and others. They mostly consisted of (very) small-scale scrub cutting or tall grass mowing (sometimes less than 0.01ha!). These surface areas were gradually extended in the 1980's and 1990's (c. 6ha by 1994), but remained a more or less anecdotal response (sometimes called 'eco-gardening') on the changes in the whole of the dune ecosystem. The same was true for Ter Yde (small-scale actions from 1994 on) and Hannecartbos (relict management from 1989 on).

Following the new management policy, which started in 1995, the first intervention was the gradual expansion of the area of young dune slacks that were kept in an open state by means of mowing or selective weeding of *Hippophae*-seedlings ('maintenance' management: 10.75ha by 2004). On the most vulnerable or inaccessible sites, relatively small-scale grassland and dune slack restoration through careful manual cutting of scrub (including the use of small machinery as brush cutters and chainsaws) and removal of litter of course continued and was even intensified (by 2004: 12.35ha, generally in small individual patches). It was mostly executed by the staff of the Nature Division, partly with the help of social employment projects. Large-scale mechanical actions, executed by specialised contractors, proved however necessary to realise the management plans. With the help of EU-funding (Life-programs ICCI and FEYDRA; Herrier and Killemaes, 1998; Herrier and Van Nieuwenhuysse, 2005), the often high goals set by the management plans could (or will) be reached in a relatively short time (already 21.47ha by 2004). At last, the (manual) treatment or removal of invasive alien trees (pest control), also took place on a large scale (20.89ha), although this figure of course includes sites where only scattered individuals were treated.

Table I gives a more detailed overview of the actions undertaken by the Nature Division since the start of active vegetation management in the Flemish coastal reserves and nature domains (in total c. 1300ha by the end of 2004). The 6ha of dune habitats that up to 1995 were managed by way of pattern-oriented or pest-controlling actions, have since been multiplied by ten and management plans, approved or in preparation, foresee a substantial extension still. An overview of Target Habitats (Fig. 3) shows that 3/4 of the actions concerned the restoration or preservation of dune slack vegetation (codes 2190/2170) and of dry dune grasslands or moss dunes (code 2130; priority habitat). This is in line with the earlier mentioned, most urgent conservation needs. Most of this management took place in De Westhoek, Ter Yde/Hannecartbos and Lombartsijde. A small but significant area of scrub or plantation removal in these dune slacks was needed to create or restore dune pools (codes 2190/3140). In Ter Yde, also the restoration of a large area of shifting dunes (code 2120) made the removal of scrub and planted trees necessary. Selective cutting of invasive (alien) trees (pest control) to restore natural dune scrub (code 2160) or woodland (code 2180) concerned some 15% of the area, in all reserves. Specific action towards the creation of humid tall herb fringes ('Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels'; code 6430) was only very locally undertaken in the Hannecartbos, but this habitat is, on a small scale, often a 'side product' of local scrub removal or natural scrub succession.

In all restoration actions involving removal of scrub or plantations, several *executive phases* could be distinguished:

1. the cutting of shrubs or trees by means of hand material (small-scale actions) or through chopping with a woodchopper (mostly large-scale actions);
2. the removal and processing of coarse woody debris;
3. the (careful) removal of stumps, fine organic litter and/or topsoil.

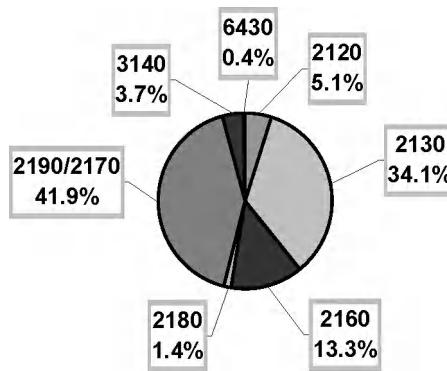


Fig. 3. Target Habitats of the management actions involving removal of scrub and pest control in the nature reserves of the Flemish coast.

As experience grew, the importance of *preparatory action* became more apparent:

1. the administrative and judicial preparation, incl. financing of the actions (is of course crucial and often time and nerve consuming, but will not be treated here in further detail);
2. the acquiring detailed knowledge of the site and conceptual preparation;
3. the planning and creation of (temporary) service infrastructure.

Even more than expected, *direct follow-up* and scrupulous *evaluation* of the results proved to be essential.

Executive phases

Large-scale action for the restoration of the open dune valley landscape of De Westhoek started in 1997, with the reclamation of 6.7ha of (partly already perishing) *Ligustrum* and mixed scrub in the late-medieval and least vulnerable southwestern dune slacks. The technique used generally followed the example of the actions undertaken some years earlier in the French nature reserve Dunes Marchand: a tractor with an improvised woodchopper first ‘smashed’ the scrub to pieces, only sparing scattered *Quercus* and *Crataegus* trees and some islands of *Prunus spinosa*. In a second stage a caterpillar crane with toothed shovel concentrated the debris and coarse litter in compact heaps. Some of the fine litter was later manually removed with rakes, but most of it was left on the site. The woody debris was burned on the spot and the ashes were transported outside of the reserve. In a last stage, the soil underneath the stakes was excavated and used for the creation of permanent service tracks. The excavations were transformed into (drinking) pools.

In later large-scale actions in the vulnerable young up to middle-aged northern dune slacks of De Westhoek, on the very vulnerable peaty soil of the fossil beach plain of the

Hannecartbos and in Ter Yde, a more ‘professional’ heavy woodchopper mounted on the 7m-arm of a caterpillar tracked vehicle was employed. Despite the heavy weight of the vehicle, the use of caterpillar tracks combined with the length of the arm and the technique of employing a thick layer of woody debris as an underground for temporary service ways resulted in a remarkably limited disturbance or compaction of the soil. Sole problem proved to be the (high) working speed: sometimes the supervising personnel was not able to correct small errors in time!

The later stages of open dune restoration proved to be more problematic. Even if the basic technique for the removal of woody debris and coarse litter (scraping it together with a toothed shovel) gave good results, removal of the finer litter caused more problems. A variety of techniques was tried out, some of them not very successful (*e.g.* the use of a street sweeper), some successful but very labour-intensive and costly (*e.g.* complete manual removal with rakes), some of them mostly creating a lot of dust... It often obliged the managers to finish off the action by cutting shallow sods (if possible less than 5cm and preserving at least part of the A1-soil horizon). Both manual (with simple shovels) and mechanical (caterpillar crane with flat shovel) techniques were successfully tried out. In De Westhoek, these sods were later used to stabilise service tracks.

As, since 1999, the use of fire (and thus the burning of woody debris) in the Flemish nature reserves was no longer considered justified, the problem augmented. The only efficient solution left was to remove debris and litter together with as little of the topsoil as possible (Fig. 4). Of course, this was only possible in more or less flat dune slacks and risked to be in conflict with the aim of restoring open dune ecosystems while respecting soils, micro-topography and relict populations. The creation of an optimal starting point for the restoration of dune grasslands on undulating dunes and in small slacks thus remains a problem that can probably only be solved through high investments in manual labour.



Fig 4. A caterpillar crane with flat shovel scrapes away woody debris, litter and part of the topsoil in a wet dune slack of De Westhoek (2000).

When accessibility, finances and legal conditions made it possible, the mixture of debris, stubs, litter and topsoil was removed from the reserve (Hannecartbos, Ter Yde), if not it was concentrated and locally stacked as an artificial dune (De Westhoek, Houtsaegerduinen). In all cases, vehicles with low soil-pressure tires or caterpillar tracks were used for transportation. Stems and branches resulting from the smaller-scale manual scrub-cuttings could mostly be chopped with an independent chopping utility and were used to stabilise footpaths in the reserves.

Preparatory action

Because of the difficult accessibility, the demarcation of the first reclaimed Westhoek-site (1997) was rather improvised and often dictated by the topographical features that were, sometimes rather unexpectedly, met with on the spot. Learning from this experience, later actions were prepared in more detail. For instance, in the last, most elaborately planned reclamation site of De Westhoek (2000), the scrub removal phase was preceded by the creation of a raster of passage ways (50mx50m) that was meticulously set out on the spot and executed with a simple woodchopper on a tractor. Meanwhile, based on vegetation mapping, topography, age of the various dune slack parts, old botanical records, etc. a complex reclamation pattern was drawn on detailed aerial photographs in order to create a site with an 'optimal' mixture of open dune vegetation and scrub of all age categories, humidity, etc. This pattern was marked on the now better accessible site, whereupon the caterpillar driven woodchopper neatly 'cut out' this pattern. It resulted, from an aerial view, in a rather artificial looking landscape pattern (Fig. 4: most northeasterly reclamation site), but should guarantee a maximum of diversity in the restored low vegetation as well as in the remaining scrub.

Another type of preparatory action was needed in the Hannecartbos, where a dying 60-year old plantation of *Alnus incana*, *A. glutinosa* and *Populus xcanadensis* was felled. Here, relict populations of *Valeriana dioica* and especially sedge populations with the Annex II-species *Vertigo moulinsiana* had to be searched beforehand and carefully marked in order to preserve these vulnerable species. All these kinds of preparatory activities may take some time and expertise, and can influence a rational execution of mechanical actions. They nevertheless prove to be essential.

A thorough study of historical sources and the situation on the site can also be very useful in the planning of necessary service infrastructure. In De Westhoek, for example, half-hardened derelict tracks dating from World War II that visibly had become almost untraceable on the site, could be 'recycled' as permanent service tracks with the help of old maps.

Control and follow-up management

As ecosystems are often rather unpredictable and natural conditions can rarely be described up to the smallest detail, small changes of the specifications on the planning documents (the contractor's base for the execution of the works) were often necessary and sometimes had to be decided instantly on the spot. A direct and intensive control of

the actions on the site proved to be essential to obtain the best possible results or even to avoid 'collateral damage'.

On the other hand and independent of action-scale, scrub-cutting and efficient litter-removal are rarely solely sufficient for successful restoration of vulnerable habitats. Regrowth of wildshoots, seedling establishment on the bared soil, etc. negatively influenced desired vegetation development in almost all reclaimed sites and during some years a follow-up management (mowing, weeding seedlings,...; mostly executed through a social employment project) always proved necessary. In some cases, periodical cutting of regrowth of e.g. *Hippophae* or *Prunus spinosa*, is already foreseen in the future management scheme. Anyway, preventive action, e.g. the preliminary search for and elimination of undesired seed-bearing trees (*Salix alba*, *Alnus glutinosa*,...) in the direct neighbourhood of the management site, might prevent later problems. Also remaining stubs, rubble, pits, etc. sometimes hampered follow-up management.

Pest control of invasive (alien) trees

Suppression of invasive alien species, mostly trees, was necessary in almost all managed dune areas. The first actions against invasive alien trees were undertaken in 1996, with the removal of 2.5ha of trees and wildshoots of *Populus (x)canescens* and *P. alba* from valuable moss dunes of the inner dune ridge of De Westhoek. Trees were simply cut and removed. In the following years, even more extensive action against especially *P. xjackii*, but also *P. (x)canescens*, *Robinia pseudacacia*, *Prunus serotina* and others, was undertaken in De Houtsaeerduinen, partially through the very careful use of a herbicide (glyphosate). In Ter Yde the problem concerned mainly wildshoots from derelict brushwood used to stabilise the dynamic dunes (mostly *Populus xcanadensis*). Because of vulnerable orchid populations in the nearby dune slacks, no herbicide was employed here. So extensive mowing and manual uprooting was used as a management technique. Where possible, stems were almost completely removed from the site and branches were burned on the spot or, later, chopped and transported. Sometimes (e.g. dispersed individuals in hardly accessible scrub) treated or felled alien trees where left on the spot. In general, litter removal was not necessary, but the removal and processing of stems and branches had often to be done with great care, e.g. when moss dunes (Habitat-code 2130) were concerned. In all cases an intensive follow-up management (repeated mowing, uprooting of wild shoots and even renewed use of glyphosate) was needed to prevent regrowth.

Evaluation and discussion

Parallel to the execution of the nature management plans, a scientific monitoring project was set up in 1997-1999, continued in 1999-2002, by the University of Ghent and the Institute of Nature Conservation, under the supervision of the Nature Division. It focused on the nature reserves of the western coastal area, especially De Westhoek and De Houtsaeerduinen and was supported by the EU-Life-project ICCI (Herrier and Van Nieuwenhuyse, 2005; Hoffmann *et al.*, 2005). However, it is still too soon after management actions to draw definite and general scientific conclusions, especially when taking into account the very abnormal hydrological conditions of 2001 and 2002. And,

as the emphasis of the study lay on the effect of extensive grazing, conclusions have less to do with the specific effects of scrub and tree removal. In any case, one of the main management questions, namely whether grazing in itself can transform scrub into valuable dunes slack vegetation or grassland, can probably only be solved after some decades of study. At the moment, however, there are no indications to suggest such a development. At Oostduinkerke and Nieuwpoort a new monitoring project was set up in 2004 (up to 2008, supported by Life-project FEYDRA) and contracted out by the Nature Division to the University of Ghent and a couple of other scientific consultants. It is of course still in the starting phase. This last monitoring project aims specifically at an evaluation of the effects of scrub and plantation removal. A provisional evaluation by the management team itself, based on empirical, non-systematic observations, of the scrub removal actions is however possible. So, some impressions rather than hard conclusions can already be presented and discussed.

The small-scale actions undertaken since the 1980's to protect relict populations of very rare species were mostly successful. Almost all target species could be saved, although accidents did happen (*e.g.* the loss of *Schoenus nigricans* due to inadequate mowing of the site), populations remained very localised and small, and were sensitive to fluctuating climatic conditions (drought, inundation,...). Nevertheless, as only very few of the species lost before the 1980's were able to recolonise the site, these results stress the importance of a management stage of careful 'eco-gardening' of vulnerable relict populations. This may be even more the case, where some vulnerable invertebrates are concerned.

Species rich vegetation is developing in almost all 'young' (25-50 years) and even 'middle-aged' (50-100 years) wet dune slacks (northern part of De Westhoek, Ter Yde), 4-6 years after large-scale scrub removal and restoration of nutrient-poor soil conditions. It includes not only the species commonly present in the early stages of natural vegetation development of newly blown-out slacks, but also some of the later-stage species. Part of the colonising plants no doubt derived from a local persistent seed bank (*Carex*, *Juncus* and *Centaurium* species, *Blackstonia perfoliata*, *Anagallis tenella*, *Sagina nodosa*,...), while most of the undesired seedlings from this seed bank (*Urtica dioica*,...) seem to be lacking. But also the relict populations in the early (<1996) managed sites (*Epipactis palustris*, *Dactylorhiza incarnata*, *Parnassia palustris*, *Gentianella uliginosa*, *Linum catharticum*,...) had a clear and positive impact on the colonisation of the newly managed sites. A good impression of the combined results of local maintenance management in young dune slacks, large-scale scrub and litter removal and follow-up by mowing or extensive grazing, is shown by the distribution of *Parnassia palustris* in 2004 (Fig. 6d).

Some remarks are however necessary. An absolute condition to obtain desired results is the thorough removal of litter and A_0 -soilhorizont or shallow sod cutting. Where removal of organic debris or the A_0 -layer was inadequate, the site became quickly dominated by competitive species such as *Agrostis stolonifera*, *Ranunculus repens*, *Trifolium repens*, *Lycopus europaeus*,... and colonisation by Red List-species was feeble. Some difference remained between areas where only the fine litter was thoroughly removed and those where sods were cut. Later stage species like *Gentianella uliginosa* and *Linum catharticum* seemed to prefer the sites, with a somewhat more closed

vegetation, where only litter was (carefully) removed, while species like *Parnassia palustris* and *Carex viridula* had a clear optimum in the open vegetation of areas where shallow sods were cut. On the other hand, after some years, there was hardly any difference left between areas where sods were removed manually or mechanically.

Secondly, at this very early stage, follow-up management by mowing or extensive grazing may not yet be essential (no control plots have been established, however), but it is probably crucial in the long run. Anyway, both the maximum slack-age able to support species rich dune slack vegetation and the obvious recovery of many species from the local persistent seed bank seem to contradict the rather pessimistic conclusions of Bossuyt *et al.* (2003) and Bossuyt and Hermy (2004). We should nevertheless not be too optimistic: in centuries-old, superficially decalcified wet dune slacks with a deep humic soil (southern part of De Westhoek), vegetation development after scrub removal mostly resulted in species and vegetation of more eutrophic soils (*Juncus subnodulosus*, *Lychnis flos-cuculi*,...).

As was feared that the chances for recovery of the vulnerable old humid and dry valley grasslands were rather low, special care was undertaken to preserve at least the old grassland soils underneath the cut *Ligustrum* scrub. But even in areas with large-scale mechanical scrub-cutting and debris removal, and probably thanks to the care that was taken as to not unnecessarily disturb soils, recovery of some of the basic species of this habitat, such as *Luzula campestris*, *Veronica chamaedrys*, *Rosa pimpinellifolia*,... was almost immediate. Others, such as *Viola hirta*, *V. canina*, *V. curtisii*, *Arabis hirsuta*, *Erigeron acer* and *Polygala vulgaris*, some of them possibly originating from a local persistent seed bank, also quickly established, but may indicate just a temporary 'clearing-effect'. In general, however, recovery from a persistent seed bank may play a minor role in the preservation of Red List-species of this habitat. *Anthyllis vulneraria* and *Primula veris*, both with new populations after scrub removal in De Westhoek, may be some of the exceptions. Most promising, however, was the establishment, within 4 years after large-scale scrub removal, of some small but completely new populations of target species such as *Helianthemum nummularium* (Fig. 6b), *Asperula cynanchica* and *Thymus pulegioides* in relatively 'young' parts of the dune system. As for some more common grassland species, (endo-)zoochorous dispersal by grazing animals may be responsible for these new establishments (Cosyns, 2004).

First results thus seem to indicate that the combination of cautious removal of scrub and litter and the introduction of extensive year-round grazing may be a successful instrument in the conservation of this priority Habitat (code 2130).

As the more radical actions of deforestation and upper soil removal (Hannecartbos) and scrub cutting with complete removal of the humic soil layer (Ter Yde) are too recent (2004) and still incomplete, they cannot yet be evaluated properly. The general impression of the experimental deforestation of 1.3ha in the Hannecartbos is however positive, as it already became clear that even large-scale action with heavy machinery on a marshy and vulnerable soil can be executed without too much damage to the soil. Intensive follow-up by manual actions (local supplementary removal of litter, removal of stubs and remaining roots, mowing regrowth and undesired tree seedlings,...) must however be foreseen.

The results of the suppression of invasive (alien) trees are less uniform and clear. Especially *Populus (x)canescens* and *P. alba*, but to a lesser degree also *P. xjackii* and *P. xcanadensis*, proved hard to handle, as wildshoots regenerating from remaining root fragments were strongly stimulated after cutting of the parental trees. Even the (controlled) use on stubs or stems of a herbicide (glyphosate) did not give completely satisfying results. The foreseen prohibition of the (even very careful) use of herbicides in public domains can however seriously affect future pest control initiatives. Action against these species will therefore include long-term and labour-intensive measures of follow-up management. Some small-scale actions against *Rosa rugosa*, *Symporicarpos albus*, etc. led to the same conclusion.

Sometimes scrub or tree removal was essential for the restoration of dried up or overshadowed dune pools. Some pools even were the product of the reclamation action itself (conversion of stakes, see above). Nevertheless, also in these cases the removal of scrub or woodland often proved to be a sound decision. In the Houtsaegerduinen a long lost population of the Annex II-species *Apium repens* grew up from the seed bank after felling overshadowing trees and shrubs and deepening of the old dune pool 'D'Achte'. In that same pool, but also in restored pools in De Westhoek, another Annex II-species, *Triturus cristatus*, appeared, while *Bufo calamita* (Annex IV) colonised most of the newly created pools in all nature reserves. Several of the newly created or restored dune pools even guarantee the survival of the protected *Characeae*-habitat (Natura 2000-code 3140) in the Flemish dunes (Denys and Packet, 2004).

One somewhat negative and generally neglected aspect of large-scale mechanical management actions may be the possible introduction of new species and genotypes through the used machinery. Although recent newcomers in De Westhoek like e.g. *Juncus acutiflorus*, *J. subuliflorus* and *Glyceria declinata* probably originated from the Ardennes where the vehicles were employed earlier, they could still be considered as harmless for the local flora. The introduction of species and genotypes from agricultural and urban habitats or far-away ecodistricts can nevertheless profoundly alter local vegetation and the genetic identity of local populations. Examples are the gradual disappearance in De Westhoek of genetic and morphological features of the autochthonous variant of *Cerastium fontanum* (= ssp. *glabrescens*) through introduction of the common *C. fontanum* (= ssp. *vulgare*) and of the local *Erodium lebelii* through introduction of the common *E. cicutarium* s.l.

Monitoring and evaluation, whether on a thoroughly scientific or on an elementary empirical base, prove to be essential for nature management, in order to be able to plan and eventually make adjustments through new actions and to be able to quickly react on negative developments. Thus monitoring should also produce direct and practical advice for nature managers. As the effects of large-scale measures can mostly not be reversed, small-scale preparatory experiments – although often difficult to execute as deadlines and contractual, legal and administrative restrictions are a severe limiting factor – are of high importance.

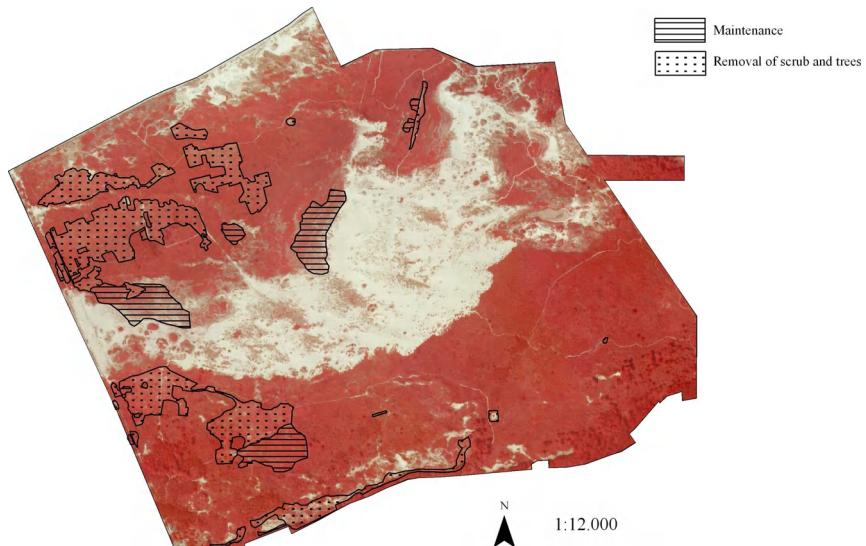


Fig. 5. Management sites in the Westhoek nature reserve (false colour aerial photography, AERODATA 2004) (cf. Table I).

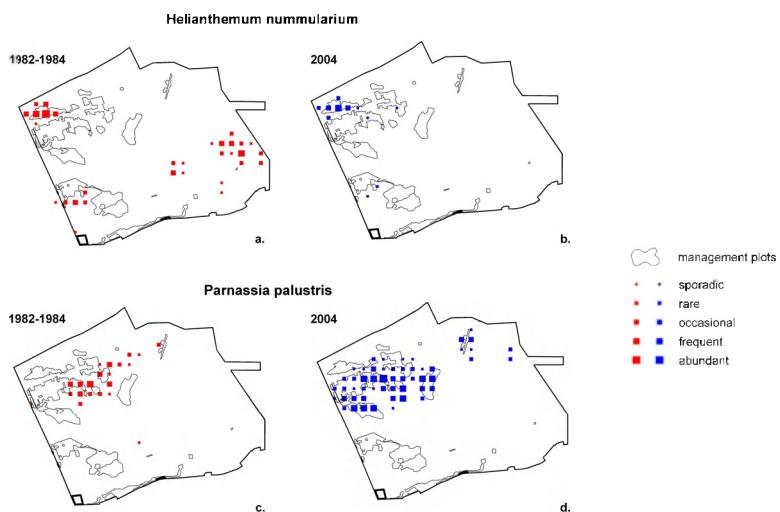


Fig. 6. Distribution of dune grassland-species *Helianthemum nummularium* and dune slack-species *Parnassia palustris* in the Westhoek nature reserve (personal data M. Leten).

Nature conservation theory and management plans often set high and not always reconcilable goals. In reality it proved not always self-evident and sometimes almost impossible to realise all of them within the strict limits set by urban planning, site status, judicial conditions, financial and personal means, technical complications and nature's own unpredictable behaviour. We consider the first results of planned management action in the nature reserves along the Flemish coast generally as very promising and have good hopes that most of our aims will be reached. The future effects of world wide changes, however, cannot yet be foreseen and only the future can judge whether the choices and realisations of this generation of nature managers will have satisfactorily resolved the dilemma's and technical problems of nature conservation in the Flemish dunes.

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Restoration of dune mobility in the Netherlands

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Abstract

Pioneer stages in Dutch coastal dunes are under threat. In several areas experiments are executed to reactivate dunes. The aim is to restore aeolian processes in order to create new possibilities for the development of pioneer vegetation. How successful are these experiments? This paper compares the results of three different projects from three different areas. The results indicate that large-scale destabilisation of dunes by removal of vegetation leads to a massive increase of dynamic, aeolian processes in an area. In order to achieve durable dune mobility, the sand must stay in movement, either by regular disturbances or by the availability of high, erodible dunes.

Keywords: Dune mobility; Coastal dunes; Restoration; Geomorphology.

Introduction

Coastal dunes are important features. Although their ecological value is widely known, sometimes we tend to forget that they are also valuable from a geomorphological point of view. The distribution of vegetation types through the landscape depends on the geomorphological setting. The specific orientation of slopes determines the establishment of specific plants. Wet dune slack vegetations are subjected to the vicinity of groundwater, mostly determined by the extent of deflation of dune slacks. The presence of all kinds of highly valuable vegetation types depends on the occurrence of dynamic, aeolian processes. We believe that a good management of the landscape should form the basis for good management of ecological values.

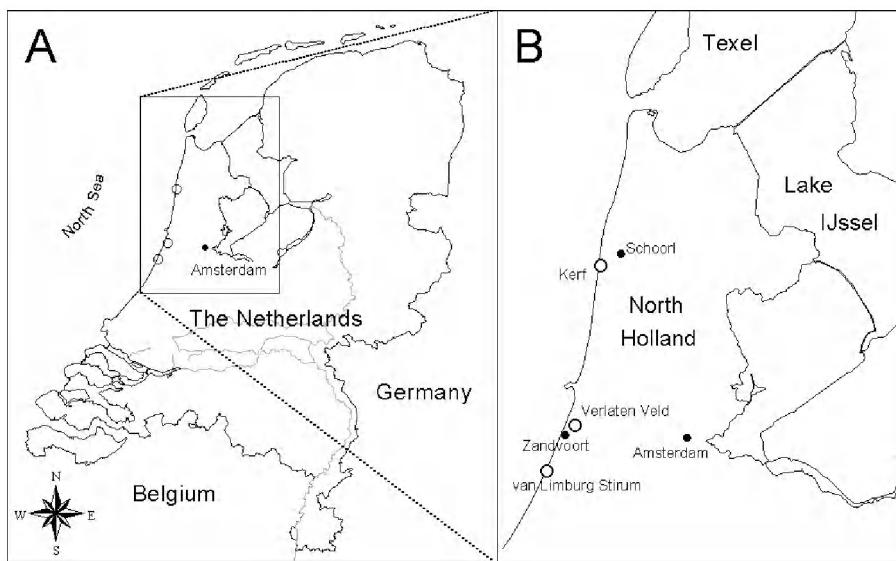


Fig. 1. Map of the Netherlands (A) with location of the sites (B).

Coastal dunes in the Netherlands are subjected to several threats. Due to stabilizing activities by man, increased nitrogen input, but possibly also climate change, all these dunes were stabilized in the past. As a result many younger and species rich vegetation types have become scarce. Managers try to reverse succession by several means. In the past, restoration of pioneer stages in dune slacks was mostly performed by removal of vegetation and topsoil in the slack. Consequently, no (sustainable) aeolian activity was restored, due to the presence of the groundwater table and the usually moist conditions at the surface, which prevent the sand from being taken up by the wind. After a number of years, the method has to be reapplied because of ongoing succession. Repeated removal of the topsoil structurally lowers the surface and finally the height of the surface will be below the average groundwater table. The landscape is modified because of steepening of slopes and lowering of the surface, and at the end, there are no further opportunities for future restoration.

Presently, more sustainable methods are developed that take account of the dynamic characteristics of a natural dune landscape. Introduction of dune dynamics (by removing vegetation) leads to a rejuvenation of the landscape through the burying of vegetation by freshly deposited sand or by abrasion of vegetation and development of (wet) deflation surfaces after wind erosion. Ideally the reactivation results in enduring aeolian activity, ensuring permanent rejuvenation and possibilities for pioneer vegetation. If this succeeds, no further interference is necessary.

Managers applied the method of reactivation of blowing sand at several scales. Most experience was gained from small scale experiments with blowouts (*e.g.* Van Boxel *et al.*, 1997; Ketner-Oostra and Sykora, 2000). Between 1995 and 2004, several larger scale projects have been started in the coastal dunes and the inland drift sands. In this

paper results from large scale projects in several dune areas along the mainland coast are discussed. Main research questions are: 1) what is the best method for large scale dune remobilisation; 2) is the result durable on a long time scale (>10 years). In this paper we give some examples from large scale measures to ensure durable landscape rejuvenation.

Methods

In this paper we present results from three different areas, with different management, different perspectives, but comparable aims. Fig. 1 shows a map of the Netherlands with the location of the sites. The Kerf is situated in the north, in the region where dune sand is poor in carbonates. The other areas are located in the calcareous dunes.

Kerf

The Schoorl dunes are managed by Staatsbosbeheer (State Forestry Service). In the area dunes are often dome or barchanoid shaped, and bordered by huge deflation plains. Many of the dunes are pocked by blowout development, with different sizes. Most of the area was stabilised in the past by human intervention. In the southwestern part, in 1997 a notch was created in the foredune, and vegetation and topsoil were removed from the dune slack behind (Staatsbosbeheer, 1997). As a result, the sea has access to the dune slack during storm surges. Beach sand is blown inland through the notch, and covers the stabilised slopes of adjacent dunes. The area was monitored intensively between 1997 and 2002 by means of yearly air photographs. Apart from the geomorphological development, ecological changes (vegetation, insects, fungi) were also monitored (Vertegaal *et al.*, 2003).



Fig. 2. *Kerf with inundation (left) and dune development (right).*

van Limburg Stirum area

The van Limburg Stirum area (VLS) is situated in the Amsterdam Water Supply dunes. The area consists of a complex pattern of dune slacks and dunes. Most of the landscape was stabilised, but locally some blowouts remained active. Near Zandvoort an extraction canal used for the extraction of drinking water was filled in again in 1995, thus restoring the former dune topography (Geelen *et al.*, 1995). The sand from the canal was still

present in the area. After restoration of the topography, the surface was left bare and dunes could develop freely. The development of the area was monitored by analysing aerial photographs, taken at a two-year interval. For details of the project, see Arens and Geelen, 2001 and 2005.



Fig. 3. Van Limburg Stirum area with slack development, facing southwest (left) and north (right).

Verlaten Veld

The Verlaten Veld (VV) is located near Haarlem, in the area of the North Holland Drinking Water Company in Kennemerland. The area is characterised by large parabolic dunes, alternated by wide deflation plains. The size of the parabolic dunes generally increases with distance from the sea. The whole area is stabilised, apart from some scattered, active blowouts. A parabolic dune was reactivated in 1998 by removal of vegetation (pine forest) and top soil (Terlouw and Van der Bijl, 1999; Arens *et al.*, 2003). Monitoring is performed by means of aerial photographs at two-year intervals, measurement of height changes every year, and frequent (4-6 weekly) recording of erosion pins. For details of the project, see Arens *et al.*, 2003.



Fig. 4. Verlaten Veld: lee face of the parabolic dune.

Interpretation of aerial photographs

For all areas, air photo interpretation was used to derive maps. For the purpose of this study, all maps were generalised by using the same legend. Because all projects share the aim of recording dune mobility, available maps were generalised to three classes: 1) strong aeolian activity; 2) weak aeolian activity; 3) no aeolian activity because of stabilisation.

- 1) Strong aeolian activity: this unit comprises all units with strong aeolian activity, either erosion or accumulation. Erosion is from bare surfaces, where pioneer establishment is prevented because of erosion of several cm per year. Accumulation is often strong, and plants often are buried completely. Also, locally slipfaces are developed. Because of sand burial, new plants may benefit.
- 2) Weak aeolian activity: this unit comprises all parts with moderate or slight accumulation, without complete burial of the vegetation.
- 3) No aeolian activity: bare surfaces get stabilised, either due to colonisation by plants, re-growth from root remnants or because of increasing moisture levels, either by a change in groundwater level or by erosion down to the groundwater. This unit is mainly used for the bare surface where vegetation was removed. This unit does not comprise surfaces which are restabilised because of plants growing through accumulation. Those parts are not mapped. Stable surfaces which were no part of the reactivation or were not influenced by sand deposition were not mapped either.

Results

The restoration activities resulted in a massive increase in aeolian activity within the areas. In the first years large areas were invaded by sand, giving rise to changes in vegetation development. Due to deflation, locally surface height was reduced considerably. After five years, stabilisation of the areas became more important.

Kerf

Parts of the dune slack are stabilised by vegetation after five years. The notch is still open, probably thanks to heavy recreational use. The width of the entrance has declined from 60m in 1999 to 36m in 2002. The dune slack is occasionally flooded by the sea, mostly in winter (Fig. 2). As a result, part of the slack is covered by water, and protected from aeolian processes. Sand is blown inland, resulting in deposition and the development of small dunes (Fig. 5). For the Kerf area, the supply of fresh beach sand and occasional flooding, in combination with high recreation pressure ensures continuous pressure acting against stabilisation. The input of fresh sand from the beach, containing carbonates, has important consequences for ecological development.

van Limburg Stirum area

In the van Limburg Stirum area, large parts are stabilised after eight years, and the landscape has changed to a mosaic of bare patches, pioneer vegetation, sand burial and stabilised surfaces (see photograph and Fig. 6). Only locally new dunes are formed, but these are mostly small. The landscape changed from a large sand drift area into a

landscape with smaller scale dune activity and blowout development. Stabilisation is mainly prevented by aeolian processes, and, occasionally, some small scale water erosion. Stabilisation is enhanced by vegetation development, either from re-growth from root remnants (mainly Sea buckthorn - *Hippophae rhamnoides* and Reed - *Phragmites australis*), or from pioneer establishment (mainly Marram grass - *Ammophila arenaria* and Saltwort - *Salsola kali*). Lower parts in the terrain are stabilised by changes in groundwater level.

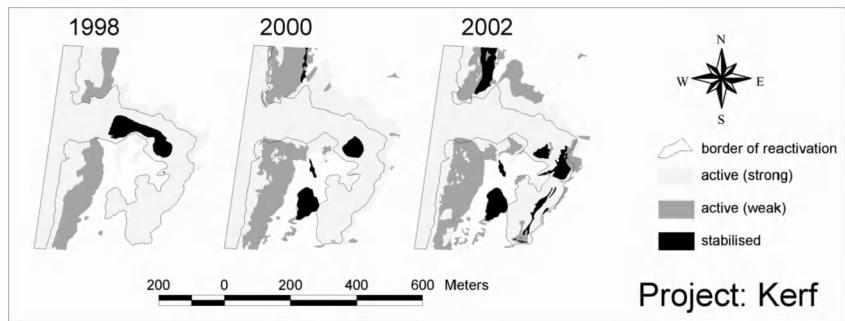


Fig. 5. Changes in extent of dynamic processes in the Kerf area between 1998 and 2002.

Verlaten Veld

On the parabolic dune, the reactivation resulted in huge erosion on the windward side and crest. Locally the height of the crest was lowered more than 4m. At the lee massive sand burial occurred (Fig. 4). In part of the area, the parabolic shape of the dune was transformed to a dome shape. The trailing edges tend to stabilise (Fig. 7). Formation of pioneer slack after migration of the dune has been observed for the first time in 2004. The dune now seems to be partly remobilised, moving over a distance of approximately $1\text{-}5\text{m.year}^{-1}$. In the western part of the area the surface is deflated down to the groundwater, on average lowered by 0.6m. A large part was already close to the groundwater, and is stabilising relatively fast. On the parabolic dunes, stabilisation is prevented by the severity of aeolian processes. Deposition and erosion is so strong that establishment of vegetation is impossible thus far.

Comparison of the projects

To compare the results of the three case studies, surface areas are calculated, expressed as percentage of the area that was de-vegetated. The sizes of the initial areas were:

- Kerf: 6.2ha (de-vegetated surface); 1998 = year 1
- van Limburg Stirum: 30.3ha (de-vegetated surface); 1995 = year 1
- Verlaten Veld: 12.7ha (de-vegetated surface); 1999 = year 1

In all areas, aeolian activity increased after the intervention, up to a maximum in the third year (Fig. 8a). From then on, the total area with activity started to decline, because of vegetation development on bare spots (Fig. 8bc). The area where vegetation is buried by drift sand, continues to expand in the first five years after reactivation (Fig. 8d). The size of this area seems to be correlated to wind activity: during years with less wind than average, the size may decrease temporarily. In the VLS area, and to a lesser extent in the Kerf, this is reflected in yearly variation of sand burial. The size of the bare, mainly erosive area is hardly or not related to meteorological conditions. Stabilisation starts from the beginning and proceeds gradually. It is striking that all lines in Fig. 8 follow more or less the same trend, which implies that meteorology is not the dominating factor in the response of the landscape after a large scale disturbance.

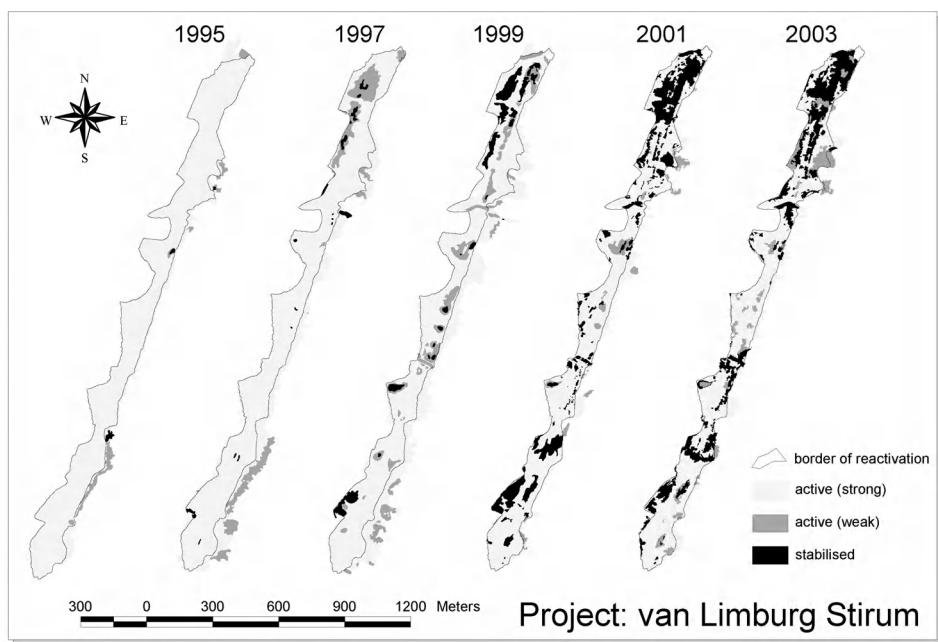


Fig. 6. Changes in extent of dynamic processes in the Van Limburg Stirum area.

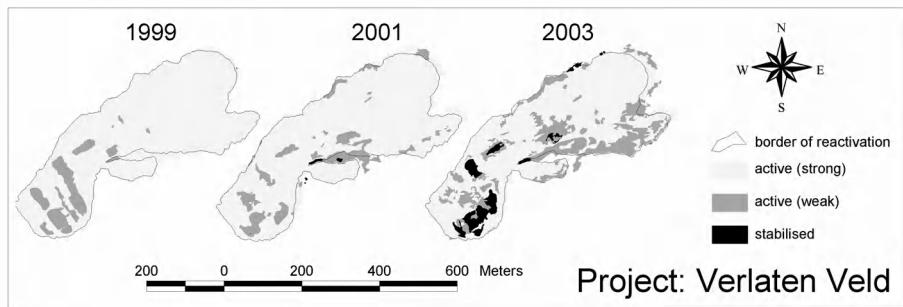


Fig. 7. Changes in extent of dynamic processes in the Verlaten Veld between 1999 and 2003.

Relatively spoken, the expansion of area with dynamic processes is the smallest in VV (Fig. 8a). The purpose here is to mobilise a large dune form. If this succeeds, the dune moves only over a small distance, which means that expansion of the area covered by sand is slow as well. Meanwhile, in the deflation plain, stabilisation proceeds. A large reduction in activity was expected in the first years of the project, since large parts of the bare area in the west are close to the ground water.

The largest expansion occurred in the Kerf area (Fig. 8a). A large surface of formerly stabilised dunes is affected by sand burial. In this case, a continuous source of sand ensures ongoing burial by sand. The size of the influenced, but not devegetated area is about half the size of the devegetated area.

In the VLS area the scale of the landscape is different. High and dry dunes are alternated with low and wet spots at relatively small distances. In the north, strong stabilisation is enhanced by re-growth of roots of *Hippophae rhamnoides* that were not removed. Dune slacks are deflated, but some were also filled with sand, because higher and drier dunes were located at their windward (western) site. Locally strong sand burial occurs, with development of slip faces at some places. As a result of these developments, the landscape tends to become a mosaic of bare spots, wet slacks, freshly formed dunes and drift sand areas. Some spots stabilise, other remain mobile and some former stable spots become mobile. The reason for the specific distribution of the different spots is not fully understood yet.

In the VV area, strong deposition in the lee faces of the parabolic dune prevents vegetation growth (see Fig. 4). In the other areas, deposition is not so strong that it results in remobilisation of buried dunes; the areas with deposition re-vegetate when the supply of fresh sand ceases. Continuous input is required in order to keep these parts dynamic. However, the input results in important ecological changes, which continues for a number of years. On the bare parts, slight erosion of about $5\text{-}10\text{cm.year}^{-1}$ prevents establishment of seedlings.

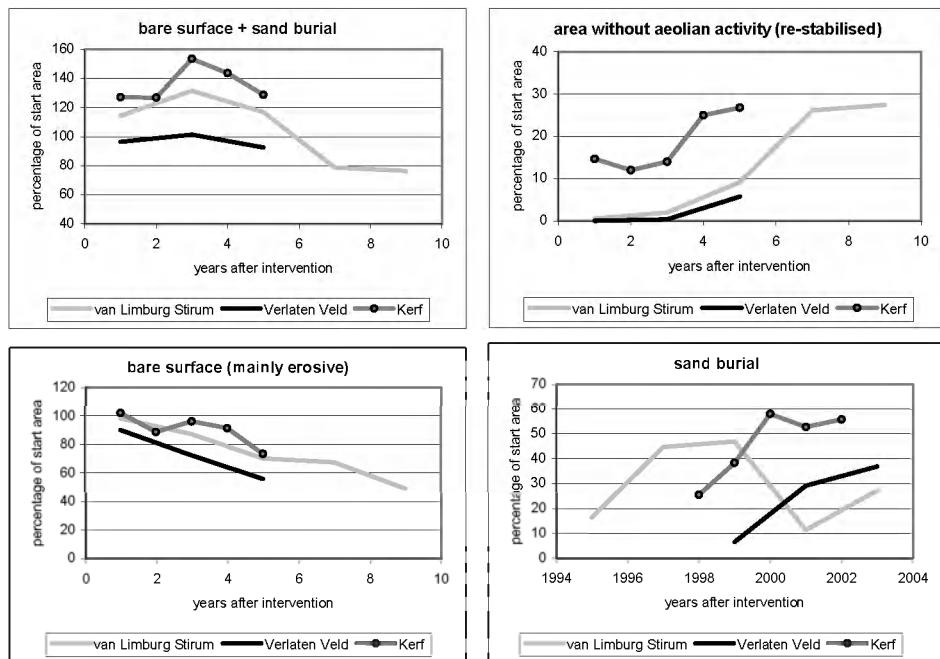


Fig. 8. Changes in dynamic and stabilised surfaces for the three areas.

Conclusion and discussion

Based on the results of the three projects, we can conclude that large scale destabilisation of dunes by removal of vegetation results in a massive increase of dynamic, aeolian processes in an area. After such an intervention, the area influenced by aeolian processes expands to a maximum after three years, followed by a gradual decline due to stabilisation of the lower parts near the groundwater. The area influenced by sand burial expands for two more years, but the expansion is smaller than the decline due to stabilisation.

In order to achieve durable dune mobility, the sand must stay in movement, either by permanent disturbances (Kerf) or by a permanent availability of high, erodable dunes. Continuous erosion prevents vegetation to stabilise the surface, whereas continuous deposition does not necessarily. Over a period of 10 years, it seems that the scale of the intervention in the VLS area is appropriate, at least for this period of time: a number of dry surfaces of at least 100m, exposed to westerly or southerly winds seems to be sufficient.

Despite the positive results of these studies, it still is too early to decide that large scale interventions will lead to durable dune mobility, on a time scale of decades.

Acknowledgements

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Remote sensing of coastal vegetation in the Netherlands and Belgium

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Abstract

Vegetation maps are frequently used in conservation planning and evaluation. Monitoring commitments, a.o. in relation to the European Habitat Directive, increase the need for efficient mapping tools. This paper explores methods of vegetation mapping with particular attention to automated classification of remotely sensed images. Characteristics of two main types of imagery are discussed, very high spatial resolution false colour images on the one hand and hyperspectral images on the other. The first type has proved its qualities for mapping of – mainly – vegetation structure in dunes and salt marshes. Hyperspectral imagery enables thematic detail but encounters more technical problems.

Keywords: Vegetation; Mapping; Remote sensing; GIS.

Introduction

Vegetation maps are essential tools for planning and evaluation in nature conservation. To a large extent, management objectives can be defined in terms of vegetation attributes, either because of their intrinsic value or because of their significance in habitat characterisation. Moreover, there is an increasing demand for biodiversity indicators, for a large part due to the European Habitat Directive but also on national or regional administrative levels. The reporting frequency seems to increase simultaneously. These tendencies underline the need for efficient tools for detailed and recurrent vegetation mapping.

From a purely scientific point of view, spatially detailed vegetation maps provide basic information for research on for instance vegetation dynamics or habitat characteristics. This paper explores the past, present and future of vegetation mapping in coastal dunes and salt marshes along the Dutch and Belgian coast. Therefore the first chapter is spent

on vegetation mapping in general. As remote sensing is always involved in one or another stage of the mapping process an overview of the techniques is given in the second part of the text. Only airborne remote sensing is mentioned since spaceborne images (so far) do not meet the characteristics required for detailed vegetation studies. The last chapter summarizes actual experience with remote sensing in coastal areas in the Netherlands.

Vegetation classification and mapping

Vegetation can be looked at in various ways, which will be reflected in its classification and mapping. We consider three major approaches:

- Vegetation is an essential **functional element** in ecosystems' carbon, water and nutrient cycling and in this respect, vegetation properties will mostly depend on features such as biomass, leaf area index (LAI) or physiological characteristics. Classification based on 'ecological behaviour' of species is a similar approach.
- Physiognomic classification is based on the outward appearance of vegetation and relates to **structure and life forms** of the dominant species. Basic physiognomic units or 'formations' are defined top down and they are generally used within a broad geographical context (Whittaker, 1962). However, vegetation structure can also be relevant on a more detailed scale, for instance as a determinant of species' habitats.
- Phytosociological classifications define plant communities in a bottom up way, starting from records of **species composition** (Westhof and van der Maarel, 1973). The system closely relates to botanical evaluation and is well established in habitat typologies for conservation in the Netherlands.

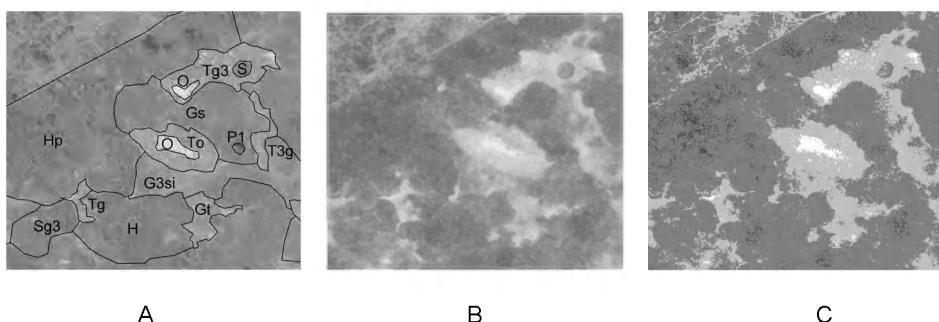


Fig. 1. Different types of vegetation maps: a) tagged vector feature map on aerial photo, b) continuous raster representing NDVI values; c) discrete raster containing five NDVI classes (NDVI=Normalised Difference Vegetation Index; see text).

An ideal classification should integrate a top down landscape ecological approach with an elaborate set of vegetation relevés into an ecotope typology (Klijn, 1997). Such typologies have only been elaborated for local applications so far. The chosen classification type will strongly determine the map properties. Conventional vegetation maps - in GIS terminology – would be characterised as single-layered vector maps, consisting of polygons (or possibly line and point features), with arbitrary shape, surface

area and attributes (Fig. 1). Vector maps can easily cope with several attributes, such as for example a hierarchical typology would demand, by linking them to a database. Quantified vegetation characteristics, such as height, LAI, biomass or vegetation indices will preferably be mapped in a continuous raster. Raster maps or grids consist of equally shaped cells (mostly squares) to which a continuous or discrete value is attributed (Fig. 1). They are advantageous for GIS calculation purposes and are compatible with georeferenced images, which are also stored as grid files. Another potential of grids is the use of ‘fuzzy’ boundaries, whereas vector features are always separated by a sharp boundary (‘crisp’). Raster maps are therefore beneficial for representation of ecological gradients such as elevation or a range in grazing intensity.

Remote sensing in a nutshell

General concepts

In general, remote sensing is based on the detection of electromagnetic radiation by sensors mounted on airplanes or satellites. Active techniques measure return signals from artificial illumination sources while in passive remote sensing, no external source is involved. LIDAR (laser) and RADAR are the most common active remote sensing systems. LIDAR is frequently used for the acquisition of detailed digital elevation models. Most applications however, can be categorised as passive remote sensing. Incident electromagnetic waves can be absorbed, transmitted or reflected, either in the atmosphere or at the earth’s surface. The signals detected by remote sensors are therefore influenced by both atmospheric conditions and landscape characteristics. Obtaining pure spectral signatures, the so-called ‘endmembers’, representing the chemical and physical properties of sudden features, requires measurements at ground level with field spectrometers. Such devices commonly register wavelengths between 350 and 2500nm, including the part of the spectrum visible by the human eye (about 400 to 700nm), near infrared (NIR, from about 700 to 1300nm) and short wave infrared (SWIR, situated between 1300 and 2500nm, Lillesand and Kiefer, 2000).

Spectral measurements are commonly presented as reflectance values, defined as the ratio of reflected to incident radiation. It is a characteristic property of materials, independent of the intensity of incident radiation. Reflectance is a function of wavelength, which in turn is related to the energy level of the radiation.

Spectral characteristics of vegetation

Fig. 2 shows examples of reflectance curves of some basic (coastal) landscape elements measured by a field spectrometer (FieldSpec Pro Fr, Analytical Spectral Devices, Inc.). Distinct patterns can be distinguished, indicating the ability to discern several land cover classes. The interpretation of spectral properties of vegetation in this paragraph is largely based on the clarifying review by Kumar *et al.* (2001).

Green plants show a strong absorption of ultraviolet and visible light due to leaf pigmentation. The predominant absorption of red and blue light causes their green appearance. About 70% of the absorbed radiation is converted into heat, while most of the remaining energy is used for photosynthesis. The dominance of chlorophyll pigments

in healthy leafs explains absorption peaks at 420, 490 and 660nm. This phenomenon is apparent in the scrub reflectance curve in Fig. 2. In senescent leafs, carotenes and xanthophylls tend to dominate, which changes the absorption pattern and through that the colour. The red absorption peak (690nm) in the mud reflection curve seems strange but is actually caused by photosynthetic pigments in the epibenthic algae (*cf.* Paterson *et al.*, 1998). Reflectance of dry (beach) sand is high in the visible wavelengths, making it easy to discriminate it from vegetated areas. At time of measurement, the moss dune plot (*Tortula ruralis* ssp. *ruraliformis*) was dried out, which explains the vegetation unlike reflectance curve in Fig. 2.

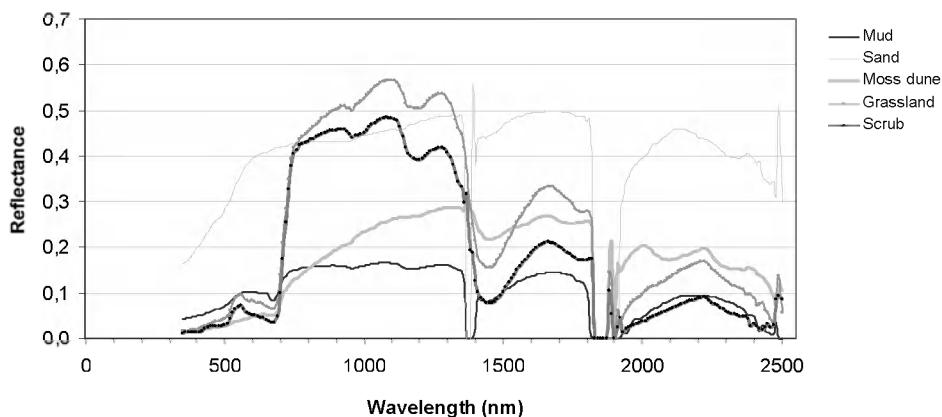


Fig. 2. Reflectance curves of some characteristic coastal habitat elements along the western part of the Belgian coast (July 2004, ASD measurements VITO).

Near infrared is hardly absorbed by green plants. More than 95% of the incident radiation is either transmitted or reflected. The characteristics of the upper epidermis and the refractive index of the cuticula determine the reflectance from the leaf surface but also the anatomical structure of the leafs contributes significantly to NIR reflectance. In multi-layered canopies, transmitted radiation is partly reflected by lower leafs, causing an increase in NIR reflection.

The contrast between red absorption and NIR reflection, known as the ‘red edge’, is an apparent spectral characteristic of healthy vegetation. It is used to calculate vegetation indices among which the Normalised Difference Vegetation Index ($NDVI = [NIR - RED] / [NIR + RED]$) is most commonly used.

The SWIR reflectance is related to the features’ water content. This part of the spectrum is characterised by distinct water absorption bands at about 1400 and 1850nm (Fig. 2).

A large number of studies deals with the spectral properties of leafs, plants or canopies (Kumar *et al.*, 2001) in which vegetation is considered from a functional ecological point of view (nutrient cycling, vegetation stress, phytomass production....). Indeed, spectral properties relate to biochemical and physical properties rather than species as such. Within a single species, plants show a variety of phenological, morphological and

physiological conditions, complicating the spectral separability of vegetation types based on species composition.

In spite of this, Schmidt (2003) found characteristic spectral signatures with statistically significant differences for the majority of 27 salt marsh vegetation types. A classification of 19 vegetation types based on canonical variance analysis of field spectra (579 bands) resulted in an overall accuracy of 91%.

Van Til *et al.* (2004) studied spectral characteristics in dry dunes on the Dutch mainland. Field spectra of 10 vegetation types were recorded in May and June and converted to 29 bands to simulate the EPS-A hyperspectral scanner (Fig. 3). Non parametric statistical tests on the May data revealed separability for 42 out of 45 pairs of types. In the June records, only 37 out of 45 pairs could be separated. It seemed difficult to spectrally discern a number of important vegetation types, such as vegetations dominated by *Calamagrostis epigejos* and *Ammophila arenaria* respectively.

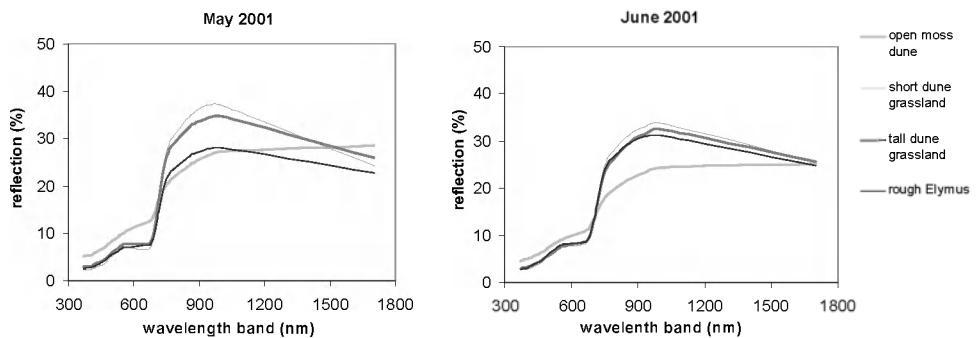


Fig. 3. Reflectance of four vegetation types of calcareous dry dunes in the Amsterdam waterworks dunes in May and June 2001 (Van Til *et al.*, 2004).

Aerial photographs

Analogue aerial photographs are the most basic remotely sensed images. The oldest black and white photos known from the Belgian coast date from WW 1. After WW 2, aerial photographs were taken quite regularly in function of cartography or coastal defence.

Panchromatic ('black and white') images integrate reflectance along a large part of the spectrum into one information 'band'. Interpretation is based on grey scale, texture, size and shape of features, patterns and contextual elements. Though seemingly trivial, context is a very important element in image interpretation. Due to its complexity, context is very difficult to translate into computer algorithms, which makes manual photo interpretation to some extent irreplaceable.

True colour images consist of three broad bands representing the red, green and blue (RGB) part of the spectrum. Due to correlation of the visual bands, the extra information content of colour images is limited. Near infrared sensitive film however, offers a considerable extra value for vegetation research (as mentioned above). In standard

infrared photos, the blue, green and red layers represent green, red and near infrared reflection respectively, making them appear as ‘false colour’ images.

Thorough interpretation requires use of stereo photo pairs which allow 3D viewing of landscape and vegetation. Several vegetation maps were produced using this technique, mostly for specific and local applications such as management planning and evaluation. Examples of merely scientific use of manual aerial photograph interpretations are rare (*e.g.* van Dorp *et al.*, 1985; Shanmugan and Barnsley, 2002).

Recurrent mapping of salt marshes in the Netherlands is carried out by the Survey Department of the Ministry of Public Works since the early seventies (Janssen, 2001). The same authority started vegetation mapping of the (fore)dunes in the 1980s. A similar program for the Belgian coast was started in the same period by the coastal defence administration of the Ministry of the Flemish Community.

Digital imagery

Digital imagery is acquired through scanning of photographs (prints or preferably films) or directly by digital remote sensors. The image quality includes four elements (Lillesand and Kiefer, 2000): the **spatial resolution**, denoting the size of one image pixel measured on the ground; the **number of bands**; the band width or **spectral resolution** and the storage precision of the information or **radiometric resolution**. The value of an 8 bit image pixel, for example can range from 1 up to 256.

The number of bands can range from one (panchromatic image) to over one hundred (hyperspectral imagery or imaging spectroscopy). Multispectral images consist of several bands.

An ideal image would have a high spatial resolution and many spectral bands but optimizing both qualities is a technical challenge. Spatial resolution of scanned film is limited by the size of the light sensitive grains, which is about 7 μm . A current scanning resolution would be 15 μm . Application of a semi-automated classification system for three band false colour NIR images, developed for Dutch coastal dunes, requires a pixel size of - order of magnitude - 20 cm (Droesen, 1999). This resolution could be achieved with aerial photos on scale 1:15 000 (Van der Hagen and van Til, 2001). The use of such a scale for high resolution orthophoto production is very cost-effective in comparison to larger scale images but the advantage of the latter is the far better applicability for manual stereo interpretation. Digital cameras obtain equal resolutions and have the advantage of skipping the - quality reducing – scanning and the ability of recording three visual bands in addition to NIR.

Line scanners, in contrast to frame cameras, consist of an array of spatial sensor elements per spectral band and images are gradually built up as the aircraft advances. Most hyperspectral scanners or imaging spectrometers belong to this group of sensors. Commercial hyperspectral sensors have about 100 to 300 bands and spectral resolutions up to 2.2nm. But a high number of bands can only be achieved at the expense of spatial resolution due to the integration time required by the sensitive elements (Charge Coupled Device) to attain an acceptable signal to noise ratio. At sub meter spatial

resolution, hyperspectral scanners can only be used in multispectral mode, thereby losing their strongest potency.

Images obtained by line scanners or frame cameras also imply a different georeferencing procedure. Camera images, in which a large surface is recorded simultaneously, are geometrically consistent and can be georeferenced and rectified quite accurately (depending on the topography). Scanned images are much more sensitive to movements of the aircraft and georeferencing requires detailed GPS and INS data (Inertial Navigation System). In practice, the best geometric accuracy attainable seems to be about two pixels or several meters (Aspinall *et al.*, 2002).

Image classification

The success of automated image classification will firstly depend on the spectral homogeneity. Images show variation in colour or reflection value due to local atmospheric conditions, angle of incident radiation, light fall-off towards the image margins, etc... and therefore need to be radiometrically corrected (see Droezen, 1999 for false colour images). Calibration to true reflectance values requires information on camera or scanner characteristics and field measurements. This processing step is useful for hyperspectral data but is often skipped in case of for instance false colour images.

Automated classification can be either supervised or unsupervised. Supervised classification is based on spectral similarities between image and training pixels (with known ground cover type). Its performance is favoured by a high spectral resolution as provided by hyperspectral images, as well as a high spatial resolution, which reduces the occurrence of mixed pixels. Unsupervised classifications do not use test pixels and carry out a clustering of pixels based on their spectral properties. This may be interesting in order to explore the spectral variability of an image although it can be hard to define the obtained classes. Another distinction can be made between pixel and object oriented classification methods. The first consider the image pixels as basic classification elements while the latter group pixels into objects prior to classification (image segmentation). Both pixel and object oriented methods can be either supervised or unsupervised (de Jong and van der Meer, 2004).

In the Netherlands, the first steps towards digital image interpretation were taken in the 1990s. False colour aerial photographs were used for semi-automatic classification of the vegetation in dry coastal sand dunes (Assendorp and Van der Meulen, 1994; Droezen *et al.*, 1995). A fuzzy classification algorithm was developed in order to discriminate five herbaceous vegetation types, based on structural characteristics. Validation with ground truth data yielded correlation coefficients of 0.8 up to 0.9 (Droezen, 1999). Janssen (2001) used multispectral CAESAR images with spatial resolution of 0.5m for classification of seven salt marsh vegetation classes and achieved an overall accuracy of 75%.

Hyperspectral GER EPS-A images with 5 m pixel size were used in dune vegetation classification by De Lange *et al.* (2004). In this study 22 vegetation classes were mapped with overall accuracies of 60 to 70%. An expert system with ancillary ecological information was used to obtain the highest accuracies.

Schmidt *et al.* (2004) used HYMAP data with 3.5m spatial resolution for salt marsh vegetation mapping. An overall accuracy of 40% was obtained for 19 vegetation types. Integration with additional laser altimetry data increased the accuracy to 66%.

Several images are available for the Belgian coast but classification is still in an early stage. During the summer of 2004, the dunes and salt marshes along the Belgian coast have been surveyed with the hyperspectral AISA-Eagle sensor. The images are presently being classified (*cf.* Bertels *et al.*, 2005).

Conclusion: towards desktop vegetation monitoring?

Mapping of coastal vegetation through automated image processing has not yet reached a fully operational stage in conservation practice although present expertise and knowledge show that certain techniques are well suited for that purpose. Table I. summarizes the properties of and classification possibilities with the main image types which are relevant for detailed vegetation mapping. But as explained below, the choice for a particular image demands a subtle assessment of different qualities.

Very high spatial resolution, false colour images certainly enable accurate classifications of a limited number of vegetation types in dry herbaceous dunes and salt marshes. Due to their potential for high geometric accuracy, these images are appropriate for the monitoring of vegetation dynamics, for instance in relation to grazing management evaluation. A cost estimate for the Amsterdam waterworks dunes (3500 ha) revealed that the manual production of a vegetation map would be about 75% more expensive. In the Netherlands an ArcView module has been developed in order to enable a wider use of this technique. Until now, mainly scanned film has been used but in the (near) future, digital camera images will probably play an important role due to their superior radiometric quality.

Table I. Main image types and their properties (* = depending on the number of bands)

	Scanned FCIR film	Digital frame camera FCIR image	Hyperspectral image
Radiometric quality	moderate	good	good
Number of bands	3	3 or 4	up to hundreds
Spectral discrimination	low	low	high*
Spatial resolution	dm	dm	m*
Geometric quality	good	good	moderate
Cost	moderate	moderate	high

In spite of their merits, false colour images only represent three (broad) spectral bands, which limits their potential for further improvement of image classifications. The spectral information is mainly comprised in the red and NIR bands, which only vaguely represent the red edge. Therefore vegetation classes delimited so far mainly represent vegetation structure. In species poor systems such as salt marshes, this leads to quite satisfactory results but in complex dune vegetations only a very rough picture of the vegetation can be obtained.

Hyperspectral data contain more detailed information on different aspects of vegetation. The work of Schmidt (2003) showed that most salt marsh vegetation types can be distinguished spectrally, at least with field spectroscopic measurements. The dataset with field spectra of dune vegetation is not large yet and first results indicate spectral overlap between important vegetation types. This is quite logical if we compare the species sets of both systems. Salt marsh vegetation can be characterised fairly well using about 15 species, while dry dunes alone would require at least 50 species. An elaborate campaign for ground reflection measurements of dune vegetation is desirable and will reveal some possibilities and limitations of hyperspectral remote sensing. But due to lower spectral and spatial resolution and atmospheric distortions in the aerial image, field measurements will always be of superior quality, representing the maximum attainable spectral separability.

At present, the use of hyperspectral images for remote sensing of coastal vegetation is still not obvious because of the constrained spatial resolution, difficulties with georeferencing and the relatively high cost. Georeferencing accuracy is of paramount importance for relating images to GPS referenced ground truth data and appears to be a key bottleneck in recent hyperspectral remote research projects (*cf.* de Lange *et al.*, 2004; Schmidt, 2003; Jacobson *et al.*, 2000).

Each application needs a fundamental assessment whether spectral or spatial resolution is most important, reflecting a trade off in respectively classification and geometric accuracy. Another end user's choice is related to the trade off between classification accuracy and detail of class-definitions. It is up to map producers to indicate the possibilities and up to the users to decide whether uncertainty is accepted in the map itself or in the classes it represents. In this respect, Jacobson *et al.* (2000) refer to different levels in the EUNIS classification.

In future research a variety of techniques need to be tested or refined. On the one hand these are related to image processing and classification. Techniques taking into account the spatial domain (*e.g.* image segmentation), feature selection techniques (*e.g.* wavelet analysis) and sub-pixel methods are only a few examples. On the other hand, many studies pointed out the importance of ancillary data. Classification of salt marshes in particular seems to improve significantly with the aid of Digital Terrain Models obtained by laser altimetry (Brown, 2004; Schmidt, 2003). In dunes, elevation data should be used more cautiously and preferably in relation with hydrology (Thackrah *et al.*, 2002; De Lange *et al.*, 2004). Finally, canopy height derived from laser scans (Ritchie *et al.*, 2001) can provide very useful additional information for vegetation mapping.

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ROLE OF SCIENTIFIC RESEARCH IN THE PLANNING AND THE MONITORING PHASE

Plenary session 3 – chair: Patrick Meire

Potentials of airborne hyperspectral remote sensing for vegetation mapping of spatially heterogeneous dynamic dunes, a case study along the Belgian coastline

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Abstract

The coastal defence and nature conservation authorities from the Ministry of the Flemish Community need detailed vegetation maps of the Belgian coast for policy planning and evaluation. From an Integrated Coastal Zone Management point of view, the development of efficient tools serving both authorities is desirable. Therefore new methods for objective, detailed and cost-efficient vegetation mapping are under investigation. This paper focuses on the application of airborne hyperspectral imagery. Two classification methods are used. The standard Spectral Angle Mapper, performed after a Minimum Noise Fraction transform, gives an overall accuracy of 59% with 15 vegetation classes. When using the Optimized Spectral Angle Mapper, the overall accuracy can be increased to 67% using the same 15 classes.

Keywords: Hyperspectral; Classification; Spectral Angle Mapper; Optimized Spectral Angle Mapper; Vegetation Mapping.

Introduction

The dynamic dunes along the Belgian coast are an important ecosystem with respect to nature conservation. They are the habitat of a specific and at least regionally rare wildlife (Provoost and Bonte, 2004). Beside their biological value they serve as a natural seawall, protecting the hinterland against floods. The integration of nature conservation and public safety requires balanced decisions and forms a major topic within the Integrated Coastal Zone Management (ICZM) in Belgium. Present day coastal defence supports an integrated approach in which natural processes are guided rather than opposed.

Vegetation maps are an important tool to support this policy. The coastal defence division (AWZ – ‘Afdeling Kust’) of the Ministry of the Flemish Community applies vegetation stability maps since the 1980s in order to assess management priorities and prevent uncontrolled, large scale blow outs in the fore dunes. Thematically more detailed maps are used for planning and evaluation of nature management, mainly by the nature division (AMINAL, ‘Afdeling Natuur’). These maps provide information on syntaxonomically defined vegetation types and can be linked to priority habitats for conservation.

Until present, these vegetation maps are made by manual photo interpretation. A main objective of the HYPERKART project is investigating the suitability of airborne hyperspectral imaging data for efficient, detailed and objective mapping of dune vegetation along the Belgian coast. Imaging spectrometers have developed rapidly over the past decades. They have more channels with better spectral and spatial resolution, individual bands are only a few nanometers wide while the spatial resolution is often less than one meter. Moreover, computer power, data-transfer and storage capacity have increased considerably in recent years. These developments have made it possible to handle and analyse the large data sets acquired by imaging spectrometers.

Within the project, the Belgian coast was imaged by a hyperspectral airborne flight campaign in July 2004, using the AISA Eagle hyperspectral sensor. Vegetation mapping is achieved by comparing image spectra with reference spectra derived from georeferenced ground truth. Therefore an extensive field survey was carried out. In this study two different supervised classification algorithms were tested to produce the vegetation maps. Beside the classical Spectral Angle Mapper (SAM) classification, an innovative classification algorithm was developed, the Optimized SAM (OSAM), which will exhaust the information content of the reference spectra.

Material and methods

The principle of hyperspectral airborne remote sensing

Light emitted by the sun is partially absorbed, partially transmitted and partially reflected by the different materials on the Earth’s surface. The nature of the material determines the degree in which different wavelengths are absorbed, reflected or transmitted. The reflected part of the sunlight determines the ‘colour’ of the material. Because of this, each material has its own spectral identity by which it can be identified. The principle of airborne hyperspectral remote sensing is based on spectroscopy. From an aircraft a location is imaged in different spectral bands in such a manner that for each pixel a quasi continuous (depending on the number of bands) reflectance spectrum is obtained (Fig. 1). High spectral and spatial resolution images acquired with airborne hyperspectral sensors offer the opportunity to map materials and therefore also vegetation in great detail. The reflected radiance measured by the sensor is converted to reflectance values which are defined as the ratio of the intensity of the reflected light to the intensity of the incoming light in function of the wavelength.

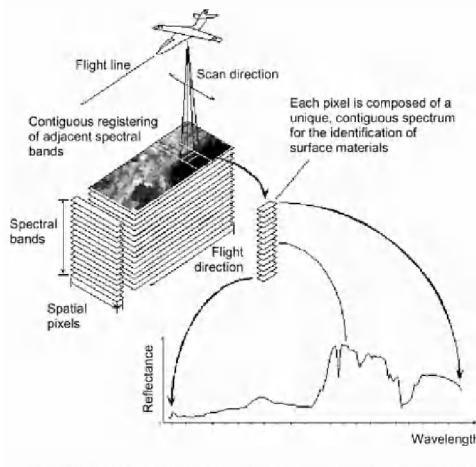


Fig. 1. Principle of airborne imaging spectroscopy.

The typical vegetation spectrum

Sunlight reaching plant leaves is either reflected, absorbed or transmitted. The probability of these processes depends on wavelength, incidence angle and roughness of the leaves as well as on their different optical properties and biochemical composition. The amount of light being absorbed by the leaves as a function of wavelength is selectively determined by the leaf pigments. The visible part of the vegetation reflectance spectrum is characterized by low reflectance values due to very strong absorption of the leaf pigments (Table I).

Table I. Leaf pigments and their absorption maxima

Type of pigment	Characteristic absorption maximum (nm)
Chlorophyll a	420, 490, 660
Chlorophyll b	435, 643
β -Carotene	425, 450, 480
α -Carotene	420, 440, 470
Xanthophylls	425, 450, 475

Absorption is strong in the violet – blue and red part of the spectrum. The green part of the solar spectrum is less absorbed causing plants to exhibit a green colour. Because the energy content of the ‘invisible’ shortwave infrared part of the solar spectrum is insufficient to trigger photochemical reactions, this part of the energy spectrum is not absorbed by chlorophyll and other leaf pigments. This results in a strong increased reflectance of the near infrared which appears around 690nm and which is typical for vegetation. This is the so-called red-edge. The absorption of the near infrared part of the spectrum is due to the leaf cell internal structure. Fig. 2 shows two arbitrary vegetation

spectra, selected from the hyperspectral image, with an indication of the different spectral features.

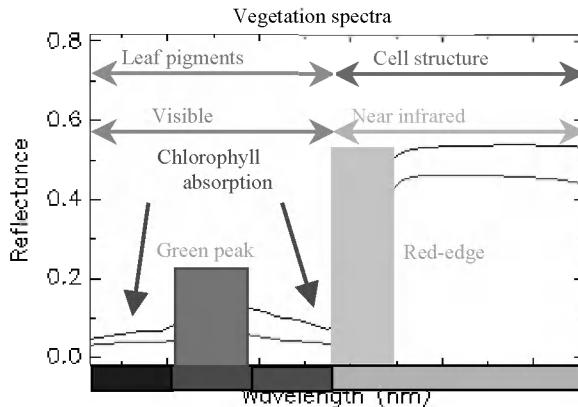


Fig. 2. Typical spectral response characteristic of green plants.

Because different plant species have different leaf pigments, internal cell structure and moisture content, they reflect light in a different way. The relative and often subtle differences between the reflectance in the visible (VIS) and near infrared (NIR) part of the spectrum is used to distinguish between the different vegetation types. Main reflectance features are position and slope of the red-edge, the amount of absorption due to the different leaf pigments in the blue and red part of the spectrum and the amount of reflection at the green peak and at the NIR plateau.

Experimental test site

This study was conducted for a test site called '*De Westhoek*', in the most western part of the Belgian coast (*De Panne*). The dune area is about 340ha large and is one of the last unfragmented dune areas along the Belgian coast. '*De Westhoek*' contains most of the (semi-)natural vegetation types that can be found in the Belgian dunes, which suits the requirements of an ideal test area. Floristically, the area is important because of its species richness: almost 400 species of vascular plants have been found in the area, which forms 1/3 of the Flemish flora, and 20% of the species are classified as rare to extremely rare. A quarter of the Flemish Red-List species is present in the area. '*De Westhoek*' also owes its conservation status to the particular faunal and fungal diversity (Hoys *et al.* 1996).

Ecological consideration

Integrated Coastal Zone Management requires an ecosystem approach of coastal defence. Rather than merely considering dune stability as a state, vegetation should be situated within its ecological functioning. Fig. 3 represents a scheme of the fore dune ecosystem including the most important vegetation patterns and processes. Vegetation mapping should focus on these vegetation characteristics in order to give a

comprehensive image of the ecosystem's functional aspects. Detailed elevation models are very useful ancillary data completing the picture.

Primary dune formation takes place along accreting coasts, where sand is available for embryonic dune formation. Under continuous sand supply these dunes develop towards marram dunes (*Ammophila arenaria*). Decrease of aeolian dynamics will lead to dune fixation with successive development of moss dunes and dune grasslands. Without management of other external 'stress factors', further vegetation succession towards scrub will take place. Vegetation regression caused by internal phenomena such as plant pathogens can change vegetation structure but will not lead to soil degradation. External factors such as trampling or natural blow outs however can lead to soil destruction and initiate secondary vegetation patterns.

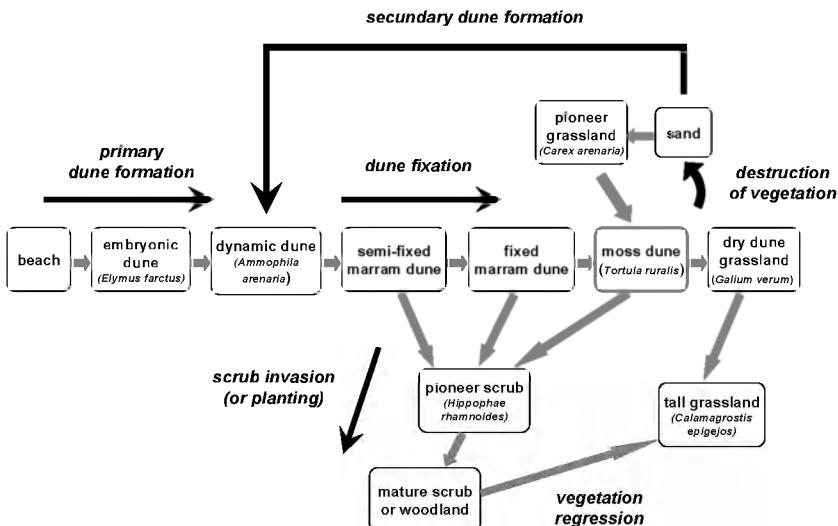


Fig. 3. Scheme of succession relations between coastal dune vegetation types within a landscape ecological framework.

Data acquisition

The AISA Eagle sensor, developed by SPECIM, Spectral Imaging Ltd. Finland, is a complete pushbroom system that consists of a compact hyperspectral sensor head and a miniature 3-axial GPS/INS sensor for monitoring the aircraft position and attitude. Table II gives an overview of the AISA Eagle characteristics.

Band settings and bandwidth are fully programmable and depend on the operation mode. In this study, 32 bands were collected with a ground resolution of 1m x 1m. The selected bands in the green and red region of the solar spectrum and the first part of the NIR-region (between 500nm and 760nm) have a bandwidth (Full Width at Half Max, FWHM) of 2.2nm. This very fine spectral sampling allows to measure the typical vegetation absorption features very accurately. Because the irradiance in the blue region, between 410nm and 500nm, is much lower than in the green, red and NIR part of the

spectrum, the signal to noise ratio in this part is also much lower. By choosing a broader bandwidth in the blue region (FWHM = 25nm), the reflected light is integrated over several channels and the signal to noise ratio is increased. In the NIR region of the vegetation spectrum, the information content is much lower than in the visible part of the spectrum and therefore again a broader bandwidth was chosen (FWHM = 28nm).

Table II. AISA Eagle characteristics

Field of view (FOV)	39.7 DEG
Instantaneous field of view (IFOV)	0.039 DEG
Spatial resolution	0.5 - 10 m
Spectral range	400 - 970 nm
Spectral channels	max. 244
Spectral sampling interval	2.3 nm
Spectral resolution (FWHM)	2.9 nm
Dynamic range	12 bits (4096)

Classification methods

Vegetation classification starting from hyperspectral images can be regarded as a technique for material identification and mapping. The unknown pixels are identified as one of several vegetation types whose reference spectra are derived from the hyperspectral imagery by means of *Regions Of Interest* (ROIs). Ideally, the reflectance spectra of a vegetation type should not vary, but in reality, it does, due to a number of factors, i.e. phenological stage, weather conditions, soil conditions, shadows, *Bidirectional Reflectance Distribution Function* (BRDF) effects, etc.

One of the most frequently applied strategies for material mapping is the use of similarity measures. This study will make use of a deterministic similarity measure to compare an unknown pixel spectrum with a library of reference spectra. *Spectral Angle Mapper* (SAM), is a common distance metric, which compares an unknown pixel spectrum \mathbf{t} to the reference spectra \mathbf{r}_i , $i = 1, \dots, K$, for each of K references and assigns \mathbf{t} to the material having the smallest distance:

$$\text{Class}(\mathbf{t}) = \arg \min_{1 \leq i \leq K} d(\mathbf{t}, \mathbf{r}_i) \quad (1)$$

Collecting ground truth data

During an extensive field campaign, several hundreds of vegetation plots were relevéed and their geographic locations were measured by using a dGPS. Some of the geographic locations were measured as polygons. Because these data were available in ‘shape’-format (SHP), it could be easily imported into commercially available image processing software. For homogeneous regions with a minimum diameter of 5m, a point measurement of the central location was performed using the dGPS. The point measurements were used to define ROIs of size 3 by 3 pixels around the central

measured location. Finally, the ROIs were used to extract the pixel spectra which are used as references in the classification algorithm.

Spectral Angle Mapper

The reflectance spectra of individual pixels can be described as vectors in an n-dimensional space, where n is the number of spectral bands. Each vector has a certain length and direction. The length of the vector represents brightness of the pixel while the direction represents the spectral feature of the pixel. Variation in illumination mainly effects changes in length of the vector, while spectral variability between different spectra affects the angle between their corresponding vectors. (Kruse et al., 1993). Fig. 4 shows two three-dimensional spectra, r and t , and indicates the Spectral Angle θ between them. This spectral angle can have values between 0 and $\pi/2$ and is calculated as:

$$\theta = \cos^{-1} \left(\frac{\sum_{i=1}^n t_i r_i}{\sqrt{\sum_{i=1}^n t_i^2 \sum_{i=1}^n r_i^2}} \right) \quad (2)$$

Where n = the number of spectral bands, t = the reflectance of the actual spectrum and r = the reflectance of the reference spectrum. The more similar the two spectra are, the smaller the spectral angle between them.

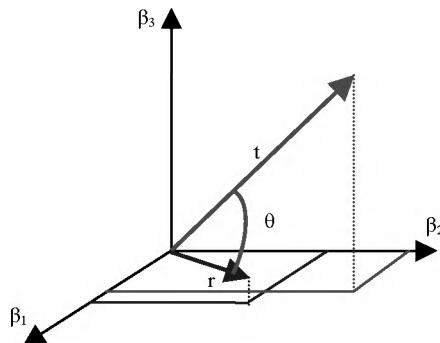


Fig. 4. Visualization of the Spectral Angle θ , between two spectra, t = target spectrum, r = reference spectrum, using three bands $\beta_1, \beta_2, \beta_3$.

Classification is done by calculating the spectral angles between the reflectance spectrum of the target pixel and the reference spectra. Each pixel will be assigned to the class according to the lowest spectral angle value.

Minimum Noise Fraction

The high spectral and high spatial resolution intrinsic to Imaging Spectroscopy, has an important drawback: imaging spectrometers deliver huge quantities of data. Much of the spectral data in the dataset are redundant. The selection of a small number of relevant spectral bands without loss of essential information for a given application is therefore a critical issue in any Imaging Spectroscopy application. The *Minimum Noise Fraction* (MNF) transform segregates the spectral bands that are dominated by noise from the bands that contain important information, contributing to the overall variance in the dataset. MNF reduces the dimensionality of the dataset and retains the small number of noise-free components. In this way the computational requirements for subsequent processing is reduced (Boardman and Kruse, 1994).

The MNF transform as given in Green *et al.* (1988) is essentially a two-step principle components analysis. The first step calculates a noise covariance matrix and decorrelates and rescales the noise in the data. The second step is a standard principle components transform where the transformed spectral bands are ranked by decreasing explained variance.

The output of the MNF transform is an image cube of n MNF bands. The low-order components have the highest information content, while most of the noise is concentrated in the high ordered bands. The inherent dimensionality can be evaluated by visual examination of the associated images. In the higher order bands surface features are no longer visible and the image is dominated by noise. An other approach to evaluate the cutoff region between signal and noise is to examine the plot of the eigenvalues. Eigenvalues for MNF bands that contain information will be an order of magnitude larger than those containing noise only. The noise-dominated bands have near-unity eigenvalues. Generally most information is concentrated in the lower order MNF bands, but rare spectra may be found in the noisier MNF bands.

Optimized Spectral Angle Mapper

The standard SAM algorithm uses the average spectrum per ROI. This implies that the intra-class variability is not retained. To preserve the intra-class variability an *Optimized Spectral Angle Mapper* algorithm (OSAM) was developed, consisting of two parts.

Firstly, for each class an *Optimal Spectral Library* (OSL) is generated. This library can be considered as ‘optimal’ since it contains the spectra that classifies as many pixels as possible in the class under consideration, without mis-classifying pixels which do not belong to that class. This is possible thanks to the calculation of the minimum Spectral Angle between a certain spectrum in a class and all pixel spectra which do not belong to the same class as this reference spectrum. In the second step, all pixel spectra are classified using the reference spectra stored in the OSL, i.e. each pixel will be assigned to the class for which the angle between a reference spectrum of that class and that particular pixel spectrum is smallest.

Results and conclusions

All classification experiments were performed with the commercial software package ENVI[®] Version 4.0. Classification was performed using ground truth data of 15 different

vegetation types. For each vegetation type a number of ROIs were used, ranging from three ROIs for wood small-reed (*Calamagrostis epigejos*) to 23 ROIs for creeping willow (*Salix repens*). After the MNF transformation the standard SAM classification was performed, using the first six MNF-bands. To clean-up the initial classification result, a standard majority 3x3 filter was applied. This filter uses a 3x3 pixels kernel and replaces the center pixel in the kernel with the class value that the majority of the pixels in the kernel has. The obtained overall accuracy reached 59% and was calculated by a confusion matrix using all ground truth ROIs. However, this accuracy is overestimated since training pixels and validation pixels are identical. All accuracies mentioned in this paper are weighted, *i.e.* they take into account the number of pixels per class.

Next, the Optimized SAM classification was applied. Fig. 5 shows the result of the OSAM classification after post-classification clean-up by a majority 3x3 filter.

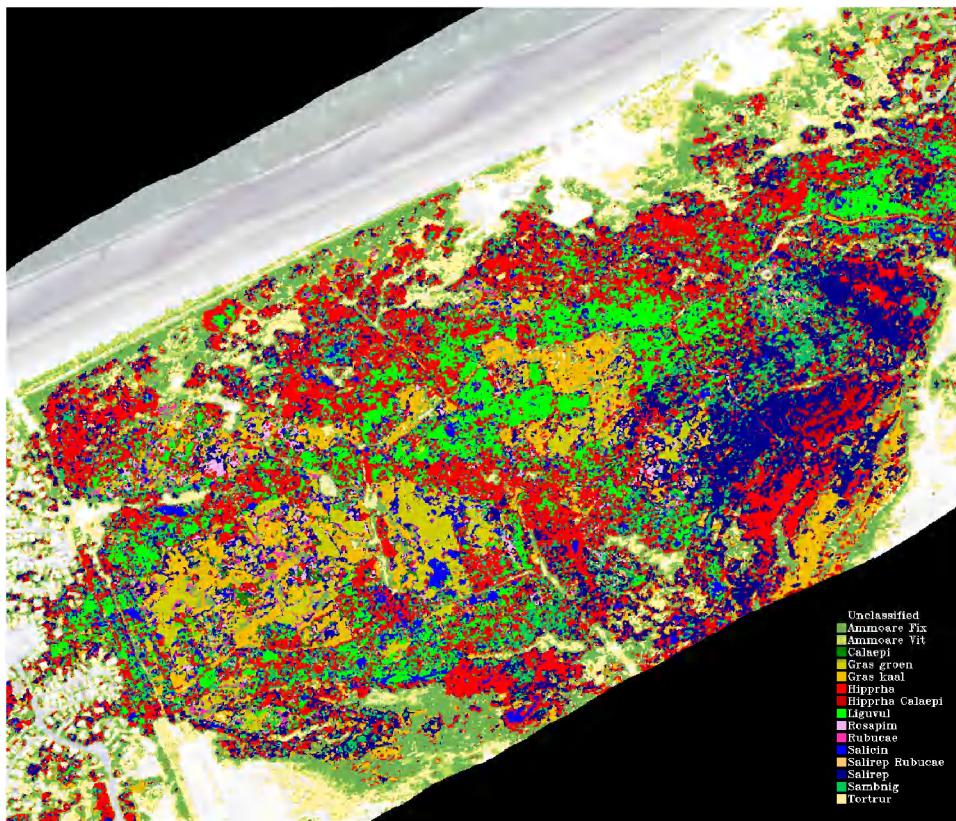


Fig. 5. Classification result obtained by the Optimized Spectral Angle Mapper (OSAM).

75% of the pixels of each class were randomly selected for training while the remaining 25% pixels were used for accuracy calculation. To obtain a statistical significant result, the overall accuracy was calculated as the mean of the accuracies calculated over 20 runs. For OSAM an overall weighted accuracy of 67% was obtained. Compared to the

accuracy obtained with the standard SAM, the accuracy obtained by OSAM can be considered as more valuable because training and validation spectra were separated.

To further increase the accuracy several measures can be taken. Firstly, the hyperspectral images used in this study have a geometric inaccuracy of 1 to 5 pixels. Because wrongly selected ground truth pixels result in bad classification performance, the different ROIs need to be manually repositioned to make sure they select the correct ground truth pixels. Secondly, several vegetation types residing in similar environments, *e.g.* different grassland types, different dune slack types and different pioneer vegetation types, have similar reflectance spectra and therefore are difficult to separate. By lumping these vegetation types the overall classification accuracy can be increased. Thirdly, different users need different vegetation maps. One user might be interested in the distribution of the broader vegetation classes, while the other user might be interested in the very detail of vegetation type distribution. It is obvious that the level of detail will influence the level of classification accuracy, *i.e.* vegetation maps indicating the broader classes have high accuracy values, while detailed vegetation maps will have lower accuracy values.

Nevertheless, the results obtained by SAM classification methods, especially the OSAM method, yield promising results. They illustrate the potential of using hyperspectral imagery for the generation of detailed vegetation maps, distinguishing a large number of vegetation types.

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Are coastal dune management actions for biodiversity restoration and conservation underpinned by internationally published scientific research?

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Abstract

Scientific research in coastal dunes, published in international journals, has mainly focussed on the understanding of processes of landscape development, vegetation succession and its interaction with animal ecology. Both fundamental and applied questions were dealt with. In theory, results of these investigations should underpin nature management practices and should give a solid foundation to monitoring. In this contribution, we review past and present, internationally published scientific research and its most important consequences for nature management and the conservation/restoration of biodiversity. Results are contrasted with contemporary management practices in order to detect management shortcomings and fields where scientific research needs to be extended and published in order to fine-tune often expensive and quite radical irreversible management practices. In general, our mini-review stresses the need for process-based research on a broad spatial scale and detailed research at a local scale for the assessment of optimal nature management actions, especially in view of potential negative feedback mechanisms.

Keywords: Nature management; Mini-review; Management actions; Ecosystem processes.

Introduction

In Europe, coastal dune habitats are listed in the CORINE biotope classification (Natura, 2000), and are considered priority habitat in the annex I of the EU Habitat Directive (Hopkins and Radley, 1998). This status implies coastal dunes deserve special conservation attention (Herrier and Killemaes, 1998). Fortunately, as far as Flanders is concerned, the coastal dunes indeed receive more than average management and nature conservation interest.

Coastal dunes are classified as semi-natural ecosystems, in which succession is initiated by fixation and driven by the complex of soil formation (humus accumulation) and

vegetation succession. Leaching and mobilisation of CaCO₃ complicate the picture and are important in nutrient dynamics. At present, tall grass- and scrub encroachment greatly overrule these fine-scaled soil processes and cause substantial loss of regional biodiversity in Flemish coastal dunes (Provoost *et al.*, 2004). Within the coastal dune system a dynamic, stressed and unconstrained landscape phase is distinguished (Provoost and Bonte, 2004). The dynamic landscape is characterized by highest diversity of system specific species, which are often threatened at a regional and international scale. During the last decades a fast (increased) development towards an unconstrained landscape is recorded, due to *e.g.* eutrophication, disturbance of hydrology and lack of agropastoral stress. These man-driven processes lead to an apparent qualitative shift toward a less specific flora and fauna. Above that, an increased invasion of garden escapes of exotic species has been recorded (Provoost and Bonte, 2004). Illustrative is that in Belgium, typical dune butterflies have become extinct or very rare (Maes and Van Dyck, 2001) and 95% of the typical dune carabid beetles are included in the Flemish Red List (Desender *et al.*, 1995).

Due to this process towards an unconstrained landscape, scrub vegetation tends to encroach, at the expense of dynamic landscape habitats like grey dunes and dune slacks. They are now heavily fragmented and patchily distributed within a matrix of closed dune vegetation (shrubs, monospecific tall grassland), often urging species to survive in a completely different landscape than the one they are adapted to. This apparent shift in landscape structure and the decline of at least regional biodiversity urges managers to take often quite radical nature management measures on relatively short terms. Removal of scrub and woodland, mowing and grazing, are the most commonly applied measures for dune grassland restoration. Well-documented examples of management schemes are available for the Dutch dunes (*e.g.* Annema and Jansen, 1998) and the LIFE initiative at the Sefton coast in the UK (Houston *et al.*, 2001). In Belgian dunes, around 15ha of scrub have been cut down and currently nearly 500ha are grazed (Herrier and Killemaes, 1998). None of these measures enable a complete regression towards a dynamic landscape, since *e.g.* soil processes changed the soil more or less irreversibly, into more stratified and organically enriched soils.

In this paper, we review the international peer-reviewed scientific literature on the relationship between coastal dune biodiversity and nature management actions and the processes, underlying biodiversity patterns. With this information we aim (i) to find out how management strategies and ecosystem processes determine biodiversity patterns in general, (ii) to what amount current management actions are underpinned by well designed (and internationally published) scientific research and (iii) what kind of future research is needed to understand how management actions can tackle the problem of the declining system specific biodiversity in coastal dunes.

Method

We scanned the Web of Science-database for papers dealing with the relation between coastal dune management and ecology. The following search items were used: “coastal dunes and management”, “coastal dunes and diversity”, “coastal dunes and

assemblage", "*coastal dunes and community*", "*coastal dunes and ecology*", "*coastal dunes and population*". Relevant papers were reviewed and screened for scientifically underpinned results on the relation between management actions, relevant processes within the coastal dune ecosystem and aspects of biodiversity. In order to avoid a bias towards locally available, but not widespread, papers, only results from papers recorded in the Web of Science were used. In total 72 papers were selected for further analyses. We admit that a larger quantity of internationally available literature has been published on grazing as a general process and on other management measures as well. Up to a certain and general level, these results will also be of value to underpin coastal dune management, but not as far as dune specific processes, landscape phases and taxa are concerned.

Results

General

The number of internationally available publications on the relation between coastal dune biodiversity aspects and nature management (including ecosystem functioning) clearly shows an increase during the last 15 years ($r_{15}=0.80$; $P<0.001$; Fig. 1). The majority (59 %) of the studies were conducted in European coastal dunes (incl. Israel), followed by North America (22%) and (South) Africa (9%). Studies in coastal dunes from Australia, South America and Asia are rare. Studies focused on a wide taxonomic range of model groups, but studies using vascular plants and to a lesser amount arthropods are clearly dominant (Fig. 2).

Management actions

On the Web of Science, we found 50 records on effects of nature management actions on biodiversity patterns. Studies have especially focussed on effects of trampling, stabilisation of mobile dunes by plantations, beach cleaning and grazing by domestic livestock (Table I). Although the number of records is low, some trends are clear: beach cleaning and dune stabilisation always had a negative impact on species diversity. Also, recreation disturbance, generally results in a decrease of species diversity. Only two studies in Mediterranean dunes (Kutiel *et al.*, 2000; Kutiel and Zhevelev, 2001) did not find a significant impact. Effects of grazing by domestic livestock can have positive or negative impact on diversity, depending on the scale of research: often diversity increases within the landscape (this is beta-diversity), but at very local scales (patch- or site-scale), alpha diversity can dramatically reduce. Unfortunately, at the international publication level, effects of sod cutting, shrub removal and mowing practices in coastal dunes are not documented.

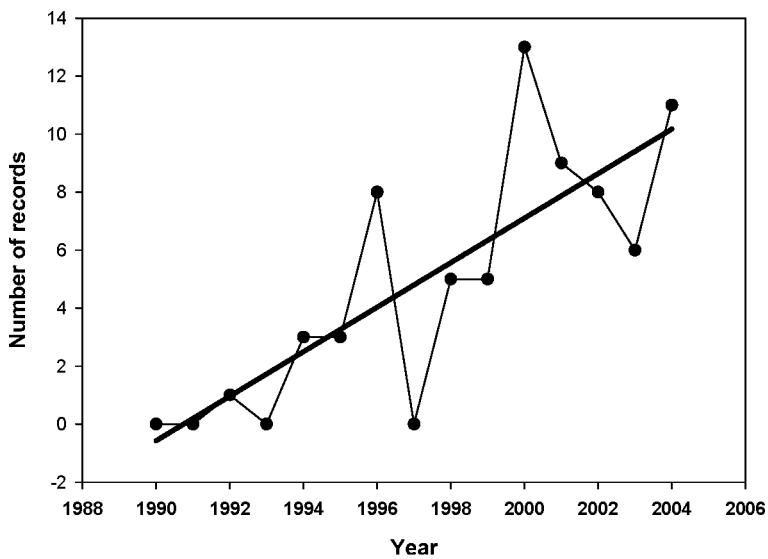


Fig. 1. The number of publications on the relation between nature management in coastal dunes and patterns of biodiversity, published between 1990 and 2004.

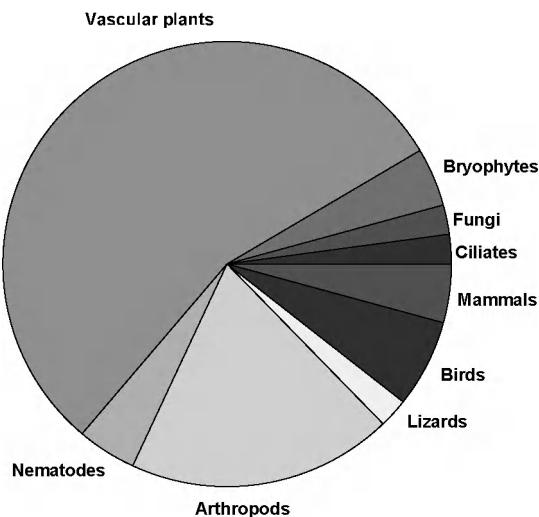


Fig. 2. Overview of used taxa within studies on the relation between coastal dune management and biodiversity.

Table I. Overview of results in literature on the effects of management actions on coastal dune biodiversity. + and – indicate positive and negative effects, respectively; Sspec: diversity of typical (=coastal dune specific) diversity; Stot: diversity of all species within taxon; HabDiv: Habitat diversity; NS: no trend in biodiversity; Refs: used references

Management action	+Sspec	+Stot	NS	-Sspec	-Stot	+HabDiv	Refs
Grazing	4	1	4	1	1	2	Desender, 1996; Kerley <i>et al.</i> , 1996; Kooijman and vander Meulen, 1996; Ten Harkel and vander Meulen, 1996; Garcia-Mora <i>et al.</i> , 1999 ; Bonte <i>et al.</i> , 2003 ; Wallis DeVries and Raemakers 2001.
Plantation/stabilisation	0	0	0	3	2	0	Lawesson and Wind, 2002; Munoz-Reinoso, 2004.
Restricting recreation	0	0	2	7	7	0	Burger, 1994; Watson <i>et al.</i> , 1996; Kutiel <i>et al.</i> , 1999; Kutiel <i>et al.</i> , 2000a; Imbert and Hoele, 2001; Kutiel and Zhevelev, 2001.
Shrub removal	1	0	0	1	0	0	Kutiel <i>et al.</i> , 2000b.
Sod cutting	1	0	0	0	0	0	Ernst <i>et al.</i> , 1996.
Beach cleaning	0	0	0	4	2	0	Griffiths and Stenton-Dozey, 1981; Brown and McLachan, 2002; Llewellyn and Shackley 1996; Jedrzejczak, 2002a,b; Verhoeven, 2002a; Brown and McLachan 2002; Colombini and Chelazzi, 2003.

Coastal dunes processes

A total of 40 records emphasize on the interaction between environmental processes within the coastal dune ecosystem and biodiversity patterns. These studies clearly indicate a decreasing diversity with increasing patterns of fragmentation, trampling and the occurrence of invasive species. Increasing aeolian dynamics does result in decreasing diversity patterns, if all species are taken into account. However, the number of dune-specific, threatened species (Red lists), increases if dynamics remain high. Two studies confirmed the Intermediate Disturbance Hypothesis with a maximal diversity in the middle gradient of the disturbance gradient (Henriques and Hay, 1998; Gordon, 2000). The relation between diversity and eutrophication is variable, but contains a trend of increasing total species richness accompanied with a decline of the number of typical dune species.

Table II. Overview of results in literature on the effects of coastal dune processes on biodiversity. + and – indicate positive and negative effects, respectively; Sspec: diversity of typical (=coastal dune specific) diversity; Stot: diversity of all species within taxon; NS: no trend in biodiversity

Process	+Sspec	+Stot	NS	-Sspec	-Stot	References
Aeolian dynamics	7	0	1	0	3	Henriques and Hay, 1998; Garcia-Mora <i>et al.</i> , 1999; Wilson and Sykes 1999; Gordon, 2000; Martinez <i>et al.</i> , 2001; Franks and Peterson, 2003 ; Bonte <i>et al.</i> , 2004b ; Jun <i>et al.</i> , 2004.
Eutrophication	0	4	0	5	3	De Vries <i>et al.</i> , 1994; Gaylard <i>et al.</i> , 1995; Desender, 1996; Pollet and Grootaert, 1996 ; Ten Harkel and vander Meulen, 1996; Beena <i>et al.</i> , 2000. Verhoeven, 2001 ; Verhoeven 2002a,b ; Wamelink <i>et al.</i> , 2003 ; Bonte <i>et al.</i> , 2004 ; Bossuyt <i>et al.</i> . 2004a; Jun <i>et al.</i> , 2004.
Acidification	0	0	0	1	1	Wamelink <i>et al.</i> , 2003.
Fragmentation	0	0	0	4	2	Obeso and Aedo, 1992 ; Bonte <i>et al.</i> , 2002 ;Bonte <i>et al.</i> , 2003 ; Bossuyt <i>et al.</i> , 2003; Bonte <i>et al.</i> , 2004b; Bossuyt <i>et al.</i> , 2004b.

Table II (*cont.*): Overview of results in literature on the effects of coastal dune processes on biodiversity. + and – indicate positive and negative effects, respectively; Sspec: diversity of typical (=coastal dune specific) diversity; Stot: diversity of all species within taxon; NS: no trend in biodiversity

Process	+Sspec	+Stot	NS	-Sspec	-Stot	References
Trampling	0	0	0	6	5	Andersen, 1995 ; Kutiel <i>et al.</i> , 1999; Kutiel <i>et al.</i> , 2000a; Imbert and Hoele, 2001; Kutiel and Zhevelev, 2001.
Invasive species	0	0	0	1	1	Hertling and Lubke , 2000 ; Webb <i>et al.</i> , 2000; Aigner, 2004.

Discussion

Although research efforts on the relation between dune management and biodiversity clearly increased during the last decade, well-documented studies remain fairly uncommon, or are not internationally available. To our opinion, this is not the result of the lack of scientific interest, but rather caused by the lack of studies beyond the local level. Dune managers are often more interested in studies dealing with local inventories of natural values and direct evaluations of management actions. Hence, these short-term studies are intrinsically focussed on local patterns, and as a result very difficult to generalize into a larger framework. Possibly, long term and well designed studies are only available within the local scientific community because of the lack of a more generally applicable framework of research.

Although information is rather scarce, it is possible to separate studies on effects of management actions from studies on underlying processes, which indirectly indicate how changes in the (a)biotic environment result in varying biodiversity patterns. Results from the first type of research do more often come to different conclusions than the latter processed aimed studies do. We believe this is partly due to often completely differing local environmental conditions, but also to the use of only a limited number of model taxa. Hence, we believe that well designed experiments on a broad regional scale with many biotic models, but focussing on a restricted number of actions in similar environmental conditions of humidity, soil productivity, vegetation typology and habitat geometry are urgently needed.

Are nature management actions underpinned by internationally published scientific research?

Nowadays, nature conservation management actions in coastal dunes mainly aim to tackle problems of shrub and tall grass encroachment and the expansion of (plantations with) non-native species. Actions taken are grazing by live stock, sod cutting, mowing and mechanical/manual removal of invasive species. With the exception of recent initiatives in e.g. the Netherlands and Belgium (Herrier and Killemaes 1998), actions aiming to restore aeolian processes are rare. These management actions act on different spatial scales: mowing and sod cutting are applied at very small scales in order to restore/conserve local populations of threatened ephemeral or subclimax species. Grazing actions take place at a larger spatial scale in order to change vegetation structural patterns and are assumed to be beneficial for the biotic and abiotic diversity within larger entities. Together with hydrological actions, restoration of aeolian processes is the only type of action, that aims at restoring biodiversity by interfering in the underlying deteriorating processes. It probably is one of the only possible ways to regress the landscape from its stressed or unconstrained phase back into its dynamic phase.

Evaluations of management actions are as a result dependent of the used reference framework and we need to distinguish between effect on small scales of the site and the entire dune ecosystem. The choice of different reference situations is to our opinion the reason why results of local actions are often contradictory. Only for grazing management, some results are available: at local scales, it seems to increase or at least conserve total diversity patterns because of an increasing heterogeneity of the habitat. In few cases, focussed on the effects of high-density grazing, opposite patterns are found. Clearly, information about optimal grazing efforts (type of grazers, densities) within landscapes of different vegetation composition and/or habitat composition is lacking. Whether grazing management is a valid option for the restoration of dune ecosystems remains unanswered, at least its positive impact has not unequivocally been proven. Nonetheless, grazing is widely applied in coastal dunes for nature management reasons. Inherently to the grazing process, it results in a spatial shift of nutrients within the system at the most and not in a substantial nutrient removal (only caused by animals taken out of the system). So, grazing alone cannot be responsible for a complete restoration of the dune system, especially in case of decalcified areas, where atmospheric nitrogen deposition stimulates increasing biomass production (Kooijman *et al.*, 1998). As a result, it seems to be an important action for conserving biodiversity but, as a measure on its own, insufficient for the regression of the ecosystem towards a dynamic landscape. It retains the landscape into its stressed phase which is accompanied by a high biodiversity, but not by a typical biotic and dynamic environment, characterised by typical and specialised biota (Provoost and Bonte, 2004). The removal of invasive species and plantations, restricting beach cleaning and recreation are certainly actions of primordial importance and may be important for restoration actions. Certainly a restriction of beach cleaning and the removal of introduced sand fixators (*Populus*-plantations) are a necessary key-action in dune ontogenesis and restoring sand dynamics.

Process-based research appears to deliver more general and straightforward results: high aeolian dynamics are beneficial for the typical dune diversity, while total diversity

decreases. As the former is inversely related to eutrophication (and soil formation), opposite diversity patterns are found for the latter. Both habitat fragmentation and trampling influence diversity patterns in a negative way. Effects of hydrological restoration and acidification in interaction with soil formation and mineralization on biodiversity remain internationally unpublished. Also, integrated research on the link between abiotic processes and biotic (cascade) interaction are lacking. Here, we think on the relation between e.g. changes in soil productivity, microclimate, nutritional value and morphology of the plant species and the presence of specific faunal elements from different functional groups (specialist and generalist herbivores, carnivores and parasites with different life histories and behaviour). Additionally, we only have limited knowledge on the underlying reason why specific species are restricted to typical dune habitats. A comparative analysis of life history characteristics between habitat specialists and habitat generalists should reveal general patterns on the underlying causes of the decline of specific biota and as a result generate general theory about underlying processes of the deteriorating biotic assemblages. As reported by Bonte *et al.* (2004a), limited dispersal abilities of typical grey dune species are responsible for their rarity in a fragmented coastal dune ecosystem.

Conclusion: from a descriptive to a process-based approach?

Our screening of internationally available literature suggests that understanding biotic and abiotic processes in coastal dune ecosystems, even if focussed on few model species within a narrow taxonomic range, results in conceptual ideas on the potential interaction between nature management and the conservation and restoration of biodiversity in coastal dunes. Therefore, we suggest encouraging process-based and multi-taxonomical studies on a wide geographical scale. Once patterns in ecosystem functioning (*sensu* recent studies of Ernst *et al.*, 1996; Imbert and Houle, 2001; Coomes *et al.*, 2002; Beckstead *et al.*, 2003; Bonte *et al.*, 2003; Franks *et al.*, 2003; Aigner, 2004; Maun, 2004) and the ecological background of species' rarity are clearly understood, more detailed action-based studies need to be performed on the fine-tuning of suggested management actions on a local scale. We especially believe that a critical evaluation of potential negative feedback mechanisms in the applied action, which induces novel stress situations, has to be performed. Bossuyt *et al.* (2004ab) documented for example the link between habitat isolation and a declining diversity, but smaller succession rate towards high productive vegetation. Similarly, the restoration of hydrological actions may hypothesize aeolian processes, or beneficial effects of grazing on vegetation structure may induce specific bottlenecks for threatened species due to increased grazing stress, resulting in a reduction of flowering and seed set, or because fragile vegetations with a scarce soil development become trampled and hence reduce survival chances of fossorial invertebrates.

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Release from native root herbivores and biotic resistance by soil pathogens in a new habitat both affect the alien *Ammophila arenaria* in South Africa

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Abstract

The European dune pioneer *Ammophila arenaria* (marram grass) was introduced in the 1870's in South Africa and has ever since been used to stabilise Cape coastal dunes. At present the alien grass is still an important drift sand stabiliser. Recently, however, the use of *A. arenaria* has been criticized due to its foreign origin and the proven facts of invasiveness in other parts of the world. One of the major explanations of the success of introduced species in recipient communities is their release from natural enemies (Enemy Release Hypothesis - ERH). On the other hand, when exotic plant species fail to invade new habitats this has been related to biotic resistance from the native communities to be invaded (Biotic Resistance Hypothesis - BRH). In its area of origin *A. arenaria* dominates the fore dune plant community of mobile dunes, but it disappears naturally when dunes become stabilised mainly due to growth control by soil-borne pathogens. We examined ERH and BRH in relation to the invasiveness of the exotic fore dune grass *A. arenaria* in South Africa. The results from our study support both ERH and BRH in the case of soil pathogens of the introduced *A. arenaria* in South African dunes, indicating that ERH and BRH may be active simultaneously. Possibly a number of exotic plant species that does not become highly invasive, such as *A. arenaria* in South Africa, experience both ERH and BRH. The balance between enemy escape versus biotic resistance will determine the invasiveness of a species in a new habitat. In the case of *A. arenaria*, the generalist nematodes and the negative soil feedback apparently originate from the local grasses, whereas the dicots were less important in sharing potential pathogens. Our results further suggest that not only the local plant species diversity, but also the type of plant species present will determine the potential for biotic resistance. The biotic resistance against invasive plant species may depend on plant competition, but also on the presence of plant species that are hosts of potential soil pathogens that may negatively affect the invaders.

Keywords: Coastal fore dunes; Invasive plants; Plant-parasitic nematodes; Plant-soil feedback; Sand stabilisation.

Introduction

Over 80% of South Africa's 3 000km coastline is made up of sandy beaches and dunes, home to many endemic plant (and animal) species. Strong winds, high salt loads and sand movement restrict the number of species present in the fore dune vegetation to a few hardy 'pioneer' species on the frontal dunes (Tinley, 1985). The misuse and destruction of the (vegetated) dunes resulted in wind-driven movement of dunes inland, threatening adjacent property (DEAT, 2000). To prevent this 'unwelcome' sand movement, (rigid) structures are erected or the dunes are artificially stabilised with vegetation, often using alien sand-binding species (*e.g.* *Acacia cyclops*, *Ammophila arenaria*; Richardson *et al.*, 1997). In the view of disturbances that South African ecosystems experience through alien plant invasions (MacDonald *et al.*, 1986), the use of alien species for restoration and stabilisation purposes is highly questionable. The concern about *A. arenaria* is justified when seen against the background of the situation in North America and Australia, where the introduced grass is clearly invasive and has a major impact on indigenous dune vegetation and dune geomorphology (Heyligers, 1985; Wiedemann and Pickart, 1996). Presently *A. arenaria* occurs along ca.1500km of South African coastline only at the sites where it was introduced and research so far does not indicate that unaided spread of *A. arenaria* occurs (Hertling and Lubke, 1999). Where the introduced grass grows, it contentedly co-exists with the indigenous fore dune vegetation (Knevel, 2001). Hence, at present *A. arenaria* is considered to be non invasive in South Africa.

Why is *A. arenaria* not invasive in South Africa?

One reason could be the climatic factors as the South African sites where *A. arenaria* occurs, are either too dry or too hot (Peter, 2000) and are subjected to higher radiation, stronger winds and lack regular frost periods needed to enhance germination (Huiskes, 1979). In addition to this, the growth of the species in its area of origin is controlled by soil-borne pathogens. It is known that pathogens can alter particular life-history characteristics by inducing morphological and/or physiological changes in host plants, and as such can have a high impact on the structure of plant communities (*e.g.* Van der Putten *et al.*, 1993). The potential importance of soil-borne pathogens will, however, depend upon both the frequency of infection and the nature of pathogen effects on the host(s), relative to other biotic and abiotic features of the local environment (Clay and Van der Putten, 1999). This interaction of *A. arenaria* with soil-borne pathogens might give a powerful indication on why the species is not invasive in South Africa at present.

One of the main explanations of the success of introduced species in recipient communities is their release from specialized natural enemies (Keane and Crawley, 2002). The release from these natural enemies (*i.e.* herbivores, pathogens) enables exotic species to increase in abundance and distribution (Enemy Release Hypothesis (ERH); Keane and Crawley, 2002). It has been found that many exotic plant species have less specialist herbivores and pathogens than similar native plant species in the invaded ecosystems (*i.e.* Mitchell and Power, 2003), supporting the ERH. However, according to the tens rule of Williamson (1996) only a minor proportion of introduced alien species become invasive in their new habitat, and even species from the same genus (*e.g.*

Ammophila) can behave very differently in their entire range of new environments. For instance, in North America both *A. breviligulata* and *A. arenaria* were introduced, but only the latter created problems (Seabloom and Wiedemann, 1994). One clarification for why many species are unsuccessful in spreading in recipient communities is described by the biotic resistance hypothesis (BRH); Invasion of native communities by exotic species can be counteracted by competitive species, as well as by local pathogens and other enemies that may control the new species following introduction (Elton, 1958; Maron and Vilà, 2001).

The introduction of *A. arenaria* into South Africa from seeds may have allowed the plants to escape from their soil-borne pathogens, supporting ERH. On the other hand, even though the current impact of *A. arenaria* on the dune systems in South Africa is considerable, the grass is considered to be non-invasive at present (Hertling and Lubke, 1999). This opens possibilities for BRH to explain the situation within the South African dune system. In order to test ERH, *A. arenaria* seedlings ^{NL} have been grown in sterilised soils from European dunes. To compare negative soil feedback from the native habitat in Europe and the new habitat in South Africa, non-sterilised soil from both Europe and South Africa has been added to the sterilised soil and *A. arenaria* ^{SA} plants have been grown to study their response. The biomass production of the test plants has been used to compare the direction and magnitude of the soil feedback in native and newly colonised soils. In order to test BRH, *A. arenaria* has been grown in sterilised and non-sterilised soils from a number of South African dune plant species. The difference of biomass production between plants grown in sterilised and non-sterilised root zone soils from the different South African plant species has been used as an indicator of negative soil feedback, which points at potential biotic resistance due to soil pathogens present in the new habitat. It is expected that there will be a specific plant-parasitic nematode community around each individual plant species, with a better performance of the plants when grown on 'foreign' soil due to the escape from their own pathogen and parasite community.

Material and method

Field survey

Root zone soil samples of *A. arenaria* and several indigenous plant species were collected from three sites along the Cape coast. At the sample sites, transects running parallel to the coastline were selected for monospecific stands of each plant species and divided into 10 plots. Within each plot a minimum of three soil and root samples of 1kg and 20g, respectively, were randomly collected. For each plant species the soil samples from a plot were pooled and stored in plastic bags in a dark cold room (5°C) until usage (after Van der Putten and Peters, 1997).

Nematode extraction and identification

Nematodes in the soil were isolated from a sub-sample of 400ml from sample by means of elutriation (Van Bezooijen, 1997) and the nematodes in the roots were isolated by the funnel-spray method (Oostenbrink, 1960). After extraction the nematodes were counted, identified, and assigned to the feeding classes (phytophagous, saprophagous or

omnivorous). Only the phytophagous nematodes (also called root-feeding or plant-parasitic nematodes) were identified up to genus level. For detailed information see Knevel *et al.* (2004).

Transplantation experiments

Two transplantation tests were carried out with *A. arenaria* grown on (1) *A. arenaria* soil from two countries (SA and NL) and different sites within countries, and (2) soil from different species origin within South Africa. In the first transplantation experiment seedlings of *A. arenaria* (NL origin as no seed production in SA) were grown in sterilised dune soil that was inoculated with *A. arenaria* soil originating from five Dutch sample sites, and from seven South African sites. From each site at least three soil samples of 100g each were collected as described for the field survey. The roots were separated from the soil, cut into pieces and re-introduced into the soil as a source of inoculation. The soil-root mixture (270g) was homogenised with 720g sterilised sand (Gamma radiated) to increase the inoculate volume (after Van der Putten *et al.*, 1988). For each site origin five pots of 1.5 l were filled with inoculated soil (NS treatment) or with sterilised soil without inoculate (S treatment). Dutch seeds were used to grow seedlings (no seed production in SA) and per pot four uniform two-week old plants were planted (growth methods follow Van der Putten *et al.*, 1988) and placed in a greenhouse in a completely randomised design under $20\pm2^{\circ}\text{C}$ and a photo-period of 12 hours.

During the experiment the soil moisture was maintained at 10% by adding demineralised water every three to seven days. To counteract the nutrient release due to sterilisation (Troelstra *et al.* 2001) and to avoid nutrient deficiency during growth, a full-strength Hoagland nutrient solution was added on day 1 of the experiment, and subsequent once every week. After six weeks, the plants were harvested and roots were separated from the shoots. Total biomass, root:shoot ratio and relative production (NS biomass/S biomass) was determined. For detailed method information see Knevel *et al.* (2004).

In the second transplantation experiment *A. arenaria* (SA origin) was grown in non-sterile and sterilised root zone soil that originated from South African *A. arenaria* and the indigenous species *Arctotheca populifolia* (Asteraceae), *Ipomoea pes-caprae* (Convolvulaceae), *Ehrharta villosa* (Poaceae) and *Sporobolus virginicus* (Poaceae). Five samples of 20kg each were collected from monospecific stands of each species and treated as described above. Half of the homogenised soil-root mixture was autoclaved and of each origin five pots were filled with 1.5 l of non-sterile (NS) or sterilised (S) soil. As in South Africa no seeds were produced by *A. arenaria*, the plants were obtained from surface sterilised stem pieces that were pre-grown in sterilised soil. Per pot four uniform two-week old plants of *A. arenaria* were planted and treated as described above. Due to a fungal infection, that did not affect the other pots, the plants growing on *A. arenaria* soil did unfortunately not survive and were therefore excluded from further analysis.

Results

For all examined species, omnivorous, saprophagous and phytophagous nematodes were found but the densities and number of nematode genera found of three different feeding classes differed greatly between the species sampled (Table I). The density of

phytophagous (soil + root) and saprophagous nematodes (soil) was highest for *I. pes-caprae* ($P<0.01$; Table I), whereas low densities were observed for *A. arenaria* (soil + root), *S. virginicus* (soil), *A. populifolia* (soil) and *E. villosa* (root) (Table I). In the root the highest saprophagous densities were found for *A. populifolia* and *A. arenaria* ($P<0.01$; Table I). No significant differences were observed for omnivore nematodes ($P>0.05$, Table I).

Table I. Mean nematode densities found in the soil (numbers per 400 ml soil, $n=10$) and root (numbers per gram dry root, $n=3$) given per feeding class for *A. arenaria*^{SA}, and four indigenous species (grass species marked with [#]). Any soil or root value within a feeding type with the same letter does not differ significantly. Contrasts obtained by Newman-Keuls after analysis by Kruskal-Wallis. Level of significance: ** = $P<0.01$, *** = $P<0.001$, ns = not significant, - = no data available

Species	Feeding class					
	Phytophagues		Saprophagues		Omnivores	
	Soil	Root	Soil	Root	Soil	Root
<i>A. arenaria</i> [#]	74.9 b	51.5 b	383.3 c	518.0 a	40	0
<i>E. villosa</i> [#]	163.3 a	842.2 a	366.7 c	237.3 ab	35	0
<i>S. virginicus</i> [#]	55.8 b	946.9 a	392.9 c	-	59.1	-
<i>A. populifolia</i>	32.5 b	35.3 b	666.7 b	547.8 a	36.7	0
<i>I. pes-caprae</i>	335.0 a	1092.9 a	929.2 a	188.4 b	82.5	0
<i>P</i> -value	***	***	**	**	ns	ns

In total, two endoparasitic nematode genera were present in the South African dune samples; *Pratylenchus* and *Meloidogyne*. However these never occurred in the same plant species at the same time. The species *E. villosa*, *S. virginicus*, and *I. pes-caprae* showed a high density for the endoparasitic nematodes (data not shown). *Pratylenchus* also occurred in stands of *A. arenaria*, but in relatively low densities, whereas no endoparasitic nematodes were found in the roots of *A. populifolia*. In spite of the lower densities of nematodes in the root zone of *A. arenaria* in South African samples, the total number of nematode taxa in the root zone of this introduced plant species was relatively high and showed the closest resemblance to the communities of the grasses *E. villosa* and *Elymus distichus* (Table II). The similarity of nematode genera between South African and Dutch *A. arenaria* populations ranged from 33-56% (Table II). Between the indigenous species and South African *A. arenaria* this ranged from 22-78% (Table II). As a consequence, monospecific *A. arenaria* stand from South Africa generally have more root-feeding nematode species in common with South African fore dune grasses, than with stands of *A. arenaria* in the Netherlands. This suggests that local root-feeding nematodes in South African dunes had used the introduced grass as an alternative host plant, rather than that the exotic plant species had introduced its own root-feeding nematode community. Also two sedimentary endoparasitic nematodes genera (*Heterodera* and *Meloidogyne*), were absent from South African *A. arenaria*, while these are common in the Netherlands (data not shown). There was only one single observation of a sedentary endoparasite for *A. arenaria*. However, this observation could not be confirmed in subsequent sampling expeditions. Therefore, the root zone of *A. arenaria*

in its new territories predominantly consists of nematodes that are usually considered as generalist root feeding nematodes.

Table II. Presence and absence of plant-parasitic nematode genera found in the rhizosphere of *A. arenaria* and indigenous dune pioneers. Within *A. arenaria* samples from the Netherlands (NL – Oostvoorne and Haringvliet; data originating from Van der Putten and Peters (1997)) are compared with different sites in South Africa (SA). Between the species *A. arenaria* is compared with seven indigenous fore dune species of South Africa (grass species are marked with *)

Sites/species	No. genera/feeding type			Similarity (%)	
	Endo parasitic	Semi-endo parasitic	Ecto parasitic	Total	with NL with SA
Within <i>A. arenaria</i>:					
Oostvoorne/Haringvliet ^{NL}	3	1	5	9	-
Koeberg ^{SA}	1	0	5	6	33%
Tableview ^{SA}	1	0	5	6	33%
Kleinemond ^{SA}	1	1	7	9	56%
Die mond ^{SA}	1	0	6	7	33%
Klein brakrivier ^{SA}	1	1	5	7	44%
Sedgefield ^{SA}	2 ¹	1	5	8	44%
Blue water Bay ^{SA}	1	1	8	10	56%
Kleinemonde ^{SA}	1	1	3	5	33%
Between species:					
<i>A. arenaria</i> ^{SA}	1	1	7	9	-
<i>E. distichus</i> * ²	1	0	6	7	-
<i>E. villosa</i> *	1	1	6	8	-
<i>T. decumbens</i> ²	1	0	4	5	-
<i>A. populifolia</i>	0	0	4	4	-
<i>I. pes-caprae</i>	1	1	3	5	-
<i>S. plumieri</i> ²	1	0	2	3	-
<i>S. virginicus</i> *	1	1	2	4	-

¹ Second endoparasitic genus is from a single observation.

² Full species name: *Elymus distichus* (Poaceae), *Tetragonia decumbens* (Aizoaceae), and *Scaevola plumieri* (Goodeniaceae).

Transplantation experiments

When grown in non-sterilised Dutch (NL) and South African (SA) *A. arenaria* soil, at eight of the 12 sites the relative production was lower than the control (ANOVA, $P < 0.01$; Table III). In 3/5 of the NL sites *A. arenaria* produced less than half of the amount of biomass produced in sterilised soils compared to the control, whereas in the

SA dune soils a considerably smaller proportion (1/7) of sites showed a similar growth reduction (Table III). This demonstrates that the *A. arenaria* seedlings experienced considerably less negative soil feedback in its new habitat compared to its original habitat, which supports the ERH. On the other hand the 5/7 of the SA sites showed a lower RP compared to the control, showing that *A. arenaria* is indeed able to develop a negative soil feedback in its new habitat, providing supports for the BRH. Between the countries no overall significant difference in RP between the sites was found (Kruskal-Wallis, $P>0.05$).

Table III. Mean relative production (RP = NS total biomass/S total biomass) (n=5) of *A. arenaria* plants grown on soil, originating from the Netherlands (NL) and South Africa (SA). Contrasts obtained by Tukey after analysis by one-way ANOVA. Level of significance: *** - $P<0.001$

Sample site	RP (\pm SE)	Sample site	RP (\pm SE)
Control	0.95 (0.232) a ***	Chemfos ^{SA}	0.43 (0.185) d
Oostvoorne 1 ^{NL}	0.47 (0.132) cd	Die mond ^{SA}	0.85 (0.256) ab
Oostvoorne 2 ^{NL}	0.46 (0.131) cd	Kleinbrakrivier ^{SA}	0.80 (0.045) ab
Oostvoorne 3 ^{NL}	0.48 (0.206) cd	Koeberg ^{SA}	0.72 (0.040) b
Haringvliet 1 ^{NL}	0.78 (0.312) ab	Milnerton ^{SA}	0.73 (0.127) b
Haringvliet 2 ^{NL}	0.84 (0.336) ab	Sedgefield ^{SA}	0.65 (0.113) bc
		Stilbaai ^{SA}	0.66 (0.329) bc

When grown in foreign soil of native species, only the sterilisation of *S. virginicus* soil significantly enhanced biomass production, whereas no such effects occurred in the other three soils origins (ANOVA, $P<0.001$; Fig. 1a). Subsequently, the plants grown in sterilised soil of *S. virginicus* showed the significant highest root:shoot ratio and a lower relative production ($P<0.001$; Fig. 1b, c). Plants grown in non-sterilised soil from *I. pes-caprae* had the least growth reduction compared to the plants in the sterilised soil (Kruskal-Wallis, $P<0.05$; Fig. 1a). These results show that the four South African fore dune plant species differed in their soil feedback to *A. arenaria*. While the soil feedback of most plant species supports ERH, the feedback from *S. virginicus* soil demonstrates that this plant species may contribute to BRH against *A. arenaria*, through negative feedback from the soil community.

Discussion and conclusion

In our study, we could confirm that the transfer of *A. arenaria* to South Africa has enabled the escape from endoparasitic nematode species that occur in their native habitat and which are supposed to be involved in the control of abundance of *A. arenaria* in stabilised dunes in the native habitat (Van der Putten and Van der Stoel, 1998). The root-feeding nematode community of *A. arenaria* in South Africa consisted mainly of rather generalist nematodes and was more similar to some local dune species, than to the community of its native European region. The nematode data found for *A. arenaria* in South Africa supports ERH when focussing on root-feeding nematodes. These results are similar to those reported in a review on aboveground herbivores and pathogens (Mitchell and Power, 2003). On the other hand most specialist nematodes are less harmful than

generalists and based on studies with root-feeding nematodes from Europe, it seems that the numbers of generalist root-feeding nematodes in the South African dunes might not be high enough to cause substantial growth reduction to *A. arenaria* (De Rooij-Van der Goes 1995). Other soil pathogens (*e.g.* pathogenic fungi) may be involved in the negative soil feedback (*i.e.* Van der Putten *et al.*, 1993).

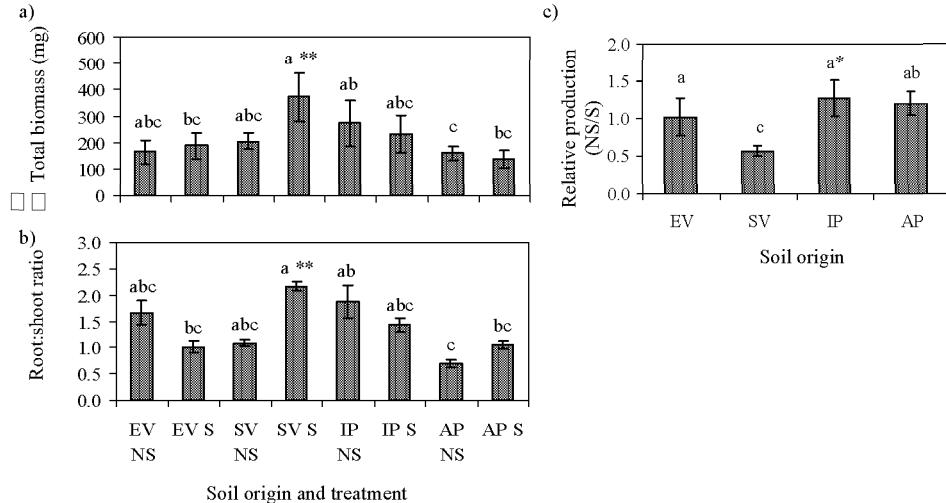


Fig. 1. Total biomass (a), root:shoot ratio (b) and relative production (c) of *A. arenaria* grown on the following soil origin and treatments: non-sterile (NS) and sterile (S) soil of *E. villosa* (EV), *S. virginicus* (SV), *I. pes-caprae*, (IP), and *A. populifolia* (AP). Contrast obtained by Tukey after analysis by one-way ANOVA, except for relative production where contrasts obtained by Newman Keuls after analysis by Kruskal-Wallis. Level of significance: * $P < 0.05$, ** $P < 0.01$.

In SA *A. arenaria* soil the seedling growth was less reduced than in root zone soil from Dutch stands where the used seeds were collected from. The use of Dutch seeds may have underestimated the negative soil feedback in SA (*i.e.* local populations more susceptible to soil pathogens of their parents), but previous tests did not confirm such reduced impacts (Van der Putten and Troelstra, 1990), so that this possibility is not very likely. The less negative soil feedback in SA soil are in the range of effects measured in beach sand (Van der Stoel *et al.*, 2002), supporting ERH. The occurrence of a substantial negative soil feedback in some SA *A. arenaria* sites shows, however, that there is pathogenic activity in the stands, supporting BRH. This activity is probably mainly due to generalist root-feeding nematodes. It should be noted that other pathogenic factors may be involved in these processes (De Rooij-Van der Goes, 1995). The elucidation of the organisms that may have caused the growth reduction in the SA soils may be very complicated (De Rooij-Van der Goes, 1995), therefore soil feedback trials with other plant species were used in order to trace the potential soil pathogens source. When grown in soil from indigenous species, only the soil from the grass *S. virginicus* had a negative effect on growth of *A. arenaria*. The other plant species had a more neutral feed back, but no positive soil feedback was observed. These results support the BRH, since

the soil pathogens of one local grass species may be able to cause growth reduction to the exotic grass. At the sampled sites the cover and abundance of *A. arenaria*, *S. virginicus* and the other sampled species differs per site, but none of the species was dominant, but sheared a co-dominance with other species. In general the species form some scattered patches of higher abundance over the fore dune area, intermingled with other species, more so than a closed dense vegetation structure (Knevel, 2001).

The results do not support the suggestion that symbiotic arbuscular mycorrhizal (AM) fungi may have provided an advantage for SA *A. arenaria* (Callaway *et al.*, 2003). However, the effects of AM fungi may have been obscured by the addition of nutrients, which were added in order to avoid interference by a possible nutrient flush (Troelstra *et al.*, 2001).

In conclusion, the results from our study support both ERH and BRH in the case of soil pathogens of the introduced exotic dune grass *A. arenaria* in South African dunes. Biotic resistance against invasive plant species may depend on plant competition, but also on the presence of plant species that are hosts of potential soil pathogens that may negatively affect the invaders. The vigour and success of aliens in areas where they have been introduced has, besides release from natural phytophagous enemies, often have been attributed to more favourable environments. Perhaps the limited invasive capacity of *A. arenaria* in South African dunes is also limited by the combination of rainfall/temperature, perhaps in combination with pathogen effects found, making the South African coast at present unsuitable for the species to be invasive. The use of *A. arenaria* should nevertheless be restricted as the grass shows many invader traits and future climatic changes might favour invasiveness.

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Integrated monitoring of nature restoration along ecotones, the example of the Yser Estuary

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Abstract

Within the framework of LIFE, one of the larger nature restoration projects in Flanders was realized on the right bank of the estuarine part of the Yser. General aim of the initiative was to restore or create beach-dune-salt marsh ecotones with salt-fresh, dynamic-stable, wet-dry and mud-sand ecotones. In order to reach this goal, several large buildings and roads were broken down, an entire tidal dock was restructured and some 500,000m³ of dredging material was removed to restore or create intertidal and coastal dune habitats and their connecting ecotones. Measures were taken to avoid abrupt topographical transitions along potential ecological gradients. It was decided to begin monitoring (2001-2004) from the very start of the restoration process (1999-2003). Monitoring was multidisciplinary and realized in a partnership between several scientific institutes (Ghent University, Catholic University of Louvain, Royal Belgian Institute of Natural Sciences and Institute of Nature Conservation with facility support of VLIZ). Monitoring included the most relevant abiotic conditions such as sedimentation and erosion, topography and ground water fluctuations, and biological response variables, *i.e.* flora and vegetation, terrestrial arthropods, benthic macrofauna and birds. It was decided to include two monitoring levels, an area-covering monitoring of the entire nature reserve (ca. 128ha) and a detailed monitoring of

changes along transects perpendicular to the main ecological gradients. In this paper we present some results of the first three years of monitoring.

Keywords: Nature restoration; Monitoring; Estuary; Coastal dune; Ecotone.

Introduction

In a society where everything seems to focus on costs and benefits, it is vital that costs are evaluated quantitatively on their benefits and that preconceived goals are followed up on their extent of compliance. Therefore monitoring has become increasingly important, not in the least when dealing with the evaluation of result commitments made in nature conservation policy. Monitoring is defined as the intermittent (regular or irregular) surveillance carried out in order to ascertain the distance-to-target from a predetermined standard or the degree of deviation from an expected norm (Hellawell, 1991). Surveillance in this definition is referred to as an extended programme of surveys, undertaken in order to provide a time series, to ascertain the variability and/or range of states or values which might be encountered over time. In short, monitoring needs predefined goals, strictly defined standards, well-designed methods, rigorous follow-up in time and is meant to finally evaluate the distance-to-target from predefined goals.

A general problem of monitoring is finding the right sampling method to detect all relevant changes. When certain management measures need to be evaluated, it is important to be able to make the difference between management dependent and independent changes. Although several attempts have been made to design general monitoring schemes (e.g. Goldsmith, 1991; Van Olmen *et al.*, 2000; Van Dyck *et al.*, 2001; Demeulenaere *et al.*, 2002), every combination of predefined goals and hence every site has got its specific characteristics and needs therefore a specific, but standardized approach (e.g. Bonte *et al.*, 2001; Provoost *et al.*, 2004). Here we report on the approach used in a nature restoration project along the Yser Estuary at the Flemish coast.

Within the framework of LIFE, one of the larger nature restoration projects in Flanders was realized on the right bank of the estuarine Yser (Hoffmann, 2004). Restoration goals were *a priori* defined in an ecological target vision (Hoffmann *et al.*, 1996) and departed from the generally accepted thesis that areas rich in ecotones are potentially important hot spots of biological diversity, both at large scale (Schilthuizen, 2000; Smith *et al.*, 2001) at regional (e.g. Ward *et al.*, 1999) as at local scale (van Leeuwen, 1966). General aim of the initiative was to restore or create beach-dune-salt marsh ecotones with salt-fresh, dynamic-stable, wet-dry, mud-sand transitions and other biologically interfering gradients. Although beach-fore dune ecotones are an important part of the project, we here focus on the estuary-inner dune ecotones.

Methods

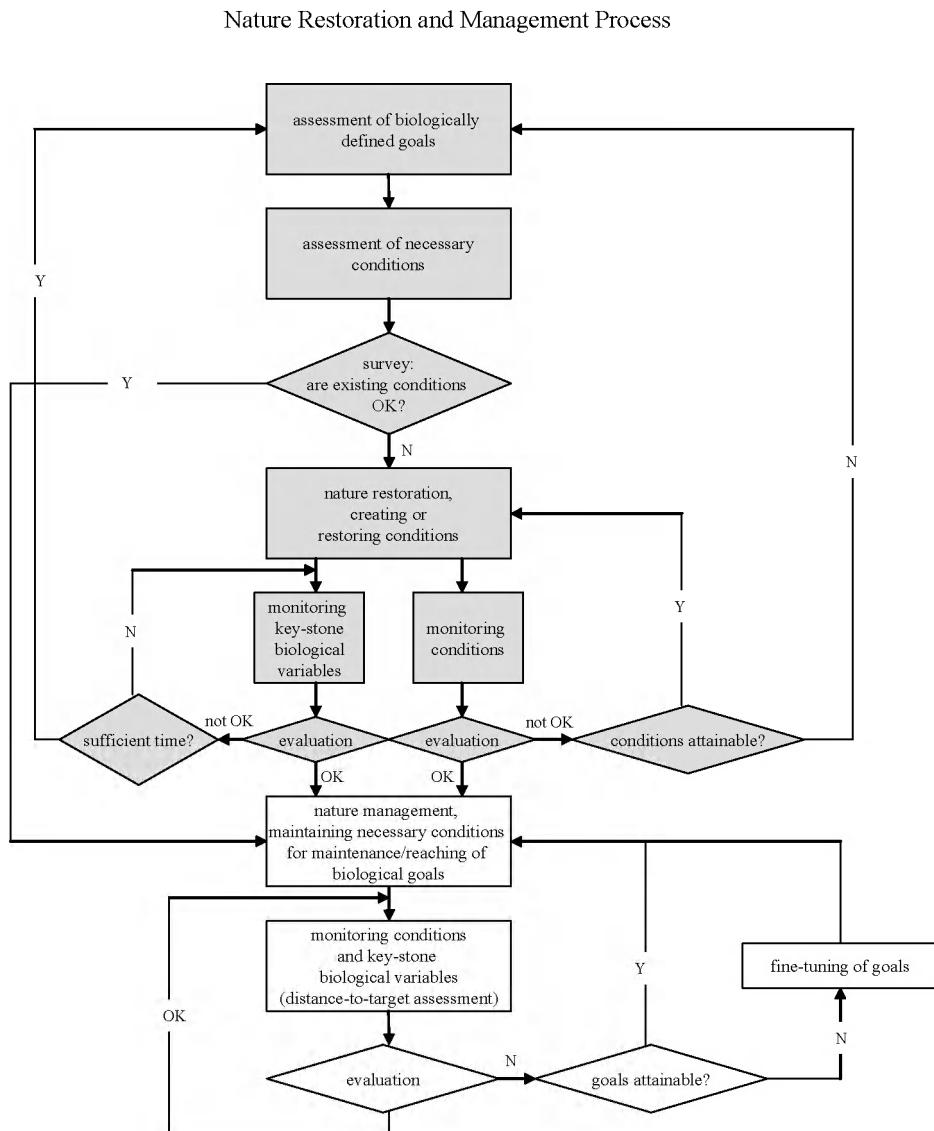


Fig. 1. General scheme of a nature restoration and management process. Steps that are dealt with in the restoration project at the Yser Estuary until 2004 are given in grey. Note that there is no end to the process and that monitoring is considered to be an inextricable part of it.

The nature restoration and management process at the Yser Estuary follows the generally applicable scheme given in Fig. 1. Hereafter, we will consecutively follow the different steps of the monitoring process, starting with the assessment of biological goals, followed by the assessment of necessary conditions, the survey of the existing conditions with a simultaneous survey of biological key-stone variables, immediately followed by monitoring of both, and finally a first evaluation of the survey result. The restoration process started in September 1999, the last large-scale measures were taken in spring 2003 (Herrier *et al.*, 2005). The monitoring programme started in the summer of 2001.

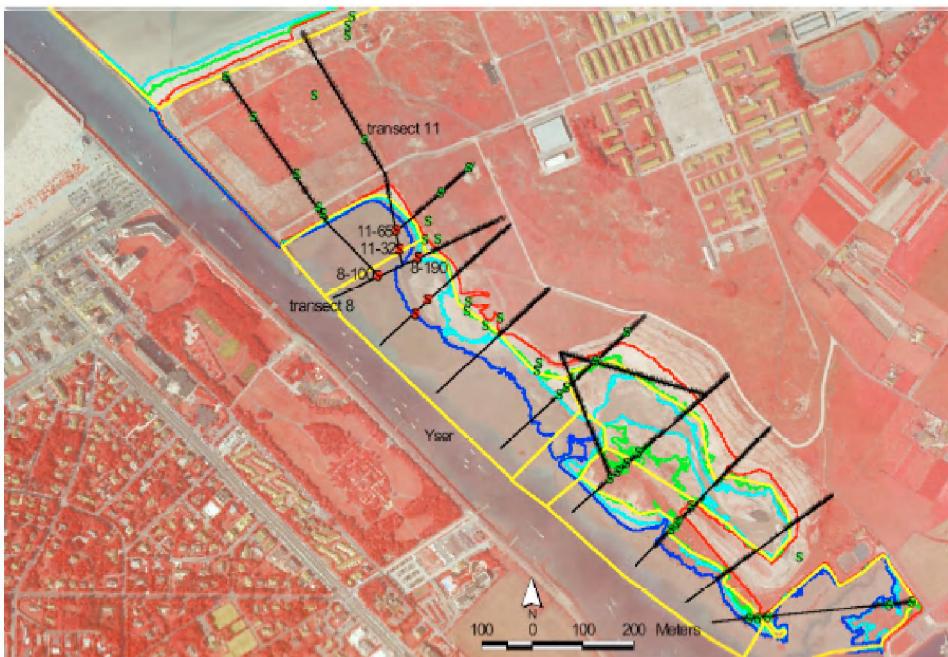


Fig. 2. False Colour Infrared aerial photograph of the nature restoration area in the Flemish Nature Reserve the IJzermonting, 29 July 2004. Monitoring transects and sampling points are indicated; black lines and circles: vegetation transects with permanent plots; green dots: invertebrate sampling sites; yellow polygons: areas distinguished for macrobenthos monitoring; red dots: permanent SE-plots; avifauna monitoring polygons are not given. Curved lines are tidal means (tide data from the period 1991-2000; Fremout, 2002), with topography based on the LIDAR-DEM (18 December 2002); dark blue: Mean Neap Tide High Water (MHWN); light blue: Mean High Water (MHW); green: Mean Spring Tide High Water (MHWS); red: Highest High Water (HHW).

Assessment of biologically defined goals

After several preliminary reports (Decler and Meire, 1992; Bossu, 1993; Herrier, 1994), a definite ecological target vision was developed in 1996 (Hoffmann *et al.*, 1996). The general goal of the nature restoration project was to restore or create typical ecotones between beach, coastal dunes and estuary without further deterministic biological goals. These transitions should be as close as possible to the situation before dominance of

human impact. Reference was obtained through interpretation of topographic maps from the 18th and 19th century. However, when aiming at ecotone restoration, a paradox occurred immediately, since monitoring needs clearly defined goals that can be measured and evaluated in distance-to-target figures. They are often defined as particular habitats or plant communities, which are considered as discontinuous entities. This contrasts with the goal to restore continuous ecotones. Based on the ecosystem vision of the Flemish coast (Provoost and Hoffmann, 1996), certain ecotopes per ecotone could be expected. Per ecotope several target habitats could be distinguished. Within the ecotope 'fore dune', target habitats were mobile open dune and calciphilous moss-dominated grey dune. Within the ecotope stabilized dune, target habitats were dry moss-dominated grey dunes, calciphilous grassland and coastal scrub. In the intertidal ecotope, target habitats were tidal gullies, mudflats, salt marsh, floodmark vegetation, young and open dunes. All of these target habitats can be evaluated on abiotic conditions as well as biological responders.

Assessment of necessary conditions

Necessary conditions for the development of the aspired ecotones are multiple. Basically though, they can be reduced to a small number of primary prerequisites: 1) Tidal movement of silt-loaded salt water in an only moderately dynamic environment, allowing a certain degree of sedimentation. This will allow spontaneous and natural development of salt marshes if condition five is met with; 2) Sand supply from the sea and aeolic sand transport is necessary for the development of new coastal sand dunes. However, since the main goal of the nature restoration process was to enlarge the intertidal salt marsh and mud flat area, bordering an *existing* dune landscape, marine and subsequent aeolic sand transport are not absolutely necessary to meet the biological goals, although the naturalness would greatly enhance when both processes would be in action; 3) Ground water conditions are vital for the development of different dune habitats and, to a minor extent to intertidal habitats (Criel *et al.*, 1999), reason why also ground water fluctuations and quality (conductivity) were investigated; 4) Topography is an indirect abiotic condition, *e.g.* dictating the annual inundation frequency of intertidal areas. Only sedimentation and erosion and topography are dealt with here.

Often overlooked but at least as important as abiotic conditions, is 5) Presence of diaspores of the organisms that are aspired to appear along the created or restored ecotones. This condition is becoming increasingly important in nature restoration projects that are realized in a highly fragmented landscape. Within the scope of this monitoring project, only the presence of angiosperm diaspores was studied (see Bossuyt *et al.*, 2005).

Creating or restoring conditions

The process of nature restoration is dealt with in this volume by Herrier *et al.* (2005) [more details are given in Hoffmann (2004)].

Monitoring of conditions

Sediment characterization

Three characteristic sediment fractions were found: 1) A fine sand fraction with a diameter of approx. 200 μm ; this fine sand has the same characteristic diameter as the sand found in the dune and dry beach area; 2) A clay fraction with characteristic diameter of 10 μm , *i.e.* the same characteristic size as the clay from the older parts of the intertidal zone; 3) A (coarse) silt fraction with characteristic diameter of 60 μm ; this fraction only appears in a limited number of samples and its origin is unknown.

Due to the large variability of the sediment distribution of the individual samples even in locations that are relatively close, it was very difficult to get a synoptic view from the point measurements. Therefore and to obtain an area-covering picture, airborne hyperspectral remote sensing techniques were used. They allow a relatively good spatial and spectral resolution, though they can never compete with actual field measurements. Three images were available: one image from the Digital Airborne Imaging Spectrometer (DAIS) in 2001 and two images from the Compact Airborne Spectrographic Imager (CASI) in 2001 and 2003 [details are given in Toorman *et al.* (2004); Adam (2004); Adam *et al.* (2005)].

Soil erosion strength is an important factor for the stability of the surface to hydrodynamic forces. Vanhonacker (2004) carried out an in-situ erosion test. Values found for the erosion strength of the soft mud and estimates of the bottom shear stress from maximum flow velocities in certain zones on the tidal flats obtained from a hydrodynamic model (see below), are of the same magnitude pointing at a dynamic system and locally at a potential for surface erosion.

Topographic measurements

A digital elevation model (DEM) was derived from a LIDAR scan (18 December 2002). Results were used to construct lines of equal tidal means in Fig. 2. The resolution is about 1 point per 4m² with a standard deviation of 7cm for the vertical positioning. Unfortunately no other LIDAR campaigns for this area have been done since; a detailed balance for the area could therefore not be made. At regular intervals along the transects, detailed ground level measurements were done in four consecutive summers (2001-04; two exemplary transects are given in Fig. 3). At six locations detailed measurements were done on a monthly basis, using a so-called ‘Sedimentation-Erosion Plot’ (SEP; Fig. 3).

The topographic measurements along the transects suggest a smoothing of the intertidal areas that were created by the restoration works (Fig. 3). At a number of locations erosion is visible, particularly along the northern edge of the former tidal dock, where the large stones (part of the former embankment) have resurfaced. This trend was foreseen in the feasibility study for the nature restoration plan (Hoffmann *et al.*, 1996) since old maps showed a recess at the same location. The concave shape of some of the transects also points at an erosion behaviour, but other transects have a convex shape indicating either stable or accumulating tidal flats (Fig. 3). The SEP-plots, that were installed at critical locations in the newly created intertidal areas show quite contrasting sedimentation-erosion patterns, ranging between an overall 25cm height increase (Fig. 3)

and 60cm height decrease. However, most of the topography changes are rather small and yearly sedimentation and erosion budget changes appear to be slow.

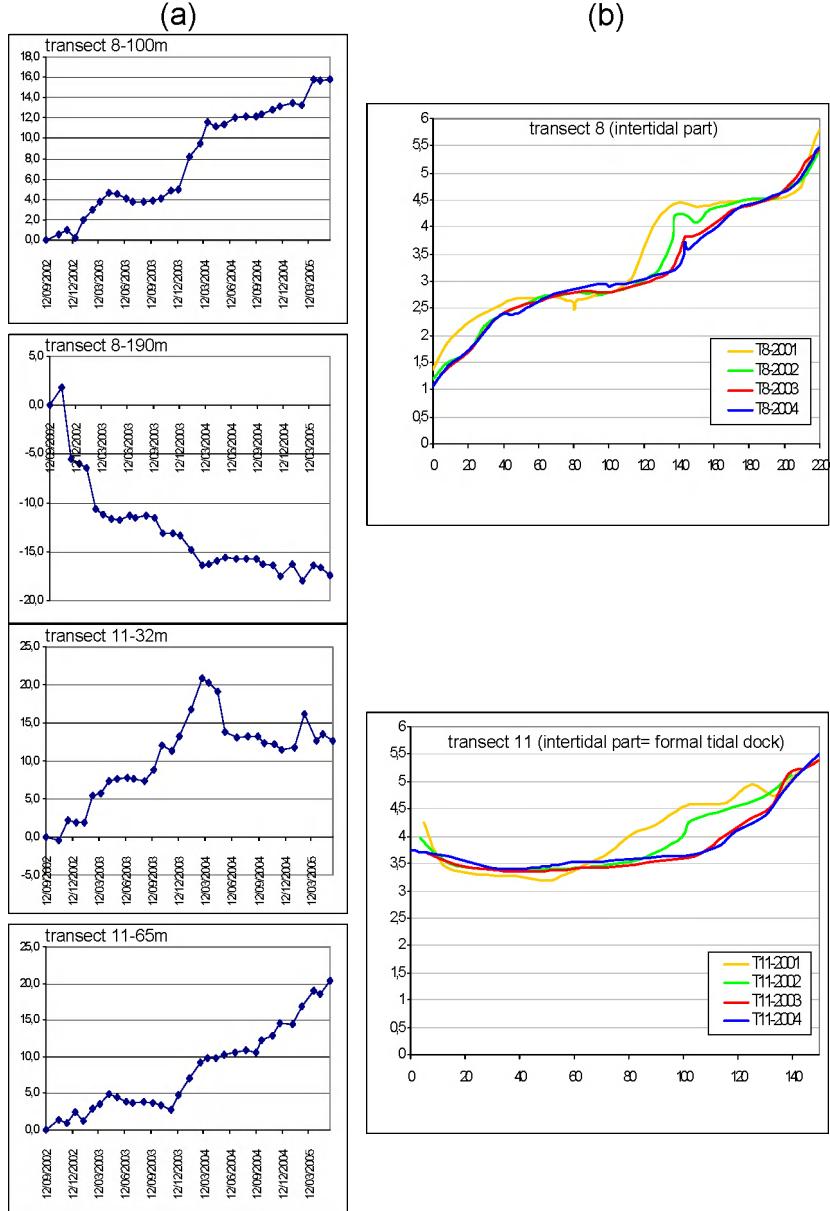


Fig. 3. (a) Monthly topographic measurements (September 2002 - June 2005) at four contrasting SEP-sites; y-axis indicates relative topography change in cm; (b) Topographic measurements in two transects in four consecutive years (summer 2001- summer 2004); y-axis in m TAW. The location of SEP's and transects are given in Fig. 2.

Hydrodynamic modelling

The hydrodynamic conditions are the determinant for the dynamic system of sedimentation and erosion in the area. In order to understand this system better, detailed numerical modelling can be useful. Caluwaert (2002) and Nolivos and Choudhury (2004) have made a 2D-vertically integrated numerical model of the study area using the TELEMAC modelling system. The calculated depth averaged flow velocities agree quite well with in-situ ADCP measurements. Work on morphodynamic modelling is ongoing, using the TELEMAC modules for bed load and suspended sediment transport.

Monitoring of key-stone biological variables

Macrofauna

(Macro)Benthic organisms are a vital component of any estuarine ecosystem. Not only do they represent an important part of biodiversity as such, they are an indispensable link in the food chain, e.g. as food for the typical estuarine benthivorous bird populations. Therefore, much monitoring attention was given to the benthic macrofauna in order to describe its biodiversity, its biomass and its colonisation of the newly created intertidal habitats (Wittoeck *et al.*, 2004). Sampling was done at low (+1m MLLWS), intermediate (+2.5m MLLWS) and high (+4.5m MLLWS) intertidal level, in several transects throughout the entire intertidal area, during three sampling events (Oct 2001-Sep2002-Jan2004). Sediment samples were taken for Coulter counter analysis of the sediment size distribution. The mudflats around an old creek (the Creek of Lombardsijde) served as a reference for the evaluation of benthic fauna development of the newly created intertidal area, since these mudflats were not directly influenced by restoration works.

The reference showed a significantly higher silt content than the newly created intertidal sections (the so-called disturbed sections); they all showed a more coarsely-grained substrate.

In all, 44 macrobenthic taxa were identified. Total number of individuals ranged from 0 to 113,100 individuals.m⁻² with a mean density of $16,509 \pm 2,334$ individuals.m⁻².

In general, a significant negative Spearman rank correlation ($r_s = 0.41$; $p < 0.0001$) was found between median grain size of the sediment samples and macrobenthic species richness: the coarser the sediment, the lower the species richness. A similar negative correlation was found between macrobenthic density and median grain size ($r_s = -0.36$; $p < 0.0001$), indicating the primary importance of silt content of the sediment for macrobenthic fauna.

A clear differentiation appeared along the altitudinal intertidal gradient (low-intermediate-high). In general, lowest densities were found in the lower part (+1m MLLWS), highest densities in the intermediate part (+2.5m MLLWS) and intermediate densities in the upper part (+4.5m MLLWS) of the intertidal section of the ecotone.

The more sheltered intertidal area showed relatively low macrobenthos density and biomass. This can possibly be explained by the coarsely-grained substrate of this section at the beginning of the project. Only locally a thin layer of silt was deposited during the past three years, not allowing the establishment of a benthic macrofauna (yet). Above that, the area is situated at the higher altitude of the intertidal gradient (Fig. 2), which proved to be poorer in species and densities than the intermediate heights.

When comparing all intermediate heights, disturbed habitats generally showed higher densities than the undisturbed reference, while total benthic biomass was significantly higher in the former tidal dock. Diversity, expressed in number of species, on the other hand, was lowest in the former tidal dock.

The most prominent species were the crustacean species *Corophium volutator* (70% of the samples), the oligochaete species *Oligochaeta* spp. (most of which (if not all) belong to the species *Tubifex costatus*) (62%) and *Tubificoides benedeni* (36%), the polychaete species *Nereis diversicolor* (45%), *Eteone longa* (24%), *Heteromastus filiformis* (22%) and *Pygospio elegans* (21%) and the mollusc species *Macoma balthica* (29%).

In time, the total number of benthic macrofauna species steadily increased from 14 in 2001, over 18 in 2002 towards 25 in 2004. Some month after restoration works were finalized, the mudflats showed on average 4.5 species. dm^{-2} . This number increased steadily during the monitoring period until January 2004 (after approx. 3 years) to 5.5 spp. dm^{-2} . Macrobenthos density on the other hand did not show a steady trend through time, probably due to much stronger season dependent density trends. Highest densities were found in the summer samples of 2002. At intermediate altitudes within the intertidal gradient, species diversity was always higher (5-9 spp. dm^{-2}) than at high and low altitudes, respectively.

Avifauna

The Yser Estuary has always been an important resting and foraging area for wintering and migrating bird species. It has never been extremely important for breeding birds, unless the inner dunes, which are long known for their small, but regionally important breeding population of Northern Wheatear (*Oenanthe oenanthe*).

Water birds were regularly counted during high water, when all birds are concentrated on high tide roosts within the nature reserve. During the monitoring period (July 2001 – June 2004), 109 bird counts were realized. Counts were more frequent in winter than in summer, but all seasons were dealt with. Included in the counts were divers, grebes, herons and egrets, cormorants, swans, geese, ducks, waders and terns. Gulls were not systematically counted.

The total number of water birds reaches quantities of up to 5000 individuals in February (more detailed information in Devos and De Groote, 2004). Expressed in number of bird days, figures raise to more than 170,000 in January-February. On a yearly basis, Oystercatcher (*Haematopus ostralegus*; throughout the entire year) and Dunlin (*Calidris alpina*; concentrated in winter and early spring) are by far the most prominent water birds (together ca. 50% of total bird days), but strong seasonal differences appear; e.g. ducks, cormorants, gulls and terns are relatively more prominent in summer, while waders are by far the most frequent water birds in winter.

Since restoration activities started, the number of bird days of Redshank (*Tringa totanus*), Dunlin and Common Ringed Plover (*Charadrius hiaticula*) increased significantly (comparison of pre and post restoration period of two years each) with more than 50%, while the number of Oystercatcher, Black-bellied Plover (*Pluvialis squatarola*) and Ruddy Turnstone (*Arenaria interpres*) increased with up to 15% (increase not significant though).

As soon as new non-vegetated higher intertidal area and lower sandy substrate became available, pioneer breeding species as Kentish Plover (*Charadrius alexandrinus*) and

Little Ringed Plover (*C. dubius*) appeared in small numbers. In 2005, the first frequent breeding activities of Avocet (*Recurvirostra avosetta*) and Common Tern (*Sterna hirundo*) were recorded.

Flora and vegetation

Being the biological foundation of most terrestrial ecosystems, vegetation is often a basic monitoring item in nature restoration and management projects. Being a multivariate variable, vegetation as such is difficult to monitor though, let alone to evaluate, since no clear-cut criteria are available to judge the distance-to-target of vegetation. On the other hand, vegetation relevés give relevant, quantitative information on the flora at a higher resolution level than individual floristic data. To combine pros and cons of both, flora data on rare and dune specific or habitat indicator species were collected for the entire area, while vegetation data were collected systematically along transects perpendicular to the most important ecotones (Fig. 2). Vegetation changes were followed through yearly sampling of permanent plots. In 2001, 181 permanent plots were laid out in 11 transects, in 2003 the number of plots was increased to over 500, the number of transects was raised to 13. Evaluation of the first successional trends was done after three years of monitoring (2001-2004; Hoffmann *et al.*, 2004). Eighteen different vegetation types were distinguished, using structural and quantitative floristic criteria. At least the intertidal types were clearly differentiated according to relative flooding frequency (Fig. 4).

Already in the first year after restoration, newly created intertidal areas were colonized by annual salt marsh species; habitat specific annuals appeared equally rapid in the appropriate sandy habitat at the floodmark (*Salsola kali* ssp. *kali*, *Cakile maritima*, *Beta vulgaris* ssp. *maritima*, *Atriplex littoralis*). Most abundantly establishing salt marsh annuals were *Salicornia europaea* and *Suaeda maritima* and to a lesser extent *Salicornia procumbens*, *Spergularia marina* and *S. media*. They gave the newly created, more or less sheltered, initially bare, silty intertidal habitats a truly vegetated appearance within two years after creation. The more exposed, and the sandier, new intertidal habitats on the other hand were colonized only slowly and sparsely, until recently giving them a rather bare non-vegetated sand flat appearance. Perennial salt marsh species did not yet or only very rarely (*Limonium vulgare*) colonize the newly created intertidal areas, not even the sheltered locations. This differentiation between annuals and perennials is well related to the seed bank data, showing the abundant presence of salt marsh annuals and the well nigh absence of perennial species (Bossuyt *et al.*, 2005).

Plant species that were formerly registered from the area, but that disappeared during the last decades (*Armeria maritima*, *Parapholis incurva*, *Juncus maritimus*, *Carex extensa*, *C. divisa*, *Halimione pedunculata*, *Oenanthe peucedanifolia*, *Trifolium squamosum*; Pire, 1862; Goetghebeur, 1976) did not re-establish yet. Pleasant exception is the recent reappearance of *Carex distans*.

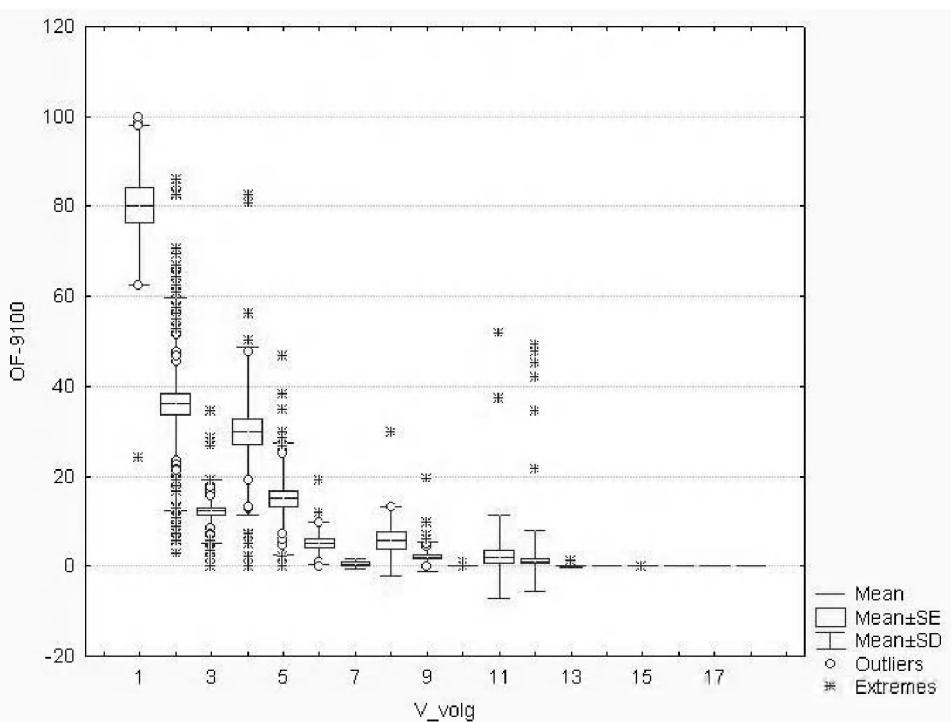


Fig. 4. Relative flooding frequency range of all 18 vegetation types, that were distinguished in 523 permanent plots in 13 transects along the salt marsh – dune ecotone in the Flemish nature Reserve 'the IJzermonding': 1: *Spartinetum townsendii*; 2: *Salicornietum brachystachyae*; 3: *Suaedetum maritimae*; 4: *Puccinellietum maritimae*; 5: *Atriplici-Elytrigietum pungentis*; 6: *Chenopodieturn rubri*; 7: *Saginion maritimae*; 8: *Atriplicetum littoralis*; 9: *Honckenyo-Agropyretum juncei*; 10: *Ammophiletum arenarii*; 11: *Bromo-Corispermum*; 12: *Echio-Verbasctum*; 13: *Phleo-Tortuletum ruraliformis*; 14: *Sileno-Tortuletum ruraliformis*; 15: *Festuca-Galietum veri*; 16: *Cladonio-Koelerietalia*; 17: *Hippophaeo-Sambucetum*; 18: RG *Urtica dioica* [Galio-Urticetea]; OF91-00: calculated flooding frequency of the altitude at which the plots are situated; syntaxonomical nomenclature follows Schaminée *et al.* (1995). Classification is largely based on the outcome of an ASSOCIA-analysis (van Tongeren, unpubl. programme).

Terrestrial arthropods

Results of part of the monitoring efforts on terrestrial invertebrates (ground beetles and spiders) are reported elsewhere in this volume (Desender *et al.*, 2005; for more details, see Desender *et al.*, 2004). Spiders and ground beetles were sampled with classical pitfalls, located at several sites along nine transects within the study area (Fig. 2) and at ten sites that are already monitored long before this monitoring project started (Desender *et al.*, 2004). Per site three replicas were installed. Other invertebrates that were studied belong to the Diptera (flies) (details in Grootaert *et al.*, 2004). To investigate flies and flying activity of other arthropods white water traps (Pollet and Grootaert, 1994) were used, during three consecutive years. In 2003, supplementary interception traps in the form of window traps were used to sample flies.

A quick colonisation of the newly created habitats by target Empididae (dance flies) was observed. These new habitats also attracted new Empididae species that were never found before in the area, while recent disturbance due to the restoration activities, (temporarily) caused target species of specific habitats to be found in other habitats as well. During the monitoring period three species of Asilidae (robber flies) were found of which one was new for the Flemish coast, while four species of Bibionidae (March flies), six species of Therevidae (stiletto flies), one species of Bombyliidae (bee flies) and five species of Stratiomyidae (soldier flies) were caught.

Special attention was given to the Dolichopodidae (long-legged flies) (details are given in Pollet, 2004). At least 47 species could be identified, including some very rare and red list species (40% of all identified species). Approx. 36% are typical representatives of river banks, while approx. 22% are more or less specific for coastal dunes. Over the three years of investigation, a gradual increase in species richness was observed at all sampling sites. Moreover, four critically endangered to fairly rare Dolichopodid species that are typical for coastal riparian or littoral habitats were recorded here for the first time. On the other hand, four species that were previously known from the intertidal environment were not recorded again/yet. It was concluded that the newly created habitats contain a relatively rich Dolichopodid fauna with several typically coastal species.

Evaluation

Monitoring is primarily focussed on the distance-to-target evaluation of initiatives, taken to reach certain nature restoration or nature development goals. The primary goal of this particular project was the creation or restoration of estuary-dune ecotones. Has this goal been achieved already after only three years?

Abiotic conditions

Indeed, the estuary-dune ecotone has been restored or created, showing continuous gradients of *e.g.* salt-fresh water, mud-sand, wet-dry, dynamic-stable. Nonetheless, most monitoring partners conclude that the degree of silt sedimentation in the lower part of the ecotone seems to be low to very low. It was shown that silt content is significantly lower at the newly created intertidal habitats than at the reference site (Creek of Lombardsijde). Topographical measures along transects have proven that no net sedimentation seems to occur, at some places (sometimes severe) erosion takes place, at others (sometimes strong) sedimentation is at work. This might very well mean that the system is evolving towards an internal equilibrium, but might also indicate that it receives no external sediments from the river. Although nothing definite can be said about the sediment-erosion balance yet, sediment input is surely vital for natural and spontaneous salt marsh development.

In connection with the dredging activities for the navigation channel, regular bathymetric surveys are done. Recent measurements of suspended material in the Yser point out that silt is mainly imported from the sea and hardly from the upstream part of the river. Most of this marine silt material is artificially exported again from the system through recurrent dredging activities. The recent deepening of the navigation channel (needed for dredging with a suction hopper dredger), will possibly have a further negative impact on

silt input to the intertidal mudflats and salt marshes. Marine silt material that is deposited at a lower level in the deepened navigation channel, will less probably be re-suspended and transported to the mudflats and salt marshes than in the case of a shallower channel.

The middle part of the estuary-dune ecotone (the upper zone of the intertidal area) is well developed; data on aeolic transport are lacking though, reason why the abiotic development of this part of the ecotone is difficult to evaluate. The same is true for the upper part of the ecotone. Newly created dunes have been stabilized with marram grass (*Ammophila arenaria*) and appear to develop positively. However, these inner blond dunes show far less aeolic dynamics than the fore dunes and seem therefore to stabilize very quickly.

Biological responders

Restoration of abiotic conditions can never be the sole goal of a nature restoration project; of course the expected biological responders should react in a positive way. Did they?

The botanists found a clear relation between spontaneous salt marsh development and silt accretion in the intertidal area, sites rich in silt and right above MHW are almost immediately colonized by salt marsh annuals, other, sandier places are far less easily colonized and often with rather eurytopic, salt tolerant plant species. It is expected that *Elymus athericus* will quickly start to dominate the salt marsh in these conditions, since this very competitive species is favoured by sandy, well-drained and oxygen-rich soil.

Desender *et al.* (2005) are also not convinced that the newly arrived typical salt marsh ground beetles and spiders will permanently establish, since they expect the dominance of sand above silt accretion to have a negative effect on the natural development of a typical salt marsh system and will endanger the maintenance of pioneer stages on the salt marsh.

Observations of the benthic macrofauna show a clear positive relation between silt content and benthic biomass and diversity. On the other hand, the benthic fauna seems to colonize the newly created intertidal habitats very quickly. Densities are already in the same order of magnitude as those found in comparable estuarine habitats from climatologically similar locations, such as Balgzand (Wadden sea; Beukema, 1979), Königshafen (Reise, 1985) and the Westerschelde (Ysebaert, 1993, 2003). Benthivorous bird species, e.g. Redshank, Dunlin, Oystercatcher and all three Plover species, forage very frequently in the newly created intertidal habitats (De Groote, 2003) and have increased in number since the intertidal area was enlarged. The enlargement alone explains at least partly the recent and frequent breeding activities of several water bird species.

It can be concluded that the creation of intertidal area is very positively evaluated, but that the sediment-erosion balance remains a critical bottle-neck. All monitoring partners conclude that further systematic monitoring is vital to further evaluate abiotic and biological changes in the still very young and quickly evolving ecosystem.

Instead of typical fore dune marram dune development, the created inner dunes in the upper part of the ecotone (above MHWS), rather show a development of more or less

ruderal, pioneer vegetation among the planted marram grass. No colonization of typical fore dune species occurred yet, but both ruderalisation and the lack of colonization by typical marram dune species are expected to be temporary phenomena.

Monitoring problems and further monitoring

Monitoring should be a recurrent element of every nature restoration and management process (Fig. 1). Since the evaluation of distance-to-target is an intrinsic part of the monitoring process, one needs initial goals with well-defined standards. Although a system of nature typology has been developed for Flanders (<http://www.inbo.be>), enabling managers to define restoration and management goals, a quantifiable standard per nature type has not yet been developed. Developing such a generally applicable standard remains a hard job to do, because of the multivariate character of every nature type and because of the local specificity of every single nature reserve and nature restoration project. Above that, not all people involved in nature conservation, development and management are convinced of neither the possibility nor the necessity to force nature into the deterministic straitjacket of pre-defined nature target types. Nonetheless, we consider it important to develop such a system in order to be able to quantify the distance-to-target and hence to be able to evaluate result commitments.

To judge the changes in environment and biodiversity after nature restoration initiatives, monitoring should be continued much longer than an initial period of three years. Changes on the short term can be due to seasonal fluctuations or due to population density fluctuations of the target species in general. Above that, biotic response variables, such as vegetation, generally react slowly on changed conditions.

In the nature restoration project at the Yser Estuary, monitoring was very intensive during the first three years, and therefore very time-consuming and costly. The further follow-up can be simplified and made less intensive in time (*e.g.* surveys every one to five years, depending on the variable to be surveyed) and space (not all 13 transects and with vegetation plots every 5m, but *e.g.* a number of plots per vegetation type or per ecologically defined part of the ecotone). Monitoring can also and perhaps preferably be focussed on a selection of positive and negative process indicators (see *e.g.* Desender *et al.*, 2005; Van Dyck *et al.*, 2001; Maes and Van Dyck, 2005; Van Reeth and Vanongevel, 2005), which are sensitive to changes in the environment.

New measures, such as the recently introduced grazing by sheep on the tidal marsh, should again be followed intensively at the beginning. The sedimentation-erosion budget should be estimated on a regular basis, certainly if positive measures (*i.e.* changes in external water management measures, ensuring better chances for silt input) are possible. Area-covering vegetation mapping would best be realized every five years.

Monitoring continues for terrestrial arthropods (spiders and ground beetles), vegetation, flora and avifauna. For the further follow-up of the sedimentation balance, it has been chosen to further develop the area-covering interpretation of hyper spectral images (part of a recently started FSR-project). Next to that SE-plots are further followed and transects are measured on a yearly basis. Sheep grazing impact on vegetation is monitored rather intensively through an ex-/enclosure technique and through research on habitat and diet selection of the sheep, using the instantaneous sampling method (Lamoot *et al.*, 2004). All these monitoring initiatives are taken by the research groups

themselves, of course in mutual consultation of the manager of the Flemish nature reserve, being the Nature Department of AMINAL (Ministry of the Flemish Community).

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PARALLEL THEMATIC WORKSHOP SESSIONS

*Workshop ‘Technical aspects’
chair: Jean-Louis Herrier*

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Dynamic dune management in practice – remobilization of coastal dunes in the National Park Zuid-Kennemerland in the Netherlands

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Abstract

In order to achieve enduring dune dynamics, new thinking led to the notion that remobilization of entire, formerly mobile but artificially stabilized dunes, is probably the way forward. Some experiments are going on at the moment. The first results are shown here. A great effort is needed to build consensus for such controversial projects.

Keywords: Remobilization; Consensus building; Dune dynamics.

Introduction

Dutch dunes were completely stabilized in the 19th and 20th century due to stopping over-exploitation and systematic stabilization programmes. Extraction of drinking water caused the groundwater-table to drop. This resulted in desiccation of formerly wet slacks. Because of a lack of large-scale dune dynamics, existing wet dune slacks dried out and the development of new wet dune slacks stopped. Rabbit diseases (myxomatosis, RHD) and nitrogen from air pollution led to grass and scrub encroachment. Consequently, pioneer stages became very rare.

The management of the National Park stopped the policy of dune stabilization and put an end to groundwater-extraction.

However, since the mid-1990s awareness grew that this was not enough, and that the process of dune mobility had to be actively restored.

Removal of vegetation and soil from desiccated dune slacks was started in order to get closer to the groundwater-table, to restore animal and plant communities and to restore dynamics.



Fig. 1. 'Bride of Harlem', reactivated dune in February 2003.



Fig. 2. Project Wurmenveld, Zandvoort, 24-04-2002; former potato fields transformed into wet dune slack.

Ecologically the projects were successful: circumstances favorable for endangered plant communities were restored and several endangered plant species, like *Parnassia palustris*, *Epipactis palustris*, *Gentianella amarella* colonized these project areas, but the projects did not result in long lasting dynamic processes.

These experiences have taught us that long lasting dynamics in the Dutch dunes may only be successful if whole dunes are reactivated, and perhaps even only if these are part of a dynamic landscape. Two large-scale experiments to investigate this option are performed in the National Park.

Experiment 1: project 'Verlaten Veld' (12ha)

Winter 1998/1999 a large-scale experiment was started north of Zandvoort, about 3km from the North Sea in a calcareous dune area. Dune geomorphologists of Amsterdam University advised on the plan. A parabolic dune (width of the parabolic head 375m) with a coniferous forest (2ha, 70 years old) on top and the adjacent deflation plain were completely denuded. About 10ha dune scrub was removed. About 60cm of the topsoil (about 70,000m³) was removed from the National Park.

The area is closed to the public. Nevertheless, a lot of people had to be convinced of the desirability of such a potentially controversial project. A Consensus Building Approach was developed. Interactive discussions and advice led to adjustment of the plan. Several categories were involved:

Professionals:

- Public servants province, state (licenses); financiers; public servants Zandvoort: excursions;
- Rangers: excursions and responsibility for supervision in the field.

Interest groups:

NGO Dutch Dune Conservation; earth value group; volunteers; meeting; excursions; publications.

Partner organizations inside and outside the National Park: excursions; information.

Politicians of the local community: excursions; articles in papers.

The general public: radio, newspapers, excursions.

The Consensus Building Approach continued, also after the project was completed, by way of excursions, publication of results, and a film shown in the visitor centre.

The project is monitored by the Bureau for Beach and dune Research. Some results of this project are discussed by Arens *et al.* (2005).

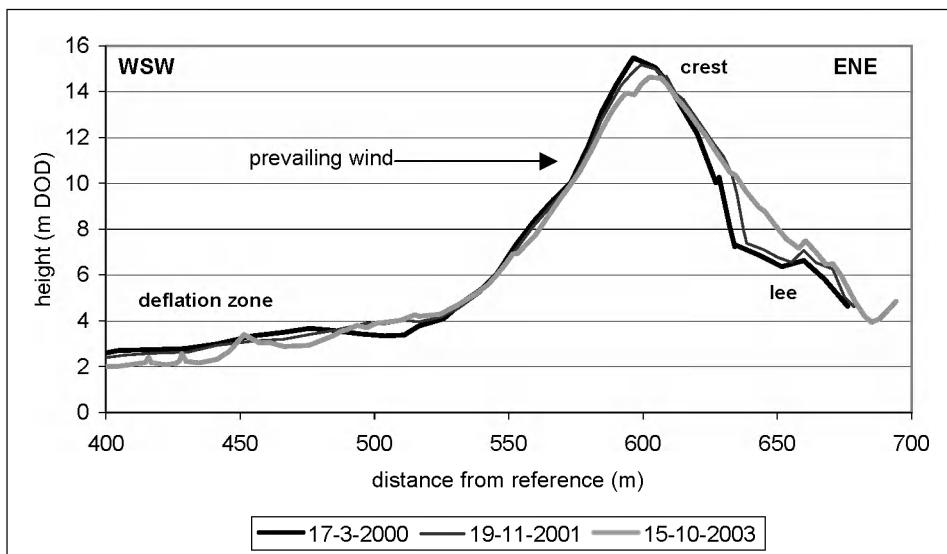


Fig. 3. Mobility of the parabolic dune, between March 2000 and October 2003. The surface of the dune slack in front of the parabolic head (left side) is dropping because of deflation. The crest of the dune is eroding and has moved about 8m downwind. Lots of sand are deposited on the lee side (right side), which has moved about 10-20m downwind.



Fig. 4. 'Verlaten Veld' in summer 2004.

The reactivated dune has remained fully mobile for six years and it looks like this will remain so for the coming years. Grazing with cattle and horses has been introduced in November 2003, grazing with European Bison is considered. This too might help keep the process going.

Experiment 2: project 'The Bride of Harlem' (8ha)



Fig. 5. Work being done in the 'Bride of Harlem'.

A second parabolic dune was remobilized winter 2002/2003. This experimental area is located north of the Verlaten Veld, about 1km from the North Sea, west of Lake Vogelmeer. It was part of a larger project where topsoil was removed from 30ha dune slacks formerly used for agricultural purposes. Sand was used for landscape restoration: filling up an old water extraction canal and improving an artificial dune lake (islands, shallow parts, dune slack). To avoid causing disturbance to visitors by sand-transporting trucks, hydraulic sand transport was used.

In a densely populated country like the Netherlands again we needed to convince a lot of people of the desirability of such a potentially controversial project. The Consensus Building Approach was used again. The location of this project is situated in a dune area with many visitors. For that reason additional information was given on temporary notice boards on site. Special attention was given to a 'critical-visitor-group' (excursion).

Consensus Building Approach continued, after the project was completed, through excursions, publication of results, film shown in visitor center.

Conclusions and recommendations

Remobilization of a complete dune has been successful at least for a period of six years. A new dune slack is formed in front of the moving dune and old vegetation is covered at the back of it. Time will tell if this management will result in durable dune mobility over longer periods of time.

Potentially controversial projects could be realized thanks to the great effort put into consensus building.

In the future we hope to remobilize an entire landscape consisting of the frontal dune ridge and two series of parabolic dunes. Here we hope to achieve that landscape-forming processes remain active for a very long time (decades).



Fig. 6. Radio Noord-Holland.



Fig. 7. 'Verlaten Veld' March 2003.

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Multi-technique survey of fine sediment transport and deposition in a managed estuary: the Authie Estuary, northern France

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Abstract

This article presents an overview of a range of simple and high-technology techniques and scientific methods used in a small, human-managed, highly dynamic, temperate macrotidal estuary to quantify the movement and deposition of fine sediment in space and time. The principle of each technique and its limitations are exposed. It is shown that this multi-technique approach is relevant to a better understanding of sedimentary processes, rhythms and rates, while the data acquired are of importance to reliable modelling. Permanent feedback from high-resolution field monitoring is still a necessary pre-requisite in forecasting the evolution of estuarine systems.

Keywords: Survey techniques; Estuarine monitoring; Sediment dynamics; Authie Estuary; northern France.

Introduction

Estuaries are highly dynamic environments of great socio-economic and ecological importance due to their position at the interface between marine and terrestrial environments. This location commonly entails an adequate supply of coarse (sand) and fine (mud) particles from both marine and continental sources. A good knowledge of the fine sediment distribution pattern in time and space is important because estuarine accretion eventually leads to the evolution of intertidal habitats towards supratidal ones, while erosion may result in damage to infrastructure. Erosion and accretion patterns may also determine the distribution of pollutants in estuaries. Moreover, by providing space, resources and habitat for wildlife, the loci of fine sedimentation are of critical ecological significance.

Estuarine management and eventual habitat restoration need preliminary studies, pertinent surveys and tools to understand the behaviour of sediment stocks and to allow the quantification of sediments budgets. It is difficult to evaluate qualitative and quantitative aspects of sediment dynamics, as a result of overall mixing inside the

estuarine system and recycling of materials. This issue is also complicated by the nature of the materials in movement and their physical properties, as well as by variations in the energetic forces driving estuarine dynamics (wind, waves, tide, river discharge). One way of maximising data collection with a view towards improving the understanding of estuaries is by diversifying the range of methodological procedures and techniques in order to attempt to match the diversity of estuarine parameters at different spatio-temporal scales.

Site presentation

The Authie is a macrotidal (spring tidal range = 8.5m) estuary linked to a short (95km-long) coastal river in northern France (Fig. 1a). This estuary experiences important sandy infilling (Anthony and Dobroniak, 2000). The estuary is located on a straight sandy coast under the influence of flood-dominant tides reinforced by wind forcing and wave action. This mixed energy context results in massive sand inputs that shape the estuary. The estuary mouth consists of an important south bank sand spit lying on an accretional supra- to intertidal sand platform, and a north bank subject to strong erosion. This contrasting dynamic pattern regulates the internal morphology of the estuary (Fig. 1b). Thus, fine sedimentation, and subsequently the development of salt marshes, ranging between the fringing and back-barrier types described by Allen (2000), are closely linked to the degree of obstruction of the estuary mouth by sand. The natural trend of this estuary is a general infilling associated with a slow northward migration of its axis and its morphological components but human actions, such as embankments going back to 1158, seem to have enhanced this evolution (Dobroniak, 2000).

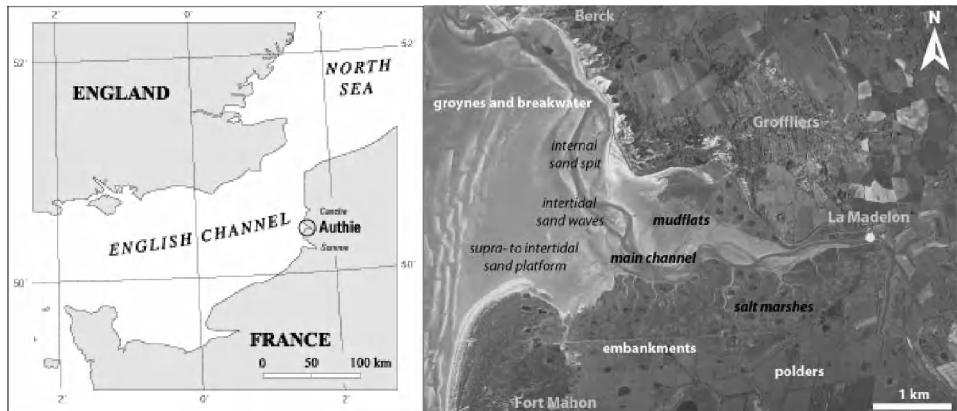


Fig. 1. (a) Location of the Authie Estuary; (b) Main morphologic (in black) and management aspects (in white) highlighted on a photograph (taken in 2000).

It appears that salt marshes have experienced an uneven development and expansion in time throughout the estuary. Special attention is focused on the western salt marshes on the north bank which experienced a rather late but quick progression (less than 50 years). Previous characterisation of superficial sediment reworking on the north bank of the estuary had confirmed the rapidity of estuarine accretion (Marion *et al.*, 2003). The

development of the internal sand spit especially leads to enhanced protection of the inner estuarine areas upstream of this spit. Notwithstanding the energetic tidal regime in this estuary, fine to very fine sedimentation occurs in sheltered areas where the estuarine morphology induces a significant decrease of hydrodynamic tidal forcing (Marion *et al.*, 2004a).

Three different salt marsh cross-shore profiles are under survey along the northern bank of the Authie which presents narrower interfaces between major morphological components (and thus better site accessibility) and overall a quickly accreting sand spit and tidal flat. The first profile is situated in the lee of the internal sand spit and exhibits a young marsh. The two others are located further inward through older marshes and present respectively a prograding pioneer zone and a micro-cliff transition to tidal flats in the direction of the main channel. A tidal channel located between these two profiles is also monitored.

The comprehension of fine sediment stock behaviour and the quantification of the estuarine sediment budget using a multi-scale approach is the global aim of the present work which focuses on multi-technique surveys of fine sediment transport and deposition.

Technical aspects

Sediment transport survey

Argus Surface Meter (ASM IV)

The Argus Surface Meter IV (ASM IV) enables an appreciation of sediment fluxes and sediment bed movements and is based on a 96cm-long vertical array of OBS (optical backscatter sensors) spaced 1cm apart (Fig. 2ab). The ASM IV is an instrument first created for high-resolution surveys of seabed elevation with a major application for the management of port dredging activities (OBS) measures infrared light scattered by the water mass. The development of a calibration technique has enabled enhancement of the sensitivity of the ASM IV to accommodate particulate reflectance at much lower concentrations than the instrument was originally intended for, *i.e.* a clear discrimination between the sediment bed and water.

Previous work has shown that the results of the ASM are strongly correlated with synchronous data obtained with a LISST (Laser In situ Scattering Transmissometer) and sediment concentrations gravimetrically determined from water samples (Gilpin, 2003). This indicates a successful calibration, and confirms the potential of the ASM IV to operate as a multi-sensor OBS (Marion *et al.*, 2004b) (Fig. 2c). At high frequency sampling (10 s recording bursts spaced 5 s), recorded data can provide snapshots of SSC profiles for two days of recording. The battery capacity is not too limitative even for long deployments at low frequency acquisition. In association with a current meter, sediment flux calculations can also be carried out. An ADCP (Acoustic Doppler Current Profiler) can provide velocity data in different locations in the water mass and enable an appreciation of vertical variations in sediment fluxes (Gilpin, 2003).

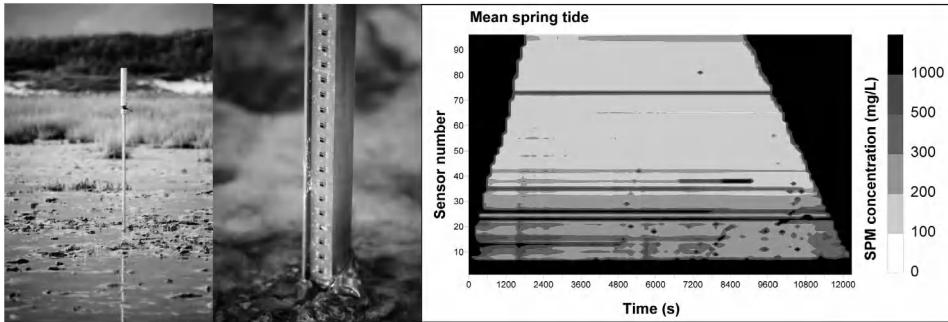


Fig. 2. (a) ASM IV on the field in the Authie Estuary (upper part of the main mudflat); (b) Zoom on the OBS sensor array; (c) Example of results (from Marion *et al.*, 2004b): snapshot of sediment transport during a tide after conversion into sediment concentrations (black areas on each part corresponding to heights without water and on the bottom to sediment level). Note that only the first 30cm of the water column are concerned by important sediment concentration and that sediment resuspension occurs at the beginning and the end of the tidal cycle.

Booner tube

The Booner tube is a shore-based suspended sediment trap which has been developed at the University of Sussex in order to obtain a continuous collection of sediment transported by water (Fig. 3a). Sediment trapped in the collecting chambers is removed during neap tides after each semi-lunar tidal cycle and the dry mass, loss on ignition and grain-size distribution determined. The signature of the successive tidal cycles can be recorded via chronological laminations (Fig. 3b). Differences of lamination colour and width seem to be linked to sediment grain-size and nature due to variations in sediment transport capacity of the flow (via current velocity fluctuations) during a single tidal cycle and the whole semi-lunar tidal cycle. Calibration efforts are still necessary to enable sediment flux calculation, expressed in $\text{g} \cdot \text{m}^{-3} \cdot \text{s}^{-1}$. The mass of sediment collected per hour of tidal inundation permits estimation of the averaged sediment flux over the period of deployment using simple equations applied to the extracted data obtained with re-circulating flume tank experiments.

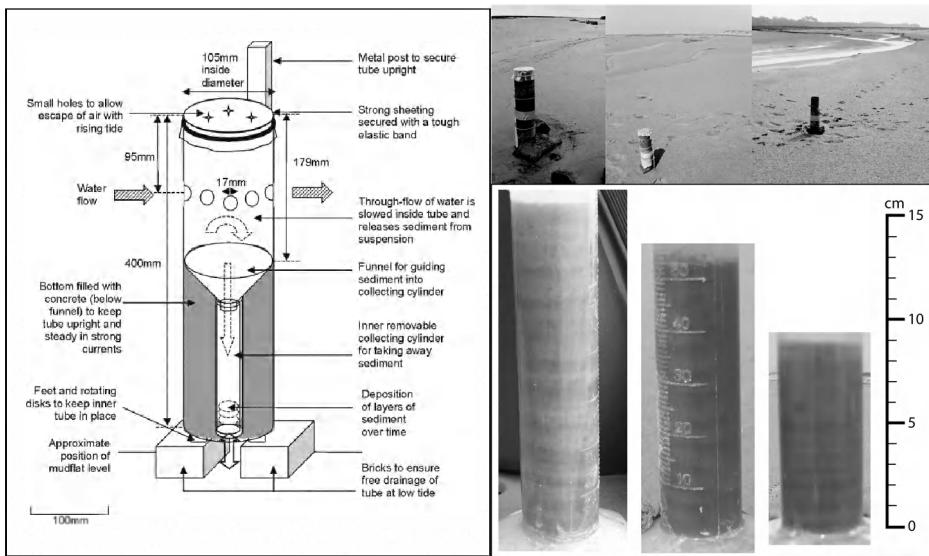


Fig. 3. (a) Boomer tube design and principle of working (from Charman, 2004); (b) Example of results: sediment collected in the clear Perspex central cylinder after a semi-lunar tidal cycle from three different locations in the estuary. Note the numerous laminations recorded.

Sediment deposition survey

Filter method

Sediment supply to salt marshes can be evaluated with the help of the filter method (Fig. 4ab) developed by Jigorel (1996). The filter technique can only be used in environments covered by vegetation because of turbulence created by the filter rack.

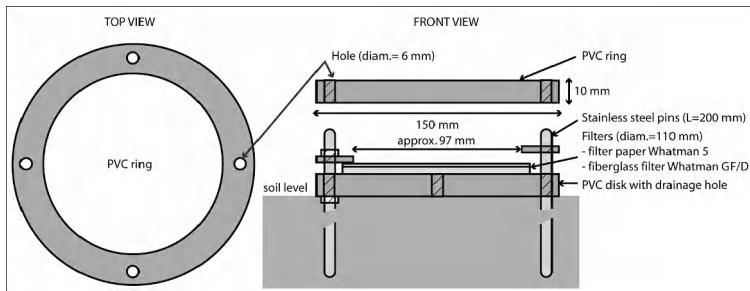


Fig. 4. (a) Station in the Spartina pioneer zone; (b) Filter rack design (adapted from Jigorel, 1996).

The filters (previously weighed) are collected during neap tides for each semi-lunar tidal cycle. They are dried at 60°C during 48h to obtain the total weight of deposition. They

are then incinerated at 500°C during 1h and weighed again, the loss on ignition representing the part of organic matter. The results are expressed in g.cm⁻² relative to the filter collecting surface (75.43cm²) and can be linked to time exposition to seawater inundation.

Altimeter

The ALTUS (SA Micrel) altimeter enables monitoring of elevation changes at high frequencies. The principle of the altimeter is to measure the time taken between the emission by the transducer of a 2MHz wave and the reception by the same transducer of the echo sent back by the target (*i.e.* sediment surface). The time measurements can then be transformed easily into distance via a preliminary coordinates calibration (altitude resolution = 0.6mm+/- 2mm in reduced range of 20 to 70cm). Its energy (four years of recording at 15min) and recording (three months at 15min) capacities allow for deployments of several months, enabling monitoring of seasonal trends in sedimentation.

Marker horizon: burrowing PVC plate

A marker horizon is an artificial layer easily distinguishable from surrounding sediments that enables measurement of vertical accretion (Cahoon and Turner, 1989). Numerous materials such as sand, feldspar, brick dust and glitter or white feldspar can be used as marker horizons but intensive bioturbation can easily remove the layer and the coring methods used to obtain the depth of the horizon exclude repeated measurements. Burrowing PVC plates have been preferred for these reasons. The distance between the burrowing plate and the sediment surface is measured with the help of a pin driven vertically in the substrate by a pre-perforated matrix with nine holes.

Rod Surface-Elevation Table (RSET)

The Rod Surface-Elevation Table (RSET) is a non-intrusive method for precisely measuring elevation changes over long periods (Cahoon *et al.*, 2002b) (Fig. 5). The central benchmark is a 15mm diameter stainless steel rod cut into 1.2m sections that are driven successively into the substrate up to the substrate resistance limits, with a 30-60cm section of the rod extending above the sediment surface to enable the RSET attachment. When fixed, the RSET provides a constant reference plane in space from which the distance to the sediment surface can be measured by means of pins lowered on the sediment surface. Repeated measurements of elevation can be made with high precision because the orientation of the table in space remains fixed for each sampling comprising nine measures. In addition, repeated sampling of eight fixed positions around the rod can be accomplished by the rod collar coupling the device, allowing for replicated measurement at the same station. Under field conditions, confidence intervals for the measured heights of an individual pin range from +/- 1.3mm to 4.3mm in a salt marsh (Cahoon *et al.*, 2002b). Data provided by the RSET are essential for long term monitoring, necessary for medium term surveys, but can be equally interesting for recording the effects of short time-scale events.

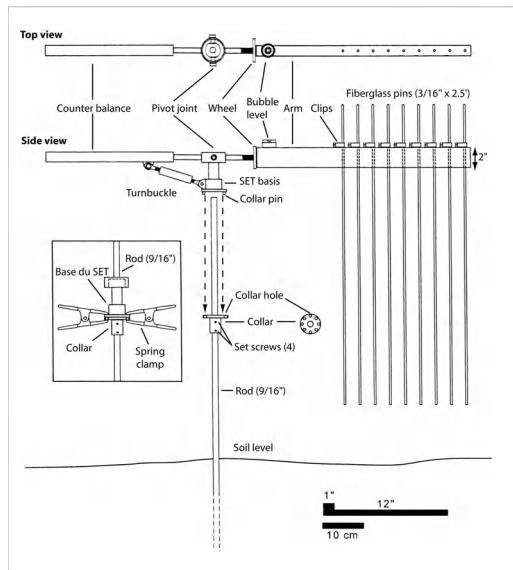


Fig. 5. Rod Sedimentation-Elevation Table (RSET) design (from Cahoon et al., 2002b).

Discussion: results from the Authie Estuary

High technology instrumentation such as the ASM IV and Altus permit high to very high frequency measurements and are relevant in studying processes over the very short term (tide). Their important autonomy and programming possibilities can allow for their deployment over periods exceeding a month at lower frequencies. However, they are cost-prohibitive when it comes to acquiring several units in order to obtain synchronous data from many stations.

Inexpensive methods such as the filter technique or Booner tubes permit large deployments, thus enabling taking into account spatial variability of sediment inputs and fluxes. These methods also enable true sediment sampling, permitting further analyses (grain-size composition, organic matter content, ...) and continuous information that may be used for temporal comparisons. Collecting at the same frequency, the data from the filters and Booner tubes can be easily linked together and can provide information on the import and export of sediment. The results will indicate whether the amount of sediment in the water is a crucial limiting factor in the development of the studied salt marsh.

Although a tendency for higher sedimentation rates at lower marsh levels (corresponding to more frequent flooding) is generally observed, sedimentation rate variability at the same elevation can be important. The composition of vegetation species, through their shape and height, can induce different wave energy and water velocity reductions and finally different sediment trapping conditions. The proximity to channels and the

efficiency of the channel system in driving sediment to the marsh can be determining factors as well. In the Authie Estuary, numerous stations have been set up along the surveyed profiles in the pioneer vegetation zone, in zones of different vegetation types, and in the transition zone with bumps and hollows corresponding to artificial hunting ponds. Other stations are located along four transects across the selected tidal channel. The filter technique is useful in understanding relationships between vegetation, elevation and sedimentation, and in underlining the factors governing sedimentation rates in different cases. Moreover, two experiments were set up to take into account intra-site variability using six filters per station during a semi-lunar tidal cycle. At the same time, the sediment resuspension rates were measured with the simultaneous collection of a second filter per station after each tide following submergence of the low marsh. Since the use of one method only can lead to over/underestimation of the sediment input, it is recommended that filters are used as well as marker horizons. This proved to be a good combination that gave insight on both the grain size distribution of sediment deposited over the marsh and the resulting vertical accretion. The RSET enables measurements of sediment surface elevations at different positions within the sedimentary profile, for depths beyond (exceeding 10m) and below (approximately 0.35m with a special rod created for shallow settlement) than those of the previous SET design, which is limited by the weight of frame and the associated type of benchmark (Cahoon *et al.*, 2002ab). Marker horizon measurements of vertical accretion predominantly incorporate surface processes, *i.e.* sedimentation/erosion, whereas RSET measurements of elevation change take in account both surface and subsurface processes, *i.e.* root growth, decomposition, pore water flux and compaction (Fig. 6).

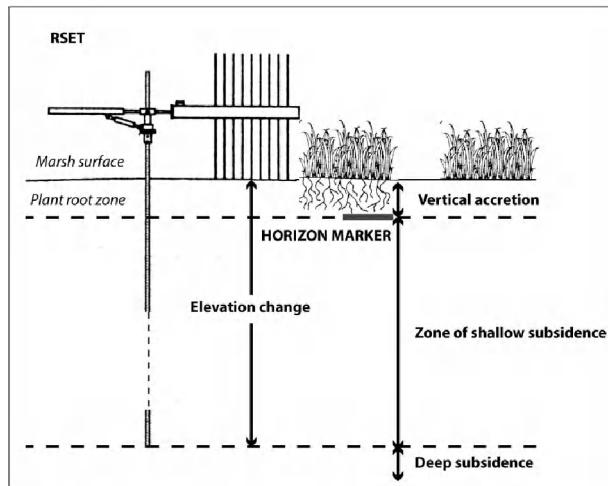


Fig. 6. RSET and marker horizon level of action and data recorded.

Their use in conjunction enables appreciation of shallow subsidence in the sedimentary profile (Cahoon *et al.*, 1995). Different stations coupling marker horizons and RSET enable a better investigation of salt marsh morphodynamics, and throw light particularly

on the interactions between sedimentation and vegetation, as well as the principal factors responsible for salt marsh elevation (biological, hydrological or geological processes).

Conclusion

There are several methods for determining sedimentation rates and patterns in estuaries at various time scales. The methods presented in this paper enable continuous and discontinuous measurement of sediment transport and deposition at different frequencies. A few examples involving the crossing of methods have shown the pertinence of multitechnique surveys to better understand the processes in action. Special attention is required for instrument calibration and field deployment, notably to ensure the representative character of the measurements (replicates). These different approaches enable monitoring of the temporal and spatial variations in fine sedimentation rates and patterns inside a macrotidal estuarine system that will eventually allow for the calculation of a realistic sediment budget based on a large data bank.

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Development of a decision support system for LIFE-Nature and similar projects: from trial-and-error to knowledge based nature management

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Abstract

The very high environmental pressure on ecosystems increases the need for active nature management. Compared to classic nature conservation this requires a considerable knowledge of ecosystem functioning, in particular about the biotope conditions required by plant and animal species and the biogeochemical processes and hydrology structuring these conditions. The amount of available knowledge on these subjects has increased rapidly and restoration projects are becoming more and more successful. However, recent evaluations show that in a majority of the projects the results are still far from optimal. One of the most frequently occurring reasons for the variable results is a poor availability of essential information to restoration managers. In particular information for analysing the basic problems, setting the right objectives, and planning effective restoration measures is lacking. A decision support system that offers easy access to up-to-date knowledge could help to increase success rates. The main aim of a running LIFE-Nature Co-op project is to develop and test such a tool for coastal dunes and raised bogs and to bring together relevant experience and knowledge on the conservation and restoration of these vulnerable ecosystems. The decision support system will assist site managers to take the proper steps in their nature restoration project: 1) description of the problem and its consequences for the functioning of the ecosystem and the presence of species, 2) analysis of the processes that have caused the problem, 3) selection of the best possible restoration objective, 4) description of restoration measures necessary to achieve the objectives, 5) development of a plan for monitoring the effects of the measures and 6) execution of the measures and monitoring. This decision support system will be accessible via an interactive interface that selects the information relevant to the user's situation. All essential information will be presented in short texts, supported by pictures of field situations. Furthermore, links to relevant literature and to field examples will be present. The latter refers to a list of recently carried out and ongoing projects, including addresses of the responsible authorities. The tool will be freely accessible on a website and can be easily updated with new knowledge and experience. Thus, an easy exchange of essential knowledge and experience is stimulated.

Keywords: Objective; Conservation; Restoration; Knowledge; Decision support system.

Introduction

Throughout Europe, nature managers try to restore ecosystems that have suffered from various threats such as drainage, habitat fragmentation, acidification and eutrophication. Compared to 'classic' nature *conservation* - which is ideally restricted to the exclusion of anthropogenic influences from nature reserves – the *restoration* of ecosystems requires a more active attitude. If we want to be able to restore ecosystem functioning, a profound insight in the key-processes is essential. We need to know which processes have led to degradation of an ecosystem, on what scale they operate, how they interact with the ecosystem and how they affect the occurrence of species. With increasing insight in ecosystem functioning as well as experience in carrying out restoration projects the success rate of nature restoration projects grows. There are however several problems and pitfalls in nature management that seriously hamper the process of increasing success rates. One of the largest problems is the poor availability of essential knowledge on ecosystem functioning for managers who plan restoration measures. Recent surveys show that only in 2.4% (Sutherland *et al.*, 2004) to 8% (Pullin *et al.* 2004) of all analysed project plans scientific knowledge was used in planning restoration measures. Furthermore, many management interventions remained unevaluated and much information is not readily accessible in suitable form (Pullin *et al.*, 2004). A limited exchange of practical experience between different projects is also mentioned by Houston (1997). All authors mention an urgent need for a conceptual framework to make evidence-based knowledge and practical experience accessible in nature restoration.

In this paper we present the basic design of a decision support system that can help nature managers in planning effective restoration measures. This tool will not supply complete designs for specific nature areas. The system points out how general problems and pitfalls in restoration management can be foreseen and avoided and supplies essential ecosystem knowledge to nature managers. Though the decision support system can eventually be used in all types of ecosystems, efforts are now restricted to restoration management in coastal dunes and raised bogs. In this paper the most important problems and pitfalls in nature restoration are mentioned and illustrated and the basic design of the decision support system will be explained.

Problems and pitfalls in nature restoration

We consider restoration projects successful if natural processes and abiotic conditions are restored (as best as possible under present ecological stress factors) and if populations of characteristic flora and fauna species are restored. By this definition only few restoration projects can be considered completely successful. In many projects, only a part of the processes and abiotic conditions are restored and only a small number of characteristic species are facilitated by the measures taken. For example, in Kooijman *et al.* (in press) 21 restoration projects in dry coastal dunes in The Netherlands are evaluated, including mowing, sod-cutting, grazing and reactivation of blow-outs. Although most measures show positive effects after 5 to 10 year, none of the measures has led to a more or less complete restoration of floral biodiversity. Effects on fauna are not studied in these projects, but in general they seem to be less positive than effects on vegetation (Van Turnhout *et al.* 2003). In another evaluation of nature restoration projects in Dutch coastal dunes (Van den Boom *et al.*, 2004), only 5 out of 33 projects

were considered successful, 16 projects showed partial positive effects and 11 projects showed hardly any positive effects. Two projects were carried out too recently to draw conclusions on the effects. In a number of restoration projects populations of characteristic plant or animal species became locally extinct due to negative side effects of restoration measures. If these species cannot recolonise from nearby populations these side effects must be considered as a partial failure of the project.

To increase the success rate of restoration measures and to avoid negative side effects, a number of problems and pitfalls must be discerned. Although the described problems and pitfalls in nature restoration seem very obvious, practice shows that in a majority of restoration projects one or more of the aspects mentioned is overlooked or undervalued!

Problems or restoration objectives are not well defined

Restoration can be focused on certain species, taxonomic groups or on a certain aspect of the ecosystem only. In this way, one can easily overlook concomitant problems or conclude that a certain measure is successful, whereas characteristic species that were out-of-focus did not recover or even disappeared from project areas. For example, during the first years of the very successful Dutch 'survival plan for woodland and nature' (OBN), measures against acidification were included in only 33% of the projects, whereas more than three-quarter of the ecosystems involved suffered severely from acidification (Van der Burg and Brouwer, 1993). In this same program, the restoration goals were mainly defined by abiotic and floral parameters. A recent evaluation showed that a part of the characteristic animal species was not or negatively influenced by restoration measures (Van Duinen *et al.*, 2004). In an evaluation of restoration measures in the coastal dunes of the Netherlands (Van den Boom *et al.*, 2004) the objectives were clearly defined for 18 out of 33 restoration projects. In 12 projects the objectives were defined too narrow (*e.g.* only based on hydrology) or too broad (*e.g.* 'creating open dune landscape' or 'increase of plant species diversity'). For 3 projects no objectives were defined. Only in 2 out of 33 projects fauna species were included in the objectives.

In some restoration projects the measure itself (*e.g.* 'raising the water table' or 'grazing') is presented as an objective. This was (partially) the case in 5 out of the 33 dune restoration projects evaluated by Van den Boom *et al.* (2004). In such cases there is a risk that restoration is declared successful when the measure is carried out in the right way (*e.g.* water tables do raise or cattle is active in the whole restoration area), irrespective of the effects on the ecosystem.

Sometimes ecosystems which are already degraded are used as a reference in planning restoration measures. This can lead to the wrong analyses of the problem or a wrong definition of objectives and subsequent evaluation of the measure. For example, the effects of mowing on plant species richness in dune grasslands which are encroached with shrubs or tall grasses were evaluated as relatively successful, since species richness was restored to 65-80% of the best sites before measures were taken. However, plant species diversity in these 'best sites' was already severely decreased compared to intact situations (Kooijman *et al.*, in press).

Insufficient insight in ecosystem functioning

The processes that have caused the problem are not or insufficiently known. The consequences of the applied measures, including negative side effects, are therefore incalculable. If knowledge of such key-processes is insufficient, then essentially a trial-and-error approach is applied. A recent evaluation of 12 Dutch restoration projects in coastal dunes showed that in a majority of the projects, some goals could not be met due to "unforeseen" reactions of the ecosystem (Graveland and Esselink, 2004). Also Van den Boom *et al.* (2004) mention two dune restoration projects in which the results differ strongly from the restoration objectives. For one of these projects and for another project in which the results were disappointing, insufficient knowledge on local conditions were mentioned as an important reason.

No or insufficient monitoring before and/or after the measure

The situation before restoration is not properly described. This may be a consequence of a too narrow definition of the problem and restoration objectives for the project area, since the parameters that are monitored do not indicate the relevant ecosystem changes. Also the monitoring period can be too short. In acidified and/or eutrophied wet dune slacks *e.g.*, seeds of characteristic plant species germinate after removal of accumulated organic matter, but these species can subsequently disappear after a few years due to re-acidification or re-eutrophication (Brouwer *et al.*, 1996; Grootjans *et al.*, 2002).

Scaling and timing of measures is not optimal

Restoration measures affect the present biodiversity, including characteristic or target species. If the scale of these measures is too large or if they are carried out in the wrong season or in a very limited period of time, the number of negatively affected species can rise alarmingly. On the other hand, an evaluation of Dutch coastal dune restoration projects has shown that measures that are designed to revitalise large-scale processes are unsuccessful if applied on a small scale (Graveland and Esselink, 2004).

The PROMME-concept for restoration management

In order to accelerate the process of optimizing the results of restoration projects, a LIFE-Nature Co-op project was started that brings together and disseminates the experience and knowledge of site managers and ecologists all over Europe. A decision support system for setting up restoration projects will be developed and will be freely accessible via an internet site. The system will include all ecological knowledge essential for successful restoration. In this project, we restrict our efforts to two types of ecosystems: coastal dunes and raised bogs. This LIFE project, entitled "Dissemination of ecological knowledge and practical experiences for sound planning and management in raised bogs and sea dunes", is carried out by the Radboud University Nijmegen in close collaboration with site managers and scientists from other European universities and institutes. At this moment approximately 60 persons from 30 institutes in 12 European countries participate in this Co-op project. In the following, we describe our approach and the first results of this project.

In nature restoration projects, many aspects have to be considered. Sufficient funding has to be raised, stakeholders need to be informed, public acceptance must be sufficient (e.g., Edmonson and Velmans, 2001; Zwart, 2001), and the whole process needs to be carried out according to all kind of legal and administrative rules. In our project we acknowledge the importance of these aspects, but we focus on the ecological aspects and actual restoration process. Based on the experiences with many restoration projects, we made a checklist for a successful application of restoration measures. It shows which steps are essential and in which order they should ideally be carried out. At the first workshop of the LIFE Co-op project in October 2004, the PRIME-concept (Problem-Reason-Instrument-Monitoring-Execution) was launched and after discussing this concept with the participants, some adjustments were made. It was felt that the phase of setting the objective of restoration projects needed to be addressed in a separate step (in between the Reason-phase and the Instrument-phase of the PRIME-concept), thus resulting in the PROMME-concept (Table I). The decision support system must help with formulating realistic and clear objectives on various time and spatial scales. The PROMME-concept is designed to check for pitfalls in the restoration process and the decision support system will give access to information that shows how to avoid them. The decision support system will provide help and detailed relevant information to go through any of the six PROMME-steps. The system can not provide a complete design for each specific situation itself, but will provide the user with the information necessary to design and carry out a restoration project on a specific site. The user will be encouraged to make the definition of the problem as complete as possible. The system will list possible causes for the problems in the project area and will support the user in selecting the most important ones in his or her particular case. Sometimes, information essential to define the problem or causal factors is lacking. The decision support system will help to identify this lack of knowledge and provide instructions for additional measurements or recommend the help of a specialist. Based on the problems and their causes, as well as the opportunities and limiting factors in and around the project area, clear and realistic restoration objectives have to be defined. For every general problem and objective, sets of restoration measures will be provided. Adding information about specific problems or site conditions that the user has given will refine these sets. Recommendations for monitoring programs and parameters will be given and finally practical information necessary for the execution will be presented, including notes on the intensity and spatial scale of measures and feedback between monitoring results and the execution of measures. An easy access to the essential literature will be provided at different steps in the decision support system.

Problems and pitfalls in coastal dune restoration

The ecological functioning of coastal dunes depends primarily on the influence of flooding by the sea and on the shifting of nutrient poor, fresh wind-blown sand. Secondarily, the floral and faunal composition is a result of groundwater level, amount of decalcification and succession (Westhoff, 1971; Grootjans *et al.*, 1997; Kooijman *et al.*, in press). These processes result in a small-scale alternation of vegetation structures. The most important factors influencing coastal dune ecosystems in Europe are increased atmospheric nitrogen deposition, active stabilisation of shifting sand by planting marram

grass and pine trees and drainage of groundwater. These factors, in combination with a decrease of rabbit activity due to the diseases myxomatosis and RHD, stimulate the growth of grasses, shrubs and trees and thereby counteract the influence of natural dynamics. This leads to the disappearance of small scale vegetation patterns and its dependant fauna (Nijssen *et al.*, 2001a, Van Turnhout *et al.*, 2003).

Restoration of coastal dunes should primarily focus on the possibilities for the restoration of the natural dynamics (Ketner-Oostra 2001; Kooijman *et al.*, 2004). However, in many dunes one or more of the following ecological preconditions for this functioning are absent: a sufficiently large dune area, atmospheric nitrogen deposition below the critical load, access of the sea to a considerable part of the dune area, and a minimal amount of bare sand. These limitations have consequences for choosing realistic objectives by site managers and thus, for the restoration measures to be executed in the project area, as is illustrated in the example below.

Table I. The PROMME-concept, a checklist that contains six essential steps for nature restoration projects in order to avoid pitfalls

Step	Description	Pitfalls
Problem	Description of the problem in terms of changes in flora, fauna and abiotic conditions on certain spots and the consequences of these changes for the ecosystem as a whole.	<ul style="list-style-type: none"> • Important aspects (including species) easily overlooked. • Reference situation insufficiently known.
Reason	Analysis of the biological, hydrological, chemical, and physical processes which led to the observed changes.	<ul style="list-style-type: none"> • Key processes easily overlooked. • Other processes easily overvalued. • Specific site conditions not recognised.
Objective	Formulation of a restoration goal, based on the current possibilities to invert the processes that led to ecosystem degradation.	<ul style="list-style-type: none"> • Current limitations not considered. • Objective not well defined, excluding important parts of the system or species groups.
Measures	Selection of the optimal combination of restoration measures for restoring the ecosystem to the defined goal.	<ul style="list-style-type: none"> • Combination, scale, intensity and/or timing of the measures lead to extinction of the species present. • Negative side-effects of measures overlooked.
Monitoring	Selection of (a)biotic indicators for ecosystem recovery and start of monitoring.	<ul style="list-style-type: none"> • Parameters not indicative. • Monitoring only starts after execution of measures • Monitoring period too short.
Execution	Actual application of the restoration measures and simultaneous monitoring and feedback.	<ul style="list-style-type: none"> • Inexperienced executors. • Be prepared for unexpected situations.

Grazing as a restoration measure in grass-encroached grey dunes

Nitrogen deposition, active stabilisation of shifting sand and a decline of rabbits as natural grazers have led to grass-encroachment in many coastal dunes. Therefore, grazing with sheep, cows or horses has become a widely applied management tool. In many grazing projects, a decrease of tall grasses was observed, sometimes in combination with a return of characteristic plant species (e.g. Kooijman *et al.*, 2005) or a reduced decrease of these species (Packham and Willis, 2001). In these and in many other studies, grazing is therefore considered a successful restoration measure. However, a close inspection of the data shows that plant species returned in much lower densities than were present in the (sometimes already deteriorated) reference situation. Moreover, the reduction of tall grasses was mainly a decrease in height of the grasses and did not lead to a change in cover. Essential problems, such as acidification, accumulation of nutrients and organic matter and the absence of bare, sandy patches were not solved. Therefore, the typical flora and fauna did not return, as was shown for characteristic carabid species of dry open dunes (Nijssen *et al.*, 2001b). In one case (Burton, 2001), rejuvenation of small scale aeolian activity did occur after trampling by cattle and facilitation of fauna species like solitary bees and wasps and Natterjack Toad (*Bufo calamita*) was reported. However, in this project problems with tall grasses and subsequent accumulation of litter and humus seemed less serious, probably due to relatively low nitrogen deposition rates.

The decision support system aims to encourage restoration managers to optimize their results and gives access to the information that is needed to do so. When dealing with grass-encroachment of grey dunes the PROMME-based decision support system at least the following aspects will be considered:

- The basic problem is disappearance of characteristic flora and fauna species of grey dunes. To recognize the impact of the problem it is of major importance to have a reference situation (in space or time) in an intact grey dune system. Also the scale on which the problem occurs in relation to the total size of the dune area is important.
- When describing the reason, problem managers will be stimulated to consider more aspects than the obvious 'encroachment by tall grasses'. What is in a specific situation the key factor for encroachment? Has encroachment started after ceasing human activities? Can increased nitrogen deposition levels be (part of) the problem? Did rabbit populations decrease? Also other processes can be involved such as accumulation of litter and/or humus or decrease of aeolian activity.
- The general objective is to facilitate populations of characteristic flora and fauna species by restoring the abiotic conditions and processes of the ecosystem. This means that not only tall grasses should be removed, but maybe also bare sandy patches or aeolian activity should be restored or the pH of the top soil should be increased. To formulate the right objectives in sufficient detail a list of characteristic ('target') species, knowledge on the resident flora and fauna and in particular the distribution of rare and characteristic species, and knowledge of the (a)biotic conditions required by the respective species is indispensable. To set realistic objectives limiting factors have to be considered, such as size of the area, recreation pressure or ongoing stress factors like high nitrogen deposition rates.
- Choosing the most effective measure (or set of measures) depends on the set of objectives, the causes of the problem, as well as the resident flora and fauna species that should be taken into account. When the objective is to remove tall grasses and

create small scale aeolian dynamics, grazing can be sufficient in sites where no humified soil has developed, but is probably insufficient in places where such a soil layer is present. In the last case, other measures like small scale sod-cutting can be applied. Of course, the type of grazer and the grazing intensity should be tuned to the objectives. The scale of the measures depends on the scale of the problem as well as on the presence of populations of characteristic species or vulnerable vegetation types in grey dunes *e.g.*, lichen-rich grasslands. To spare these species and vegetation types measures can be carried out on a smaller scale, phased in space and time, or certain parts of the area can be exclosed.

- Monitoring is necessary to evaluate the efficiency of the measures taken and provides information needed to chose the proper timing of subsequent steps in the restoration management, if measures are phased in time and space. Moreover, it creates the possibility to stop or fine-tune measures when negative effects occur. It is very important to choose parameters which indicate if the measure leads to desired as well as undesired situations. Monitoring should start well before the taking of measures, since the effect can only be determined when the starting situation is sufficiently known. Continuation of monitoring should be planned and secured beforehand for a period long enough to determine the effects of the measure.
- Execution of measures can take place after all aspects mentioned above are taken care of. Supervision by nature managers while carrying out the measures is recommended, especially when the measure is put out to a contractor with no ecological background.

An internet site for supporting restoration management

Site managers, being partners in the LIFE Co-op project will test the concept decision support system. An internet site containing the PROMME-concept and the decision support system for restoration of coastal dunes and raised bogs is planned to be operational in 2006. This tool will be free to use and will give access to up-to-date essential ecological knowledge on these two types of ecosystems, field examples and addresses of experienced site managers. When the decision support system proves to be a useful tool for site managers in LIFE-Nature and similar nature restoration projects, the system can be extended to other types of ecosystems.

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Managing the Flemish dunes: from eco-gardening to mechanical disturbances created by bulldozers

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Abstract

The 'Conseil Général du Département du Nord' is the manager of 480ha of Flemish dunes located at the far North of France. These spaces, initially preserved by the action of the 'Communauté Urbaine de Dunkerque' are now the property of the 'Conservatoire de l'Espace Littoral et des Rivages Lacustres'. Characterised by an aelian dynamism and by the winter flooding of their damp depressions, these systems had represented a very high patrimonial richness before man, by these actions (the pumping of the aquifers, the parcelling out of dune massifs, the fixation of sand by plantations, the destruction of rabbits), reduced to nothing the natural expression of perturbations (storms, floods, important sandbanks) and made dune massifs become wastelands and low marshes and dry lawns disappear. The first step for preservation was the in extremis safeguard and the maintenance by seateurs (1989) then by motor scythes (1992) of micro-habitats with a high richness over a 2ha total surface lost in very important pre-forested systems. Rapidly, the objectives of preservation obliged us to put into practice the restoration of natural environments by stripping and clearing the ground (1994 and 1997). But these operations of a large scale (10ha) were always based on a 'fixist' and 'museographical' approach to the environment (the maintenance of a representative sample of habitats). The management which consists of stopping certain pioneer and post-pioneer stages of vegetation can in fact correspond to a counter-natural step as these dune systems make the proof of a very high dynamism and permanent evolution. Today the management of dune space is done by bulldozers: first the pre-forested vegetation is totally destructed (16ha in 2004) leaving systems of bare sand freely evolving and accepting their spontaneous wastelanding over more than 50% of their surfaces. The return to uncontrolled vegetal dynamism is only accepted if perturbations are periodically created in order to regularly produce the starting or reappearance conditions of the different series of vegetation. The last stage of our managing operations would consist, with a middle-term effect, in reducing the stability of the edging dune row and in favouring the development of wind passages with their devastation or saving effects on the dune we intend to preserve.

Keywords: Flemish dunes; Alkaline marshes or dune wetlands; Dune dry grasses; Grazing;
Mechanical disturbances.

Introduction

Characterized by a very dense population, a heavy industrial past and a performing agriculture, the North department territory has seen many of these natural habitats disappear. The coastal areas have not been spared by this logic of sacrifice, especially around the Dunkerque metropolitan area and its vast industrialo-portuary complex: over 85% of the dunes originally present have thus disappeared. The entire departmental coastline is 38km long. In the 1950's, there were 25km of dunes; 7km today are located and protected east of Dunkerque. These are located in the immediate proximity of the Belgian border.

The dunes are situated in Leffrinckoucke, Ghyselde, Zuydcoote and Bray-Dunes. Today most are preserved, thanks to the Land Mastership Program first initiated by the Urban Community of Dunkerque, then by the North Department Council (Conseil Général du Nord) and the 'Conservatoire de l'Espace Littoral et des Rivages Lacustres' (Seashore and Wetlands Conservatory). This organization is now the owner of about 480ha of seaside dunes, now managed by the North Department Council (Conseil Général du Nord). These are the Dewulf dunes (203.7ha), the Marchand dune (108.2ha), and the Perroquet dunes (169.7ha). These ranges of dunes are considered to be young by the geomorphologists, since they were formed after the last marine transgressions from the 7th and 12th centuries, and are presently being reworked by aeolian sedimentation.

One of their characteristics is found in their dynamism coming from an active morphology. In fact, the dominant winds from the south-west have modelled the dunes to a 'Flemish' type (parallel to the coast), whereas the north-east winter winds, more violent, have shaped in these ranges of dunes some vast parabolic depressions with flat bottoms locally named 'pannes', in which ground-stored water occasionally surfaces. These 'pannes' form truly unique ecosystems that are constantly on the move.

Very rich spaces

These habitats with a particular ecology (winterly floods) are peaty systems that host a remarkable flora. This flora and its different habitats thus make up one of the major ecological interests in the Flemish dunes. Next to this typical vegetation of the humid lands, the Flemish dunes welcome beautiful complexes of dry grasses considered as habitats whose conservation is a top priority for European authorities (appendix 1 of the European Directive 'habitats, fauna and flora').

The Marchand dune is classified as a natural reserve of 83ha, and was awarded the title of 'biogenetic reserve' by the European Council. All of the dunes are selected to fit in the Natura 2000 network as a future Zone of Special Conservation (ZSC). Some rare or endangered vegetal species can be encountered in these spaces, a few having strong boreal affinities, as much on the humid series level as on the dry grasses level. Among the humid series, the main species with patrimonial interest are *Parnassia palustris* var. *condensata*, *Carex viridula* subsp. *Pulchella*, *Pyrola rotundifolia* subsp. *arenaria*, *Epipactis palustris*, *Herminium monorchis*, *Gentianella* gr. *uliginosa*, *Equisetum variegatum* and diverse *Dactylorhiza* species (*D. incarnata*, *D. praefermissa*, *D. fuchsii*), ...

The dry series includes *Viola curtisii*, *Viola canina* subsp. *canina* var. *dunensis*, *Jasione montana* subsp. *maritima* that accompany sheets of mousses and lichens. This series

welcomes remarkable associations of dry grasses of *Festuca* sp., *Carex arenaria*, *Corynephorus canescens*, *Phleum arenarium* and *Tortula ruraliformis* or even of *Luzula campestris* and *Gaillardia vernum* subsp. *maritimum*. Some *Helianthemum numularia* var. *obscurum*, *Rosa pimpinifolia* and xérophile screens of *Calamagrostis* and *Thalictrum minus* var. *durensis* can be seen too.

Spaces particularly threatened by bushes overgrowth

These spaces, before the voluntarist management operations started in the early 1990's, had found themselves highly threatened by the omnipresent overgrowth of bushes that affects all the dunes areas.

The ‘pannes’ were invaded by the ligneous creeping trees, especially by the *Salix repens* var. *argentea* and the *Hippopae rhamnooides*; they were colonised by dry grasses (themselves threatened by *Hippopae ligustrum vulgare*, *Crataegus monogyna* and *Rosa canina*). These invasions were worsened by anthropic factors such as the drying out of the dunes because of water pumping in neighbouring spaces, the parcelling of the dunes and their fixation, which prevents any rejuvenating process by the aeolian dynamic. Myxomatosis eliminated most of the rabbits and traditional practices of grazing and clearings were abandoned, so that arbustive colonization and forestation accentuated.

Without ‘natural disturbances’, alkaline lower-marshes and dry grasses subdued by this vegetal dynamic were rapidly invaded by bushes, eliminating by then pioneer and herbaceous stages from these spaces, as well as remarkable and characteristic species.

Facing this situation, managers decided as early as 1988 to intervene and restore the bushy ‘pannes’. First manually, then mechanically (in 1991), they eliminated ligneous vegetation to recreate vast open spaces of alkaline lower-marshes, then of dry lawns.

Some of us could think that a ground-clearing operation is far from a concept of nature preservation. Forest development could be considered as a logical result of natural and spontaneous dynamics. Upholding open spaces can thus appear as a biased will of the managers deciding to conserve or to restore anthropic spaces of high patrimonial value resulting from clearing practices that have spread from Neolithic to Middle Age. This passionate debate is not relevant in the case of the dunes. Dunes welcome a significant sample of rare primary grasses (that existed before man's action) in Western Europe. These grasses, and secondary grasslands resulting from clearings as well, are now threatened by the absence of natural disturbances or of agricultural habits like grazing that would slow down, stop or reverse brushwood overgrowth dynamics.

Different and evolutive approaches

Clearing the dune thickets

The first step to be considered was to open micro-habitats, where bush growth was recent, in order to save a mosaic of spaces rich in characteristic dry grasses as well as humid area species disseminated all over the dunes. This ‘in extremis’ rescue management aimed to operate a qualitative conservation of remarkable habitats. This looks like a museographical approach of natural patrimony conservation. Without the means or power to do anything better, the managers succeed in preserving a significant sample of remarkable vegetal stages by blocking their evolution through mechanical cuts

and exportation of cut products, or through extensive grazing. This approach could be qualified as eco-gardening, and concerns 2ha of exceptional habitats over a dozen micro-sites.

Scouring the humus-rich soil

Soon came the question of the presence or the maintenance of pioneer and post-pioneer stages, which are naturally fugacious. The 2nd step taken was scouring. The goal then was to gain knowledge and enable the process of re-colonization of 'new' habitats, first by typical species of the dune 'pannes', then by dry grasses species.

The scouring work was implemented in priority in the 'pannes' where herbaceous plants have disappeared under 1.5m water-thirsty thickets of *Salix repens* (dune willows) and Hippophae, where a few typical species of lower alkaline marshes subsisted in closing thickets. These operations initially realized on surfaces of about 4m² by spading enabled to find from the 1st year on: *Agrostis stolonifera*, *Blackstonia perfoliata*, *Centaurium littorale*, *Carex viridula* subsp. *pulcella* and *Sagina nodosa*.

After this experience, vast operations of mechanical scouring were programmed. This meant exporting organic and humiferous material accumulated at the surface, and using a mechanical shovel to superficially dig from 10 to 50cm.

The aim of these works was to bring ground level closer to the end of spring ground water level, to recreate water conditions specific to the 'pannes': winterly flooding and progressive drought through the spring. All of this was meant to allow installation and healthy growth of pioneer species of humid sands *Centaurium littorale*, *Centaurium puchellia* and *Sagina nodosa* and then to allow their evolution towards panne vegetation: *Carex trivervis* of lower marshes and *Carex serotina* and *Parnassia palustris* of high-level alkaline lower marshes.

The scourings have allowed re-colonization of humid sand habitat species on over a hectare, thus confirming observations made in the first 4m² sectors of experimental scouring. Other species have thus come enriching these habitats, such as *Scirpus setaceus*, *Graphallium luteo-album* (the latter has only made one brief appearance).

Since 1994, botanical follow-ups have been realized (by guardians and interns) to monitor the evolution and, when necessary, take note of the appearance of new species.

Bankings were realized through scouring by terrasse levels to enhance the surfacing of 'sleeping' grain banks and to move them towards favorable zones for germination of seeds.

The excellent results of these management operations put forward the very big potential of dunes (with the presence of 'sleeping' grain banks to recreate remarkable habitats). These experiences allowed the CRP/CBNB (State Botanic Conservatory) to work on the seeds' crypto-potential of dune sands of Picardie.

Restauration of dry grasses through the destruction and disposal of bush cover

After the first actions were implemented, the North Department Council decided to restore vast open spaces through destruction and disposal of pre-forestial vegetal cover. To do this, it developed an original method to eliminate and export a dense 3.5m high bushy vegetation. A forest tractor was equipped with a chain.

Its rotation cut vegetation in two successive passages. The 0.20m-0.40m long pieces of wood products presented the advantage of being removable.

On the opposite, a simple shredding of vegetation would have prevented its exportation out of the site.

If this vegetation had been left on the site in a thick layer, it would have brought a thick layer of organic material that would have encouraged the installation of a nitrophile vegetation.

The pieces of wood produced were then gathered thanks to a claw specially created for, able to rake deep up to 0.20m and to completely pull out stumps and roots without mixing the different sandy layers. Also, swaths formed after raking were installed parallel to the dominant winds in order to stop aeolian erosion, and then burnt. The ashes were evacuated.

From 1994 to 1998, 7ha of open spaces have been restored, which, being far from the ground water level, evolved towards dry grasses in the central zone of the Natural Reserve of the Marchand dunes.

In order to realize a well-finished quality work, the North Department Council has established a convention with a local social reinsertion association (*Ecoflandres*) to help the actual departmental team.

It seemed essential from the beginning to organize manual cuts with exportation of the by-products to thin-up soils and to limit the development of nitrophile species. These operations were doubled by punctual operations of manual stump-removal.

After and in addition to annual scything, implementation of an extensive horse grazing allowed to contain and eliminate the few ligneous rejects and to reduce again development of the following nitrophile species: *Cirsium arvense*, *Eupatorium cannabinum* or typical species of dunes like *Senecio jacobaea*.

These different interventions (grazing and scything) encouraged the return of typical dry grasses species of dunes, which after 5 years have more or less mingled with nitrophile species still present at that time and that have finally disappeared.

With time, management by scything or by grazing has enabled dune lawn habitats to develop at the expense of nitrophile habitat.

After 8 years of work, the presence of numerous typical dune grasses species such as *Phleum arenarium*, *Tortula ruraliformis*, *Erodium lebelli et circutarium*, *Galium verum* and *Luzula campestris* allows to record similar development of grasses in a form very close to the classical and original dune grasses.

A study of the ‘Centre Régional de Phytosociologie, Conservatoire Botanique National de Bailleul’ showed that the restored lawns, five years after the clearing operations, are of the *Phleo arenarii* type - *Tortuletum ruraliformis*, dunes lawns of the black dunes of mosses, and therophytes on stabilizing dry limestone sand, in conjunction with numerous variants like sand on the verge of decalcification or richer limestone sand in a warmer situation...

In some areas, we can observe more acidophilic elements such as *Luzula campestris* or *Vicia lathyroides*. Other nitrophilic and anthropic relics such as *Calamagrostis epigeos*, *Holcus latanus* or *Poa* sp. equally form habitats more pasture-like, in mosaic habitats with lawns.

In fact clearing has revealed an original relief (military trenches, holes and depressions due to bomb explosions, ...) that condition the associations of vegetal expression.

In spaces where the relief is tormented, grasses are located on dunes summits, whereas prairie stretches find themselves in the most humid hollows where fertilizing elements accumulate.

Besides, thin raking after each scything in order to export organic materials has enabled the return, after 5 years, of the very rare *Botrychium lunaria* – 50 in 2003 – a species that had not been observed for about 30 years on the Marchand dune, just like the *Ophrys apifera*.

Which new approaches?

The excellent management results obtained on structured and existing relics (2ha) either by soft clearing of brushwood and scything, by punctual scouring (2ha) or by heavy clearing of pre-forestial stages (10ha) resulted in a dunes high reactivity and evidenced a need to reconsider our actions in a dynamic approach. Before installing an extensive grazing scheme, managing operations need a heavy follow-up (scything, raking) for years to contain new shoots and to favour the open space vegetation we are trying to promote. Managing nature may appear as a paradox because nature is supposed to escape human control. It is our will to fix different stages of particular vegetation ‘as it is’, though on a bigger scale. When habitats in natural spaces, and more particularly in dunes, show a very high dynamism, isn’t keeping them static a risk of denaturing them? In fact, in these systems more than anywhere else, everything moves, everything changes and nothing stays the same... If we want to keep them as they are, we must accept to fight against nature, again and again.

It therefore seems necessary to change our approach, to give those spaces their dynamic aspect back, and to accept the natural spreading of bushes in the new spaces we have created. But on the opposite side, we have to regularly recreate the starting conditions in other places, because we are not ready yet to completely abandon years of patrimonial management approach based upon previous habits if natural disturbances don’t occur.

Instead of replacing the disturbance results (replacing their effects), the managers decided to replace disturbances by other disturbances so that the same effects will result. Because storms and wild fires don’t occur on the sites, the departmental team does not hesitate to significantly disturb the dunes by destroying, or by using heavy machineries to excavate large areas in order to recreate the starting conditions of vegetal dynamics with the creating of wide spaces of bare sand.

The dune is then left to its own dynamism without any intervention, except for the implementation of a grazing program upon 50% of its surface. The regular disruption with scrapers (16ha have been treated in the winter of 2003-2004) should allow the system to maintain its mosaic of spaces in a long term, using the soil seeds ‘bank’ and seeds coming from the spaces mechanically managed right now.

Here, no tree or bush exportations. The purpose was to limit the cost of exportation and to open more spaces by stocking these scything by-products over 5% of the cleared spaces. We hope these piles of material will activate the rabbit population by creating warrens and will preserve a typical xylophage population. Those spaces will eventually be wintering places for micro mammals and amphibians. A close follow-up is to be done to control the development of fallow lands within these places.

Nature should thus take its rights back and impose its dynamic rules. The real purpose of management would be to create – and only to create – the starting conditions to allow the habitats to destroy and model the spaces that characterize them.

A next step in this process would consist, if we use this ‘non-interventionism’ reasoning, in reducing the stability of the dune strand and encouraging the ‘siffle-vent’ or the ‘caouderque’ and their devastating or saving effects. These last terms are to the reader’s appreciation, according to his scale of values about naturality of these spaces and nature conservation technics.

Should we preserve exceptional microhabitats through delicate ‘pruning shears’ intervention? Should we try to create the conditions of their reappearance through the use of scrapers? That is the question.

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Large herbivores in coastal dune management: do grazers do what they are supposed to do?

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Abstract

After some decades of rather sparse and more or less ad-hoc nature management (e.g. local shrub-cutting, sod-cutting, mowing), the manager of the Flemish coastal nature reserves [Nature Department (Coastal Zone Management Cell) of AMINAL, Ministry of the Flemish Community] decided to introduce a more coherent and relatively large-scale nature management approach. Since the mid-nineties, several large areas were cleared from scrubs and in the larger nature reserves different herbivore species were introduced. On historical grounds and based on general management expectations, several ungulate species were introduced (sheep, donkeys and different horse and cattle breeds). Since the herbivore introductions from 1997 onwards, research has been done on the foraging behaviour and habitat use, diet selection and preference of some of the introduced herbivores and on their potential contribution to seed dispersal. Above that, several monitoring research programmes were carried out, following the impact of the ungulates on flora, vegetation and different faunal groups in order to evaluate the effectiveness of grazing in realizing the predefined management goals. Here we summarize some results of the research focussing on the driving forces in grazing management and try to conclude on the impact they will have through their habitat use, foraging behaviour, diet selection and other behavioural aspects. We formulate generalized conclusions on the suitability and usefulness of year round grazing by domestic animals in these rather low productive, spatially and temporally heterogeneous dune ecosystems.

Keywords: Nature management; Grazing; Seed dispersal; Coastal dune; Monitoring.

Introduction

After a general ecosystem vision for the Flemish coast was realized (Provoost and Hoffmann, 1996), and management plans for the larger Flemish coastal Nature Reserves (Houtsaegerduinen and Westhoek) were made (Hoys *et al.*, 1996ab), the manager of both nature reserves decided to start with grazing as main management measure in at least part of both reserves. Before grazers were introduced in the latter nature reserve, large parts, dominated by scrubs of Sea-buckthorn (*Hippophae rhamnoides*) and Wild privet (*Ligustrum vulgare*) were cut down and removed first. Before 1996, local

management measures had been undertaken at several locations, but never at a large scale (sod-cutting, mowing, local shrub cutting and juvenile shrub uprooting, ...).

Grazing management has been implemented to maintain species-rich, alkaline dune grassland (so-called *Polygalo-Koelerion* within the *Cladonio-Koelerietalia*) (Provoost *et al.*, 2004) and to avoid further growth of the dense scrubs that cover large parts of both areas. Conservation management concentrates on the prevention of further expansion of dominant, highly competitive graminoids, like *Calamagrostis epigejos*, *Holcus lanatus* or *Arrhenatherum elatius* and shrub species, such as *Hippophae rhamnoides* and *Ligustrum vulgare*. It was expected that the herbivores would decrease the vitality and abundance of at least some of these competitive species through direct consumption or through damage induced by trampling and movement patterns. Likewise, grazing was expected to create structural diversity within monotonous vegetations, due to the dominance of one of the aforementioned plant species. Finally, conservation management also hoped that fragile habitats that are rather vulnerable to intensive grazing activity, like alkaline moss-dominated grey dunes (so-called *Tortulo-Koelerion* within the *Cladonio-Koelerietalia*), would not lose their dune specific species diversity due to trampling activity.

Since the introduction of large grazers from 1997 onwards, monitoring takes place, using an ex-/enclosure technique (described by Bonte *et al.*, 1998; Provoost *et al.*, 2004). Response variables that are monitored are flora, vegetation, terrestrial arthropods (mainly focussing on spiders, ground and dung beetles) and avifauna.

Parallel to this monitoring initiative, more fundamental research is being done on habitat and diet selection (Lamoot, 2004) and on seed dispersal through ungulate endozoochory (Cosyns, 2004) and epizoochory (Couvreur, 2005; Couvreur *et al.*, 2005b). Since the monitoring programme started in 1996, a large quantity of publications, reports and MSc-theses were published (an up-to-date list is given in Anonymus, 2005). Not all of these publications deal with nature management in a direct sense, reason why they are not found, when screening international literature on its relevance for nature management (Bonte and Hoffmann, 2005).

Here, we will primarily focus on the introduced domestic herbivores, on their habitat use and foraging behaviour, their diet selection and their possible contribution to endozoochorous plant seed dispersal. We will refer to some of the monitoring results to underpin conclusions on the realization of management goals.

Methods

General research methodology on the driving forces, *i.e.* the introduced herbivores, is described thoroughly in Lamoot *et al.* (2004b, 2005) and Cosyns (2004) for the study of habitat use, foraging behaviour and diet selection of large herbivores and in Cosyns and Hoffmann (2005) and Cosyns *et al.* (2005) for research of endozoochorous seed dispersal. Here, we include data collected from donkeys grazing in the FNR the Houtsaegerduinen since 1997, from Shetland pony and Scottish Highland cattle grazing in the FNR Westhoek (southern grazing block) since 1997 and 1998, respectively, from Konik pony and Scottish Highland cattle grazing in the FNR Westhoek (northern grazing block) since 1998, from Shetland pony grazing in the Doornpanne since 1996, from Mergelland sheep and rabbit in the FNR Ter Yde and IJzermonding (sheep since 1999),

from Haflinger pony and rabbit in the Fossile dunes of Ghyvelde (France) (ponies since 1996) and from Galloway cattle in the FNR D'Heye since 1998.

Results

Habitat use, forage behaviour and diet of large herbivores

Since most herbivores were grazing in different areas, each with their specific dune habitats and their area-specific spatial arrangement, we cannot compare habitat use and forage behaviour of those herbivores in an absolute sense. To be able to give a relatively reliable comparison we therefore lumped the initially distinguished vegetation types into a restricted number of structurally defined vegetation groups. Even then, comparison is not always possible, since those structurally defined habitats do not necessarily show the same floristic composition and spatial arrangement. Nonetheless, we believe general conclusions can be drawn from the observations on the use of grassy habitat, scrub and woodland (Table I). Cattle, horse breeds and donkeys show quite different grazing investment. While the only ruminant spends only 38% of its time on foraging (excluding rumination time), donkeys spend more than half of their time on foraging, while both horse breeds need up to $\frac{3}{4}$ of their time to collect their food. All grazer species show strong preference for grassy habitat and for graminoid forage. None of the species shows much interest in scrubs or woody plants, but interspecific differences do occur. Cattle are more often grazing in woody environment than the horse breeds; donkeys take an intermediate position. None of the animals focuses on woody plants as food object though. Within scrub and woodland, all species remain to their preference for graminoid food. As far as number of bites is concerned, forbs are hardly different from woody species, being far less favoured than graminoids by all herbivore species (Table I).

Looking at a higher resolution lever for habitat preference indications (Table II) as far as grazing is concerned, in which relative area taken by every vegetation type per site is taken into account, we find that grasslands, if available, are highly preferred, followed by rough grassland if grassland is not at hand. We should keep in mind though, that spatial arrangement of vegetation types is not taken into consideration. Donkeys are avoiding scrub strongly, while all grassy habitats are preferred or strongly preferred. The only herbivore species showing some preference for woodland is cattle.

Mean grazing time and mean daily grazing time per ha of a particular vegetation type give a good general idea of the consumption within these vegetation types, and, hence, of the potential impact of grazing on these vegetation types (Table III). Keeping in mind that spatial arrangements of vegetation types are different between sites, we notice that donkeys spent more time in sparsely vegetated dune habitats, than cattle and Shetland pony, although not consistently through time. Again, data are strongly influenced by the fact that cattle spent far less time on foraging than the horse breeds and donkeys. Although cattle show grazing preference for grassland and grassland with shrub invasion, they spent less time there than the Shetland ponies, their companions at the same site.

Table I. Mean values of several grazing variables based on continuous focal animal sampling during six hour sessions (Lamoot *et al.*, 2004b), averaged over one year for Scottish Highland Cattle (C), Shetland pony (S) and Haflinger pony (H) and over three years for Donkeys (D). Distinguished general vegetation groups are grassy vegetation, scrub and woodland. Distinguished forage classes are graminoids (all monocots), forbs (non-woody dicots) and woody plants. GT(%): percentage of total time spent on grazing; Bite rate: # bites per minute grazing; n.a.: data not available. Mean body weights: Scottish Highland cows: 481±21kg; Highland bulls: 520±43kg; Shetland mares: 205±8kg, donkey mares: 175±7kg (Haflinger mare body weight not measured). Highland cattle and Shetland ponies graze in the Flemish Nature Reserve the Westhoek (data from the southern grazing block of approx. 60ha), donkeys graze in the FNR Houtsaegerduinen (approx. 79ha), Haflinger ponies graze in the NW-French fossile dunes of Glyvelde (approx. 60ha). Adapted from Lamoot (2004)

Dependent variable	Independent variable	C	S	D	H
General grazing variables					
GT (%)		38	71	56	68
# bites.h ⁻¹		703	1339	444	n.a.
Bite rate		29.2	31.5	14.3	n.a.
GT (%).habitat⁻¹					
Grassy		59	77	70	95
Scrub		24	13	23	3
Woodland		17	10	10	2
% of bites. habitat⁻¹					
Grassy		75	81	74	n.a.
Scrub		14	9	17	n.a.
Woodland		11	10	9	n.a.
% of bites.forage class⁻¹					
Graminoids		87	91	80	n.a.
Forbs		8	9	11	n.a.
Woody		5	0	9	n.a.
% of bites.habitat⁻¹.forage class⁻¹					
Grassy					
Graminoids		65	74	59	n.a.
Forbs		6	7	8	n.a.
Woody		4	0	7	n.a.
Scrub					
Graminoids		12	8	14	n.a.
Forbs		1	1	2	n.a.
Woody		1	0	1	n.a.
Woodland					
Graminoids		10	9	7	n.a.
Forbs		1	1	1	n.a.
Woody		0	0	1	n.a.

Large herbivores in coastal dunes

Table II. Jacobs' index of selection (Jacobs, 1974) of Highland cattle (C), Shetland ponies (S), Donkeys (D) and Haflinger ponies (H) for different vegetation types: $D_i = (p_i - A_i)/((p_i + A_i) - (2 * p_i * A_i))$ with p_i the mean proportion of the total grazing time spent in the i th vegetation type and A_i the proportion of the area covered by the i th vegetation type. The value of D_i ranges from -1 to +1, with negative and positive values indicating avoidance and selection of the vegetation type, respectively; strong avoidance (--): $D_i < -0.4$; avoidance (-): $-0.4 < D_i < -0.08$; no selection (0): $-0.08 < D_i < 0.08$; preference (+): $0.08 < D_i < 0.4$; strong preference (++): $D_i > 0.4$. Adapted from Lamoot (2004)

Vegetation type	Westhoek			Houtsaegerduinen			Ghyvelde
	Area (%)	C	S	Area (%)	D	Area (%)	H
Grasslands	9	++	++	5	++	0	
Moss dunes & open vegetation	11	--	-	8	++	35	-
Rough grasslands (*)	8	-	++	4	++	32	++
Grassland with shrub invasion	7	+	+	2	+	0	
Rough vegetation	9	0	0	4	++	3	--
Scrub	41	-	--	67	--	7	--
Woodland	14	+	-	11	0	23	--

(*) Rough grassland is dominated by *Carex arenaria* in Ghyvelde, in both other areas the dominant graminoid is *Calamagrostis epigejos*.

Table III. Mean grazing time per hour, registered during six-hour sessions (in min.h^{-1}) and mean daily grazing time per ha (min.ha^{-1}) of a particular vegetation type for Scottish Highland cattle (C), Shetland ponies (P), both grazing in Westhoek-South (data of 2001) and Donkeys (D), grazing in Houtsaegerduinen (data of 1998 and 2000). GT: grazing time in minutes per hour, not including ruminating (cattle). Adapted from Lamoot (2004)

Vegetation type	Westhoek-South				Houtsaegerduinen			
	2001		1998		2000			
	C min.h^{-1}	C min.ha^{-1}	S min.h^{-1}	S min.ha^{-1}	D min.h^{-1}	D min.ha^{-1}	D min.h^{-1}	D min.ha^{-1}
Grasslands	6.5	7	13.0	14	6.3	10	3.3	5
Moss dunes & open vegetation	0.3	0.4	2.3	2	11.0	10	5.3	5
Rough grasslands	1.5	2	7.3	10	5.2	9	3.7	7
Grassland with shrub invasion	3.3	5	5.7	8	1.2	4	1.3	5
Rough vegetation	2.0	2	4.5	5	1.7	5	8.2	13
Scrub	5.5	1.3	5.3	1.3	0.6	0.7	8.3	1
Woodland	3.8	3	4.2	3	7.3	5	0.7	0.5
GT in min.h^{-1}	22.9		42.3		33.3		30.8	

The introduced herbivores generally show a wide range of plant species in their diet. Observations on Konik ponies in the FNR Westhoek-north revealed that they ate at least 114 plant species, Donkeys in the FNR Houtsaegerduinen consumed at least 138 different plant species (Hoffmann *et al.*, 2001; Cosyns *et al.*, 2001; Cosyns and Hoffmann, 2004; Cosyns, unpubl. data), Cattle in Westhoek-north ate from at least 104 plant species (Cosyns and Hoffmann, 2004), while Shetland ponies in Westhoek-south were seen biting at least 81 plant species (Goerlandt, 1999). Table IV mentions the 15 most frequently bitten plant species during the seed set period (May-October) by the respective herbivores grazing in the FNR Westhoek and Houtsaegerduinen. These numbers depend of herbivore specific preferences, but also on plant species availability.

Therefore, these figures do not allow to deduce diet preferences, since availability of the plant species at each of the sites is not known exactly. Neither do the figures tell us anything definite about the absolute impact on plant species. Rare species that are bitten only now and then will be heavily influenced by grazing (*e.g.* *Clematis vitalba*), while very common species (*e.g.* most graminoids and woody plants mentioned in Table IV) are, in a relative sense, far less severely attacked. Above that, different plant species show different defence mechanisms against grazing. All herbivores are observed to bite graminoid species most frequently, with *Calamagrostis epigejos*, *Holcus lanatus*, *Carex arenaria*, *Festuca juncifolia* and *Poa trivialis* as leading victims.

Herbivore contribution to endozoochorous seed dispersal

138 plant taxa germinated from dung of Scottish Highland cattle, Galloway cattle, Haflinger pony, Konik pony, Shetland pony, Mergelland sheep, Donkey and Rabbit under greenhouse conditions (Table V). The total number of species that has ever been recorded to be dispersed (potentially) endozoochorously by Ungulate and Lagomorph species in temperate regions mounts up to 272 plant taxa (Cosyns, 2004). Data on epizoochory by donkeys as compared to endozoochory are given in Couvreur *et al.* (2005a, b) and are not treated here.

We notice that cattle, Konik ponies and sheep seem to be dispersers of larger amounts of plant species, while donkeys and rabbits might be less good dispersers. We should keep in mind though, that the total number of species depends on the quantity of seeds present at the sites, number of seeds consumed by the animals, herbivore-specific characteristics of the digestive system, number and volume of samples. Therefore, figures cannot be used reliably to compare individual herbivore species characteristics as vector for endozoochorous seed dispersal.

Large herbivores in coastal dunes

Table IV. The 15 most frequently bitten plant species per herbivore species in different nature reserves, during the period of seed set (May-October); data largely from Cosyns (2004) and Cosyns (unpubl. data). Ws: FNR Westhoek-south, Wn: FNR Westhoek-north; H: FNR Houtsaeerduinen; Herbivores: C: Scottish Highland Cattle; S: Shetland pony; K: Konik pony; D: Donkey. Figures represent % bites (*i.e.* the proportion of all bites taken from one plant species compared to the total number of bites (including the less frequently bitten plant species); it may concern bites of the entire plant, of leaves (by far the most frequent), stems, roots and rhizomes, inflorescences, fruits or litter

Site	Wn	Ws	Ws	Wn	H
Herbivore	C	C	S	K	D
<i>Aegopodium podagraria</i>		0,22			
<i>Agrostis stolonifera</i>	1,20		1,43	1,43	
<i>Ammophila arenaria</i>					2,08
<i>Arenaria serpyllifolia</i>				0,81	
<i>Arrhenatherum elatius</i>					4,62
<i>Avenula pubescens</i>					1,83
<i>Betula pendula</i>	0,26				
<i>Bromus sterilis</i>					7,42
<i>Calamagrostis canescens</i>	1,34			2,84	
<i>Calamagrostis epigejos</i>	9,27	3,40	8,52	20,64	9,67
<i>Carex arenaria</i>			0,75	0,59	18,11
<i>Carex disticha</i>			0,40		
<i>Carex flacca</i>				0,56	
<i>Carex riparia</i>	0,57				
<i>Cerastium semidecandrum</i>					2,54
<i>Cirsium arvense</i>			1,85	0,75	
<i>Claytonia perfoliata</i>	5,05		0,98	0,92	
<i>Clematis vitalba</i>		1,10			
<i>Crataegus monogyna</i>		0,76			
<i>Elymus repens</i>					2,60
<i>Eupatorium cannabinum</i>				1,06	
<i>Festuca juncifolia</i>					15,46
<i>Festuca rubra</i>		0,33			
<i>Galium aparine</i>	0,69				
<i>Holcus lanatus</i>	20,99	24,20	17,91	18,10	
<i>Juncus biflorus</i>	0,51		0,16	0,91	
<i>Juncus inflexus</i>			0,14		
<i>Juncus subnodulosus</i>	0,53	4,10	1,13	2,11	
<i>Koeleria albescens</i>					1,94
<i>Ligustrum vulgare</i>	0,98	0,30			
<i>Lycopus europaeus</i>	5,89				
<i>Lythrum salicaria</i>	1,44				
<i>Phleum arenarium</i>					2,31
<i>Phragmites australis</i>			0,16		

Site	Wn	Ws	Ws	Wn	H
Herbivore	C	C	S	K	D
<i>Poa pratensis</i>			1,36	0,71	1,38
<i>Poa trivialis</i>	16,49	19,30	1,26	11,93	1,52
<i>Populus alba</i>					1,95
<i>Prunus spinosa</i>		1,30			
<i>Rosa pimpinellifolia</i>		1,60			7,05
<i>Rubus caesius</i>	0,50	1,10	0,48	0,76	
<i>Salix cinerea</i>	1,08	0,37			
<i>Salix repens</i>		1,10			
<i>Urtica dioica</i>	2,13				

Table V Plant species of which seeds germinated from fresh dung samples of several Ungulate and one Lagomorph species from different sites at the Flemish Coast (samples collected during seven fortnightly sessions between 17 July and 10 October 2000; Claerbout, 2001), supplemented with observations by Cosyns (2004). Sampling sites: Ws: FNR Westhoek-south, Wn: FNR Westhoek-north; H: FNR Houtsaegerduinen; Y: FNR Ter Yde; IJ: FNR IJzermonding; He: FNR D'Heye; D: NR Doornpanne; G: NR Fossile dunes of Ghyvelde. Animals: Cattle: Scottish Highland Cattle (Ws and Wn) and Galloway (He); Horse: Haflinger pony (G), Shetland pony (Ws, D), Konik pony (Wn); Sheep: Mergelland sheep (IJ). *: species only mentioned to germinate from dung from the Flemish coastal dunes (Cosyns, 2004). Data adapted from Claerbout (2001) and Cosyns (2004)

	Animal species	Cattle	Donkey	Horse	Rabbit	Sheep
	Sites	Ws, Wn, He	H	G,Wn,Ws, D	G,D,IJ, Y	Y,IJ
	N (# dung samples)	34	14	58	22	20
	Total volume of dung	85 L	35 L	145 L	55 L	50 L
N°	Plant species					
1	<i>Achillea millefolium</i>	X	X	-	-	X
2	<i>Agrostis capillaris</i>	X	X	X	X	X
3	<i>Agrostis stolonifera</i>	X	X	X	X	X
4	<i>Aira praecox</i>	X	X	X	X	X
5	<i>Anagallis arvensis</i>	-	-	X	X	X
6	<i>Anchusa officinalis</i> *	-	-	X	-	-
7	<i>Anthoxanthum odoratum</i>	X	-	X	X	X
8	<i>Anthriscus caucalis</i>	X	X	X	X	X
9	<i>Aphanes inexpectata</i>	X	-	X	X	X
10	<i>Arabidopsis thaliana</i>	X	-	X	X	-
11	<i>Arenaria serpyllifolia</i>	X	X	X	X	X
12	<i>Artemisia vulgaris</i> *	-	X	-	-	X
13	<i>Calamagrostis epigejos</i> *	X	X	X	X	X
14	<i>Calamagrostis canescens</i> *	-	-	X	-	-
15	<i>Capsella bursa-pastoris</i>	X	X	X	X	X
16	<i>Cardamine hirsuta</i>	X	-	X	X	X
17	<i>Carex arenaria</i> *	X	X	X	X	X

Large herbivores in coastal dunes

	Animal species	Cattle	Donkey	Horse	Rabbit	Sheep
	Sites	Ws, Wn, He	H	G, Wn, Ws, D	G, D, II, Y	Y, IJ
	N (# dung samples)	34	14	58	22	20
	Total volume of dung	85 L	35 L	145 L	55 L	50 L
N°	Plant species					
18	<i>Carex flacca</i> *	X	-	X	-	X
19	<i>Carex trinervis</i> *	-	-	X	-	-
20	<i>Carex viridula</i> *	-	-	X	-	-
21	<i>Centaurium erythraea</i> *	X	-	X	-	X
22	<i>Centaurium littorale</i> *	X	-	X	-	X
23	<i>Cerastium fontanum</i>	X	X	X	X	X
24	<i>Cerastium semidecandrum</i>	X	-	X	X	-
25	<i>Chelidonium majus</i> *	-	X	-	-	-
26	<i>Chenopodium album</i>	X	X	X	X	X
27	<i>Chenopodium murale</i> *	-	-	X	-	X
28	<i>Chenopodium rubrum</i>	-	-	X	X	X
29	<i>Cirsium arvense</i>	X	-	X	-	X
30	<i>Claytonia perfoliata</i> *	X	-	X	X	-
31	<i>Cochlearia danica</i> *	-	-	X	X	X
32	<i>Conyza canadensis</i> *	X	X	X	X	X
33	<i>Crepis capillaris</i>	X	X	-	X	X
34	<i>Cynoglossum officinale</i> *	X	-	X	X	-
35	<i>Diplotaxis tenuifolia</i> *	-	-	-	X	X
36	<i>Epilobium ciliatum</i> *	X	X	X	-	-
37	<i>Epilobium hirsutum</i>	X	X	X	-	-
38	<i>Epilobium obscurum</i>	X	-	-	X	-
39	<i>Epilobium parviflorum</i> *	X	-	X	X	X
40	<i>Epilobium roseum</i> *	X	-	X	X	X
41	<i>Epilobium</i> sp.	X	X	X	X	X
42	<i>Erodium cicutarium/lebelii</i>	X	-	X	X	X
43	<i>Erophila verna</i>	X	-	-	X	X
44	<i>Eupatorium cannabinum</i>	X	X	X	X	X
45	<i>Fallopia convolvulus</i> *	-	-	X	-	X
46	<i>Festuca arundinacea</i> *	X	-	-	-	-
47	<i>Festuca filiformis</i> *	-	-	X	-	X
48	<i>Festuca rubra</i>	X	X	X	X	X
49	<i>Galium aparine</i> *	X	X	X	X	-
50	<i>Galium mollugo</i>	X	X	X	X	X
51	<i>Galium palustre</i>	X	-	X	-	-
52	<i>Galium uliginosum</i> *	X	-	X	-	-
53	<i>Galium verum</i>	X	X	X	X	X
54	<i>Geranium molle</i>	X	X	X	X	X

	Animal species	Cattle	Donkey	Horse	Rabbit	Sheep
	Sites	Ws, Wn, He	H	G, Wn, Ws, D	G, D, II, Y	Y, IJ
	N (# dung samples)	34	14	58	22	20
	Total volume of dung	85 L	35 L	145 L	55 L	50 L
Nº	Plant species					
55	<i>Geranium robertianum</i> *	X	-	-	-	-
56	<i>Gnaphalium uliginosum</i>	X	-	X	-	X
57	<i>Helianthemum nummularium</i>	X	-	X	-	X
58	<i>Hieracium umbellatum</i> *	-	-	-	-	X
59	<i>Holcus lanatus</i>	X	X	X	X	X
60	<i>Hydrocotyle vulgaris</i> *	X	-	X	-	-
61	<i>Hypericum perforatum</i> *	X	-	-	-	X
62	<i>Hypericum tetrapterum</i> *	X	-	-	-	X
63	<i>Hypochaeris radicata</i> *	-	X	-	X	-
64	<i>Juncus articulatus</i>	X	X	X	X	X
65	<i>Juncus bufonius</i>	X	X	X	X	X
66	<i>Juncus inflexus</i>	X	-	X	X	-
67	<i>Juncus subnodulosus</i> *	X	-	-	-	X
68	<i>Koeleria albescens</i> *	-	X	X	X	-
69	<i>Leontodon saxatilis</i> *	-	X	X	X	X
70	<i>Lotus corniculatus</i>	X	-	X	-	X
71	<i>Lotus pedunculatus</i>	X	-	X	-	-
72	<i>Luzula campestris</i>	X	-	X	X	X
73	<i>Lychnis flos-cuculi</i> *	X	-	-	-	-
74	<i>Lycopus europaeus</i>	X	-	X	-	X
75	<i>Lysimachia vulgaris</i> *	X	-	X	-	-
76	<i>Lythrum salicaria</i> *	X	X	X	-	X
77	<i>Matricaria matricarioides</i>	X	-	-	X	-
78	<i>Medicago arabica</i> *	-	-	X	-	X
79	<i>Medicago lupulina</i>	X	X	X	-	X
80	<i>Medicago minima</i>	X	-	-	-	X
81	<i>Mentha aquatica</i> *	X	-	X	-	X
82	<i>Mercurialis annua</i>	-	-	-	-	X
83	<i>Myosotis arvensis</i>	-	-	X	X	-
84	<i>Myosotis ramosissima</i> *	X	-	X	X	X
85	<i>Oenothera glazioviana</i> *	X	X	X	X	X
86	<i>Ononis repens</i> *	X	-	X	-	X
87	<i>Ornithopus perpusillus</i>	X	-	-	-	X
88	<i>Phleum arenarium</i>	-	-	-	X	X
89	<i>Phleum pratense</i> *	X	X	X	X	X
90	<i>Plantago coronopus</i>	X	X	X	X	X
91	<i>Plantago lanceolata</i>	X	X	X	X	X

Large herbivores in coastal dunes

	Animal species	Cattle	Donkey	Horse	Rabbit	Sheep
	Sites	Ws, Wn, He	H	G,Wn,Ws, D	G,D,II, Y	Y,IJ
	N (# dung samples)	34	14	58	22	20
	Total volume of dung	85 L	35 L	145 L	55 L	50 L
Nº	Plant species					
92	<i>Plantago major</i>	X	X	X	X	X
93	<i>Poa annua</i>	X	X	X	X	X
94	<i>Poa pratensis</i>	X	X	X	X	X
95	<i>Poa trivialis</i>	X	X	X	X	X
96	<i>Poa sp</i>	X	-	X	-	-
97	<i>Polygonum aviculare</i>	X	-	X	-	X
98	<i>Potentilla anserina</i> *	X	-	X	-	-
99	<i>Potentilla reptans</i> *	X	-	X	X	X
100	<i>Prunella vulgaris</i>	X	-	X	-	-
101	<i>Ranunculus bulbosus</i> *	X	-	-	-	-
102	<i>Ranunculus repens</i>	X	X	X	-	X
103	<i>Ranunculus sceleratus</i> *	X	-	X	-	-
104	<i>Ranunculus trichophyllus</i> *	-	-	X	-	X
105	<i>Rubus caesius</i>	X	X	X	X	X
106	<i>Rumex acetosella</i>	X	-	X	X	X
107	<i>Rumex conglomeratus</i> *	X	-	X	X	X
108	<i>Rumex crispus</i> *	X	X	X	-	X
109	<i>Rumex obtusifolius</i>	X	-	X	X	X
110	<i>Rumex sp.</i>	X	-	X	-	X
111	<i>Sagina nodosa</i> *	X	-	-	-	-
112	<i>Sagina procumbens / apetala</i>	X	X	X	X	X
113	<i>Samolus valerandi</i> *	-	-	X	-	X
114	<i>Saxifraga tridactylites</i>	-	-	-	X	X
115	<i>Scirpus setaceus</i>	X	-	X	-	-
116	<i>Sedum acre</i>	X	-	X	X	X
117	<i>Senecio jacobaea</i>	X	X	X	X	X
118	<i>Senecio sylvaticus</i> *	X	-	X	X	-
119	<i>Senecio vulgaris</i>	X	-	X	X	X
120	<i>Silene latifolia</i> *	X	X	X	X	X
121	<i>Solanum dulcamara</i> *	-	-	X	-	-
122	<i>Solanum nigrum</i> *	X	X	X	X	X
123	<i>Sonchus asper</i>	X	-	X	X	X
124	<i>Sonchus oleraceus</i>	X	X	X	X	X
125	<i>Stellaria graminea</i>	X	-	-	-	-
126	<i>Stellaria media</i>	X	X	X	X	X
127	<i>Taraxacum sp.</i>	X	-	X	-	X
128	<i>Trifolium arvense</i>	X	-	X	-	X

	Animal species	Cattle	Donkey	Horse	Rabbit	Sheep
	Sites	Ws, Wn, He	H	G, Wn, Ws, D	G, D, II, Y	Y, IJ
	N (# dung samples)	34	14	58	22	20
	Total volume of dung	85 L	35 L	145 L	55 L	50 L
N°	Plant species					
129	<i>Trifolium campestre</i>	X	-	X	X	X
130	<i>Trifolium dubium*</i>	X	X	X	X	X
131	<i>Trifolium repens</i>	X	X	X	X	X
132	<i>Trifolium scabrum</i>	-	-	-	-	X
133	<i>Urtica dioica</i>	X	X	X	X	X
134	<i>Veronica chamaedrys+arven</i>	X	X	X	X	X
135	<i>Veronica officinalis</i>	X	-	X	X	-
136	<i>Veronica serpyllifolia</i>	X	-	X	X	X
137	<i>Vicia cracca*</i>	-	X	X	-	X
138	<i>Viola curtisiai*</i>	-	-	X	-	-
	<i>Total number of species</i>	110	54	113	77	100

Evaluation: did grazers do what they were supposed to do?

Habitat use, forage behaviour and diet of introduced herbivores

*Did they spare the vegetation that is vulnerable for trampling disturbance? Plant communities encountering a low foraging activity will not be influenced severely by the grazers. The impact can be expected to be highest in those vegetation types with an intensive grazing activity, not neglecting the fact that certain plant communities will be more vulnerable to the same amount of trampling, grazing or nutrient addition than others (e.g. the more vulnerable *Tortulo-Koelerion* (moss dunes) against the less sensitive *Polygalo-Koelerion* (dune grassland) within the *Cladonio-Koelerietalia*). In the Westhoek, moss dunes were not intensively used by ponies and cattle. Cattle foraged only in moss dunes in winter, ponies grazed there in winter and spring. Donkeys in the Houtsaegerduinen on the other hand, clearly foraged more in moss dunes, compared to the cattle and ponies in the Westhoek. However, we can reasonably assume that this grazing activity is not a threat for the moss dunes. The large herbivores move steadily while foraging, without disturbing the fragile moss layer. When the herbivores do not forage but travel through the moss dune, they use paths.*

*Did the herbivores have a strong impact on rough graminoid species, characterized by litter accumulation (e.g. *Calamagrostis epigejos* and *Holcus lanatus*) and did they influence scrub vegetation through their habitat use? Our results demonstrate that ponies (Shetland, Konik and Haflinger), cattle (Scottish Highlander) and donkeys are foraging predominantly in grass-dominated habitat and thus will have a relatively strong impact on this habitat. As a consequence of the vegetation selection within the grassy habitat not all distinguished grassy vegetation units will receive a similar grazing pressure. The large herbivores are foraging much less in scrub than in the grass-dominated habitat, and*

therefore the grazing pressure and thus the grazing impact on scrub will be much lower. Of course, the relative area taken by the different vegetation types influences the amount of grazing impact on each of them. For example, grassland, foraged intensively by Shetland ponies and Highland cattle in Westhoek-south, takes a relatively small part of the total area, and thus the grazing pressure per ha grassland is high.

Although cattle and donkeys grazed considerable time in scrub and woodland, grazing pressure on these habitats remains very small since they cover a large part of the fenced areas. Cattle grazed almost as long in scrub (5.55min.h^{-1}) as in grassland (6.55min.h^{-1}), but the grazing pressure of cattle per ha scrub ($0.22\text{min.h}^{-1}\text{ha}^{-1}$) is much lower than their grazing pressure per ha grassland ($1.17\text{min.h}^{-1}\text{ha}^{-1}$). The same can be concluded for donkeys. Although they spent 16-27% of their grazing time in scrub, the grazing pressure per ha scrub is minimal ($0.11\text{-}0.15\text{min.h}^{-1}\text{ha}^{-1}$). Because the donkeys initially did not move through the dense scrub to forage, their grazing activity in scrub was often limited to the edges of the scrub.

Did the herbivores have a strong impact through the diet selection? Important to predict the herbivore impact is not only the question ‘where do they graze?’, but also ‘what do they eat?’ Cattle and donkeys only performed browsing activity when foraging in scrub, while Shetland ponies when foraging in scrub, only consumed graminoids and forbs there. In winter, Highland cattle and donkeys spent half of their grazing time in scrub (11.7min.h^{-1} and 15.8min.h^{-1} , respectively). These long grazing times in combination with the browsing activity implies that there are at least indications that cattle and donkeys can have a significant impact on scrub development. Scrub enlargement of *Ligustrum vulgare* and *Salix repens* is likely to be restrained by the browsing activity of donkeys and cattle, respectively, at least locally. *Hippophae rhamnoides*, which is considered as a problematic invasive shrub species, is browsed by cattle, but only occasionally consumed by donkeys (almost exclusively berries). Hence, in the Houtsaegerduinen, donkey introduction as only measure will not be sufficient to avoid further encroachment of *Hippophae rhamnoides*, as has been suggested by van Breukelen *et al.* (2002).

Calamagrostis epigejos is a graminoid species that is considered as a problematic dominant species and conservation management aims to prevent the further expansion of it. Data on the diet composition illustrate that *Calamagrostis epigejos* belongs to the most frequently foraged plant species; in case of the donkeys it forms even a major contribution to the diet. Since *C. epigejos* is a species which suffers from grazing, we can expect on the basis of our diet data that this species will decrease in biomass and litter mass over time due to grazing. From 1998 to 2001, grazed plots that were initially dominated by *Calamagrostis epigejos* in Westhoek and Houtsaegerduinen showed a significantly decreased cover degree of *C. epigejos*, a decrease of litter cover and a significantly increased number of plant species, while the ungrazed control plots showed a significant cover increase of *C. epigejos* over the same period without significant change in number of plant species (Vervaeet, 2002). Thus, the herbivores seem to be suitable to avoid further dominance of *C. epigejos*. A decrease in cover by *C. epigejos* was also found in Meijendel, a dune area in the Netherlands, grazed by ponies and cattle (de Bonte *et al.*, 1999). The lower cover of *C. epigejos* creates the possibility for other plant species to germinate and establish (see below).

Does the habitat and diet selection create spatial heterogeneity? Another aspect of the grazing behaviour of large herbivores is the terrain use, *i.e.* the way the herbivores use the (theoretically) available space. It is typical of grazing management in heterogeneous landscapes that some sites are intensively grazed by the herbivores, while others are hardly ever visited. Consequently, some sites experience a high grazing pressure and are thus intensively ‘managed’, and others receive no or ‘less’ management. In the Westhoek, foraging behaviour of the cattle is more distributed over the entire fenced area, while the foraging behaviour of the ponies was concentrated in particular areas. One central grass-dominated patch in the Westhoek counted 27.8% of the cattle location observations and 54.3% of the pony location observations. Consequently, the impact of grazing by cattle will be more distributed, while the grazing pressure of the ponies will be more aggregated. Similarly, Vulink (2001) found that Konik ponies concentrated on short grassland for most of the year, while cattle foraged more evenly dispersed all over the available space (Oostvaardersplassen, the Netherlands). If ponies would be the only large herbivores in the Westhoek, it would be very probable that smaller grass-dominated patches enclosed by scrub, would not be ‘managed’ at all. In that case, invasion of competitive grass and shrub species into these patches would not be hampered. Although the terrain use of donkeys in the Houtsaeerduinen is not concentrated at one specific site, some parts of the area encounter a higher grazing pressure than others. Closed scrub covers large parts of the reserve and, similarly to the ponies, the donkeys initially did not forage in or move through these scrubs. Later (after several years) they gradually explored the scrub area and created small paths that enabled them to graze grass-dominated islands within the scrub.

Does defecation behaviour influence spatial heterogeneity? Nutrient transfer is often mentioned as one of the possible impacts of grazing management. A depletion of nutrients would occur in the preferred grazing sites, whereas areas with faeces concentration would show an accumulation of nutrients, especially in nutrient-poor systems. Such a nutrient transfer is found in areas grazed by sheep (Bakker *et al.*, 1983) and cattle (Bokdam and Gleichman, 2000; Bokdam, 2003). According to our observations (Lamoot *et al.*, 2004a), we can state that this process is not likely to occur on a large scale in nature reserves grazed by equids. Since we found that the equids under consideration generally defecate where they graze, they do not relocate nutrients between different habitats. Patches with highest grazing pressure will receive a proportional concentration of faeces and urine.

Seed dispersal and its conservation interest

Cattle, horse breeds, donkeys, sheep and rabbits all appear to be potentially highly relevant dispersal agents for a wide variety of plant species in the coastal dunes. It was shown that they are able to disperse large amounts of viable seeds, including seeds of plant species that are of conservation interest. However, probably due to the low abundance of these plant species in vegetation, only low numbers of species and small amounts of viable seeds were recorded from dung. Out of the 107 Flemish red list species, that were found in all study sites together, only 11 species occurred from dung samples. A higher proportion of nature conservation target species (as defined by

Provost and Hoffmann, 1996) that are known from the study sites (*i.e.* red list and characteristic species) were recorded from dung, *i.e.* 36 out of 143 plant species.

Within the structurally heterogeneous coastal dune landscape the potential long-distance seed dispersal capacity of ungulates may enhance intra and inter habitat seed dispersal, *e.g.* between species poor *Calamagrostis* dominated grassland and species rich dune grassland.

Considering the number of grazing animals, their defecation frequency and habitat use and the amount of viable seeds of target species found in their dung, an estimate can be given of the amount of target species that could possibly be introduced in species poor *Calamagrostis* dominated grassland by ungulates. Within Westhoek-south, endozoochory could contribute to potential seed dispersal of 10 out of the 30 target species of dune grassland. However, because of the observed interspecific differences in seedling densities, arrival time and subsequent establishment will most probably differ between plant species. If all areas of the Westhoek would be included in one large grazed block, two more plant species can be expected to get endozoochorously dispersed and hence possibly get deposited in target areas, such as *Calamagrostis epigejos* dominated grassland and deforestation areas. It was already shown that grazing activity helps to open the initially very dense *Calamagrostis* sward, enabling new species to arrive, germinate and establish. Whether other target species will ever arrive at target areas and by what means, remains highly speculative. Wind, could be one of the most plausible dispersal agents, but anemochory is generally an overestimated long-distance seed dispersal modus (Soons, 2003).

Since large herbivores have always been part of natural ecosystems, their role as epi- and endozoochorous dispersal vectors is probably indispensable for maintaining species richness. Grazing, being an important nature management tool for conservation and restoration of many habitats in northern temperate regions, obtains therefore an additional argument. Until now, much attention was given to the contribution of livestock to diversity of vegetation structure and plant and animal diversity patterns, both at the local and the landscape scale, through their activities of selective grazing, trampling and defecating (recent review in Cosyns and Hoffmann, 2004). But herbivores will also influence plant diversity through processes that affect colonisation rates (Olff and Ritchie, 1998). Our results clearly show the importance of large herbivores as (long-distance) seed dispersal vectors for many more plant species, than could be assumed from the morphological dispersal adaptations of seeds. The growing evidence of the role that large herbivores can play in the seed dispersal process, urges for a well-considered nature management policy that not only focuses on amelioration of habitat conditions, but also considers the spatial arrangement of suitable but still unoccupied patches for critical plant species. If plants can bridge gaps in space and time, this may favour a sustainable conservation of critical plant populations. It is shown here that the use of large herbivores like donkeys or other large herbivores as managers might help to reach this goal, through the epi- and endozoochorous dispersal of seeds (see also Couvreur *et al.*, 2005).

General conclusions

We have many reasons to state that the introduced ungulates in coastal dunes contribute substantially to the initial management goals. They will certainly diminish dominance of

rough, litter accumulating graminoid species like *Calamagrostis epigejos*, *Holcus lanatus*, *Arrhenatherum elatius*, *Carex arenaria* and others, enabling target species of dune grassland (*Polygalo-Koelerion*) to colonize gaps in the grassland sward. We further believe that endozoochorous dispersal will have an accelerating effect on target species arrival in gaps in monospecific grass-dominated habitats, gaps that most likely will have been created by grazer activity.

Impact of grazers on scrub encroachment, let alone scrub decrease, will be far less important, although Scottish Highland cattle will have a relevant impact on scrub structure and, in the end, scrub area. The horse breeds only seem to act as followers, after cattle has created gaps in the scrub; donkeys appear to act intermediate between cattle and horse breeds. Together with cattle, they show quite some browsing activity, but they hardly ever take initiative to penetrate closed canopy scrub.

It remains to be studied what contribution is added by sheep grazing. Some preliminary results of permanent plot research in the FNR de IJzermonding, points out that, within a dune grassland environment, rough grass and litter cover diminishes under sheep grazing, while total number of species increases (Hoffmann *et al.*, 2004). Research on how they interact with tidal marsh vegetation is still in progress.

Further research remains to be done on the carrying capacity of the relatively low productive coastal dune areas, since year round grazing puts (temporary) severe pressure on primary production. Some areas might well be overgrazed on the long run, when maintaining herds with 75-95 kg.ha⁻¹, as is the case in Westhoek-south. Further enlargement of grazed area would further differentiate grazing activity and impact, but will simultaneously increase the unpredictability of the outcome of the grazing management.

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The importance of seed bank knowledge for the restoration of coastal plant communities – a case study of salt marshes and dune slacks at the Belgian coast

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Abstract

Knowledge on seed bank density and species composition is crucial for predicting the probability that target species will establish in the plant community on a restored site. A general overview of data available for plant species occurring in coastal plant communities showed that information on seed persistence is up to now very limited. The available data suggest that restoration of coastal plant communities cannot rely on the seed bank, except for annual species of salt marshes, and that the seed bank is to a large extent composed of species of nutrient rich habitats. This was confirmed by two case studies in dune slacks and salt marshes on the Belgian coast. Seed density in dune slacks was found to be relatively high, but the seed bank contained almost exclusively seeds of species of nutrient rich habitats, resulting in a very low similarity ratio between seed bank and vegetation. Germination from the seed bank would rather hamper the establishment of target species because competitive pressure imposed by fast growing species of nutrient rich habitats would increase. In salt marshes, the similarity between seed bank and vegetation was higher, because there is a higher contribution of typical salt marsh species in the seed bank, although not all target species are equally represented. To allow predictions of future species composition on restored sites, seed bank studies should be an essential part of each coastal restoration project.

Keywords: Ecological group; Seed longevity index; Seed persistence; Target species; Dune slack; Salt marsh.

Introduction

Coastal plant communities, such as salt marshes, dune slacks and dune grasslands, contain several species that are endangered in a West-European context (Bakker *et al.* 2002, Grootjans *et al.* 1999). To avoid extinctions of these populations, it will be necessary to conserve the remaining habitats, and to restore habitats and disappeared plant communities. On restored sites, target species can establish in the plant community through dispersal from source plant communities, or through germination from viable

seeds in the soil seed bank (Bakker and Berendse, 1999). This soil seed bank can also contain seeds of non target species, which may rather hamper the establishment of target species by interspecific competition (Bossuyt *et al.*, 2002). Knowledge of the seed bank composition of the site to be restored and the seed persistence characteristics of plant species of the target communities is hence essential to predict restoration success.

This knowledge is however very limited for coastal plant communities (Bekker *et al.*, 1999; Owen *et al.*, 2001; Wolters and Bakker, 2002). Some studies on temperate salt marshes concluded that the seed bank contained mainly annual species, and that the dominant perennial species in the vegetation were not present in the seed bank (Ungar and Woodell, 1993; Ungar and Woodell, 1996; Egan and Ungar, 2000; Wolters and Bakker, 2002). This results in a low similarity between seed bank and vegetation. Seed densities in temperate salt marshes ranged from 936 to 15,605 seeds.m⁻², with mainly seeds of *Juncus gerardii*, *Glaux maritima*, *Salicornia* sp., *Spergularia maritima* and *Suaeda maritima* (Ungar and Woodell 1993; 1996; Egan and Ungar, 2000; Wolters and Bakker, 2002). In contrast, studies on arctic salt marshes found a dominance in the seed bank of perennial graminoid species and a higher seed density, up to 83,953 seeds.m⁻² (Jutila, 1998; Chang *et al.*, 2001; Jutila, 2001).

In dune slacks and dune grasslands, the seed bank is mainly composed of non target species of nutrient rich habitats (Bekker *et al.*, 1999; Owen *et al.*, 2001; Bossuyt and Hermy, 2004). Seed densities in dune slacks increased with increasing slack age, up to 14,646 seeds.m⁻² (Bekker *et al.*, 1999; Bossuyt and Hermy, 2004), while seed densities in dune grassland were found to be very low (three seeds.m⁻²) (Owen *et al.*, 2001). Also in early successional dune habitats where there is still frequent sand movement by wind erosion, the seed bank is as good as absent (eight seeds.m⁻²) (Looney and Gibson, 1995).

From the results of these studies, it seems that relying on germination from the seed bank for restoration of coastal plant communities is at least to be questioned. A general overview and comparison of the possibilities in different coastal plant communities is however still lacking. Therefore, the objectives of this study are:

- providing a general overview of the data available on seed persistence characteristics of species of coastal plant communities;
- comparing seed bank and vegetation composition in two plant communities at the Belgian coast: dune slacks and salt marshes;
- discussing the potential of the seed bank for restoration possibilities of coastal plant communities.

Material and methods

General overview of seed bank knowledge

We derived a list of 274 diagnostic and differentiating species occurring in coastal plant communities based on Schaminée *et al.* (1996; 1998) and Stortelder *et al.* (1999). For each of the 274 species the number of records available in the database of Thompson *et al.* (1997) was calculated. For species with at least five records, we calculated the average seed longevity index (SLI) (Bekker *et al.*, 1998). The seed longevity index

varies between 0 and 1 and is a measure for the longevity of the seeds in the soil. Then, all species were assigned to one of the seven following ecological groups, based on Cosyns *et al.* (1994): species of beaches and dunes with sand movement, species of mud flats and tidal salt marshes, species of nutrient rich marshes and grasslands, species of medium nutrient rich grasslands, species of nutrient poor calcareous rich marshes and grasslands, species of nutrient poor marshes and grasslands with acid soils, species of forest edges and clearings and species of shrub and forest vegetations. For each ecological group, we calculated the average number of records available and the average SLI for species for which at least five records are available.

Case studies

The study area for the dune slack seed bank study consisted of two nature reserves [Ter Yde (260ha) and the Westhoek (340 ha)] near the western Belgian coastline. In each reserve, the management aims at the conservation and restoration of dune slack vegetation. Management measures include mechanical removal of *Hippophae rhamnoides* shrubs, mowing, grazing and in some cases small scale sod cutting or topsoil removal. Dune slack vegetation consists of a mixture of forb and graminoid species, in a matrix of small shrubs. For each slack in the region, information concerning date of origin was available.

We selected 20 slacks in different successional stages, ranging from 5 to 55 years. Vegetation data were collected during the summer of 2001 in a variable number of 1x1m plots in each slack. In each plot, the cover of all species was estimated with a decimal scale. A total of 228 plots was surveyed. Seed bank data were collected by a seedling germination method in October 2002. In each slack, again a variable number of randomly positioned 1x1m plots was sampled. In each plot, 10 samples were taken at random with an auger of 3.5cm diameter down to 10cm depth, after removal of the litter layer. A total of 134 plots was sampled for seed bank analysis. The soil samples were sown and brought into favourable conditions for germination, and the germinated seedlings were identified and counted. For four age classes of dune slacks (less than 10 years old, 10-20 years, 20-30 years and more than 30 years), we calculated the contribution of the seven ecological groups in the vegetation and the seed bank, by dividing the sum of the cover or the number of seeds of the species of each ecological group in each plot by the total cover or number of seeds found in that plot. We also calculated a similarity ratio (van Tongeren, 1995) between vegetation and seed bank for each age class, based on relative abundance values.

Salt marsh data were collected in the nature reserve the Yzermonding (128ha). A restoration project of estuarine habitats has been realized between 1999 and 2003, creating an intertidal area of ca. 28ha with potential estuarine mudflat and salt marsh. To estimate seed bank potentials, vegetation and seed bank data of the relict salt marsh area of 4ha were collected in 2001 in 30 plots, divided over six vegetation types (see Table II). In each plot, the cover of all species was estimated with a decimal scale. Seed bank data were also collected by a seedling germination method, analogous to the study in the dune slacks. In the salt marshes, 20 soil samples of the upper 7cm of the soil were taken in each plot with an auger of 5cm diameter. In a similar way as described above, we

calculated the contribution of the seven ecological groups in the vegetation in the seed bank for the six vegetation types. Here also, the similarity ratio coefficient between seed bank and vegetation was calculated for each vegetation type.

Results

General overview of seed bank knowledge

From the 274 diagnostic and differentiating species described from coastal plant communities, species of nutrient rich marshes and grasslands are the best represented in the database of Thompson *et al.* (1977), with an average of 21 records for 61 species (Fig. 1). In contrast, very few information is available of species of beach habitat, salt marshes, medium nutrient rich grasslands and forest and shrub vegetation, with on average less than five records in the database. This means that the seed longevity index can not be calculated for the majority of the species growing in these habitats.

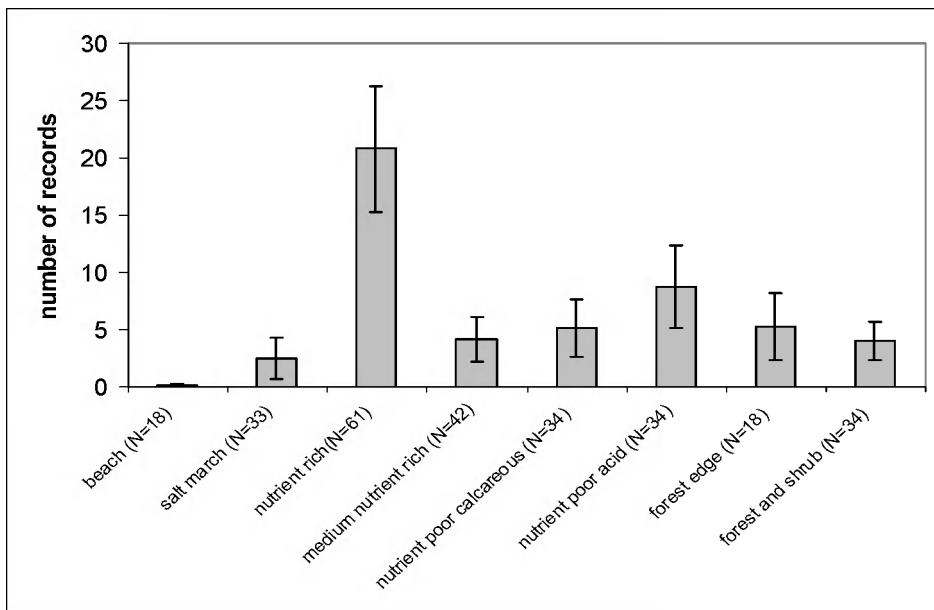


Fig. 1. Average number of seed bank records in the database of Thompson *et al.* (1997) for species of seven ecological groups, considered diagnostic or differentiating for coastal plant communities. The 95% confidence interval is indicated.

The average seed longevity index was highest for species of salt marshes, species of nutrient poor acid habitats and species of nutrient rich and medium nutrient rich grassland and marshes (Fig. 2). The seed longevity index was lower for species of nutrient poor, calcareous rich habitats and forest edges, although the differences were not significant, and very low for forest and shrub species.

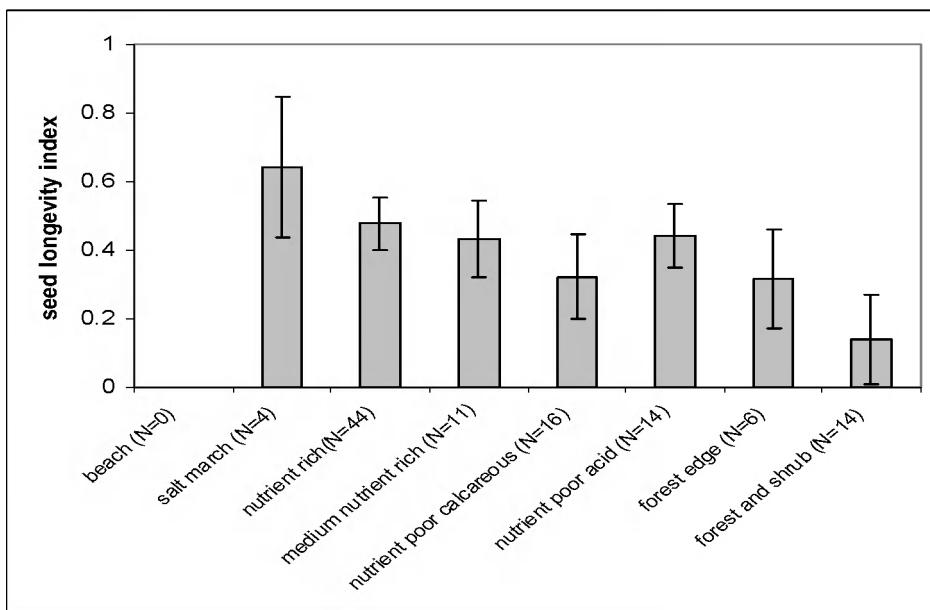


Fig. 2. Average seed longevity index for species of seven ecological groups considered diagnostic or differentiating for coastal plant communities. The 95% confidence interval is indicated.

Case studies

There were 132 species recorded in the vegetation of the dune slack plots and 56 species germinated from the dune slack seed bank samples, of which 52 occurred both in vegetation and seed bank. The total number of seedlings found corresponded with an overall seedling density of 2345 seeds.m⁻², ranging from 339 seeds.m⁻² in the youngest slack to 9160 seeds.m⁻². The most abundant species in the seed bank were *Juncus articulatus* (578 seeds.m⁻²), *Urtica dioica* (267 seeds.m⁻²), *Eupatorium cannabinum* (205 seeds.m⁻²), *Lythrum salicaria* (232 seeds.m⁻²) and *Mentha aquatica* (173 seeds.m⁻²).

Species of nutrient rich marshes and grasslands made up approximately 50% of the cover in the vegetation, while their seeds counted for 68 up to 98% of the total seed content of the seed bank, depending on the age class (Table I). Species of medium nutrient rich and nutrient poor calcareous grassland and marshes have also an important contribution in the vegetation, while they are badly represented in the seed bank, although their importance in the seed bank increases with slack age. The specific target dune slack species belong to these ecological groups. The similarity ratio coefficient between seed bank and vegetation was very low, and increased with increasing slack age, up to 0.08.

Table I. Relative abundance (%) of species of seven ecological groups in the vegetation and the seed bank of dune slacks of four age classes

Age class (years) Number of slacks	Vegetation				Seed bank			
	< 10 N=4	10-20 N=3	20-30 N=8	> 30 N=5	< 10 N=4	10-20 N=3	20-30 N=8	> 30 N=5
Beach	0	1	1	0	0	0	0	0
Salt marsh	0	0	0	0	0	0	0	0
Nutrient rich	48	44	49	47	96	81	68	86
Medium nutrient rich	15	30	18	19	3	13	3	2
Nutrient poor calcareous	17	9	10	14	0	0	1	6
Nutrient poor acid	9	7	10	8	0	2	5	4
Forest edge	6	6	7	7	1	5	22	1
Forest and shrub	4	4	4	4	0	0	0	0
Similarity ratio	0.04	0.05	0.07	0.08				

Table II. Relative abundance (%) of species of seven ecological groups in the vegetation and the seed bank of six plant community types in salt marshes

Vegetation type	SSt (N=5)	TSb (N=11)	TSm (N=2)	PPu (N=4)	Aae (N=5)	AAI (N=3)
	Vegetation					
Beach	0	5	11	13	29	26
Salt marsh	100	92	81	79	44	21
Nutrient rich	0	3	8	7	19	46
Medium nutrient rich	0	0	0	1	3	3
Nutrient poor calcareous	0	0	0	1	4	4
Nutrient poor acid	0	0	0	0	0	0
Forest edge	0	0	0	0	0	0
Forest and shrub	0	0	0	0	0	0
Seed bank						
Beach	0	0	0	1	6	2
Salt marsh	13	55	47	52	47	17
Nutrient rich	80	41	39	20	32	60
Medium nutrient rich	0	0	1	0	5	14
Nutrient poor calcareous	0	1	1	1	2	7
Nutrient poor acid	0	0	0	0	0	0
Forest edge	7	3	11	26	8	1
Forest and shrub	0	0	0	0	0	0
Similarity ratio	0.12	0.66	0.38	0.11	0.07	0.14

SSt = Spartinion - *Spartinetum townsendii*; TSb = Thero-Salicornion - *Salicornietum brachystachya*; TSm = Thero-Salicornion - *Suaedetum maritimae*; PPu = *Puccinellion maritimae* - *Puccinellietum maritimae*; AAe = *Armerion maritimae* - *Atriplici-Elytrigietum pungentis*; AAI = *Atriplicion littoralis* - *Atriplicetum littoralis*.

In the vegetation of the salt marshes (Table II), 67 species were recorded, while overall seed density in the soils was 3014 seeds.m⁻², divided over 85 species. The most abundant

species were *Salicornia* sp. (516 seeds.m⁻²), *Spergularia* sp. (391 seeds.m⁻²), *Chenopodium rubrum* (315 seeds.m⁻²), *Sagina maritima* (295 seeds.m⁻²) and *Spergularia marina* (204 seeds/m²). In four of the six vegetation types (SSt, TSb, TSm and PPu), species of salt marshes had a very important contribution in the vegetation. In three of these vegetation types, these species also contributed to a large extent to the seed bank, up to 55%. The rest of the seed bank was mainly composed of species of nutrient rich marshes and grasslands. In the AAe and AAI vegetation type, species of beaches and habitats with moving sands have a contribution of 30%, but seeds of these species were not abundantly present in the seed bank. In these vegetation types, species of nutrient rich marshes and grasslands become also more important, both in the vegetation and in the seed bank. In general, the similarity ratio coefficient between seed bank and vegetation was higher than for dune slacks, ranging between 0.07 up to 0.66 in the TSb vegetation type.

Discussion

An analysis of the seed bank records available in the databank of Thompson *et al.* (1997) showed that there are indeed few data available on seed persistence of plant species considered diagnostic or differentiating for coastal plant communities. In particular for species of beaches and habitats with moving sand, there are almost no data records, and a minimum of five records (necessary to calculate longevity index) was available for only four species of salt marshes (*Spergularia maritima*, *Salicornia europaea*, *Glaux maritima* and *Juncus gerardii*). In contrast, for the non specific common species of nutrient rich habitats, a seed longevity index could in most cases be calculated. A lack of general seed bank knowledge means that it is difficult to predict seed densities and species composition in the soil of a particular site to be restored.

The limited data that are available for salt marsh species indicated that most annual species of salt marshes have a persistent seed bank, since the average seed longevity index for these four species reaches a value of 0.62. Species of calcareous rich habitats, medium nutrient rich habitats, beaches and habitats with moving sand have a low seed longevity index, confirming the results of seed bank studies in grasslands (Davies and Waite, 1998; Willems and Bik, 1998; Bossuyt and Hermy, 2003). Some authors suggested that the transient character of seeds of dune grassland species may be the result of the stable, reliable and safe nature of dune grassland habitats with a high probability of successful germination and establishment, so that there is evolutionary no need for developing dispersal strategies in time (Owen *et al.*, 2001). On the other hand, the substrate in dunes with a high level of sand movement is very dynamic and is not expected to favor seed dormancy (Looney and Gibson, 1995). Besides, it may be that the sandy soils are not a suitable medium for the development of prolonged dormancy, due to an excess of aeration (Owen *et al.*, 2001). This, however, contrasts with the observation that seeds of species growing on nutrient poor and acid soils that are in most cases sandy (e.g. heathlands), have a relatively high seed longevity index (Bossuyt and Hermy, 2003), which is also confirmed here. In general, species of forest and shrub vegetation have a very low seed longevity index (Bossuyt and Hermy, 2001). The highest seed longevity index is found for species of nutrient rich habitats. This means that the high seed density of these species in the soil of coastal habitats is likely to

hamper or disturb the wanted restoration process. These species are often fast growing and competitive and may hence increase the competitive pressure on the target species. These general findings are confirmed by the results of the case studies. A relatively high seed density was found in dune slack habitats, and seed density increased in the course of succession. However, a very large percentage of the seeds concerned species of nutrient rich habitats, and the seed density of target species was very low. This is also indicated by the very low similarity ratio coefficient between seed bank and vegetation. Germination from the seed bank on restored sites, *e.g.* after cutting of shrub vegetation, will hence mainly result in the establishment of non target species, while target species will have to establish after dispersal from other source populations. Also in salt marshes, a high seed density was found and a relatively high proportion consisted of seeds of salt marsh specific species, which resulted in a higher similarity ratio coefficient between seed bank and vegetation. Not all target species are however equally represented, since it concerns mainly annual species and seeds of perennial salt marsh species, such as *Puccinellia* sp., are absent (Ungar and Woodell, 1993; Ungar and Woodell, 1996; Egan and Ungar, 2000). This means that the similarity ratio coefficient is especially high in vegetation types with a high contribution of annual species such as Thero-Salicornion communities. Species of beaches and habitats with moving sands were indeed not found in the soil seed bank, even if they had a high cover in the vegetation, which indicates that these species (*e.g.* *Salsola kali*, *Elymus athericus* and *Beta vulgaris* spp *maritima* but with the exception of *Atriplex littoralis*) do not produce persistent seeds. The contribution of seeds of species of nutrient rich habitats is also high in the salt marshes. This should however be less problematic than in dune slacks or grasslands, since germination and establishment of these species may be very difficult in this stress imposing environment (Wolters and Bakker, 2002).

It is clear that the amount of data available up to now on seed persistence of coastal plant communities is very limited. Moreover, the available data suggest that in most cases, restoration of coastal plant communities cannot rely on the soil seed bank (Bekker *et al.*, 1999; Owen *et al.*, 2001; Bakker *et al.*, 2002; Wolters and Bakker, 2002). This means that there is still a need for a general insight into seed bank dynamics of coastal plant communities through general seed bank research. This also implies that a study of the seed bank density and species composition should be integrated in each particular restoration project. The results of seed bank studies will allow a better prediction of future plant community composition and of the probability that target species will establish through germination from the soil seed bank.

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Donkeys as mobile links for plant seed dispersal in coastal dune ecosystems

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Abstract

Long-distance seed dispersal is a key factor in vegetation dynamics, especially in highly dynamic ecosystems such as dune landscapes. To assess the role of large herbivores in long-distance seed dispersal in dunes, we examined epi- and endozoochory by free-ranging donkeys, released for grazing in a Flemish dune nature reserve. At least 29, respectively 53, plant species were dispersed epi- and endozoochorously by the donkeys. Comparison of the species with the local vegetation using dispersal-relevant plant traits, showed that epi- and endozoochory are additive and complementary dispersal mechanisms, epizoochory being restricted to a narrower range of dispersal-functional plant types. To estimate potential dispersal distances of the seeds, we used empirical studies of the movement and behaviour of the donkeys, in combination with experimental epi- and endozoochorous seed retention times of selected plant species in the dune reserve. The mean potential dispersal distances indicated that the donkeys disperse seeds over the entire 100ha nature reserve, hereby providing a mobile link function between fragmented dune habitats for at least 20% of the local plant species. The influence of large herbivores on dune vegetation dynamics through seed dispersal should be considered in nature management decisions.

Keywords: Endozoochory; Epizoochory; Grazing; Large herbivore; Long-distance dispersal; Nature management; dispersal distance.

Introduction

Vegetation dynamics in highly dynamic landscapes, such as dune ecosystems, partly depends on long-distance seed dispersal. Seed dispersal drives plant spatial dynamics by

influencing the distribution of populations and communities, both at local and regional scales (*e.g.* Cain *et al.*, 2000; Bullock *et al.*, 2002; Levin *et al.*, 2003; Ozinga *et al.*, 2004). Long-distance dispersal is an extremely important determinant of range shifts of plants, as demonstrated in the case of Holocene plant migrations (Clark *et al.*, 1998; Higgins and Richardson, 1999; Cain *et al.*, 1998; Pakeman, 2001), and in the context of actual and future plant migrations in response to land use changes (Poschlod and Bonn, 1998; Takahashi and Kamitani, 2004) and climate change (Watkinson and Gill, 2002).

To allow a successful colonization of newly formed suitable patches of dune habitat, the presence and functioning of long-distance dispersal vectors is crucial (Bossuyt *et al.*, 2003). Although wind is probably a major dispersal vector in dune landscapes, wind dispersal does – in general – not lead to a displacement of seeds further than a few metres, and is mostly confined to seeds with a low falling velocity (Bullock and Clarke, 2000; Tackenberg *et al.*, 2003). Whereas on open sandy patches wind dispersal may be very efficient (Poschlod and Bonn, 1998), it is likely that other dispersal mechanisms, such as zochory, are more important in more densely vegetated parts of dunes. In the past agricultural history (Poschlod and Bonn, 1998; Pykälä, 2000; Bruun and Fritzberger, 2002), Western European semi-natural landscapes *e.g.* coastal dunes have often been grazed by livestock (De Smet 1961, Massart 1908). Nowadays the use of large herbivores to maintain semi-natural vegetation is commonplace in nature management (Eggermont *et al.*, 1996). In addition, the ongoing debate about reintroduction of plants (Strykstra, 2000) to surpass certain bottlenecks for nature restoration – such as seed dispersal limitation (Zobel *et al.*, 2000; Turnbull *et al.*, 2000; Verheyen *et al.*, 2003) – urges for a better knowledge of dispersal possibilities of plants in endangered ecosystems.

Large herbivores can disperse seeds both externally (in fur or hooves) and internally (via the digestive tract). Both mechanisms – referred to as epizoochory and endozoochory, respectively – are considered very efficient long-distance dispersal modes, providing mobile link functions between habitats (see Lundberg and Moberg, 2003; Couvreur *et al.*, 2004a). In spite of the inherent difficulty of tracing zochorous long-distance dispersal – which is influenced by complex animal behaviour – recent studies of epizoochory (Fischer *et al.*, 1996; Kiviniemi, 1996; Stender *et al.*, 1997; Kiviniemi and Telenius, 1998; Mrotzek *et al.*, 1999; Heinken, 2000; Graae, 2002; Heinken and Raudnitschka, 2002; Couvreur *et al.*, 2004ab, 2005ab) and endozoochory (Janzen, 1984; Welch, 1985; Gardener *et al.*, 1993; Malo and Suárez, 1995; Pakeman *et al.*, 1998; Heinken *et al.*, 2002; Cosyns, 2004; Cosyns *et al.*, in press; Couvreur *et al.*, 2005a) all point to the large potential of these mechanisms.

In this paper, we compile results on the seed-dispersing role of donkeys used as a management tool in a species-rich coastal dune nature reserve in Belgium. Our principal objectives were (1) to present a list of plant species dispersed by epi- and endozoochory, (2) to compare the zochorous species with those present in the study area, using morphological and ecological plant traits relevant for dispersal, and (3) to estimate potential dispersal distances of the dispersed seeds. For these purposes, we use empirical data from recent studies by Couvreur *et al.* (2004b, 2005b), Cosyns *et al.* (2005), and Lamoot *et al.* (in press), and we highlight zochory in the context of coastal dune management.

Material and methods

Study site and vegetation

The study site was the 100ha coastal dune nature reserve 'Houtsaegerduinen', in western Flanders, Belgium ($51^{\circ} 05' N$, $2^{\circ} 35' E$) (Fig. 1).

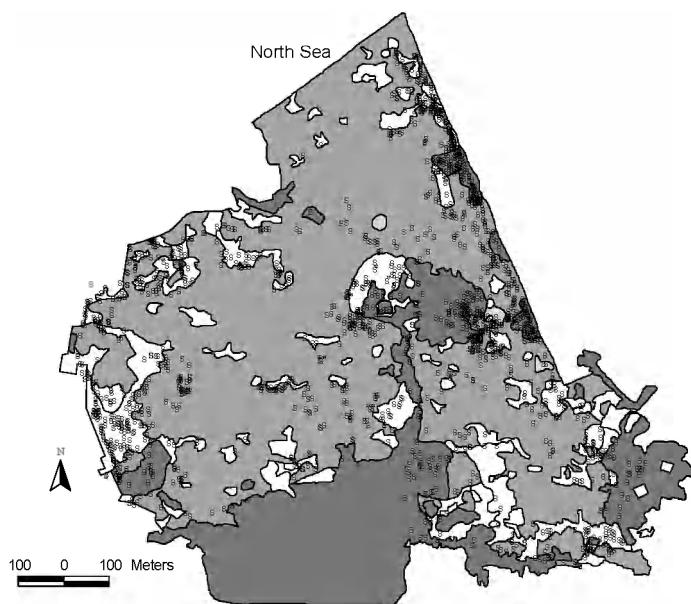


Fig. 1. Study site, the 100ha Flemish nature reserve 'Houtsaegerduinen' along the North Sea coast. Four main vegetation types are indicated with different colours (grassland and moss dune, white; tall herbage vegetation, light grey; shrub, intermediate grey; forest, dark grey). Black circles represent locations of donkeys, recorded with 15min intervals (see 'Material and methods').

The variation in abiotic conditions and the historical land use in this coastal dune ecosystem have led to relatively high plant species richness and a range of different plant communities. Although the dune landscape is dominated by *Hippophae rhamnoides* and *Ligustrum vulgare* shrubs, patches of herb-dominated vegetations are scattered within the scrub (which covers 58% of the area), as small and mostly species poor remnants of dune grassland and mossdune (13%) or as species poor *Calamagrostis epigejos*-*Arrhenatherum elatius* dominated tall herbage vegetation (4%), which established after scrub degradation. About 25% of the study site was forested with *Alnus glutinosa*, *Populus canescens* and *P. x canadensis* trees. Flowering and fruiting of the plant species in the study site is concentrated from April to October. For nature management purposes, six donkeys were released in the reserve in 1997. The herd comprised 15 animals in 2000, the time of data collection. Plant species nomenclature follows Lambinon *et al.* (1998).

Epi- and endozoochory: data collection and analysis

Epi- and endozoochorous material was collected in the field, using the donkeys in the study site as experimental animals. Their entire fur was brushed during 15 minutes with a fine horse brush, and freshly deposited excrements were collected. Sampling occurred in four different time periods between June and October 2000. In the case of epizoochory, 41 samples were collected: respectively 8, 11, 15 and 7 donkeys were brushed in each of the four time periods. In the case of endozoochory, the number of sampled donkeys was 4 in the first, and 8 in each of the three other periods. In the laboratory, the samples were sown on sterilized potting soil, and allowed to germinate in a greenhouse (see also Couvreur *et al.*, 2005a). During six months, species and seedlings were recorded, and immediately removed to prevent competition and flowering.

To gain insight in the selectivity of epi- and endozoochory, the resulting species list was compared with the local species pool. For this purpose, all 335 species in the study site were assigned to dispersal-functional plant types, resulting from cluster analysis based on dispersal-relevant plant traits, using Gower's Similarity Coefficient and the Sum of Squares method in the program Clustan Graphics 5.08 (Clustan Ltd. 2001). The used plant traits were seed weight, length and width, plant height, life span, dispersal strategy, reproduction type, group, and seedbank persistence, derived from Klotz *et al.* (2002) and Grime *et al.* (1988) (see Couvreur *et al.*, 2005a). Consequently, the species identified in the epi- and endozoochory samples were evaluated with respect to these functional plant types, to see whether certain plant types were overrepresented (see also Couvreur *et al.*, 2005a).

Animal movement and seed dispersal distance

Estimating zoolochorous dispersal distances requires information on animal behaviour and seed retention times. Therefore, the movement rate and habitat preference of the donkeys in the study site were derived from observational data (see also Lamoot *et al.*, in press). The data were recorded during 32 observation sessions, conducted between May 2000 and June 2001, and more or less evenly distributed between morning (6-12h), afternoon (12-18h) and evening (18-24h). Each session consisted of a 5h45 min visual observation period on one randomly chosen focal animal, whose exact position was located on a map every 15min (total locations = 768; see Fig. 1). The mean distance travelled in 15min was calculated from the Euclidean distances between each pair of consecutive donkey locations. To estimate mean potential seed dispersal distances, the mean observed movement rate was multiplied with experimentally defined mean zoolochorous retention times of seeds. In the case of epizoochory, retention data on horse fur were used, as measured by Couvreur *et al.* (2005b). This is justified since the behaviour of donkeys and horses is quite similar (Cosyns *et al.*, 2001) and since donkey fur is at least as suitable for seed dispersal as horse fur, given the fur characteristics of both animals (see also Couvreur *et al.*, 2004b). In the case of endozoochory, seed retention data in donkey gut as measured by Cosyns *et al.* (2005) were used.

Results

In total, 6675 seedlings of 66 plant species (Table I) were identified from the zoochory samples, covering 20% of the 335 species recorded in the study area. The endozoochory samples contained more species and seedlings (4349 seedlings of 53 species) than the epizoochory samples (2326 seedlings of 29 species). The most abundantly germinating species were *Urtica dioica* (70% of the seedlings in the endozoochory samples), *Cynoglossum officinale* and *Galium aparine* (41% and 31% of the seedlings in the epizoochory samples, respectively). The epizoochory samples contained relatively more grasses (Table I). Of the 66 species, 16 occurred in both epi- and endozoochory samples, 13 were exclusively present in the epizoochory samples and 37 exclusively in the endozoochory samples. Species dominant in the study area (e.g. *Calamagrostis epigejos*, *Arrhenatherum elatius*, *Rubus caesius*) as well as rare species (e.g. *Leontodon saxatilis*, *Myosotis arvensis*) were dispersed zoochorously.

Despite some shared species, the epizoochorously dispersed flora was complementary to the endozoochorously dispersed flora in terms of species composition and plant traits. This was shown by the different distribution of the epi- and endozoochorously dispersed species among the five clusters of dispersal-functional plant types represented in the study site (Table I). While the species exclusively dispersed by epizoochory were almost confined to one dispersal-functional plant type, the species exclusively dispersed by endozoochory belonged to a wide range of plant types. The species dispersed by both mechanisms showed an intermediate selectivity.

The mean distance covered by the donkeys in 15min was 41.9m, indicating a mean rate of 167.6m.h⁻¹. To assess the mean potential epizoochorous dispersal distances of the seeds, we used epizoochorous seed retention data of six species studied by Couvreur *et al.* (2005b), which were – in terms of seed characteristics – comparable to at least some of the epizoochorous species in the study site. In the case of endozoochory, gut retention data of five of the endozoochorously dispersed seeds were available from Cosyns *et al.* (2005). Combination of the donkey movement rate with the mean retention times of dispersed seeds (ranging between 0.29 and 1.52h in the case of epizoochory, and between 64.2 and 79.5h in the case of endozoochory), resulted in mean potential seed dispersal distances ranging between 50 and 250m in the case of epizoochory (Table II), and in the order of magnitude of 10 km in the case of endozoochory (Table III). However, as donkeys do not move in straight lines and are limited by the size of the fenced nature reserve, the realized dispersal distance must have been 1.4km at most. Although the donkeys' preferred habitat is grassland (Fig. 1; ratio of proportion of grassland visits and proportional grassland area is 2.5), they frequent all habitats in the study site (Fig. 1).

Table I. Distribution of the different categories of zoolochorously dispersed species over the five dispersal-functional plant types represented among the 335 species in the study site (adapted from Couvreur *et al.*, 2005a). Between brackets are the number of seedlings and the number of animals carrying the species

Tall woody perennials with large, heavy seeds (berries or wind-dispersed) and a transient seedbank (n=74)	Biennial grasses and herbs with intermediately long seeds adapted to epizoochory (n=63)	Biennial herbs with light seeds adapted to dispersal by wind and ants (n=51)	Perennial herbs with short seeds and various dispersal strategies (n=77)	Biennial or perennial grasses, sedges and herbs with unspecialized seeds, often also reproducing vegetatively (n=70)
sp. excl. in epi (n=13)	0	10	3	0
	<i>Cynoglossum officinale</i> (95/32)	<i>Oenothera biennis</i> (70/6)		
	<i>Arctium minus</i> (137/6)	<i>Ceratium semidecandrum</i> (4/3)		
	<i>Arrhenatherum elatius</i> (30/9)	<i>Sonchus asper</i> (1/1)		
	<i>Myosotis arvensis</i> (24/11)			
	<i>Bromus hordeaceus</i> (2/1)			
	<i>Phleum arenarium</i> (2/2)			
	<i>Bidens tripartita</i> (1/1)			
	<i>Dactylis glomerata</i> (1/1)			
	<i>Geum urbanum</i> (1/1)			
	<i>Rumex obtusifolius</i> (1/1)			
sp. excl. in epi+endo (n=16)	0	5	3	2
	<i>Galium aparine</i> (712/19; 60/13)	<i>Lythrum salicaria</i> (6/2; 25/4)	<i>Urtica dioica</i> (103/17; 3010/10)	<i>Poa trivialis</i> (18/11; 168/12)
	<i>Anthriscus caucalis</i> (211/14; 1/1)	<i>Senecio jacobaea</i> (18/7; 9/5)	<i>Epilobium ciliatum</i> (1/1; 1/1)	<i>Poa pratensis</i> (1/1; 60/14)
	<i>Phleum pratense</i> (2/2; 63/13)	<i>Sonchus oleraceus</i> (2/2; 9/6)		<i>Holcus lanatus</i> (10/9; 89/9)
	<i>Plantago major</i> (1/1; 43/3)			<i>Artemisia vulgaris</i> (1/1; 68/4)
	<i>Poa annua</i> (2/2; 24/7)			<i>Agrostis capillaris</i> (3/2; 29/8)
				<i>Festuca rubra</i> (3/2; 29/2)
sp. excl. in endo (n=37)	2	6	9	12
	<i>Calamagrostis epigejos</i> (26/5)	<i>Galium mollugo</i> (54/2)	<i>Oenothera glazioviana</i> (19/3)	<i>Veronica chamaedrys</i> (64/10)
	<i>Rubus caesius</i> (3/3)	<i>Juncus biflorus</i> (16/7)	<i>Arenaria serpyllifolia</i> (13/6)	<i>Galium verum</i> (60/6)
		<i>Plantago lanceolata</i> (16/4)	<i>Silene latifolia</i> subsp. <i>alba</i> (3/2)	<i>Trifolium repens</i> (20/3)
		<i>Trifolium dubium</i> (11/3)	<i>Chelidonium majus</i> (2/2)	<i>Juncus articulatus</i> (17/7)
		<i>Aira praecox</i> (3/2)	<i>Conyza canadensis</i> (2/2)	<i>Achillea millefolium</i> (4/3)
		<i>Plantago coronopus</i> (1/1)	<i>Crepis capillaris</i> (2/2)	<i>Eupatorium cannabinum</i> (4/3)
			<i>Hypochoeris radicata</i> (2/1)	<i>Cerastium fontanum</i> (3/2)
			<i>Capsella bursa-pastoris</i> (1/1)	<i>Epilobium hirsutum</i> (2/1)
			<i>Solanum nigrum</i> (1/1)	<i>Epilobium montanum</i> (1/1)
				<i>Leontodon saxatilis</i> (1/1)
				<i>Ranunculus repens</i> (1/1)
				<i>Rumex crispus</i> (1/1)

Donkeys disperse seeds in dunes

Table II. Mean retention time in horse fur (comparable to donkey fur) of seven experimental plant species as measured by Couvreur *et al.* (2005b). The retention times were used to assess the mean potential dispersal distances of the seeds by epizoochory, based on a mean movement rate of 167.6m.h⁻¹ of donkeys (see ‘Results’). In the last two columns, a brief description of the seeds is given, as well as some epizoochorous species in the study site with comparable seed morphology

Experimental epizoochorous species	Mean retention time on horse fur (h)	Mean potential dispersal distance (m)*	Seed description	Comparable epizoochorous species in study site
<i>Anemone nemorosa</i>	1.19	199.4	Intermediate size, not adhesive	<i>Arrhenatherum elatius</i>
<i>Geum urbanum</i>	1.52	254.8	Intermediate size, adhesive	<i>Arctium minus, Anthiscus caucalis, Cynoglossum officinale, Galium aparine, Senecio jacobaea</i>
<i>Ranunculus acris</i>	0.98	164.2	Intermediate size, not adhesive	
<i>Prunella vulgaris</i>	1.18	197.8	Very small, not adhesive	<i>Myosotis arvensis, Lythrum salicaria</i>
<i>Centaurea jacea</i>	0.63	105.6	Small, elongate, not adhesive	<i>Holcus lanatus, Festuca rubra, Poa trivialis</i>
<i>Oenothera biennis</i>	1.43	239.7	Very small, not adhesive	<i>Oenothera biennis, Cerastium semidecandrum, Urtica dioica</i>
<i>Heracleum sphondylium</i>	0.29	48.6	Large, flat, not adhesive	

* this distance is not the realized dispersal distance, since animals do not move in one direction and since the size of the nature reserve does not allow dispersal over more than 1.4km.

Table III. Mean retention time in donkey gut of five plant species as measured by Cosyns *et al.* (2005). The retention times were used to assess the mean potential dispersal distance of the seeds by endozoochory, based on a mean movement rate of 167.6m.h⁻¹ of donkeys (see ‘Results’). In the last two columns, a brief description of the seeds is given, as well as some endozoochorous species in the study site with comparable seed morphology

Experimental endozoochorous species	Mean retention time in donkey gut (h)	Mean potential dispersal distance (m)*	Seed description	Comparable endozoochorous species in study site
<i>Agrostis capillaris</i>	69.0	11564.4	Intermediate size, not adhesive	<i>Agrostis stolonifera, Holcus lanatus, Festuca rubra</i>
<i>Carex arenaria</i>	68.7	11514.1	Intermediate size, slightly adhesive	
<i>Plantago lanceolata</i>	64.2	10759.9	Intermediate size, adhesive (mucus)	<i>Plantago major, Plantago coronopus</i>
<i>Poa pratensis</i>	66.0	11061.6	Very small, not adhesive	<i>Poa trivialis, Poa annua</i>
<i>Trifolium repens</i>	79.5	13324.2	Small, not adhesive	<i>Trifolium dubium</i>

* this distance is not the realized dispersal distance, since animals do not move in one direction and since the size of the nature reserve does not allow dispersal over more than 1.4km.

Discussion

Epi- and endozoochory

Donkeys are clearly able to contribute to long-distance dispersal through epi- and endozoochory in coastal dune ecosystems. At least one fifth of all species (66 of 335 species) in the study area was dispersed by the donkeys, and it is likely that more intensive sampling would reveal more species (see Cosyns *et al.*, in press). Despite 13 species in common, the epizoochorous species composition was additive and complementary to the endozoochorous one in terms of species trait syndromes. The exclusively epizoochorous species were almost exclusively confined to one of the five dispersal-functional plant types represented among the species in the study site (*i.e.* the biennial grasses and herbs with intermediately long seeds adapted to epizoochory), while the exclusively endozoochorous species were spread over all five plant types, and the shared species showed an intermediate behaviour (Table I).

Dispersal distances

In terms of seed dispersal distances, epizoochory and endozoochory present an interesting contrast. Seed retention in guts includes an extended lag prior to defecation of at least 12h in the case of donkeys (Cosyns *et al.*, 2005). In contrast, seeds that are attached to fur immediately start to fall (*e.g.* Couvreur *et al.*, 2005b). This difference in time lag explains the calculated mean potential seed dispersal distances in the case of epi- and endozoochory (Tables II and III). However, these mean potential dispersal distances only confirm that the donkeys disperse seeds over the entire study site, as it is obvious that animals do not move in straight lines. Moreover, the suggested shorter dispersal distances of epizoochorous seeds are biased since few very adhesive seeds were used as experimental seeds (while the abundant species observed in donkey fur were very adhesive, *e.g.* *Cynoglossum officinale*, *Anthriscus caucalis*, *Arctium minus*, *Galium aparine*). In fact, there is no theoretical maximum to epizoochorous dispersal distances. Seeds can remain in fur until an animal molts or dies, but in practice the turnover of seeds is relatively fast (Couvreur *et al.*, 2005a). The potential for long-distance endozoochory depends on the survival of seeds ingested by the dispersers and the effects of the digestive system on the mean retention time of germinable seeds. Our field study shows the germination of many seedlings of a wide variety of grassland species. This implies that a large number of seeds must have been consumed to compensate for the generally low germination success after gut passage (Cosyns *et al.*, 2005). In fact, the efficiency of endozoochory for most temperate grassland species may be questioned, since the process of mastication and gut passage appears to impose a high cost. Furthermore, seeds dispersed in animal faeces experience a very different post-dispersal environment compared to seeds that fall on bare ground (Bakker and Olff, 2003). However, the fact that zoochory is an explicit long-distance dispersal mechanism will increase the chance of escaping density-dependent mortality (Connel, 1971; Janzen, 1970), and is hypothesized to result in directed dispersal (Wenny, 2001). As the donkeys' preferred habitat is grassland (Fig. 1 and Results), most species may indeed have a greater chance to be dispersed in grassland. Nevertheless, the donkeys also connect other habitat types, as they frequent all habitats in the study site (Fig. 1).

More detailed modelling of the complex mechanism of zoolochory could yield estimations of realized seed shadows (see Vellend *et al.*, 2003 in the context of endozoochory; Higgins *et al.*, 2003 and Couvreur *et al.*, unpublished, in the context of epizoochory). For testing such models, seed numbers observed on animals are invaluable as an independent source of data (Levin *et al.*, 2003).

Implications for nature conservation and management

The present study highlights the relevance of donkeys as long-distance seed dispersal vectors. For ecosystem conservation and restoration purposes, the dispersal possibilities of plants are of crucial importance, especially in view of the present degree of habitat deterioration and fragmentation, leading to dispersal limitation. Therefore, our results contribute to the scientific basis required to guide decisions concerning the introduction of large domesticated herbivores for nature management purposes. As dispersal vectors, they provide a critical ecosystem function in a conservation context by linking fragmented patches of natural habitat (see Pykälä, 2000; Lundberg and Moberg, 2003; Couvreur, 2004a), with a reasonable chance of directed dispersal (cf. Wenny, 2001). In our study site, a 100ha coastal dune landscape, the donkeys disperse seeds among all habitat types throughout the reserve. To utilize the full seed dispersal potential of both wild ungulates and domesticated herbivores in fragmented habitats on a larger scale, connections between different patches of similar habitat as well as connections between nearby coastal dune nature reserves should receive attention. Especially in the context of climate change (Watkinson and Gill, 2002), it might be crucial to allow plant species to migrate across the limits of the nature reserves in which they might not much longer be able to survive.

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Monitoring Bryophytes and lichens dynamics in sand dunes: example on the French Atlantic coast

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Abstract

Bryophytes and lichens communities growing on nine non-forested coastal dunes along the Atlantic seaboard of France were studied from vegetation surveys during three years. Coastal dune systems provide opportunities for the study of plant successions and colonisation processes. The distribution of species and the relationships between bryophytes and lichens *versus* pedologic factors has been investigated on 1x1m permanent plots and were analysed by multivariate analyses. This study has shown that the different species are distributed in five groups in the different dune habitats. These groups are composed with several Mediterraneo-Atlantic species which distinguished them from other communities described in bryophytes and lichens successions in Europe. The significative relationships between the five groups and pedologic factors such as pH-water, percentage of total calcium and total nitrogen permit to evaluate the chemical variations of the soil along the dune-transect. The knowledge of relationships between the responses of the species and the abiotic variations of the soil determine functional groups. The monitoring of these functionnal groups is a good tool to understand evolutionary processes of dune-ecosystems and their management.

Keywords: Vegetation survey; Communities; Succession; Functional groups; Management.

Introduction

The management of the Atlantic littoral dunes is supported by the identification and monitoring of indicator species that make it possible to evaluate the modifications of the ecosystem (Favennec *et al.*, 1996; Favennec, 1997; 1999) The 'biomonitoring' is a follow-up in time of the state of the vegetation and utilises the response of species or associations of plants in order to detect or to predict the changes of the environment and to follow its evolution. The idea of biomonitoring appeared at the end of the 19th century when Nylander (1866) used the abundance of lichens to measure the effects of air pollution. The various aspects of biomonitoring were summarized by Arndt *et al.* (1987) and Arndt (2000) classifying indicators as 'reactive' (sensitivity) and 'accumulative' (potential of accumulation) bioindicators.

The 'biointegrator' concept (*sensu* Garrec and van Haluwyn, 2002) is based on the study of populations or communities. Changes in specific composition, the appearance or

disappearance of species and changes in density inform about the state of the ecosystem. This concept was previously developed by Blandin (1986) to designate plants which ‘by their qualitative and/or quantitative characteristics testify to the state of an ecological system and which by variations of these characteristics, make it possible to detect possible modifications of this system’. The cartography of lichenous diversity is used at the European level as indicator of environmental quality (Asta *et al.*, 2003).

The vascular plant vegetation of French dunes has been studied intensively (Duffaud, 1996; Géhu, 1993, 1977; Despeyroux, 1984; Lahondère, 1980). Some studies on bryophytes (Pierrot, 1980, 1974; Bonnot, 1971; Fustec-Mathon and Mathon, 1960; Turmel, 1950; Duchauffour, 1948; Camus and Charrier, 1911) and lichens (Botineau and Houmeau, 1980; des Abbayes, 1951; Piquenard, 1904) have described distribution patterns on different parts of dunes. However, no recent study specifically studying the ecology of mosses and lichens developing in the littoral dunes in France is available.

During the year 2001, an observatory of the mosses and lichens on nine non-forested dunes of the Atlantic coast of France was set up – in collaboration with personnel from the French National Forests Commission (ONF) – in order to identify the distribution patterns of the mosses and lichens in relation to the dynamics of the dunes (environmental factors), and to relate the edaphic parameters to these patterns.

Materials and methods

Study area

The study area consists of nine sites of littoral dunes. The sites were selected on the basis of the patrimonial interest of the vegetation. Each site has already been the subject of several floristic, geomorphological, landscape studies, and inventories (Natural Zone of Faunistic Floristic and Ecological Interest, Important Birds Area).

The sites were distributed from Brittany to the south of Les Landes (Fig. 1): in Morbihan (administrative department 56): the domaniale dune of Quiberon, Plouharnel; in the Loire-Atlantique (44): pointe de Pen Bron (la Turballe); in the Vendée (85): the pointe d'Arçay (la Faute/mer); in Charente Maritime (17): dunes de St Trojan on the Oléron island and the Pointe Espagnole (la Tremblade); in Gironde (33): the dune of le Flaman (Vendays-Montalivet) and the dunes of the Cap Ferret; in Les Landes (40): domaniale dunes of Mimizan and Tarnos.

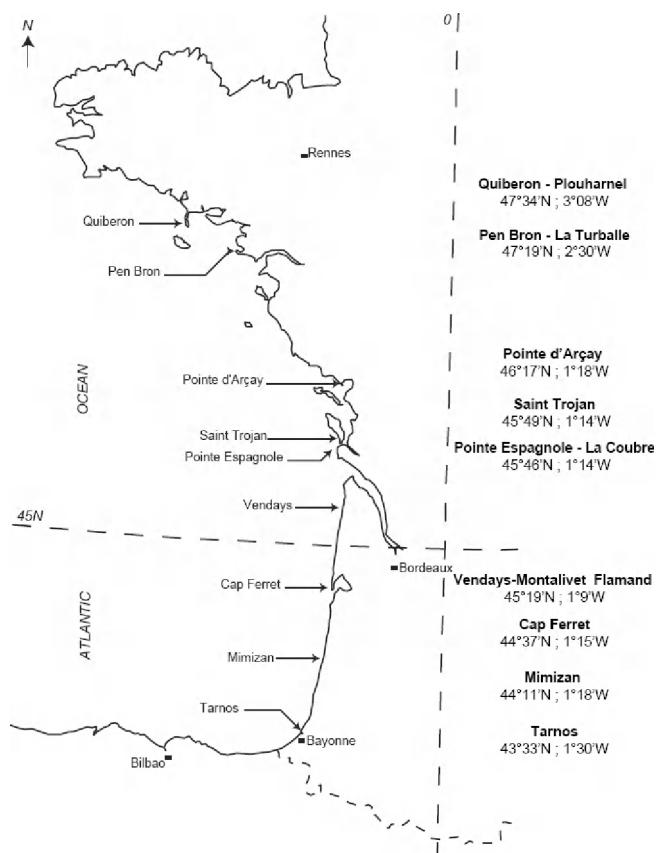


Fig. 1. Study area: location of the observatory composed of nine non-forested dunes on the French Atlantic coast.

Vegetation survey and sampling data

Synchronic study

In Autumn 2001, the mosses and lichens were inventoried on the entire non forested dune (from the beach to the *Pinus* plantations). The sampling design takes account of the geographical characteristics of the zone of study and the different habitats of the dunes. Two or three transects were selected per site, each transect comprising three permanent plots per habitat (semi-fixed dune SFD, fixed dune FD, rear fixed dune RFD). One hundred and twenty four (124) plots were taken using a removable quadrat (1x1m) with square mesh of 10cm. This method makes it possible to provide quantitative information on the relative frequency of species (Greig-Smith, 1964; Gordon, 1969; Poissonnet, 1969; Clément, 1987). The percentage cover of species was measured on each quadrat; 10 classes of values were recorded (1: presence; 2: 1-10%; 3: 11-20%; 4: 21-30%; 5: 31-40%; 6: 41-50%; 7: 51-60%; 8: 61-70%; 9: 71-80%; 10: 81%) or more.

Diachronic study

A vegetation survey was carried out on 77 permanent plots (1x1m) in order to follow the modifications within the mosses and lichens communities over time. The analysis of the average (\pm standard deviation) of the relative frequency of the species makes it possible to highlight dynamic fixation processes. The readings were taken every year in autumn during 3 years. Percentage cover was measured in three habitats of the dune: semi-fixed dune (n=15), fixed dune (n=32), rear fixed dune (n=30).

The life-strategies

The species are classified according to During (1979, 1992). Important traits of species which are observed in the system of 'life-strategy' are the vegetative form, reproduction, life-span, and effects of the environment (constant or fluctuating) on these traits. In order to obtain a result at community level, the system was modified by supposing *a priori* that the life-strategy of each species identified in the community tends to be standardized at its community level (highlighting of common traits), even if each species taken separately has its own life-strategy.

Environmental factors relating to the distribution

Each plot (n=124, 1x1m) was characterized by five environmental parameters related to its distribution on the littoral dune:

- (1) The Atlantic coast (Z-L) divided in three parts: the south of Brittany (1), the Middle West (2), and Aquitaine (3).
- (2) The position of the plot in relation to the habitats of the dune (Z-T): coefficient 1 for the semi-fixed dune (DT), 2 for the fixed dune (DF), 3 for the rear fixed dune (ADF).
- (3) Species Richness (NbSp) corresponds to the total number of species of mosses and lichens listed on the quadrat.
- (4) The percentage of bare sand ('sable nu') is the relative frequency measured on the square.
- (5) The percentage of cover of the vascular vegetation (Phan) is also taken from the relative frequency measured on the quadrat.

Soil analyses

As bryophytes and lichens have no roots, they are in direct contact with the superficial soil layer (Ketner-Oostra and Sykora, 2000). Soil analyses were carried out on 142 relevés. The sand samples were collected in autumn 2001 from the surface soil layer (0 to 5 cm depth) on microstations of 10x10cm. The vascular plant vegetation was recorded (presence/absence) for each sample. A minimum of 15 samples per community is used for the analyses. The cover of bryophytes and lichens was recorded at each station. Analyses were conducted on samples that were dried in an oven at 65°C for 24h and then sieved through a 2mm sieve.

- The pH-H₂O was measured on suspension of 10g of air-dried soil in 25ml of distilled water, after shaking for 1 min and leaving to stand for 1min (Forster 1995).
- The conductivity was measured with a conductivity meter on the supernatant of 10g of soil suspended in 50ml of distilled water, after shaking for 45min (Baize, 1988).

- The percentage organic matter (%OM) in the soil was determined by measuring the total ash content (Aubert, 1978). The soil was dried in an oven at 105°C for 24h. The samples were then combusted in a muffle furnace for 24h at 430°C. After weighing (W1 initial dry weight and W2 dry weight after combustion), the result is given by the formula: %OM=((W1-W2)/W1)x100.
- The percentage of total calcium (%Ca) was determined using the Bernard calcimeter method (French standard AFNOR X31-105).
- The percentages of carbon and total nitrogen (%C,N) were measured using a Perkin Elmer Series II 2400 CHN analyser, on 30-40mg of soil samples dried at 105°C and homogenised by grinding.

Data analysis

The species of mosses and lichens growing on the ground or the litter layer were recorded in autumn 2001. A data matrix of 124 quadrats (1x1m) including 29 species of mosses and lichens was analysed by Detrended Correspondance Analysis. (DCA, Benzecri, 1973; Ter Braak, 1996) to define vegetation patterns.

To examine the relations between the environmental factors and the distribution of the vegetation, the data matrix of 124 quadrats and the 29 species of mosses and lichens and five environmental factors were analysed with Canonical Correspondence Analysis (CCA). The importance of the relation between the species and the parameters taken separately, was tested with a Monte-Carlo permutation test.

The means and the standard deviations of each soil factor were calculated for each community; and were compared by a one way analysis of variance (ANOVA); the communities were compared pairwise by a Tukey test (Glantz and Slinker, 1990).

The relationships between the soil characteristics and the distribution of the communities were examined. A matrix of 142 samples (6VE) including the five groups of species of mosses and lichens was analysed by Canonical Correspondence Analysis (CCA). The importance of the relation between the groups of species and measured parameters taken separately was tested by the Monte-Carlo permutation test.

Results

Vegetation patterns

The results of the DCA (matrix of 124 quadrats x 29 sp) is shown in Fig. 2. The first three axes account for 28.1% of total inertia. The first axis (16.7%) reflects a gradient of dune fixation related to the distance from the beach. From the score of the species on axis 1 of the DCA and the analysis of the scattergram, five groups are distinguished.

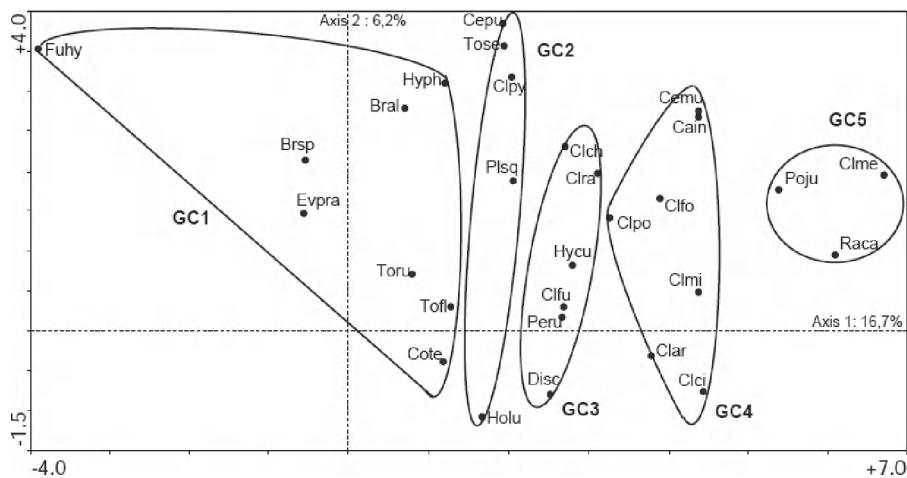


Fig. 2. Scatterplot of the two first axes (axis 1: 16.7%; axis 2: 6.2%) of Detrended Correspondance Analysis. Diagram shows the 29 species in five groups: GC1, GC2, GC3, GC4, GC5. See Table I for the code of the species.

Table I presents the 29 species ordered according to their score on axis 1 of the DCA (= 16.7% of total inertia) as well as the five groups of species. The discriminating species of each group (in bold) are those whose presence is higher than 10% in the 124 plots and of which percentage cover (F.R.) is higher than 10%. *Racomitrium canescens* (GC5) is the only discriminating species whose presence lies between 5 and 10%. An adaptation of the system of life-strategy defined for the species by During (1992) is used. The result obtained proposes a life-strategy for each identified community.

Distribution of the species

The relations between the distribution of the species and the five environmental factors was examined by CCA (Fig. 3). The position on the transect (Z-T), the geographical distribution along the coastal zone (Z-L), the percentage cover by the phanerogams (Phan) and the species richness (NbSp) are the factors which have importance after the Monte-Carlo permutation test ($P<0.05$) (Table II). They were strong determinants for the graphical representation of the species. The first three axes account for 91% of inertia. The position on the transect, percent cover of vascular vegetation were determinants of axis 1 (58.7%). It represents a gradient of fixation/stabilisation. The distribution on the coastal zone was determinant of axis 2 (19.7%). It expresses a geographic gradient from North to South.

Table I. The five groups of mosses and lichens in relation with the life strategies system (During, 1992). The species are ordered by their scores along the first DCA axis (Fig. 2). The discriminating species of each group (in bold) are those whose presence is higher than 10% in the 124 permanent plots and of which the percentage cover (F.R.) is higher than 10%

Species	(DCA) Communities	Life-strategy of the Communities
<i>Funaria hygrometrica</i> (<i>Fuhy</i>)		
<i>Evernia prunastri</i> var. <i>arenaria</i> (<i>Evpra</i>)		
<i>Bryum spp.</i> (<i>Brsp</i>)		
<i>Brachythecium albicans</i> (<i>Bral</i>)	GC1	Ephemeral colonist
<i>Tortula ruraliformis</i> (<i>Toru</i>)		Colonist <i>stricto sensu</i>
<i>Collema tenax</i> (<i>Cote</i>)		(+ Opportunists)
<i>Hypogymnia physodes</i> (<i>Hyph</i>)		
<i>Tortella flavovirens</i> (<i>Tofl</i>)		
<i>Homalothecium lutescens</i> (<i>Holu</i>)		
<i>Ceratodon purpureus</i> (<i>Cepu</i>)		
<i>Toninia sedifolia</i> (<i>Tose</i>)	GC2	Colonist <i>stricto sensu</i>
<i>Cladonia pyxidata</i> (<i>Cipy</i>)		(+ Perennial stayers)
<i>Pleurochaete squarrosa</i> (<i>Plsq</i>)		
<i>Dicranum scoparium</i> (<i>Disc</i>)		
<i>Peltigera rufescens</i> (<i>Peru</i>)		
<i>Cladonia furcata</i> (<i>Clfu</i>)	GC3	Perennial stayers
<i>Cladonia chlorophaea</i> (<i>Clch</i>)		
<i>Hypnum cupressiforme</i> (<i>Hycu</i>)		
<i>Cladonia rangiformis</i> (<i>Clra</i>)		
<i>Cladonia portentosa</i> (<i>Clpo</i>)		
<i>Cladonia arbuscula</i> (<i>Clar</i>)		
<i>Cladonia foliacea</i> (<i>Clfo</i>)		
<i>Cetraria muricatum</i> (<i>Cemu</i>)	GC4	Perennial stayers /
<i>Cladonia mitis</i> (<i>Clmi</i>)		Strees tolerant species
<i>Campylopus introflexus</i> (<i>Cain</i>)		
<i>Cladonia ciliata</i> (<i>Clci</i>)		
<i>Polytrichum juniperinum</i> (<i>Poju</i>)		
<i>Racomitrium canescens</i> (<i>Raca</i>)	GC5	Strees tolerant species /
<i>Cladonia mediterranea</i> (<i>Clme</i>)		Colonist <i>stricto sensu</i>

Table II. Level of significance of parameters connected to the 29 species of 124 permanent plots, tested with Monte-Carlo permutation test. P<0.050 is the chosen significance margin; Z-T : position on the transect Z-L: geographic zone Phan : % cover of phanerogams NbSp: species richness in mosses and lichens Sable nu : % bare sand

Parameters	P	F
Z-T	0.005	12.76
Z-L	0.005	5.17
Phan	0.005	2.48
NbSp	0.005	2.28
Sable nu	0.100	1.49

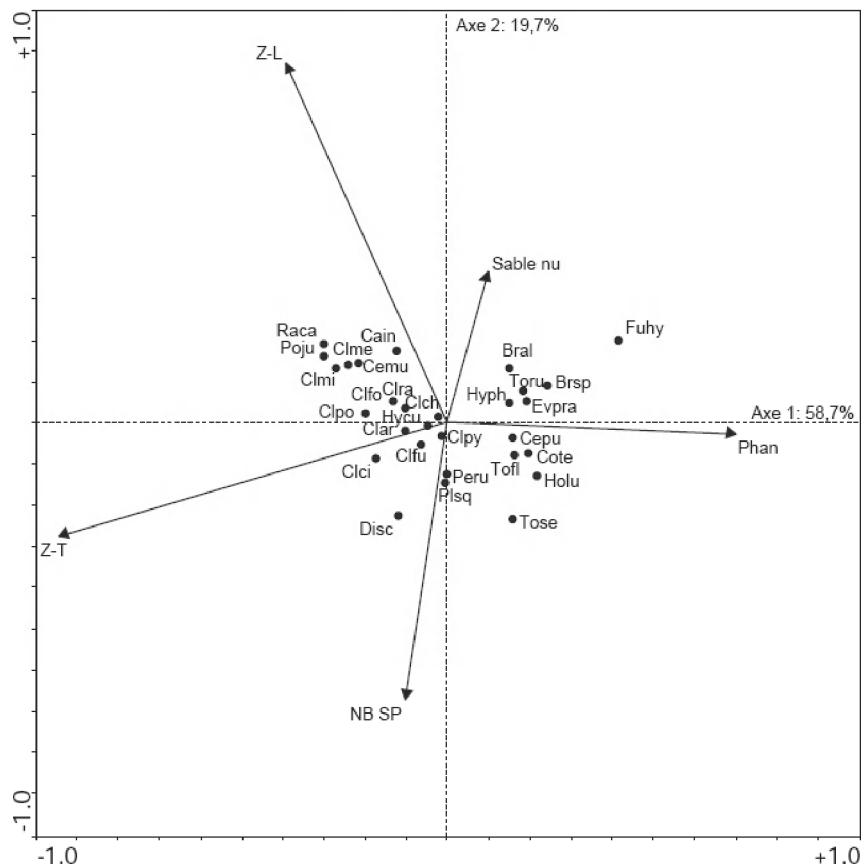


Fig. 3. Distribution of the species. Scattergram of the two first axes (axis 1: 58.7%; axis 2: 19.7%) of Canonical Correspondance Analysis CCA. Diagram shows the relation between the 29 species and the environmental parameters. See Table I for the code of the species.

Relation between the communities and soil

Five communities were identified through analysis of the vegetation patterns. Table IV presents the average values (+ Standard Deviation) obtained for each soil analysis under the communities. The analysis of variance (ANOVA) is used to compare the various groups according to each parameter. The groups present statistically significant differences ($P<0.001$) for four factors analysed from the surface soil layer: pH, total calcium, the percentage of organic matter, and total nitrogen.

The relations between the edaphic parameters and the five communities were examined by CCA (Fig. 4). The pH (pH-water), the percentage of total nitrogen (%N), the total calcium rate (%Calcaire) and the percentage of total carbon (%C) are the significant edaphic factors (Monte-Carlo permutation test: $P<0.05$) (Table III). They were strong determinants for the graphical representation of the species. The first three axes account for 97% of total inertia. pH and calcium content were determinants of axis 1 (64.6%), reflecting a gradient of acidification and decalcification. The percentages of carbon and nitrogen were determinants of axis 2 (23.9%), represent a trophic gradient.

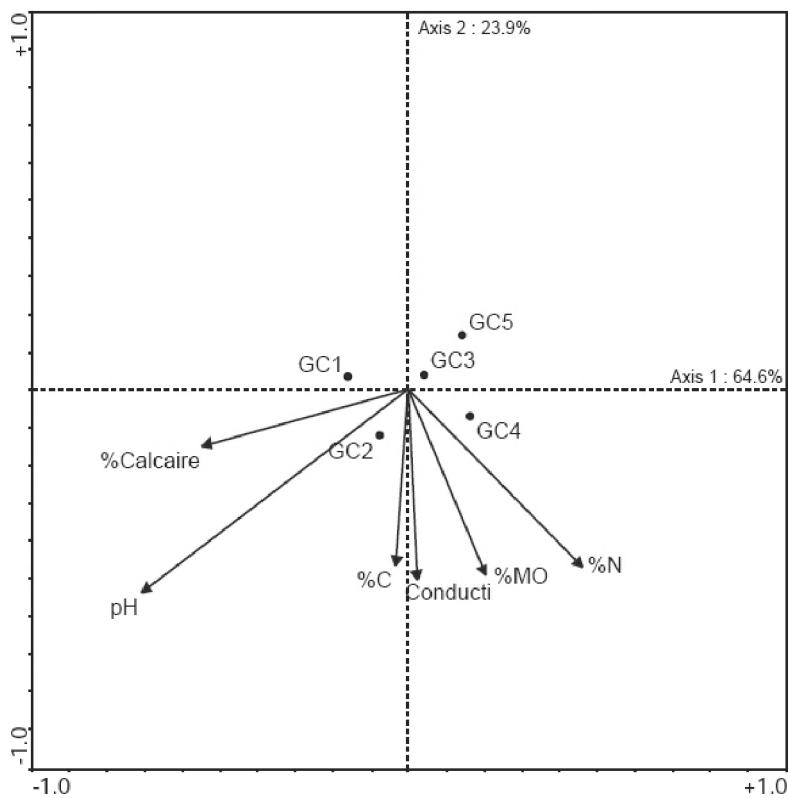


Fig. 4. Relations between the five communities and the soil. Scattergram of the two first axes (axis 1: 64.6%; axis 2: 23.9%) of Canonical Correspondance Analysis CCA.

Table III. Rate of significance of edaphic parameters connected to the five groups of species of 142 relevés of the soil surface, tested with Monte-Carlo permutation test ($P < 0.050$ is the chosen significance margin)

Parameters	P	F
pH	0.005	8.52
%N	0.005	6.24
%Calcaire	0.015	3.61
%C	0.030	2.52
Conductivity	0.420	0.98
%MO	0.845	0.37

Table IV. Results of the analyses of soil surface layer ($N = 142$; 0-5cm depth) for each community ($n=5$). The means (Moy) and the standard deviation (StD) are shown for each parameter (pH, Conductivity, Organic Matter, Carbon and Nitrogen Total, Calcium). There is a significant statistical difference between the different groups for pH, Calcium, Organic Matter and Nitrogen total

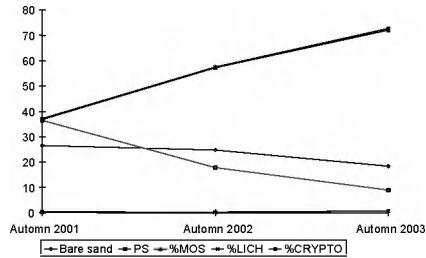
Groups	No. Relev.	pH Moy	StD pH Moy	%Ca Moy	StD Ca Moy	Cond Moy	StD Cond Moy	%MO Moy	StD MO Moy	%C C Moy	StD C Moy	%N N Moy	StD N Moy
GC1	42	7.80	0.65	7.16	6.86	69.90	16.98	1.29	1.88	1.32	1.02	0.02	0.01
GC2	22	7.88	0.40	4.59	3.90	68.53	15.81	1.47	1.43	1.21	0.65	0.03	0.02
GC3	33	7.17	0.83	3.92	6.03	62.62	40.75	1.25	1.60	1.14	1.33	0.03	0.06
GC4	30	7.14	0.87	3.10	4.09	82.30	58.08	2.36	2.26	1.59	1.62	0.08	0.10
GC5	15	6.77	0.75	0.16	0.26	49.45	21.78	0.90	0.48	0.48	0.25	0.03	0.01

The different communities

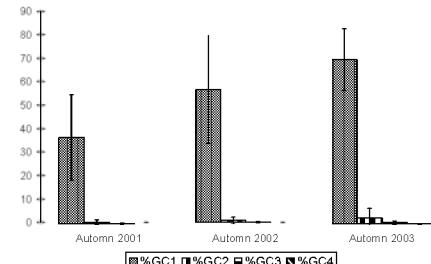
Group 1 (GC1) is composed of eight species. It is characterized by four acrocarpous mosses, like *Tortula ruraliformis*, *Bryum ssp*, *Tortella flavovirens*, and a pleurocarpous moss, *Brachythecium albicans*. These species have small sizes but are growing in height, they resist the weak sand accretion. The lichens are represented by *Collema tenax*, small lichen with gelatinous thallus, which colonizes in first of the parts of dunes recently disturbed (James *et al.*, 1977), and two normally epiphytic lichens, *Evernia prunastri var arenaria* with fruticose thallus and *Hypogymnia physodes* with foliaceous thallus, here, they are terricolous. This group is in relation to a high pH (pH 7) and a high content of total limestone in sand. It is present on the whole of the sites in the semi-fixed dune (SMD). This group presents many species at strategy of transitory and colonizing colonizer in a strict sense (*sensu*, During, 1992). In this part of the dune, the mosses have an important role in the fixing of bare sand (Warming, 1909) and their presence makes it possible to appreciate a certain stability (progressive evolution) of this part of semi-fixed dune.

In Semi-fixed dune (n=15)

5a : Vegetation level

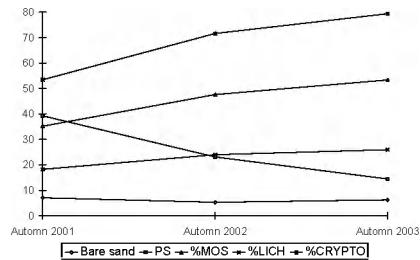


5b : Community level

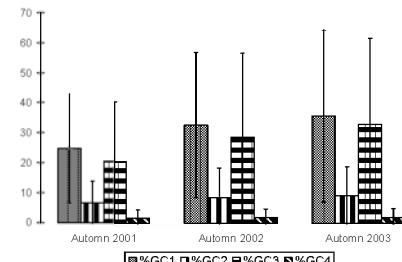


In Fixed dune (n=32)

5c : Vegetation level

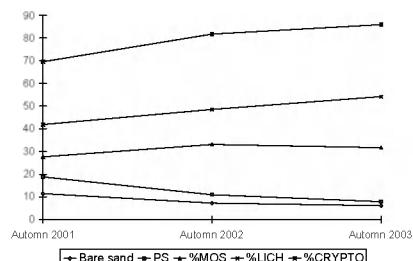


5d : Community level



In Rear fixed dune (n=30)

5e: Vegetation level



5f: Community level

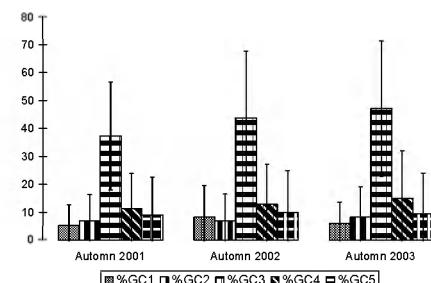


Fig. 5. Diachronic analysis of the percentage cover of mosses and lichens per habitat on 77 permanent plots; 5a and 5b Semi-fixed dune (SFD), 5c and 5d Fixed dune (FD), 5e and 5f Rear fixed dune (RFD).

This community presents by its discriminating species (*Tortula ruralifohurmis*) affinities with the bryolicheic cover of *Phleo - Tortuletum* in the 'black dunes' of the Western North of France (alternatives with *Brachythecium albicans* in dune in the process of decalcification and *Homalothecium lutescens* on sands more calcareous, both with pH 7) and of *Hornungio petraea - Tortuletum* (endemic) on dunes of Normandy and Brittany (Géhu and de Foucault, 1978). *Funaria hygrometrica* is an acrocarpous moss with fugitive strategy (During, 1992), it is characteristic of the soil disturbed by fire (Clement and Touffet, 1988, Esposito *et al.*, 1999), its presence remains limited in time and space for the dunes not undergoing this type of degradation.

Group 2 (GC2) includes five species. It is characterized by a pleurocarpous moss *Homalothecium lutescens* and two acrocarpous mosses, *Pleurochaete squarrosa*, mediterraneo-atlantic species, always observed without sporophyte on the Atlantic coast (Pierrot, 1980) and *Ceratodon purpureus*, accompanied by two lichens with squamulose thallus *Cladonia pyxidata* and *Toninia sedifolia*. The most part of the species of the group presents a strategy of colonist stricto sensu (During, 1992) and develops small carpets, forming a protective biological crust (Budel, 2001) from semi fixed dune (SFD) to the fixed dune (FD). It is influenced by a pH and a high rate of total limestone. *Cladonia pocillum* vicarious of *Cladonia pyxidata*, is indicating basic soil (James *et al.*, 1977). Certain species of this group are represented only on some sites, on the calcareous dunes of the Middle West and in the South Brittany in particular for *Toninia sedifolia*. It seems to be connected in *Fulgensietum fulgentis* Gams (James *et al.*, 1977) = *Toninio - Psoretum decipientic* Stordiek (Khalife, 1985) which is a community largely widespread (but threatened) in the center and the south of France (James *et al.*, 1977). This community requires a thorough study on the dunes.

Group 3 (GC3) includes six species, the lichens are dominant. *Cladonia rangiformis* and *Cladonia furcata*, *Cladonia* sub-genus *Cladonia* with fruticose complex thallus are often ubiquitous (James *et al.*, 1977) and a pleurocarpous moss *Hypnum cupressiforme* characterize this group and testify to a stop of powdering. An acrocarpous moss, *Dicranum scoparium*, and two lichens, *Cladonia chlorophaea* with complex thallus, and *Peltigera rufescens* with foliaceous thallus are also present. The latter testify to the presence of humus and by their development of the stop of a powdering. This group is influenced by the acidification, the increase in the nitrogen content (%N), factors related to the presence of humus. The presence of *Peltigera rufescens*, of which the photobionte is a cyanophyte, *Nostoc*, able to fix atmospheric nitrogen, sometimes being able to cover with broad surfaces, can be connected the increase in the percentage of measured total nitrogen, by leaching out in the medium (Scott, 1956). The species characteristic of this group have a strategy of perennial stayers (During, 1992). This group seems to translate, by its development, the passage of the semi-fixed dune at the fixed dune, dependent on weak variations of the ecological parameters (acidification, increase in the humus, stop of powdering). It is often represented the most on the studied dunes; it is present on broad surfaces on the parts of Fixed Dune (FD).

Group 4 (GC4) is composed of seven species. It is characterized by a diversity of *Cladonia*, *Cladonia foliacea* with foliaceous thallus and *Cladonia* of the *Cladina* sub-genus (= *Cladina*) to fruticose complex thallus, *Cladonia ciliata*, *Cladonia mitis*, *Cladonia arbuscula*, *Cladonia portentosa* like *Cetraria muricata*, lichen with fruticose

thallus. This group is influenced by the acidification and the decalcification of the substrate related to the increase in humus (%OM, %C). It translates the presence of parts of dunes acidifying themselves more than into fixed dune and decalcifying themselves, representing an evolution of the soil into a podzolisation (micropodzol sensu James and Wharfe, 1989). Only one moss is represented, *Campylopus introflexus*, classified invasive (Muller, 2001). The community is characterized by the species with strategies of competitor and stress tolerators developing on all the sampled sites of the dune fixed (FD) at the rear fixed dune (RFD).

Group 5 (GC5) is clearly distinguished in the graphical representation and includes three species. It is characterized by two acrocarpous mosses, *Racomitrium canescens* and *Polytrichum juniperinum*, with one *Cladina*, *Cladonia mediterranea*. This Mediterraneano-Atlantic species (des Abbayes and Duvigneaud, 1946) also tends to replace other *Cladonia* of the *Cladonia* sub-genus in the stage of *Quercus ilex* (Ozenda and Clauzade, 1970). This group is clearly influenced by the reduction in the pH in aged dune. It is only present in parts of acidified dunes and clearly or entirely decalcified (calcium below 0.5%) in stabilized dunes. It is a community which develops on dry sunny sands (Augier, 1966) with a strategy of stress tolerator and colonist (During, 1992). It is present in the most aged fixed dunes (FD) at the rear fixed dune (RFD).

Diachronic study on permanent plots per habitat

The trends in the change in cover of different mosses and lichens communities during three years are summarized in Fig. 5. The 77 Permanent plots (1x1m) on the dunes are subjected to disturbances.

The semi fixed dune is subjected to a powdering by sand and an average regular trampling, the rabbit by scraping exposes sand and of fires (recreational activity) punctually disturb the surface of the sand. Fig. 5a presents the evolution of the mean of percentage of cover (n=15) at vegetation level. Bare sand decreases regularly as well as the phanerogams while the proportion of cryptogams (13 species) primarily represented by the mosses (eight species) almost doubled between 2001 and 2003 respectively from 37 to 72%. The lichens (five species especially *Collema tenax* and *Cladonia furcata*) are not very present (<1% in 2003). Fig. 5b presents the survey at community level. GC1 is the dominant community, *Tortula ruraliformis*, *Tortella flavovirens* and *Bryum spp.* quickly colonize the bare sand (36% in 2001 and 70% in 2003). Percentage cover of GC2 (*Ceratodon purpureus* and *Homalothecium lutescens*) and GC3 (*Hypnum cupressiforme* and *Cladonia furcata*) communities is less than 5% but increase. GC4 community is only established in 2003, represented by *Cetraria muricata* (<1%).

The fixed dune is subjected to low powdering, rabbit disturbances and a regular trampling. Fig. 5c presents the evolution of the mean of percentage of cover (n=32) at vegetation level. The bare sand is small (<10%) during the survey. The percentage of cover of phanerogams regularly decreases and cryptogams (21 species) is high (>50%). The covering of mosses (nine species) is the double of the lichens (12 species primarily of *Cladonia*). Fig. 5d presents the survey at community level. GC1 and GC3 are the dominant communities and are in extension (+10% between 2001 and 2003). Three other communities (GC2, GC4, GC5) are stable and increase slightly.

The rear fixed dune is subjected to an extreme regular trampling (recreational activity and hunting), an action of the rabbit and the wild boar (tilling) and a powdering intervene punctually. Fig. 5e presents the evolution of the mean of the percentage of cover ($n=30$) at vegetation level. The bare sand is small (<10%) during the survey. The percentage of cover of Phanerogams is low (<20%) and decreases, the cryptogams one (24 species) is very high (>70%). Lichens are dominant (12 species, especially *Cladonia* and *Cladina*) and increase, mosses (12 species, *Hypnum cupressiforme*, *Pleurochaete squarrosa*, *Racomitrium cespitosum*) are stable (30%). Fig. 5f presents the survey at community level. All the communities are represented, GC3 is the dominant community and raises some (+10% of 2001 to 2003) with GC4 (light increase). The proportion of each community is stable and increases slightly.

Discussion

Vegetation patterns

The non-forested dunes of the Atlantic coast of France accommodate many species of mosses and lichens which present interesting biological characteristics. The populations develop on great surfaces in the fixed parts of the dune and densely cover the sand. They form a biological crust (Büdel, 2001) allowing the fixing of sand (stability). Mosses and lichens are distributed in five communities to identifiable life-strategies by their common biological-trait. The results obtained of the analysis of the soil surface layer confirm the observations of several authors; the dunes are characterized by a heterogeneous sandy substrate low in nutrients (Cowles, 1899; Olson, 1958; Géhu-Franck, 1978; Gerlach, 1993; Gerlach *et al.*, 1994; Berendse *et al.*, 1998). Each particular substrate tends to establish a characteristic uniform lichenous vegetation under the influence of similar ecological factors (James *et al.*, 1977; Ozenda and Clauzade, 1970) and the changes of the composition of the groups of species are connected significantly to certain edaphic factors in the dunes like Ketner-Oostra and Sykora (2000) showed. According to the studies carried out on the dunes (Watson, 1918; Richards, 1929; Brown and Brown, 1969; Topham and Hitchc, 1985), authors distinguished several factors so that the lichens constitute a significant part in the vegetation of the littoral dunes, such as the stability of sand, its moisture retention properties, the frequency and the permanence of the dewfall and the fog, and from the humus and calcium carbonate contents of sand (James *et al.*, 1977). The species of the communities highlighted are comparable with those described in the littoral dunes of the north of Europe (Ketner-Oostra and Sykora, 2000; Magnusson, 1983) but the communities present on the Atlantic coast of France a composition of Mediterranean-Atlantic species like, *Tortella flavovirens*, *Pleurochaete squarrosa*, *Cladonia mediterranea* which also distinguish them compared to other groups described in the south of Europe (Gallego Fernandez *et al.*, 1995; Esposito *et al.*, 1999). The influence of the littoral microclimate is thus not to be neglected in the distribution of the communities in particular for factors like the sunning (heliophilous, thermophilous species) and of the relative humidity of the air.

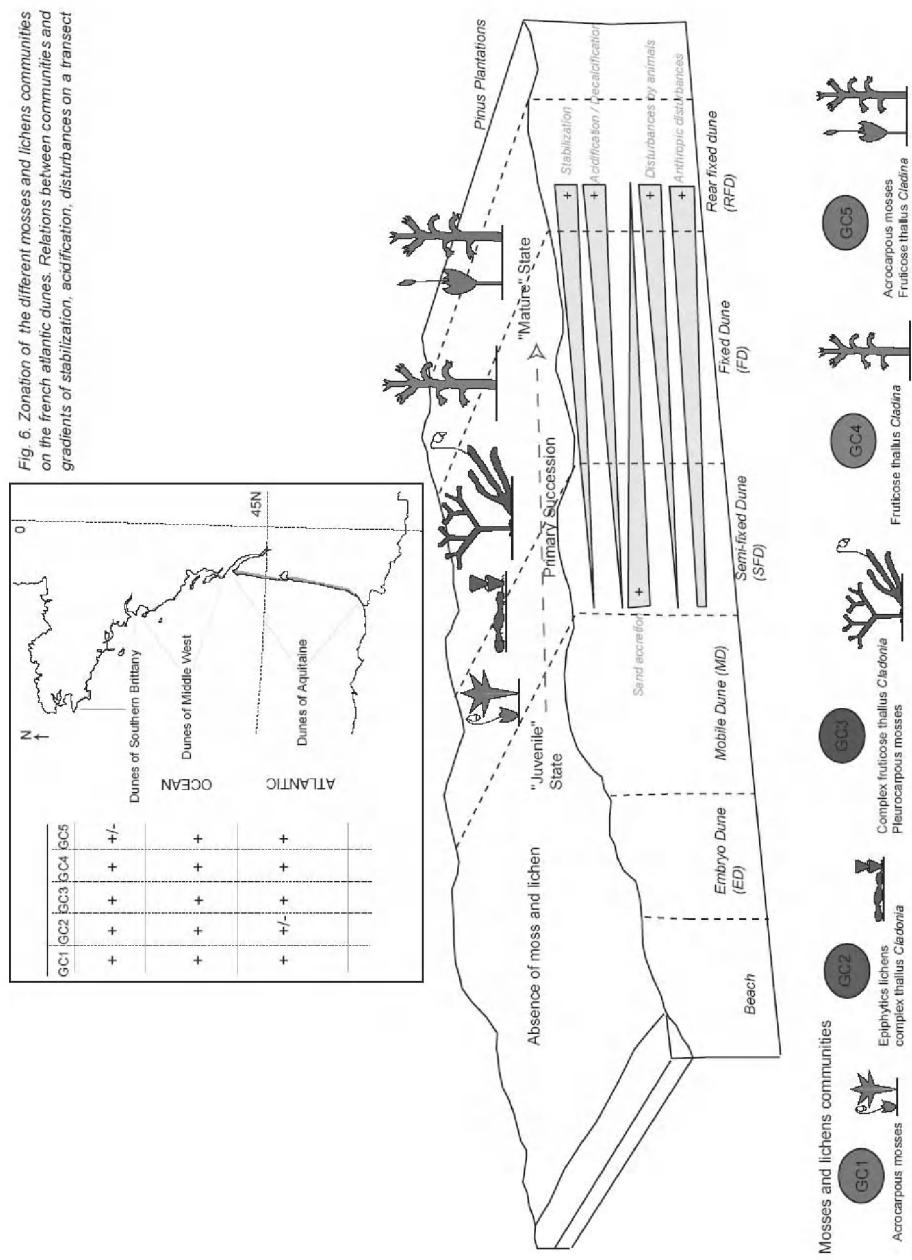
The distribution of each community in certain parts of the dunes seems to represent the modifications in the chemical composition of the soil surface layer by the description trophic of the gradients, acidification and decalcification of the beach to the forested

dune. Fig. 6 summarizes the characteristics of the five mosses and lichens communities and lichens in relation to the edaphic gradients and their distribution on the non-forested coastal dunes.

Groups GC1 and GC2 are present in the zones at semi-fixed to fixed dune; they are communities with colonist life-strategy (During, 1992). The distribution of the species in these parts is thus related to the probability of being covered by sand (or resistance to burial for the arenicolous species) and the competition with the higher plants which present a strong covering.

Groups GC3, GC4 and GC5 are perennial stayers and stress tolerators; their presences reflect a low sand accretion rate. They are comparable in composition with mosses communities (Géhu and Géhu-Franck, 1973; Augier, 1966) and lichens (James *et al.*, 1977; Gilbert, 2000) of the moors on sunny dry sands. The species of GC3 group (*Hypnum cupressiforme*, *Cladonia rangiformis*, *Cladonia furcata*), but especially of the GC4 (*Cladina*), of the GC5 (*Cladonia mediterranea*, *Polytrichum juniperinum*) are present in the relevés of three associations of dry moors of south-west France described by Géhu (1977) whose especially coastal moor with *Festuca juncifolia* and with *Erica cinerea*. This one develops from the zone of contact between the grey dune with *Helichrysum stoechas* and the pine forest in back dune and penetrates towards the interior only of a few kilometers on the coasts of Les Landes and of la Gironde whose optimum is north of Adour at the south of Mimizan (Géhu, 1977).

The ‘continental’ vegetation thus influences the composition of vegetation in the littoral zone (border-effect), which can explain the diversification of the communities in the parts fixed on the dune by species with wide ecological amplitude. In fixed dune and rear fixed dune, zones fixed in the past by the vegetation, the ecological conditions change. A fall of the pH related to a decalcification like with the increase in the humus (James *et al.* 1977) also influence the changes in the composition of the vegetation. Moreover, as Dawson *et al.* (1984) showed for the alpine tundras, the lichens compounds are mobile with the profile of the soil and they contribute to the formation of the soil and the other processes of evolution of the soil leading to a podzolisation. Communities (GC3, GC4, GC5) prefer a dry habitat little subjected to low disturbances. According to Gallego Fernandez *et al.* (1995, 1997) the presence of lichens and the height of the community are biological indicators.



Various authors proposed to group the species according to the common response (response-trait) to the environment or according to their common effects (effect-trait) on the processes of the ecosystem (Noble and Slatyer, 1980; Gitay and Noble, 1997; Lavorel *et al.*, 1997, McIntyre *et al.*, 1999). The monitoring on permanent plots allows observation of stabilization dynamics (fixing of sand) and the mechanisms of response to the disturbances which take part in it. The results suggest that the dynamic ones and the mechanisms vary according to the species, which have certain common response-trait (sensu Gitay and Noble, 1997), and according to the habitats, characterized by variations of the environmental conditions. These mechanisms allow the coexistence of the mosses and lichens populations, forming patches of the semi-fixed dune to the rear fixed dune. In a general way, an increase in the covering of the cryptogamic carpet with a seasonal effect was observed. This increase is more important during the winter, the local climatic conditions (cool and wet winters) seem to support photosynthesis for the growth and the reproduction. The summers being dry, the drying of the communities is accentuated by the wind, they reduce the periods of development.

Dynamic states

Although being frequently established in extremely unfavourable habitats, the lichens require very strict ecological conditions to develop (Clauzade and Rodon, 1966). This explains why there are close relationships between the bryolichenic vegetation of a determined zone on the dune and the ecological characters of this one, which makes it possible to use the mosses and lichens communities as bioindicators. The use of the biological traits is important to define the life-strategies of the species and the communities allowing a functional typology of habitats (Lavorel *et al.*, 1997). The results obtained in this survey (Jun *et al.*, 2004; Jun, 2005) show that the terricolous bryolichenic communities allow to carry out a typology of the ecosystem 'littoral dune' and to evaluate its states of dynamic. The various communities highlighted reflect three states of stability of the dune (Table V).

The bryolichenic communities highlight the dynamic stages of maturation (stabilization) of the dune by the passage of a juvenile state (conditioned by the abiotic processes) in dune of transition, dominated by the acrocarpous mosses (colonist), in a mature state in fixed dune and in rear fixed dune (characterized by the biotic interactions). The bryolichenic communities substitute themselves and diversify in these the last two habitats, in particular the populations of *Cladonia* and pleurocarpous mosses (perennial stayer), as soon as the physical disturbances of the medium (wind erosion and gradient of powdering by sand) decrease.

This phenomenon of diversification is conditioned and accentuated by the ecological characteristics of each site. The climate allows the development of Mediterranean-Atlantic species. The animal and human disturbances as well as the stress factors of soil (pH and oligotrophy) and the dynamic states of degradation of the vegetations between the rear fixed dune and the forest border (with Ericaceae and Cistaceae and forests of protection with *Pinus pinaster*, *Quercus ilex* or *Q. suber*) condition the 'zones of contacts' (Delcayrou, 1997) and the diversity and the availability of the microhabitats. The cryptogamic communities of the rear fixed dune, especially *Cladina* and acrocarpous mosses (perennial stayer, competitor, stress-tolerator), reflect the

multiplicity of the situations in the trajectories of evolution before the close vegetation translating to the forested dune. In a general way, the maximum of diversity out of mosses and lichens could be observed in sites presenting broad zones of semi fixed dune and fixed dune (one or more dune ridge), a minimum of anthropic disturbances (trampling) and a zone of contact to mixed forest (pines and oaks) of semi-diffuse type to diffuse.

Table V. The five communities of mosses and lichens show three states of stability of the dune: summary table

Communities	Species	State of Stability	Habitat
<i>Acrocarpous Mosses & Epiphytic Lichens</i>	<i>F. hygrometrica</i> <i>E. pr. var. arenaria</i> <i>B. spp.</i> <i>B. albicans</i> <i>T. ruraliformis</i> <i>C. tenax</i> <i>H. physodes</i> <i>T. flavovirens</i>		<i>Semi Fixed Dune</i>
<i>Mosses & small lichens</i>	<i>H. lutescens</i> <i>C. purpureus</i> <i>T. sedifolia</i> <i>C. pyxidata</i> <i>P. squarrosa</i> <i>D. scoparium</i>	Juvenile State	
<i>Pleurocarpous Mosses</i>	<i>P. rufescens</i> <i>C. furcata</i> <i>C. chlorophaea</i> <i>H. cupressiforme</i> <i>C. rangiformis</i>		<i>Fixed Dune</i>
<i>Cladina & Cladonia</i>	<i>C. portentosa</i> <i>C. arbuscula</i> <i>C. foliacea</i> <i>C. muricatum</i> <i>C. mitis</i> <i>C. introflexus</i> <i>C. ciliata</i>	Mature substitution State	<i>Rear Fixed Dune</i>
<i>Cladina & Mosses</i>	<i>P. juniperinum</i> <i>R. canescens</i> <i>C. mediterranea</i>	Mature diversified State	

Monitoring and management

The analysis of the biotic interactions within the communities confirms that the lichens take a significant part in the processes of maturation of the ecosystem (Jun, 2005). For their precise distribution, their composition and their possible roles in the ecosystem, the terricolous mosses and lichens communities can be regarded as « keystone species » (sensu Aronson *et al.*, 1995) in the functioning of the fixed parts of the littoral dune called ‘grey dunes’, priority habitats of the European Directive Habitats. The monitoring of the communities obtained can contribute to obtain an ecological diagnosis on the dunes and make possible the management decisions of these lands. Mosses and lichens inform us about the functioning of the dunes by their distribution, and their capacities to resist to the disturbances.

Because of their size (from 0.5 to 5cm, even 10cm in height) smaller than the phanerogams, and their natural discretion, it is more difficult to take into account on the management of the dune, plants which patterns are complex or that present difficulties in the identifications. The natural dune dynamics are at the origin of the modifications of the favourable conditions for their development with a greater reactivity in the changes than for vascular vegetation. The ‘health of an ecosystem’ corresponds to its faculty of resilience after disturbance. The patches of the communities (mosaic) of the carpet reflect the resilience of the habitats of the ‘grey dunes’. Consequently, it is necessary to integrate the mosses and lichens communities in the reflections of management of these very vulnerable habitats and to allow the perennity of the species in satisfactory population.

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Nomenclature

Purvis *et al.* (1992) for lichens.
Smith (1978) for bryophytes.
Tutin *et al.* (1968-1980) for vascular plants.

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PARALLEL THEMATIC WORKSHOP SESSIONS

Workshop ‘Hydrology and management of dunes and estuaries’
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The role of hydrogeological research in the realization of a combined pumping and deep infiltration system at the excavation 'Duinenabdij'

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Abstract

Hydrogeological interventions in ecologically valuable areas must be well studied beforehand. Modelling of these interventions based on field observations and field studies is herein a valuable step. This is illustrated with an example in the western Belgian coastal plain. A new drainage system had to be designed for the preservation of the archaeological excavation site 'OLV Ten Duinen'. This site is situated in a valuable and protected dune area. A system of pumping and deep infiltration of water was studied to optimise the draining of the site but to minimise the effects in the nearby dunes. A double pumping test was used to derive the relevant parameters. These were then used to simulate and find the optimal configuration of the extraction and deep infiltration wells.

Keywords: Hydrogeology; Parameter identification; Double pumping test; Modelling; Deep infiltration.

Introduction

The archaeological site of the medieval abbey 'OLV Ten Duinen' is situated in the dunes of Koksijde, Belgium (Fig. 1). Because of its low topographic level and the occurrence of a shallow semi-permeable layer, the excavation suffered from high water levels during the winter periods. Since the former draining was ineffective, a new drainage system was needed to preserve the archaeological relics. Furthermore, the conservation of the ecologically valuable dunes surrounding the site was a second objective in the realisation of the system. A profound knowledge about the hydrogeological characteristics of the concerning aquifer was indispensable to plan this system. A study of relevant literature (Lebbe, 1973, 1978; Lebbe *et al.*, 1984; Baeteman, 1985; Van Houtte *et al.*, 1992; Lebbe *et al.*, 1996; Van Houtte, 1998) provided a first insight in the hydrogeological constitution of the groundwater reservoir. The aquifer is composed of Quaternary sediments existing of three sandy, permeable layers, which are separated by

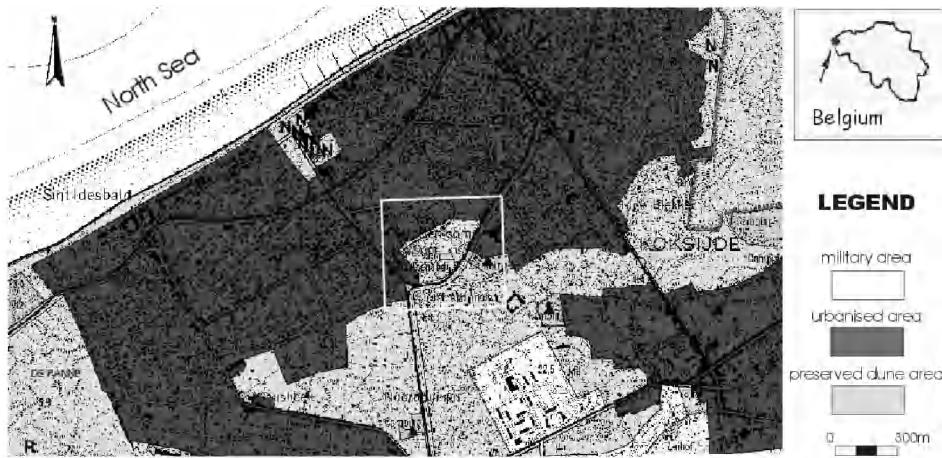


Fig. 1. Situation of the study area (white rectangle) and preserved dune areas.

two silty, semi-permeable layers (Fig. 2). Underneath, the aquifer is bounded by a Palaeogene clay layer considered impermeable in the scope of this study. The occurrence of the two semi-permeable layers was confirmed by the interpretation of borehole descriptions and geophysical borehole measurements, viz. electromagnetic conductivity measurements, in wells at different locations on the site (Louwyck, 2001; Lust, 2002). Because the entire groundwater reservoir contains fresh water (De Breuck *et al.*, 1974), the fluctuations of these conductivity measurements give a qualitative insight in the lithological constitution of the aquifer.

The former drainage system extracted only water above the shallow semi-permeable layer which caused a smaller infiltration through this layer. This explained largely its ineffectiveness to drain most of the recharge water away. A solution is to pump below the shallow semi-permeable layer so that a large part of the recharge water would flow through this layer deeper in the groundwater reservoir. However, this pumping would not only cause a descent of the water table at the excavation, but would also affect the surrounding dunes. Therefore, it would be necessary to deep infiltrate the pumped water in the two undermost permeable layers at the borders of the site. Modelling this system of combined pumping and deep infiltration, given the specific hydrogeological constitution, revealed the importance of an accurate knowledge of the hydraulic parameters of the concerning hydrogeological layers, particularly the hydraulic resistance of the two semi-permeable layers (Louwyck, 2001). Estimations of the parameters based on the interpretation of pumping tests executed in the vicinity of the study area were not reliable, because of the heterogeneous nature of Quaternary deposits in the Belgian coastal plain (Baeteman, 1999). The performance of a pumping test at the excavation was therefore inevitable. Moreover, in order to achieve a reliable deduction of the hydraulic resistance of both semi-permeable layers, it was necessary to execute a double pumping test affecting the two undermost permeable layers. The drawdowns recorded during these two tests were simultaneously interpreted by means of an inverse numerical model and this interpretation resulted in reliable parameter values. The model

simulating the system of combined pumping and deep infiltration based on the deduced parameter values gave a profound insight in the system’s effectiveness: not only the excavation would be drained properly, also the surrounding valuable dunes would be protected (Lebbe *et al.*, 2002; Lust, 2002).

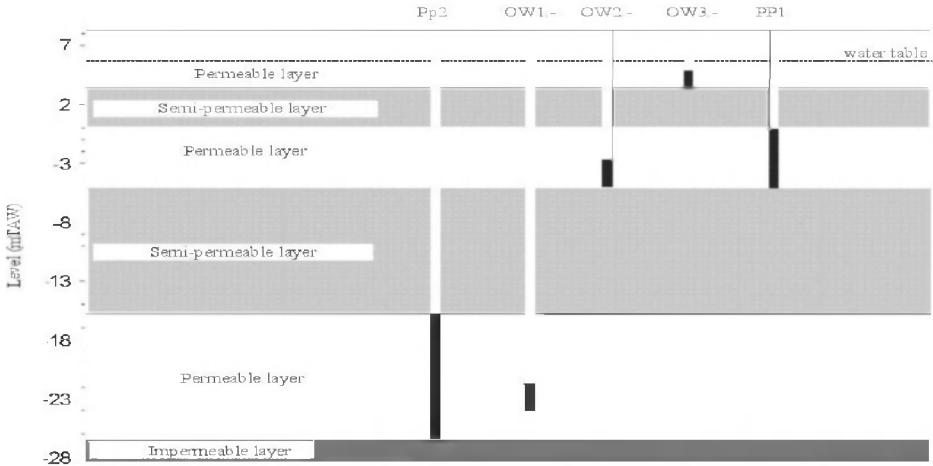


Fig. 2. Schematic constitution of the groundwater reservoir and position of screens (black) of pumping (PP-) and observation (OW--) wells. The mTAW is the Belgian ordnance datum, referring to mean low low seawater level, about 2.3m below mean sea level.

Methodology

Fig. 3 shows schematically the groundwater flow during a pumping test in an aquifer

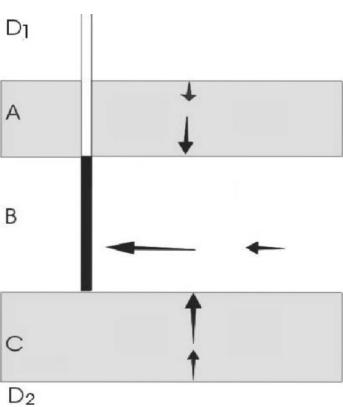


Fig. 3. Schematised flow towards a pumping well in a layered aquifer.

with permeable (B,D₁,D₂) and semi-permeable (A,C) layers (Vandenbohede and Lebbe, 2003). An amount of water is extracted from the permeable layer B, which causes a horizontal movement of water in this layer towards the pumping well. This groundwater flow is mainly characterised by layer B’s horizontal conductivity K_h ($\text{m} \cdot \text{d}^{-1}$) and specific elastic storage S_s (m^{-1}). The effect of pumping can be observed by the lowering of hydraulic head or drawdown s (m) in observation wells with screen in this layer. The pumping also causes a vertical movement of water from the adjacent semi-permeable layers to the permeable layer. This is called hydraulic leakage and is principally determined by the vertical conductivity K_v ($\text{m} \cdot \text{d}^{-1}$) and specific elastic storage S_s of layers A and C. The drawdown in observation wells with screen in D₁ or D₂ is caused by this leakage. The resulting groundwater flow towards the pumping well is treated by the following radial flow equation:

$$K_h \left(\frac{\partial^2 s}{\partial r^2} + \frac{1}{r} \frac{\partial s}{\partial r} \right) + K_v \frac{\partial^2 s}{\partial z^2} = S_s \frac{\partial s}{\partial t} \quad (1)$$

with r (m) the distance from the pumping well, z (m) the depth, and t (d) the time after starting of the test. Groundwater flow towards a pumping well can be considered in a layered heterogeneous groundwater reservoir with constant parameter values in each layer. Using drawdowns observed on different distances and times during a pumping test, one can deduce the mentioned hydraulic parameters by solving (1). HYPARIDEN (HYdraulic PARameter IDENTification) (Lebbe, 1999) is a set of computer codes developed as a generalised interpretation method for single and multiple pumping tests in layered heterogeneous aquifers. It is based on an axial symmetric, numerical model AS2D, specifically designed for the simulation of pumping tests. In that sense, the model has several advantages over frequently used numerical groundwater flow models in the analysis of pumping tests. HYPARIDEN also includes an inverse numerical model allowing the derivation of optimal values of hydraulic parameters or groups of hydraulic parameters from the observed drawdowns. All observations from different wells and on different times are involved together in the parameter identification process and in the case of a multiple pumping test, all observations from all tests are simultaneously interpreted. The algorithm of the inverse model is obtained by the combination of the forward numerical model and a non-linear regression algorithm. In the first step the forward model calculates the drawdowns on the concerning observation places and times. The second step involves a number of sensitivity analyses. Based on these sensitivities and the differences between calculated and observed data, the calculation of adjustment factors for the derivable hydraulic parameters is finally performed. By successive execution of these three steps the optimal values of the hydraulic parameters are derived iteratively along with their joint confidence region. In this study, the double pumping test was executed in the north eastern corner of the site. The relative position of pumping and observation wells is pictured in Fig. 4. The location of the well screens is shown in Fig. 2. During the first pumping test, a discharge of $178\text{m}^3\cdot\text{d}^{-1}$ was pumped on pumping well PP1 with screen situated over the entire depth interval of the middle permeable layer. Drawdown measurements were performed in this pumping well and in the observation wells on different times during the duration of the test, which is two days. In the second test PP2 with screen in the deepest permeable layer was used as pumping well. The discharge amounted to $599\text{m}^3\cdot\text{d}^{-1}$ and the duration of the test was three days. Again, the drawdown was measured in the pumping and observation wells on different times. Between the

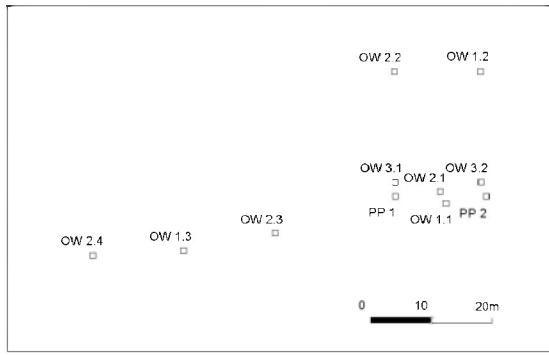


Fig. 4. Position of pumping and observation wells.

pumping well PP1 with screen situated over the entire depth interval of the middle permeable layer. Drawdown measurements were performed in this pumping well and in the observation wells on different times during the duration of the test, which is two days. In the second test PP2 with screen in the deepest permeable layer was used as pumping well. The discharge amounted to $599\text{m}^3\cdot\text{d}^{-1}$ and the duration of the test was three days. Again, the drawdown was measured in the pumping and observation wells on different times. Between the

two tests a 'period of recovery' of two days was needed to ensure the observations of the second test were not influenced by the first test.

After interpretation of the observed drawdowns by means of HYPARIDEN, which has resulted in reliable parameter values, it was possible to simulate the system of combined pumping and deep infiltration. In fact, an estimate of the drawdown due to simultaneously pumping and deep infiltrating in the different wells of the system was simulated. Knowing the hydraulic parameters of the groundwater reservoir and the discharges for the individual wells, this drawdown can be calculated by application of the rule of superposition (Lebbe, 1999):

$$s_l(x_m, y_n, t) = \sum_{p=1}^{nw} \frac{Q_p s_{AS2D}(l, r_p, t)}{Q_{max}} \quad \text{with} \quad r_p = \sqrt{(x_p - x_m)^2 + (y_p - y_n)^2} \quad (2)$$

where $s_l(x_m, y_n, t)$ is the drawdown (m) in layer l at x-coordinate x_m (m) of the m^{th} row of a mesh-centred grid, and y-coordinate y_n (m) of the n^{th} row of the grid, and at time t (d) after starting of the pumping system; x_p and y_p are respectively the x- and y-coordinates (m) of the p^{th} pumping well; Q_p is the discharge rate ($\text{m}^3 \cdot \text{d}^{-1}$) of the p^{th} pumping well; nw is the number of pumping wells; $s_{AS2D}(l, r_p, t)$ is the drawdown in layer l at distance r_p (m) from the p^{th} pumping well at time t calculated with discharge rate Q_{max} ($\text{m}^3 \cdot \text{d}^{-1}$) by means of the AS2D model. Note that the discharge rate Q_p is less than zero when the p^{th} well is a deep infiltration well. Thus, this rule states that the drawdown due to pumping on a multiple well field is equal to the sum of drawdowns due to pumping on each individual well and the drawdown due to pumping on an individual well is proportional to the discharge rate. The MULTPU-code in HYPARIDEN is designed to simulate drawdown due to a multiple well field by application of (2). Remark that (2) is only valid if the

groundwater flow is linear, meaning that in case of considerable interaction between the pumped aquifer and the surface waters, this model is not appropriate. In this study the assumption of linearity is justified and thus the estimated drawdown calculated by means of MULTPU is similar to the one calculated by means of MODFLOW, a groundwater flow model which can deal with interaction between groundwater reservoir and surface waters. In this particular case one could even state the requirement of boundary conditions makes the MODFLOW model less realistic and the estimated drawdown less accurate (Lust, 2002). To



Fig. 5. Location of pumping (closed bold line) and deep infiltration (northern bold line) zone.

simulate the combined pumping and deep infiltration system by application of (2), knowledge about its technical design is required, viz. the exact location of the different wells, the position of their screen, and their individual discharge rate. Fig. 5 shows the exact location of the pumping and deep infiltration zone. The 26 pumping wells with screen in the middle permeable layer are located around the relics of the excavation; the 24 deep infiltration wells with screen in the middle permeable layer are located at the northern boundary of the site. In between the latter wells, 12 deep infiltration wells with screen in the deepest permeable layer were constructed. The simulation of the system was performed with a discharge rate equal to $60\text{m}^3\cdot\text{d}^{-1}$ for each pumping well, a discharge rate equal to $-49,33\text{m}^3\cdot\text{d}^{-1}$ for each deep infiltration well with screen in the middle permeable layer, and a discharge rate equal to $-40\text{m}^3\cdot\text{d}^{-1}$ for each deep infiltration well with screen in the deepest permeable layer.

Results

The sensitivity analyses indicate that the optimal value of seven relevant hydraulic parameters or parameter groups could be deduced from the observations of the double pumping test (Lebbe *et al.*, 2002; Lust, 2002). Table I gives an overview of these parameters and their optimal value calculated by means of the inverse numerical model. The number between parentheses refers to the layer number, taking into account the layers are counted starting with the deepest permeable layer, the deepest semi-permeable layer, etc. C_v (d) is

Parameter group	Optimal value	Unit
$K_h(1)$	42.00	$\text{m}\cdot\text{d}^{-1}$
$K_h(3)$	13.80	$\text{m}\cdot\text{d}^{-1}$
$C_v(2)$	49.70	d
$S_s(1)$	7.120×10^{-5}	m^{-1}
$S_s(3-4)$	7.800×10^{-5}	m^{-1}
$S_s(2)$	2.090×10^{-5}	m^{-1}
$C_v(4)$	735.0	d

the hydraulic resistance of a semi-permeable layer, which is the thickness of the layer (m) divided by its vertical conductivity ($\text{m}\cdot\text{d}^{-1}$). Figs 6 and 7 show the time-drawdown and distance-drawdown graphs for respectively the first and second pumping test. The crosses indicate the observed drawdowns, the solid lines are calculated with the forward numerical model by using the optimal values of the hydraulic parameters. At first sight one can observe a good agreement between the observed and calculated drawdowns. Analysing the 424 residuals we inferred their distribution as normal with zero mean and total sum of squared residuals equal to 1.919. Remark the absence of observations in the uppermost permeable layer because of their insignificance: the high hydraulic resistance of the uppermost semi-permeable layer caused a drawdown with the same magnitude of observed natural head fluctuations. This high resistance is also the reason why the hydraulic parameters of the uppermost permeable layer are not identifiable, which means these parameters have little influence on the drawdown in the other layers. A rough estimate of their values is thus sufficient in the interpretation of the double pumping test and the simulation of the combined pumping and deep infiltration system. It's already been mentioned HYPARIDEN enables to deduce the optimal values along with their joint confidence region. The analysis of this confidence region gives an idea about the accuracy of the deduced values and their mutual dependency (Lebbe, 1999). For the double pumping test in this study, all parameter values show a moderate mutual

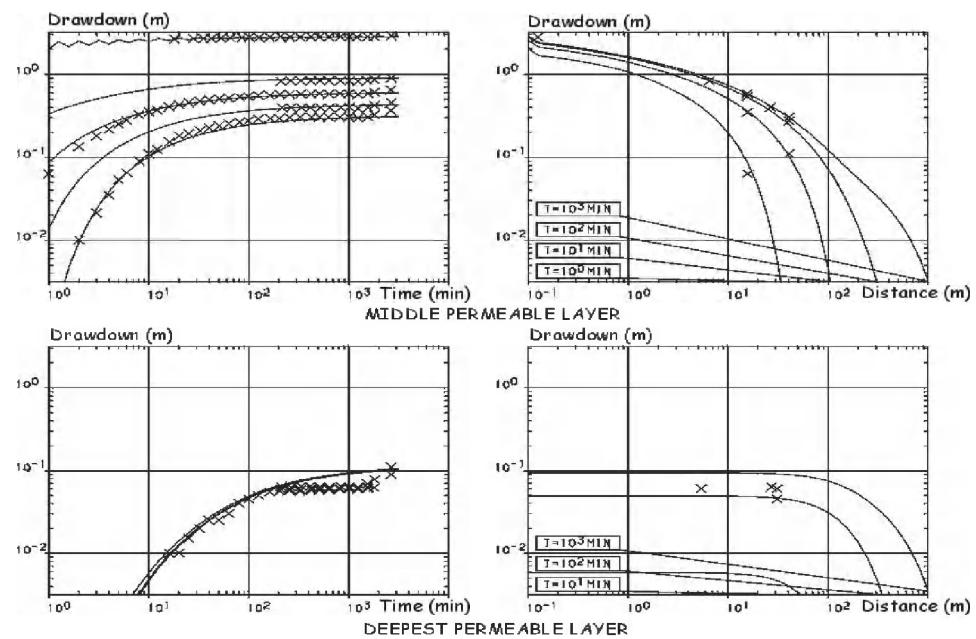


Fig. 6. Observed (crosses) and calculated (solid lines) drawdowns for the first pumping test.

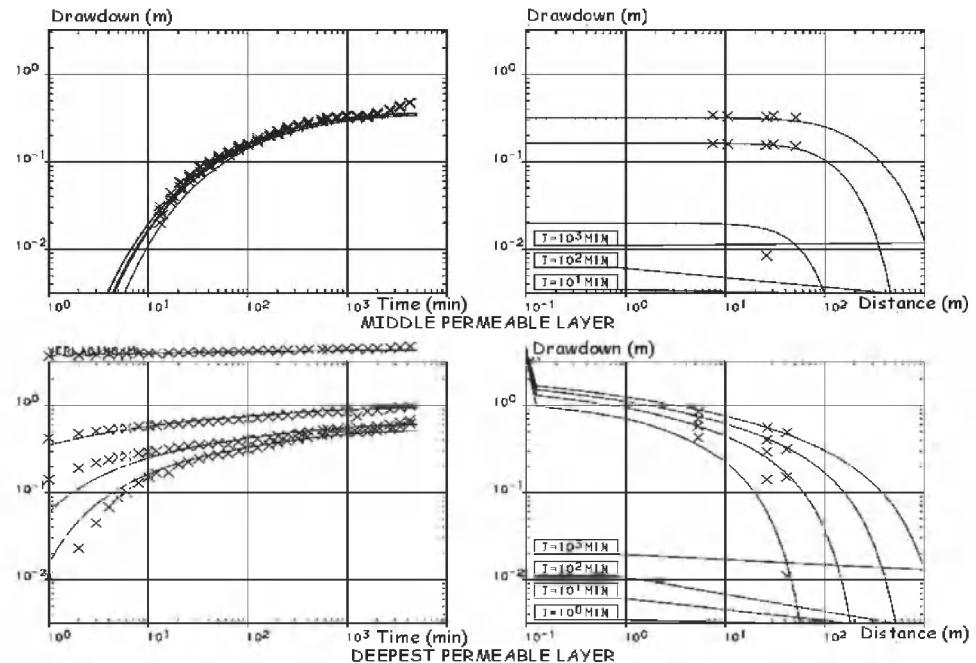


Fig. 7. Observed (crosses) and calculated (solid lines) drawdowns for the second pumping test.

dependency (Lebbe *et al.*, 2002; Lust, 2002). Moreover, the first five parameter groups in Table I are accurately inferred. The optimal value for $S_s(2)$, the specific elastic storage in the deepest semi-permeable layer, is less reliable. Finally, the deduction of the hydraulic resistance of the shallow semi-permeable layer is not accurate due to the lack of significant drawdown measurements in the uppermost permeable layer. However, by calculating the difference between the hydraulic head in the two uppermost permeable layers and estimating the infiltration rate of groundwater through the shallow semi-permeable layer, we can assign this parameter a more reliable value by application of Darcy's Law (Louwyck, 2001; Lust, 2002).

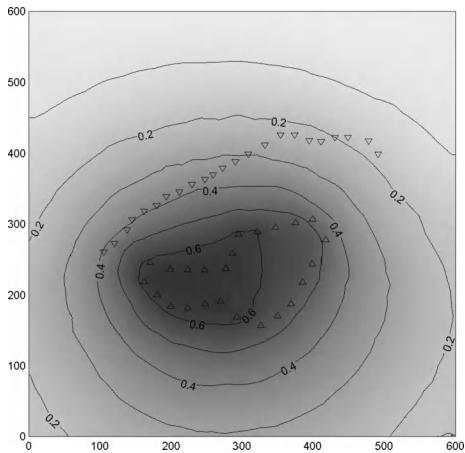


Fig. 8. Calculated drawdown (m) due to drainage system after 10^5 min in upper permeable layer. Triangles indicate position of pumping (triangle up) and deep infiltration (triangle down) wells.

estimated hydraulic resistance of the uppermost semi-permeable layer equals to 1300d (Lebbe *et al.*, 2002).

Figs 8, 9 and 10 show the contour lines of the drawdown simulated by means of MULTPU in the three permeable layers due to the combined pumping and deep infiltration of the drainage system after 10^5 minutes. The dimension of the simulated area is 600m x 600m and the y-axis is parallel to the north-south direction. Negative drawdown values are indicating a rising of the hydraulic head. In the middle permeable layer (fig. 9), which is directly influenced by the system, we see the appearance of a large 'depression funnel' and 'infiltration cone' at respectively the pumping and deep infiltration zone. A funnel and cone is also appearing in the deepest permeable layer (fig. 10), although less accentuated and not following the exact shape of the

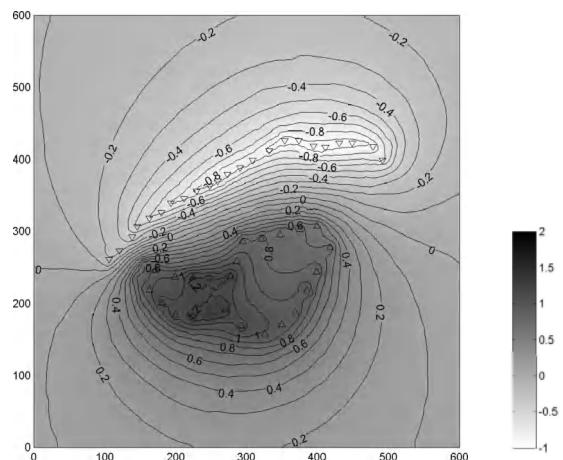


Fig. 9. Calculated drawdown (m) due to drainage system after 10^5 min in middle permeable layer. Triangles indicate position of pumping (triangle up) and deep infiltration (triangle down) wells.

well configuration because of the absence of pumping wells in this layer and the occurrence of the deepest semi-permeable layer. The high hydraulic resistance of the shallow semi-permeable layer and the dispersal of deep infiltrated water over the two deepest permeable layers are the reason why an infiltration cone is absent in the uppermost permeable layer (fig. 8). Looking more closely to this graph, the calculated lowering of the water table at the excavation is significant. Note that the lowering at the western part is higher than the lowering at the eastern part. It can also be seen that the drawdown in the surroundings is minimal and especially the northern part of the area is protected because of the location of the deep infiltration zone. In this particular case a configuration with a deep infiltration zone surrounding the entire area could be considered as ideal (Louwyck, 2001). However, not only hydrogeological requirements were playing a role in determining the most suitable configuration.

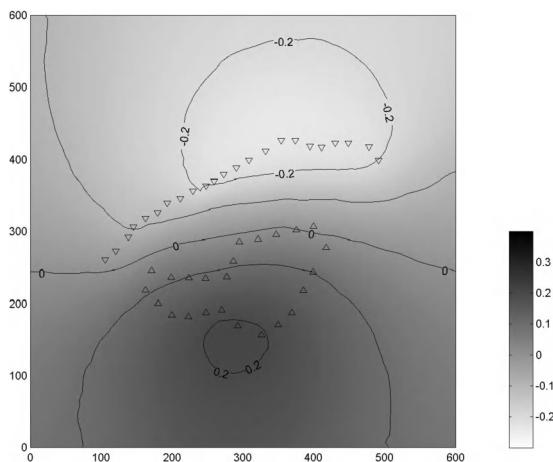


Fig.10. Calculated drawdown (m) due to drainage system after 10^5 min in upper permeable layer. Triangles indicate position of pumping (triangle up) and deep infiltration (triangle down) wells.

areas. In fact, the different steps in handling a hydrogeological problem in an efficient and scientific justified way could be inferred. Relevant literature was studied to have a first insight in the hydrogeological constitution of the concerning groundwater reservoir. Then supplementary information was gathered by means of borings, geophysical borehole measurements (conductivity measurements) and the performance of a double pumping test. The interpretation of this field data has made it possible to fill the gaps in the hydrogeological knowledge required to model the proposed drainage system accurately. The simulation of the system has showed its effectiveness in taking care of the problem.

Conclusions

Simulating the system of combined pumping and deep infiltration has proved its effectiveness in draining the excavation site without endangering the surrounding valuable dune area. In general, the system of combined pumping and deep infiltration is an outstanding method to create a local lowering of the water table. Moreover, the location of the deep infiltration zone can be chosen in a way the vulnerable area is optimally protected. Furthermore, this study has illustrated the important role of field tests and mathematical modelling in the planning of hydrogeological interventions in ecologically valuable

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Sustainable groundwater management of a dune aquifer by re-use of wastewater effluent in Flanders, Belgium

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Abstract

In July 2002 the Intermunicipal Water Company of the Veurne Region (IWVA) started with the production of infiltration water by the re-use of wastewater effluent. This new treatment plant, called 'Torreele', contains the following treatment steps: pre-screening, microfiltration (MF), cartridge filtration, reverse osmosis (RO) and ultraviolet irradiation (UV). The 'Torreele' plant is designed to produce $2,500,000\text{m}^3\cdot\text{yr}^{-1}$ of infiltration water, this is 40% of the current drinking-water demand. The flowchart is shown in Fig. 1. The whole project was developed to create a sustainable groundwater management of the existing dune water catchment. Because of the presence of salt water north and south of these dunes, the drinking-water production capacity was limited – increased production could cause saline water intrusion into the dune aquifer –. and by the end of the 1980's the IWVA was unable to further satisfy the increasing demand of drinking-water. Artificial recharge of the sandy unconfined dune aquifer was chosen as the best alternative: the production capacity could be increased and still the natural groundwater extraction could substantially be lowered. Pilot tests using membrane filtration techniques showed that, although stringent quality standards were set, wastewater effluent could be used as the source for the production of infiltration water. This presentation will describe the results of infiltration in the dunes, a period that will cover over three years. The infiltration water recharges the sandy unconfined dune aquifer, the residence time of the recharged water in the aquifer is minimum 40 days.

Keywords: Re-use; Membranes; Infiltration; Groundwater management.

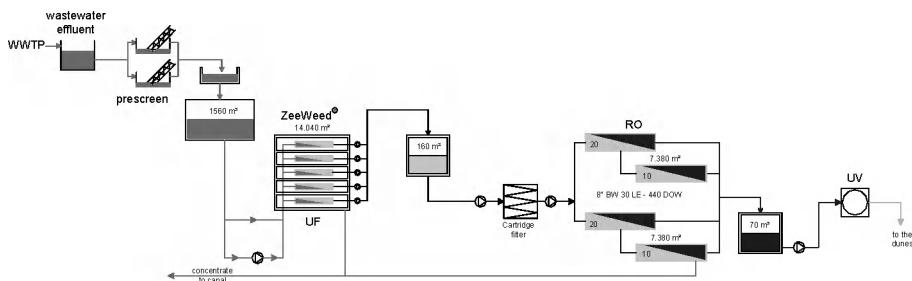


Fig. 1. Flowchart of the 'Torreele' plant.

Introduction

In the western part of the Flemish coastal plain, the options to obtain groundwater for potable water supply are limited to the unconfined aquifer under the dune belt. This dune region is of great ecological value, and as the Intermunicipal Water Company of Veurne-Ambacht (IWVA) historically produced potable water out of dune water, there has been a conflict of interests.

To comply with the ever increasing demand, not only the groundwater extraction increased but since the seventies of the previous century the IWVA took water from neighbouring companies, especially during the summer period when the demand is greater due to tourism. Fifteen years ago the IWVA started investigating alternative drinking-water production. This resulted in an infiltration project in St-André (Fig. 2). The infiltration water is produced in the newly built 'Torreele' plant, where wastewater effluent is used as the source and membrane filtration as the treatment technique.

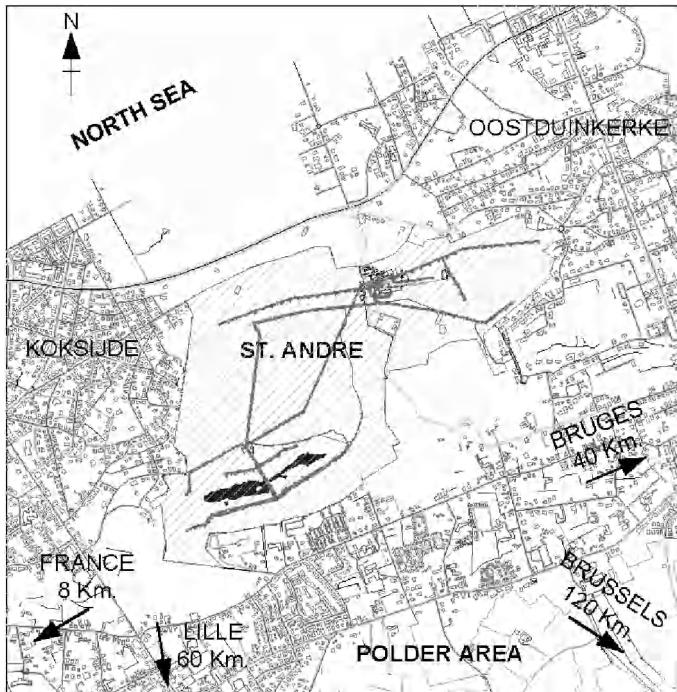


Fig. 2. Localisation of St-André and the infiltration project.

History of dune water extraction at the Flemish western coast

During World War I, the Belgian Army developed a water catchment in Cabour. In 1924 the infrastructure was taken over by the IWVA. As the company expanded, in 1947 a second dune water catchment, St-André, was started. Twenty years later a third water

catchment, the Westhoek in De Panne, was needed to fulfil the increasing drinking-water demand (Fig. 3).

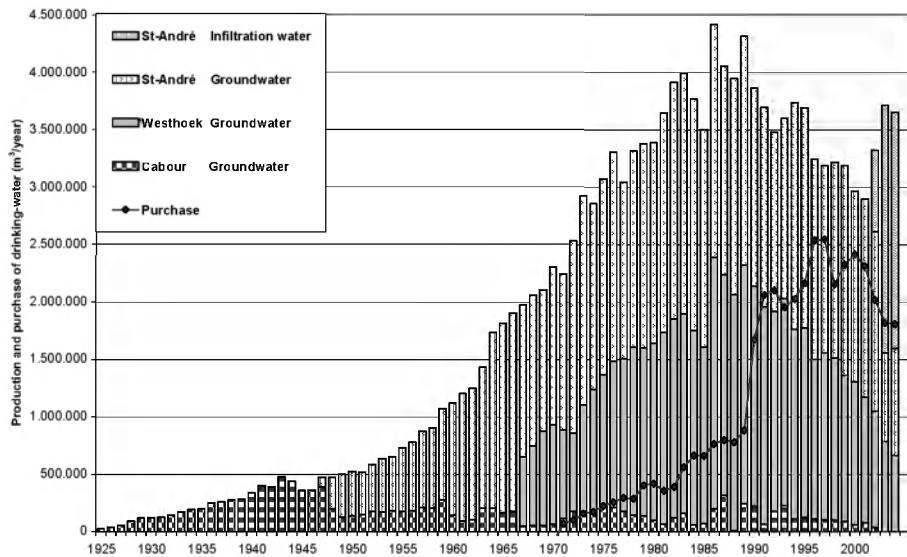


Fig. 3. Evolution of production and purchase of drinking-water by the IWVA.

The Flemish coastal dunes, that covered an area of 6,000ha in 1900, gradually declined. Nowadays only 3,400ha of these coastal dunes are left; 330ha or almost 10% are owned by the IWVA. The company played a role in preserving dune areas when St-André (125ha), initially planned for residential use, was purchased parcel by parcel. No opposition to dune water extraction is known in that period; economy prevailed.

The world changed after 1968: ecology suddenly became an important issue and this was translated into law. Today all IWVA dunes have to be preserved according to the EU Bird Directive and EU Habitat Directive.

From the beginning, the IWVA was confronted with the limits of the dunes as a source for drinking-water production. By the presence of salt water north and south of the dunes (under the sea and under the 'polder area'), too much extraction resulted into saline intrusion. In Cabour the salinity of the produced potable water increased in the nineteen-thirties and since the nineteen-fifties the extraction was limited to a maximum of $200,000\text{m}^3\text{yr}^{-1}$. St-André never had a problem with salinity. On the contrary, in the Westhoek the salinity increased rapidly since the nineteen-eighties. First the most saline wells were closed and starting in 1996 the extraction was gradually decreased. However by then the IWVA had already changed its policy and aimed, following the 1992 conference in Rio de Janeiro, for a sustainable groundwater extraction in its dunes. Artificial recharge of the unconfined dune aquifer, enabling a decrease of natural groundwater extraction, and related to ecological management of the dunes, was planned.

Ecological management of St.-André

In 1994 an ecological management plan for the dunes of St-André was launched. This plan was based on proposals of the Institute of Nature Conservation (Provoost *et al.*, 1993), an administration of the Flemish government. The goal was the restoration of the dunes as they were in the beginning of the 20th century when extensive pasture was done. To achieve this so-called ‘Massart landscape’, Shetland ponies were introduced after part of the Sea buckthorn was removed. Other measures taken were the removal of exotic trees (*e.g.* Wild rum cherry, Silver leaf poplar) and the conversion of a Pinus bush into an indigenous bush.

Besides those ‘ecological actions’, the recreational part of the area was re-managed. The many paths crisscrossing the area were reduced to one central path with a small inner circle within the area. Hiking with horses was also limited to one path situated at the border of the water catchment. A visitor’s centre was opened in 1996.

An ecologist, hired since 1995, is responsible for the execution of the management plan and the functioning of the visitor’s centre. Education plays an important role with a focus on the value of water and the rational use of it, and on the ecological importance of the area. During the last years the scientific evaluation of the management plan has also become an important part of the ecologist’s job.

The vegetation is monitored in 21 zones of 20 by 20m on a yearly basis. Those zones are spread over the water catchment of St-André in a way to have a good indication on the evolution in the area. The Institute of Nature Conservation is involved.

Besides specific plants are monitored all over the area. For the fauna the same is done for dragonflies, grasshoppers and butterflies. During the summer and migration period of birds, they are ringed to get an evolution on the number, age and sex of the birds.

All this information is used for the evaluation and adjustment of the ecological management. In 2003 and 2004 some valuable species (*e.g.* Bristle Club-rush, Blue pimpernel, Blunt-flowered rush, Pond weed, Brookweed) have been monitored around two bombing wells near the infiltration pond. They are the indication that the infiltration project offers opportunities for natural development in the area.

Artificial recharge in St.-André

After many years of pilot testing, the full scale plant treating wastewater effluent for the production of infiltration water, started on July 8th, 2002 (Van Houtte and Verbauwheide, 2003). This plant, called ‘Torreele’, according to the area where it has been built, is situated near the wastewater treatment plant (WWTP) of Wulpfen, 3km south of St-André. The WWTP Wulpfen, operated by Aquafin, treats domestic wastewater from the IWVA distribution area.

Based on the experience of the pilot tests, the IWVA has chosen the following steps to further treat the effluent: microfiltration (MF), cartridge filter, reverse osmosis (RO),

ultraviolet irradiation (UV). The RO filtrate, which had a low salt content, initially was mixed with 10% of MF filtrate for partial re-mineralization. Since half May 2004, this is no longer done and RO filtrate is directly re-mineralized by dosing chemicals. This water is recharged in the sandy unconfined dune aquifer. After a residence time in the aquifer of minimum 40 days, the water is recaptured by wells with filter elements between 8 and 12m depth. After aeration and sand filtration, to remove the iron and manganese, potable water is produced.

The infiltration area has been located in a zone where infrastructure was present (Fig. 2). No 'virgin' dune areas had to be accessed. Stringent standards were set for the quality of the infiltration water, especially concerning nutrient content (Table I). The infiltration water should be totally recaptured. For this reason, the wells surround the infiltration area and the extraction volume is 1.4 the volume of infiltration.

Table I. Standards for infiltration water and average quality of infiltration water

Parameter	Standard	7/2002 – 5/2004	6/2004 - 5/2005
pH	>6.5 and <9.2	5.62 – 7.67	6.05 – 7.16
Temperature (°C)	25	15.5	15.2
Conductivity ($\mu\text{S.cm}^{-1}$)	1,000	148	48
Totale hardness (°F)	< 40	3.6	<1
Sodium (mg Na. l^{-1})	150	17	11
Total phosphorous (mg P. l^{-1})	0.4	<0.2	<0.1
Nitrate (mg NO ₃ . l^{-1})	15	6.8	2.1
Ammonia (mg NH ₄ . l^{-1})	1.5	0.31	0.19
Sulphate (mg SO ₄ . l^{-1})	250	10	<1
Chloride (mg Cl. l^{-1})	250	21	2.5

Benefits of artificial recharge

The IWVA is allowed to infiltrate 2,500,000 $\text{m}^3.\text{yr}^{-1}$. The infiltrated volume should be totally re-extracted. An extra 1,000,000 $\text{m}^3.\text{yr}^{-1}$ of natural groundwater can be extracted in the infiltration area (ZP2), and 700,000 $\text{m}^3/\text{yr}^{-1}$ in another zone of St-André (ZP1). This volume is a reduction for natural groundwater extraction by 300,000 $\text{m}^3.\text{yr}^{-1}$ compared to the pre-infiltration period. In the Westhoek the natural groundwater extraction had to be reduced by 700,000 $\text{m}^3.\text{yr}^{-1}$ to a maximum of 1,000,000 $\text{m}^3.\text{yr}^{-1}$.

The first years of infiltration showed that the quality of the infiltration water was very good (Table I). The nutrient and salt content are far below the standards and it even improved when MF filtrate no longer was used to produce infiltration water.

The first important action taken by the IWVA after infiltration started in July 2002, was to stop the production in Cabour. This is an old and small dune ridge 3.5km inland.

In the Westhoek, where groundwater extraction was reduced since almost 10 years, the extraction could further be reduced to 750,000 $\text{m}^3.\text{yr}^{-1}$ in 2004 (Fig. 3). It resulted in a

substantial rise of groundwater levels (Fig. 4) within the catchment itself (UG32 and WP5.2), but also in the neighbouring nature reserve, where more wet zones were reported over the past years. There is a net outflow of groundwater out of the dunes which will on the longer term restore the quality of the dune aquifer.

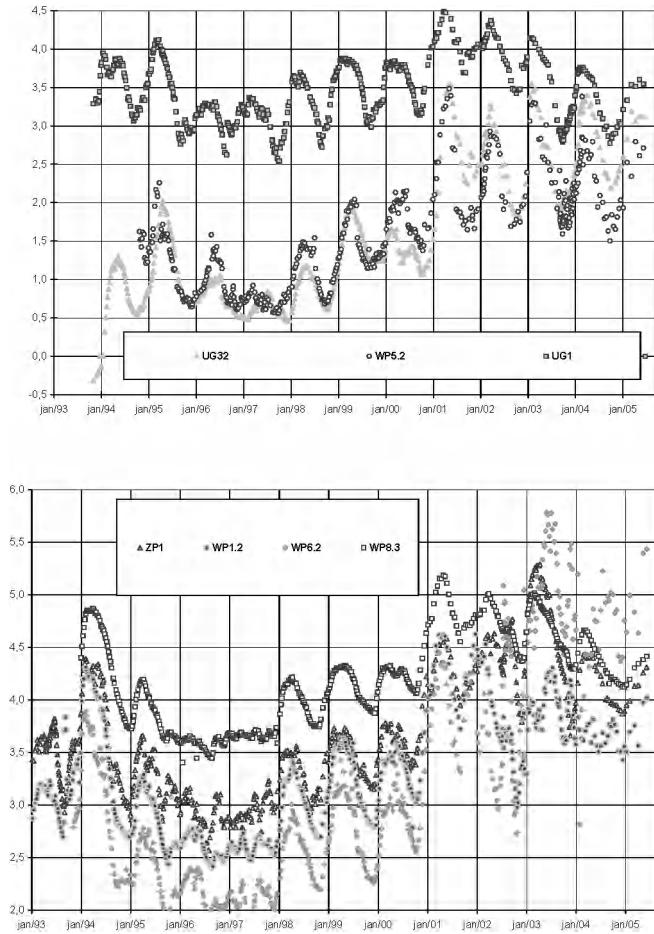


Fig. 4. Groundwater levels (in mTAW) in the Westhoek (upper chart) and St-André (lower chart).

In St-André, the extraction of natural groundwater was reduced since the start of infiltration (Fig. 3) and this resulted in an increase of groundwater levels (Fig. 4). The level at the centre of the infiltration area (WP6.2), near the infiltration pond, is about the same as in Ter Yde, a dune area 3km east of St-André uninfluenced by groundwater extraction. The groundwater in that zone is close to ground level creating opportunities for phreatophytes. North of St-André (WP8.3) there is also a relative increase of groundwater levels, which means that more dune water is running off towards the sea.

indicating the extraction of groundwater is sustainable. Groundwater samples taken from different wells in and around the infiltration area showed that the infiltration water is totally recaptured.

Since the infiltration started, the drinking-water produced in St.-André is soft. This is an important progress for the customers (comfort) and for the environment. Individual softeners are no longer needed, saving on the consumption of water, energy and chemicals. Also less soap should be consumed.

Long term vision on groundwater management

The IWVA opted for a status-quo in St-André but will further reduce the groundwater extraction in the Westhoek. From currently $1,000,000\text{m}^3\cdot\text{yr}^{-1}$ allowed to a maximum of $500,000\text{m}^3\cdot\text{yr}^{-1}$ in 2010. It means that the overall production capacity in 2010 would be $4,700,000\text{m}^3\cdot\text{yr}^{-1}$, $2,200,000\text{m}^3\cdot\text{yr}^{-1}$ being natural groundwater. This is a reduction of 40% compared to 2002, before infiltration started. These volumes guarantee a sustainable groundwater extraction assuring the good quality of the dune water on the long term. As the extraction is limited to restricted areas it will further benefit to the natural development of those dunes and in this way the EU Bird and Habitat Directives would be respected.

Conclusion

The authors are well aware that it will never be possible to convince all environmentalists, but they believe that the IWVA made substantial efforts to reconcile ecology and economy in its dunes. Thanks to infiltration and reduced groundwater extraction, the groundwater levels already restored considerably and will further do, especially in the Westhoek. This guarantees the preservation of specific habitats in the dunes. The income from drinking-water sponsors the natural management of the dunes and the education of the visitors. Without this, the government should have to spend more money to respect the Bird and Habitat zones they defined.

Ten years of natural management in St-André resulted already in an opener landscape. Some important species (flora and fauna) are more abundant or did come back in the dunes.

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The importance of groundwater and other ecohydrological impacts in the management of salt marsh plant communities

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Abstract

Salt marshes are characterized by the presence of plants tolerant of some degree of salinity, although freshwater inputs can also be a significant component of the ecosystem. Sources and routes of freshwater can include river flow into the estuary, groundwater flow along a defined aquifer or channel and diffuse seepage as well as rainfall. In addition both fresh and saltwater flows can be the agents of transport to and from the marsh itself of sediment, mineral nutrients, pollutants and particulate and dissolved organic carbon. A common feature of many valley salt marshes is the presence of seepages of freshwater, particularly along the edge of the upper marsh, local upwelling or flow through permeable soil layers within the marsh. They can often be distinguished by the presence of plant species not fully tolerant of seawater. The commonest is *Phragmites australis* which can be seen as isolated clumps marking localized freshwater seepages or more widespread in areas where the soil salinity is reduced by a generalized freshwater input. While surface and groundwater flow can provide necessary plant nutrients excessive nutrient loading can result in hyper-eutrophic conditions with major effects on the biodiversity of the flora and fauna. Groundwater flows can cause the transport of these nutrients over considerable distances necessitating the use of special techniques to determine their source. This study also showed that excessive nutrient levels could be transported through to near-shore sediments with possible effects on marine habitats. Generally, however, salt marshes can be regarded as sinks which control the eutrophication of coastal waters by removing excessive nutrients. More is known about groundwater dynamics in wet coastal grasslands, enabling the prediction of changes. The installation of extensive instrumentation at specific sites has enabled the development of numerical models to study the groundwater dynamics of the forest-marsh interface. The next major step will be to integrate these various models in such a way that for any given salt marsh the underlying ecological processes can be understood sufficiently to develop management techniques. It has been demonstrated that current measures may be inadequate to restore fully the ecological processes of a healthy robust estuary or to reinstate the full beneficial functions of the estuarine ecosystem. This shows that the successful management of estuaries and coastal waters requires an ecohydrology-based catchment-wide approach. This will require a change in thinking and in management concepts for all estuaries and coastal waters.

Keywords: Salt marsh; Groundwater; Ecohydrology; Habitat creation.

The salt marsh habitat

Salt marshes are characterized by the presence of plants tolerant of both immersion in water for varying periods and some degree of salinity, although freshwater inputs can also be a significant factor in many marshes. There are various sources and routes of freshwater into a salt marsh. These can include river flow into the estuary, groundwater flow along a defined aquifer or channel or diffuse seepage, and also directly as a result of rainfall on the marsh and through surface flow from adjacent slopes. However, in general terms little attention has been paid to freshwater inputs and impacts on salt marshes except from the point of view of the effects of rainfall on the acceleration of seed germination of many plant species and the effect of river flow on the overall salinity of the water body at particular points in an estuary.

It has been shown that saltwater flows can be the agents of transport to and from the marsh itself of sediment, mineral nutrients, pollutants and particulate or dissolved organic carbon (Hazelden and Boorman, 1999). It would seem probable that where there are freshwater flows in a salt marsh a similar effect may be expected. Additionally as excessive nutrient levels in an estuary (White *et al.*, 2004) can affect the marsh plant communities it would seem likely that nutrients brought in by freshwater could have a similar impact.

Water routes in salt marshes

A common feature of many valley salt marshes is the presence of seepages of freshwater, particularly along the edges of the upper marsh and local upwelling or flow through permeable soil layers within the marsh. Affected areas can often be distinguished by the presence of plant species not fully tolerant of sea water. The commonest is *Phragmites australis* which can be seen as isolated clumps marking localized freshwater seepages or more widespread in areas where the soil salinity is reduced by a generalized freshwater input. In addition freshwater from adjacent agricultural land often drains onto salt marsh or into the creeks, bringing with it nutrients or pesticides.

Salt marshes are commonly developed on fine-textured sediments with the particle-size in the clay and fine silt range, and consequently the permeability of such soil might be expected to be low. An inspection of many salt marshes shows that this is a simplification of the true picture. At low tide, water is seen to seep from the sides of marsh creeks from a variety of fissures and holes in the otherwise slowly permeable marsh clays and silts. These more permeable layers can be either physical or biological in origin. Physically cracks and fissures develop when the soil dries out and the clay shrinks. Although these will close up on rewetting, they remain a permanent feature of the soil structure. In addition, coarse-textured horizons within the soil (perhaps sand and shell debris deposited during a storm) give rise to more permeable layers within the soil. More permeable layers, of biological origin, can result from the residual channels left after the death and decay of roots and other underground plant material. They also result from the burrowing activities of varied intertidal fauna, from crabs and molluscs through to the many different groups in the meso- and micro-fauna. Water movement paths are

also created in the marsh soil by the burial of layers of organic matter such as are created when the autumn fall of leaf material is buried by high rates of accretion during equinoctial tides. These layers are quite persistent as they are sometimes visible a hundred millimeters below the surface which, in a marsh with a mean annual accretion rate of around 3mm, represents an age of the order of 30 years.

Thus within a marsh developed on mainly fine material there is a wide range of potential routes for water movements. In addition there are a significant number of marshes based on coarse silts and sands where water movements are not nearly as restricted. In such marshes water flows and the associated fluxes are likely to be considerably enhanced in comparison with those in more typical marshes.

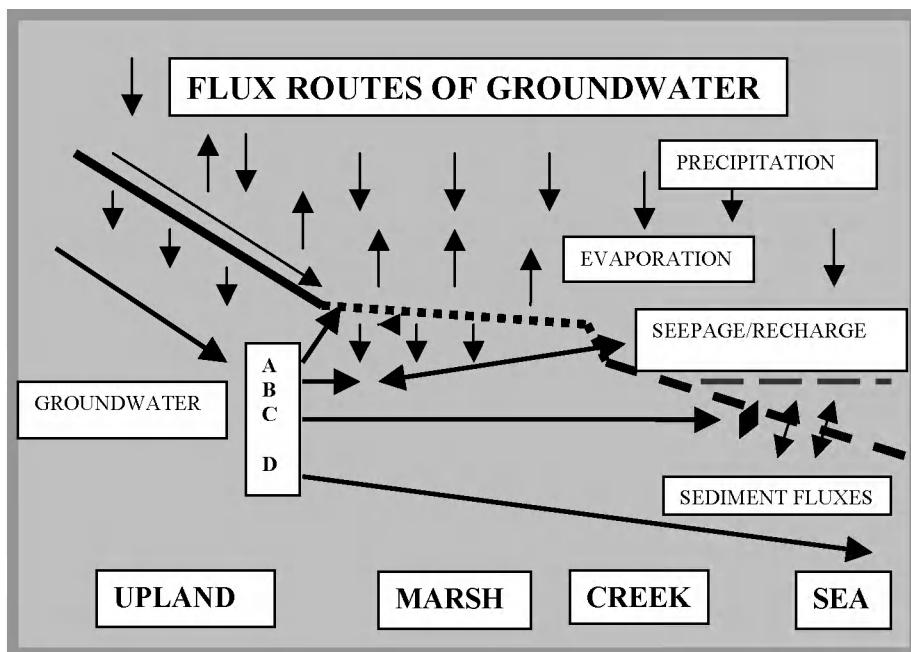


Fig. 1. Diagrammatic representation of the principal routes of water flow in a typical salt marsh. Specific groundwater routes:- A – seepage at junction between marsh and higher ground; B – horizontal percolation outwards through marsh soils and recharge during tidal immersion; C – seepage below main marsh layers; D – seepage through subsoil/underlying strata below the marsh.

While there is much variation in the precise details of the water flow routes in the marsh it is the major routes that should be of most concern and these are summarised in Fig. 1. The two major driving forces are the flow of groundwater from the higher ground ('upland') adjoining the marsh and the bidirectional flow from the tidal waters on the seaward side of the marsh. There is also the direct impact of rainfall on to the marsh surface. All three of these have a more or less visible effect on the side of the marsh which they directly impact (the landward edge, the seaward edge and the top surface

respectively), but within the body of the marsh there are complex interactions at various points depending on the magnitude and timing of each of them. The magnitude of local water movements will depend on differentials in the pore water pressure as well as the hydraulic conductivity of the sediments at a particular point in the marsh.

The dynamics of porewater nutrients has not so far been studied in great detail in salt marshes but it is clear from work on the porewater of an intertidal sand flat that nutrient concentration gradients can generate diffusive fluxes to and from the deeper sediments and that the increased oxygenation during emersion affected nitrification and nitrate reduction rates (Kuwa et al., 2003). Microbial nitrate reduction occurred in the deeper subsurface sediments and this process was supported by the downward diffusive flux of nitrate from the surface sediment. It might be expected that in the less porous salt marsh soils similar processes might occur at a slower rate, however, even in the more porous sandy sediments both the soil water content and the levels of the water table changes little during immersion suggesting that porosity was not a particularly important controlling factor.

Hydrological impacts on salt marshes

While surface and groundwater flow can provide necessary plant nutrients excessive nutrient loading can result in hyper-eutrophic conditions with major effects on the biodiversity. It has been shown that groundwater flows can cause the transport of these nutrients over considerable distances (Mayer et al., 2000). This study also showed that excessive nutrient levels could be transported through to near-shore sediments with possible effects on marine habitats. This is an extreme situation and more generally salt marshes can be regarded as sinks which control the eutrophication of coastal waters by removing excessive nutrients from the system (Teal and Howes, 2000).

As well as affecting the concentrations and fluxes of nutrients, organic matter and sediment associated with a salt marsh, the hydrology of the marsh can also affect the physical conditions within a marsh. It has been shown that variability in evapotranspiration and tidal flooding can affect the soil volume and consequently the precise level of the surface of the marsh (Paquette et al., 2004). This effect is of primary importance in making accurate measurements of accretion/erosion in marsh development. Such measurements are crucial both in the study of salt marsh processes and in the monitoring of success in salt marsh creation. Undetected changes in marsh levels could also have significant consequences for physical and biological processes on the surface of the marsh; in particular on the patterns of seed dispersal and germination and thus the subsequent resultant patterns of plant colonization.

The discussion so far has related to salt marshes in temperate, relatively damp and cool, areas. In drier and warmer areas of the world the input of freshwater becomes of increasing importance to the salt marsh. In South Africa it has been shown that the salt marsh plants are only in active growth during the winter rainfall period (Bornman et al., 2002). During the dry season plants are dependant for their survival on access to saline groundwater. The occurrence of winter rainfall ensures the replenishment of the saline

groundwater with freshwater both decreasing the depth of the water table and reducing its salinity thus facilitating plant growth.

Techniques for studying salt marsh hydrology

Groundwater flows, with the possibilities of their transporting nutrients over considerable distances, necessitate the use of special techniques to determine their source. In one study, involving the leakage of partially treated sewage, the molecular marker coprostanol was used to assess nutrient inputs to a marsh (Mayer *et al.*, 2000). Radio-isotopes have also been used to trace groundwater pathways. Routes and flux rates of submarine groundwater discharge in a Massachusetts salt marsh were determined using four radium isotopes (Charette *et al.*, 2003). These workers also showed that under drought conditions seawater-sediment interactions were important in delivery of certain dissolved substances to coastal waters. In another study in North Carolina the isotopic composition of dissolved inorganic carbon was used to define a component of the surface water-groundwater system (Gramling *et al.*, 2003). The work demonstrated that, when precipitation was low, artesian groundwater discharge accounted for virtually all the freshwater input to the marsh while in wet periods there was a negligible groundwater contribution.

Studies continue to collect long-term real-time data on the ecohydrology of salt marshes and to develop mathematical models to interpret the various processes involved (Crowe *et al.*, 2004). More is known about groundwater dynamics in wet coastal grasslands, enabling the prediction of changes (Mohrlok, 2002). Reeves and Fairborn (1996) installed extensive instrumentation to enable the development of a numerical model to study the groundwater dynamics of the forest-marsh interface. The next major step will be to integrate these various models, possibly through the use of a decision based support system, in such a way that for any given salt marsh the underlying ecological processes, including the magnitude and direction of the various fluxes, can be understood sufficiently to develop effective management techniques.

Groundwater and the implications for salt marsh management

The most direct effect of groundwater on salt marshes is the opportunity it offers for the transport of pollutants into the salt marsh ecosystem. Salt marshes adjacent to intensively used farm land can have significant concentrations of selective herbicides (Fletcher *et al.*, 2004). The transport was by both surface and sub-surface routes. While it was not possible to demonstrate a detectable effect on the vegetation the residual herbicide concentrations measured in this study were above the UK environmental safety guidelines.

The implications of groundwater quality for the management of salt marshes can also be inferred indirectly. Studies in Japan showed that the use of excessive fertilizer could affect the use of the water for irrigation (Fujiwara *et al.*, 2002). Seawater intrusion into the aquifer was also shown to be having an impact on water quality but the situation was complicated by the activity of cation exchange phenomena.

As well as the ionic transport of plant mineral nutrients there can be significant fluxes of dissolved inorganic carbon with significant contributions from the degradation of organic carbon (Cai *et al.*, 2003). These studies showed that the groundwaters in the marsh in South Carolina are mixtures of sea water and freshwater and that the end-members are modified by the input of CO₂ from the degradation of organic matter. Furthermore the work demonstrated that there were significant groundwater fluxes of dissolved inorganic carbon from the land to the sea via the salt marshes.

Mention has already been made of the serious effects groundwater pollution can have on salt marshes but while efforts are being made to reduce the inputs of excessive nutrient levels as yet there has been little work on controlling groundwater pathways. However, in a situation where the reverse problem has occurred, that of saline intrusions in fresh groundwater, a degree of groundwater control has been achieved by modelling the discharge matrix and then by the selective drawdown through controlled pumping (Zhou *et al.*, 2003).

The relation of the salt marsh and freshwater flows is often seen simply in terms of a stream or river flowing to the sea, through an area of salt marsh, and measurement of the incoming river flow will thus be considered to characterise the freshwater input. However, in practice salt marsh areas often have many freshwater inputs from a number of distinct areas with very different types of land cover and land use. Such was the case in a study of salt marshes in South Carolina where, through the development of a conceptual model, it was shown that the monitoring of creek headwaters could give early warning of possible harmful effects on tidal areas with serious implications both for conservation and economically important activities (Holland *et al.*, 2004).

Hydrological aspects of salt marsh creation

The re-creation of salt marshes on land which was originally salt marsh would in the hydrological sense seem fairly straight forward. However, there can be problems caused by the changes that will have taken place to the sediment and soils while the land has been used for agriculture or grazing (Hazelden and Boorman, 2001). The most obvious physical change is the 'ripening' of the soil; this is the irreversible drying of the sediment by evapotranspiration during which the bulk density increases and porosity decreases. Soil structure, a semi-permanent network of cracks throughout the soils delineating soil 'peds', also develops, and the salt (NaCl) will have been leached from at least the upper layers of the soil. On some newly-created salt marshes the old agricultural soil is rapidly buried by the accumulation of new sediment, which provides a good medium for the germination and growth of salt marsh plants. However, where this does not happen, the establishment of salt marsh vegetation may be hindered in these dry, dense soils.

The physical properties of reclaimed marsh soils are little altered by the reversion of the land to salt marsh, and their burial by new sediment. However, the relatively dense subsurface layer will affect subsequent creek development. Drainage patterns established

on a site prior to its reversion to salt marsh will, to a great extent, control those that subsequently become established.

In some sites salt marsh re-creation may be complicated by other factors. It has been shown that some grassland communities of saline areas are very much dependant on the up-welling of groundwater through a saline peat layer (Beyen and Meire, 2003). In order to compensate for the loss of such areas it was necessary to make detailed hydrological studies, albeit on a fairly local scale, to locate the relative rare occurrence of sites suitable for this type of habitat creation.

Even when there are no such special conditions for the re-creation of salt marsh the changes in the soil hydrological regime which occurred while the marsh was under agricultural use, and no longer subject to regular tidal flooding, are considerable. The effects of the changes in tidal level were limited to small changes in the level of the underlying water table (Blackwell *et al.*, 2004). Consequently there were major adjustments following the return of tidal flooding. Not only was there the direct effect of the immersion in saltwater but there were also a wide range of changes in both physical and chemical soil properties. Changes in soil water table resulted in the soil environment changed from an oxidising to a reducing environment. In the short term there were changes in soil pH, with the topsoil water becoming markedly acid. There were also large decreases in the rates of decomposition of organic matter. All of these effects have serious implications for the establishment of salt marsh vegetation and subsequent salt marsh management.

The sustainable long-term management of created salt marshes must be a key part of any such programme and there are a range of issues involved (Boorman and Hazelden, 2004). While the successful establishment of vegetation cover may only take a few years much longer time periods are needed before anything like full ecosystem function is achieved. A recent study of the rate of ecosystem development in created *Spartina alternifolia* marshes (Craft *et al.*, 2003) showed, while most of the functional ecological attributes have achieved equivalence to those in nearby natural marshes in 5 to 15 years, the levels of pools of organic carbon and nitrogen are still lower than in the natural marshes even 28 years after marsh creation. This work involved the study of a wide range of ecological processes and this may not always be possible when there is extensive marsh creation.

It is important however to note that simpler methods of assessment may give misleading results. Studies in a range of healthy and impaired salt marshes in Louisiana showed that the state of the above-ground biomass was not a good indicator of marsh health (Turner *et al.*, 2004). However, the work did show that marshes under stress have a reduced below-ground biomass which could be detected long before there was any detectable effect on the vegetation above-ground thus giving the possibility of applying appropriate management techniques.

Ecohydrology – the new approach

The case for salt marsh creation in order to compensate for lost or degraded marshes has been well made but at present the remedial measures suggested are considered to be inadequate to fully restore the ecological processes of a healthy robust estuary or to reinstate the full beneficial functions of the estuarine ecosystem (Wolanski *et al.*, 2004). These authors consider that the successful management of estuaries and coastal waters requires an ecohydrology-based catchment-wide approach. This will necessitate changing present practices which are based on local administrative units and on the narrowly focused approaches of managers of specific activities (including fisheries, water resources and urban development). Without this change in thinking and in management concepts estuaries and coastal waters will continue to degrade whatever management plans are put in place.

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Supporting dune management by quantitative estimation of evapotranspiration

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Abstract

Research was conducted in the nature reserve De Westhoek (B) in order to estimate the hydrological impact of shrub removal in favour of the recolonisation and development of herbaceous vegetation types in the dune slacks. Dune slacks are one of the most rare ecotopes in Europe. Therefore, the evapotranspiration of herbaceous and shrub vegetation types was estimated based on experimentally obtained data and modelling. Analysis of the experimentally obtained stomatal resistance values revealed that there was no difference in the minimal stomatal resistance values (in absence of any stress) between herbs and shrubs. Stomatal resistance was modelled based as a function of climatic variables. Maximal rooting depth was similar in both vegetation types, and was maximal 60cm. For both vegetation types more than 60% of the roots were found in the upper 15cm. The mean leaf-area-index (LAI) of herbaceous and shrub vegetations is respectively 2.11 ± 0.34 and $3.27 \pm 0.20 \text{ m}^2 \cdot \text{m}^{-2}$. Evapotranspiration of both vegetation types was modelled with a multi-layer dynamic vegetation model FORUG and seasonal evapotranspiration amounted roughly 200 and 550mm for the herbaceous and shrub vegetation types respectively. Although these estimates can be somewhat refined, from these results it can be concluded that shrub removal, and the replacement of this vegetation type by a herbaceous vegetation type, will not result in a lowering of the groundwater table. This knowledge can help managing hydrologically disturbed dune ecosystems.

Keywords: Dune slack; Stomatal resistance; LAI; Rooting depth; Modelling.

Introduction

The Flemish dunes comprise a number of very specific and rare ecotopes (Provoost and Hoffmann, 1996), especially moist dune slacks are considered as one of the most important ecotopes concerning biodiversity. During the last decades the lowering of the groundwater table and the shrub encroachment have led to a decrease of the rich diversity of the herbaceous vegetations and of the surface of these vegetations. In several hydrologically intact dune areas, shrub vegetations are recently partly removed, enabling the development and recolonisation of herbaceous vegetations.

However, large-scale intervention in the vegetation dynamics of a relatively natural ecosystem like coastal dunes requires a profound insight of the most important ecological processes, like evapotranspiration. Therefore, knowledge of water consumption of a number of the most important herbaceous and shrub species for these ecosystems can allow to support management decisions, especially large-scale shrub removal projects.

The main objectives of this paper are (i) the study of the evapotranspiration characteristics of the different vegetation types based on ecophysiological research of representative herbaceous and shrub species and vegetation types, (ii) the study of the leaf-area-index of different vegetation types, and (iii) the integration of objectives (i) and (ii), so that the evapotranspiration of the different representative vegetation types can be estimated, together with the influence of shrub removal on the hydrological balance, to support active dune management.

Material and Methods

Site description, investigated species and meteorological data

The study is carried out in the nature reserve De Westhoek (De Panne, Belgium). To investigate the water consumption of the different vegetation types 22 representative test sites are selected. The test sites are chosen in typical herbaceous and shrub vegetations and a clear felled location. The height of the test sites varied between 5.17 and 6.33m asl, and the mean groundwater level at these sites varied between a depth of 14 till 129cm below soil level. At the sites the plant-water relations are investigated based on the selection of some specific plant species. The evapotranspiration of the total vegetation will be estimated using this model species. Ecological as well as physiological parameters restrict the choice of the model species, e.g. the leaves have to be large enough to perform ecophysiological measurements. The selected model species for the shrubs are *Salix repens* L., *Hippophae rhamnoides* L. and *Ligustrum vulgare* L.. For the herbaceous vegetation *Calamagrostis epigejos* (L.) Roth and *Holcus lanatus* L. are selected to represent the grasses, *Hydrocotyle vulgaris* L. and *Mentha aquatica* L. to represent the small herbs, and *Lythrum salicaria* L. and *Rubus caesius* L. to represent the tall herbs.

The main part of the research was conducted during the 2002 growing season, while also some orientating parts of the experiments were conducted during the 2001 season, and extra control measurements were conducted during the 2004 growing season.

Meteorological data for the period April till October 2002 were obtained from the Royal Meteorological Institute of Belgium. Air temperature, wind speed, relative humidity and precipitation were measured at Koksijde (B), shortwave radiation was measured at Oostende (B). All data were measured at an hourly frequency, only precipitation was measured at a 6-hourly interval.

Stomatal resistance

Ecophysiological research concerning transpiration was executed at the leaf-level. As the exchange of water vapour occurs mainly through stomata in the leaves, the stomatal resistance r_s gives an idea of the transpiration rate at leaf level. Stomatal resistance was

obtained in two ways. A first method is the so-called replica method (Samson *et al.*, 2000). In this approach stomatal dimensions and stomatal density are obtained from stomatal imprints. Therefore, uncoloured nail varnish is applied to the leaf. After drying, a piece of transparent tape is pressed on to the nail varnish. When removing the tape, also the adhered nail varnish is removed. Afterwards the tape is fixed on a micro slide. By analysing the imprints under a microscope the anatomical characteristics and the minimal stomatal resistance r_s can be estimated. A second way to obtain values of the stomatal resistance is by measuring it indirectly by a porometer (Delta-T Devices Ltd, Cambridge, UK). The advantage of this method is that the physiological variability of the stomatal resistance can be measured in relation to climatic variables *in situ* (light intensity, leaf and air temperature and relative humidity of the air). Diurnal courses of the stomatal resistance were regularly measured throughout the 2002 growing season for all selected species. These diurnal courses of the stomatal resistance can be used to derive the minimal stomatal resistance.

Stomatal resistance will be modelled in function of climatic variables according to the approach developed by Jarvis (1976). Therefore, several models will be tested (*e.g.* Dolman and Van Den Burg, 1988; Ogink-Hendriks, 1995; Samson, 2001) (see Sevenant *et al.*, 2003).

Rooting depth

Soil samples were taken with an earth-drill (diameter 8cm) in three herbaceous and three shrub vegetations. At each sampling point five replicates were taken. Each time soil columns of 15cm were taken. The upper sample was subdivided in three sub-samples (with a height of 5cm). The sampling depth depended on the rooting depth, when no roots were any longer observed in the soil sample, one additional sample was taken. Sampling was often impeded by a high groundwater table.

Soil samples were transported to the laboratory and stored in a freezer. After thawing, the samples were dried for two days at 50°C. The samples were weighted and passed through a sieve (0.5mm) under water. After sieving, the organic material and roots were transferred to a beaker filled with water. The organic material sank to the bottom so that organic material and roots could be separated. This method is based on the one described by Schuurman and Goedewagen (1965).

Leaf-area-index

To be able to scale up transpiration at the leaf-level to species- and stand-level, leaf-area-index (LAI) is used as a scaling factor. Leaf-area-index is defined as the single sided surface of leaves per square metre of soil ($m^2 \cdot m^{-2}$). Just as stomatal resistance LAI is determined in several ways, namely destructively and non-destructively. For the destructive approach, well known areas (*e.g.* 0.5-1m²) of each plot were sampled destructively, which means that all photosynthetically active plant parts (leaves, and green stems of herbs) of these areas were removed. At the laboratory, the leaf area of a well defined sub-sample of the leaves was measured using a planimeter (Li-3000, Li-COR, Nebraska, USA), hereafter the overall sample and the sub-sample were dried (48h at 50°C) and weighted which allowed the calculation of the LAI of the stand.

During the 2004 growing season ten plots with a diameter of five meter thought to be representative for the herbaceous vegetation were selected in order to cover the various herbaceous vegetation types in the study area. In these plots five sub-plots ($30 \times 30 \text{ cm}^2$) were randomly selected and the leaf area was determined as described above. For each of the three selected shrub species three plots were chosen from which each 1 m^2 was sampled. Again LAI for these plots was determined as just described.

The LAI was also determined by means of a non-destructive optical method. Therefore, the SUNSCAN (Delta-T Devices Ltd, Cambridge, UK) was used. Measurements were conducted at the same sites that were harvested for, but of course prior to, destructive determination of the LAI. A square plot ($5 \times 5 \text{ m}^2$) was chosen. The first measurement was taken in the middle of this plot, with the sun shining in the back of the observer. The next eight measurements were conducted from the border, starting from the North and then clockwise. Measurements were taken from the corners and middle of each side. The sensor was always pointed to the middle of the plot.

The FORUG model

Based on the above-mentioned experimental results the actual evapotranspiration for each vegetation type and for different periods of the growing season will be estimated with the FORUG model (Samson, 2001). This multi-layer dynamic vegetation model is based on the one-layer model of Penman-Monteith (Monteith, 1965). The model takes the following layers into account: a shrub layer (if relevant), a herbaceous layer, a humus layer and a soil layer. The model calculates leaf transpiration, and soil and interception evaporation.

In each considered vegetation layer calculation of the radiation interception and knowledge of the minimal stomatal resistance (in absence of stress) allowed the calculation of actual stomatal resistance (in stress conditions). The knowledge of the actual stomatal resistance and the available energy in each layer allows solving the energy balance in each layer, and thus the calculation of the evapotranspiration in each layer.

Groundwater table dynamics

In the selected test sites the groundwater table dynamics was followed during the growing season 2002. Dataloggers (Diver, Eijkelpamp Agrisearch Equipment, Giesbeek, The Netherlands) registered the depth of the groundwater with a frequency of 30min.

Results and discussion

Stomatal resistance

When comparing the stomatal characteristics of the investigated species, obtained with the replica method, differences in transpiration rate can be expected. The dimensions of the stomata almost have the same range for the different species (data not shown). However, stomata of *Ligustrum vulgare* and the upper side of *Lythrum salicaria* are larger. In spite of the almost equally dimensions, the theoretical minimal resistances of

the different species are not (Table I). This is due to the different stomatal densities of the species, e.g. *L. vulgare* and the lower side of *Calamagrostis epigejos* have high stomatal densities where *Hippophae rhamnoides* has a low stomatal density (Table I). As the leaves of *Salix repens* are covered with a layer of hairs, the replica method was not applied for that species but for *Salix tristis*. The replica method was not applied to the species *Holcus lanatus* and *Rubus caesius*. The results in Table I show that the theoretically calculated minimal resistance can vary greatly between species.

Table I. Stomatal density (10^8 stomata m^{-2} leaf area) and theoretical minimal stomatal resistance r_s ($s.m^{-1}$) estimated with the replica method (l = lower leaf side; u = upper leaf side).(from Sevenant et al., 2002)

Plant species	Stomatal density	r_s
<i>Ligustrum vulgare</i>	3.09 ± 1.05	19 ± 7
<i>Calamagrostis epigejos</i>	2.68 ± 0.61 (l); 0.13 ± 0.05 (u)	41 ± 10
<i>Lythrum salicaria</i>	1.74 ± 0.16 (l); 0.51 ± 0.25 (u)	59 ± 16
<i>Mentha aquatica</i>	2.08 ± 0.37	85 ± 22
<i>Hydrocotyle vulgaris</i>	1.14 ± 0.24 (l); 0.41 ± 0.14 (u)	97 ± 23
<i>Salix tristis</i>	1.55 ± 0.25	120 ± 29
<i>Hippophae rhamnoides</i>	0.25 ± 0.03	546 ± 116

The r_s data presented in Table I show a very high variability. To check this variability on one hand and because the replica method only yield one single theoretical minimal stomatal resistance value, which cannot be coupled to possible differences in stomatal dynamics and responses to climatic variables, the stomatal resistance was also measured using a porometer. Fig. 1 shows a typical diurnal course of the measured stomatal resistance. It is clear that the diurnal course of r_s is highly variable, but mostly they were comparable concerning the order of magnitude. Measurements of stomatal resistance can also be related to climatic variables. A typical example of such a relationship is also shown in Fig. 1. This figure clearly demonstrates that an increase in light intensity leads to a decrease in r_s .

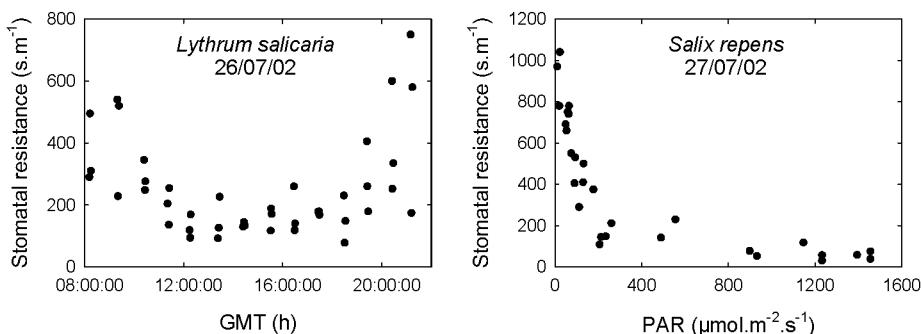


Fig. 1. (Left) A typical diurnal course of the stomatal resistance obtained from porometer measurements on *Lythrum salicaria*. (Right) Relationship between the photosynthetic active radiation (PAR) and the stomatal resistance for *Salix repens*.

In order to obtain more continuous stomatal resistance data from the discontinuous porometer data, stomatal conductance ($g_s = r_s^{-1}$ in m.s^{-1}) was modelled in function of climatic variables. The best results were obtained with the formula:

$$g_s = g_{s,\max} \frac{PAR}{PAR + a} [b - c \ln(VPD)]$$

where $g_{s,\max}$ is the maximal stomatal conductance under non-limiting conditions (m.s^{-1}), PAR is photosynthetic active radiation ($\mu\text{mol.m}^{-2}.\text{s}^{-1}$), and VPD is the vapour pressure deficit of the air (hPa), a , b and c are parameters.

No better results were obtained when the different herbaceous and shrub species were considered separately, so all data were pooled in two groups, namely one group for the herbaceous and one for the shrub species. The data set was split up for different periods during the growing season in order to be able to take the seasonal dynamics of the stomatal resistance into account. Values for $g_{s,\max}$ are given in Table II.

Table II. Values for the maximal stomatal conductance $g_{s,\max}$ (m.s^{-1}) of herbs and shrubs for different periods during the growing season

Period	Herbaceous vegetation	Shrub vegetation
April-June	0.0237	0.0435
July-August	0.0655	0.0370
September	0.0266	0.0182

Rooting depth

Maximal rooting depth between the herbaceous and shrub vegetation did not differ, and was at maximum 60cm. At both vegetation types more than 60% of the roots were found in the upper 15cm.

From the seasonal groundwater table data, and taking the capillary rise and rooting depth into account, we could conclude that none of the plots suffered from water stress. So, in this study soil water stress had not to be considered when modelling evapotranspiration.

Leaf-area-index

The leaf-area-index was determined during the 2002 growing season, and yielded for the herbaceous vegetations LAI values between 0.85 and 1.73 and for the shrub vegetations between 3.06 and 5.20. Because these values were judged as being very low compared to other ecosystems, LAI was determined again during the 2004 growing season.

Again it was found that the LAI of herbaceous vegetations is indeed low, and range between 0.87 and 4.60, with a mean LAI of 2.11 ± 0.34 . The LAI of shrub vegetations is higher and range between 2.25 and 3.94, for *S. repens* and *H. rhamnoides* respectively. A mean LAI for the shrub vegetations is 3.27 ± 0.20 .

Optical determination of the LAI of the shrubs with the SUNSCAN systematically overestimated LAI, with a mean value of 5.67 ± 0.48 . There could be several reasons why an overestimation is observed with the optical method compared to the destructively determined values. Two important reasons for this deviation could be, (i) a wrong input

value for the Ellipsoidal Leaf Angle Distribution Parameter (ELADP) used for the LAI calculations, and (ii) besides leaf area also the woody area is measured with the SUNSCAN so the Plant-Area-Index (PAI) instead of LAI is measured. In this experiment a fixed value for the ELADP was used, whereas the ELADP depends upon the mean leaf angle (Wang and Jarvis, 1988).

Modelling evapotranspiration

Because stomatal resistance modelling yielded the best results when the data of the different species were pooled together to only two groups, namely herbs and shrubs, and because it is not useful to determine LAI for the individual selected herbaceous species, evapotranspiration was modelled for a mean herbaceous and mean shrub vegetation type. These mean types are characterised by a mean $g_{s,max}$ (see Table II) and LAI (see above). Diurnal courses of the modelled evapotranspiration for a herbaceous and a shrub vegetation are shown in Fig. 2 for a sunny day and in Fig. 3 for a rainy day (only shrub vegetation).

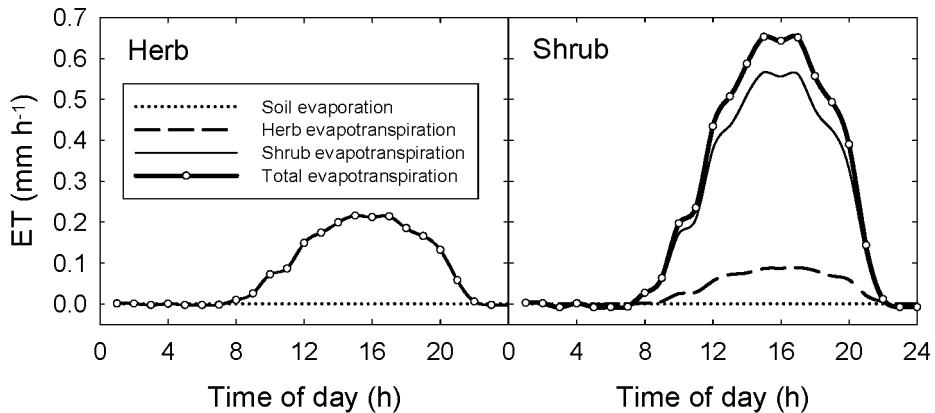


Fig. 2. Diurnal course of the evapotranspiration during a sunny day (day 227, August 1, 2002) of a typical herbaceous (left) and shrub vegetation (right).

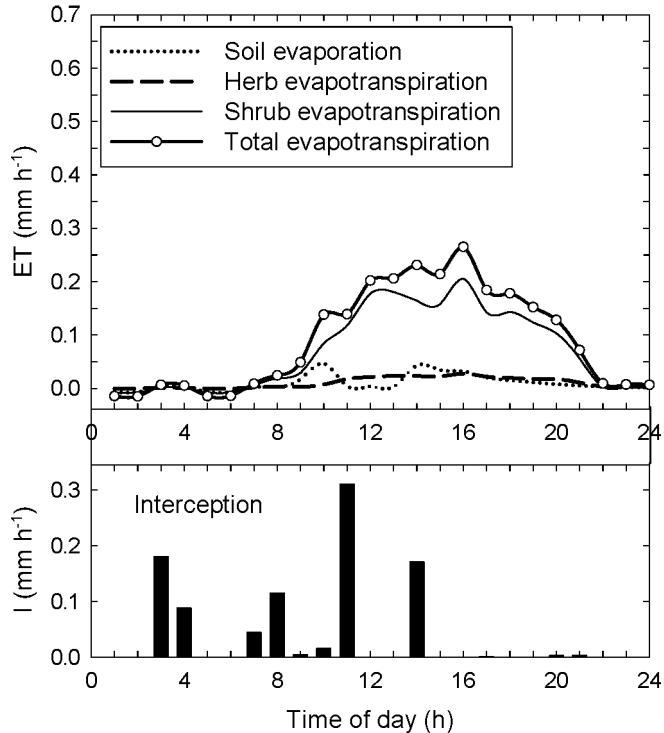


Fig. 3. Diurnal course of the evapotranspiration (upper panel) and interception evaporation (lower panel) during a rainy day (day 217, August 5, 2002) of a typical shrub vegetation.

Seasonal evapotranspiration values for a typical herbaceous and shrub vegetation are given in Table III. In this table a large difference between total evapotranspiration values for both vegetation types is shown. This difference is largely due to the high transpiration capacity of the shrub layer. Also the interception from the soil and humus (together mentioned as the soil layer) is an important contributor to total evapotranspiration in the shrub vegetation, due to the rather thick humus layer in this vegetation type.

Table III. Seasonal (day 92 till 305) evapotranspiration values (ET) (mm) for a typical herbaceous and shrub vegetation, with and without interception evaporation (the soil layer comprises the soil and the humus layer)

Vegetation type	Layer	ET excl. interception	ET incl. interception
Herbaceous	Soil	26	49
	Herbs	138	150
	<i>Total</i>	165	199
Shrub	Soil	22	100
	Herbs	55	60
	Shrub	357	395
	<i>Total</i>	434	554

From the above it is clear that the daily and seasonal evapotranspiration of the shrub vegetation is larger than those of the herbaceous vegetation. This can be explained by the higher LAI of the shrub vegetation, as this higher LAI provides a higher area for transpiration, and a larger interception capacity. The higher canopy height, and the canopy architecture, of the shrub vegetation compared to that of the herbaceous vegetation leads to a higher roughness length resulting in a lower aerodynamic resistance above this vegetation type and consequently a higher evapotranspiration.

Conclusions

Based on our experimental observations and model predictions, we can state that the evapotranspiration of shrub vegetations is higher than that of herbaceous vegetations. Consequently, shrub removal, and the replacement of this vegetation type by a herbaceous vegetation type, will not result in a lowering of the groundwater table. This knowledge can help managing hydrologically disturbed dune ecosystems.

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TOURISM/RECREATION & NATURE DEVELOPMENT/ RESTORATION

Plenary session 4 – chair: Kazimierz Rabski

Investments as a lever for sustainable equilibrium between ecology and recreation at the Belgian coast

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Abstract

Nature and tourism: it wasn't very often a very successful marriage at the European coasts. Like the Spanish 'costas', the Flemish coast was buried under concrete. This was of course devastating for the different vulnerable ecosystems and forced policymakers to take action. Not only did many countries start nature restoration projects like the Feydra-project in order to alter this trend. The problems were also tackled at the basis. Since the beginning of the nineties the tourism policy in Flanders did no longer focus just on the classic recipe of sun, sea and sand. Tourists also discovered the beauty of the polder-complex, tourists enjoyed bicycle trails,... This paper presents the evolution of nature and tourism 'from threat toward opportunity' / 'from conflict to dialogue' and vice versa. We will focus on four case studies spread over 15 years, showing the positive evolution of integrating rather than tolerating visitors in European Natura 2000-areas.

Keywords: Recreation; Nature conservation; Integrated coastal zone management; Flanders.

Introduction

Pour sauver les dernières parcelles qui ont gardé quelque peu de leur aspect primitif, il faut agir tout de suite. Car si l'on n'y prend garde, les cultures, les usines, les chemins de fer, les carrières, les villas,... auront bientôt tout envahi, et la génération qui nous suit ne verra plus les dunes littorales.

J. Massart (Pour la protection de la nature en Belgique, 1912)

At first glance nature and tourism seem to be a very good combination. Magnificent sunsets on the horizon or a beautiful dune 'panne' with flourishing orchids are arguments tourists cannot resist. Ironically, these elements, which provide a very attractive character, are often threatened by their own success (Tourtellot, 2004).

Since the introduction of paid leave in Belgium in 1936, coastal tourism has known an explosive growth. As a result of this evolution, at present day, the coastal region represents half of the economic tourism sector in Flanders. The dark side of this economic success has been the creation of a long 'floodline city' on the North Sea coast. Towns like Ostend and Nieuwpoort have been connected by large-scale creation of infrastructure such as roads, cutting through nature and leaving only scattered patches of old natural beauty behind. Fortunately, times are changing, and the loss of ecological

infrastructure had made many people realise change was needed, nowadays resulting in multiple projects in which tourism and nature are helping each other to flourish together. However, the road to success has been very long.

Firstly, we will discuss several projects which started in an atmosphere of conflicts in the mid 1990's, and nevertheless have resulted in a win-win situation for both nature and tourism. Secondly, we will look into two more recent projects, which have also started by focusing on goals related to a synergetic approach of nature and tourism.

The Flemish Dune Decree: one construction site too far

The end of the wild construction west

The Flemish Dune Decree might well be the perfect illustration of the conflict model of the early nineties. This decree has made sure the last threatened dune areas were protected by official environmental planning. In short, the decree designated 336a as 'protected dune area' (where 'hard' functions such as human residence were still possible until then) and 769a as 'agricultural areas important to dune areas'.

The dunes had been the victims of ground speculation, non-permitted constructions, pressure of recreation and unprofessional ecological management for decades. A giant 'Atlantic Wall' emerged from the nature reserve 'De Westhoek' in De Panne all the way to the old swimming pool of Knokke-Heist 66km to the northeast. The mere sight of this structure would make many foreign constructors doubt their own profession. Of the original 6,000a of dune areas in the early 20th century only 2,830a of scattered dune areas are left (Provoost *et al.*, 2003). This includes the two largest dune areas 'Westhoek-Calmeynbos' and 'Het Zwin', which account already for 870a, and many smaller dune patches which have lost much of their ecological value. This means that even Flanders' largest dunes reserve 'De Westhoek' does not have enough space for typical dune-dynamic processes to take place (Herrier, 1994). The rise of fisherman's house-style buildings was unstoppable and the concrete mills hardly ever stopped pouring their production over the dunes. The broker sector was at a record high, but the following question rose '*would tourists continue to visit a coast covered by concrete?*' (ETC, 2003).

Nature conservation organisations and luckily the Flemish Council and the Flemish Government realised that it was not almost, but already too late for nature conservation and urban planning. The so-called 'Decree Issuing Measures for the Protection of Coastal Dunes', more popularly known as the 'Dune Decree' could be considered as an emergency measure to protect the few there was left of the dunes right at the end (Herrier, 1994).

Ten years of Dune Decree: a reason for celebration?

Despite the acquisition of a quantitative equilibrium by protecting natural equity, there was no qualitative protection because of the absence of a well-funded maintenance obligation for landowners. This meant that still more than 75% of Flemish dunes were managed without concern for natural conservation in mind in 1999 (Provoost, 1999). Nevertheless, we feel the Dune Decree has been a U-turn milestone for the Flemish coast.

The Decree's merits notably are:

- Although the dune decree has not been really connected to the ruling nature legislation (which could have created new opportunities for other endangered biotopes), the decree still was a big legal step forward in linking urban planning and nature conservation. Until the mid 1990s both policy issues urban planning and nature conservation had been rather strictly separated. The new link was a step forward for the management of the coast because it did not stick to strict policy domains or on-the-spot decisions.
- Another stimulus for the Decree has been the use of scientific data for its preparation. The Belgian Institute for Nature Conservation prepared the Dune Decree in 1993 by making an inventory of the difficult issues concerning the relation nature conservation - regional urbanisation designating plans (called 'gewestplannen') (Kuijken *et al.*, 1993). This inventory was a very strong argument backing the politicians behind the dune decree not to succumb to the lobbying of various stakeholders.
- Finally, the dune decree was a 'revolutionary' U-Turn for nature recovery. The dunes were/are so badly damaged that an area equilibrium was no longer sufficient. In the slipstream of the Dune Decree steps were taken to systematically acquire and restore dune areas. Results became quickly visible. Examples include the demolition of the building 'Home George Theunis' in a coastal dunes nature reserve 'Ter Yde' near the city of Oostduinkerke, the demolition of 'Home Fabiola' in the Zeeleep dune area of Ostend, the sanitation of illegal campsites or the construction of slufters in the city of De Panne and the demolition of the 'Swimming Pool' building in Knokke-Heist. The River IJzer Estuary Project also came a step closer to realisation thanks to the Dune Decree (Deboeuf and Herrier, 2002).

In short: the dune decree has created the first win-win situation for nature and tourism.

The River IJzer Estuary: nature as a catalyst for tourism

Seal Plan ('Plan Zeehond'): a sustainable alternative to concrete

When a Belgian Naval Base was allocated from the IJzer Estuary in the mid 1980s rumours came about concerning the new designation of the area. Wild dreams even changed 124a into a 500 boat-yachting port with a neighbouring bungalow-'park'. Even before the 1993 Belgian government's decision to move the naval base a plan had been published to build a port with a connecting road cutting off (and thus eliminating) the then 50a nature reserve (with only 10a salt marshes).

The non-governmental organisation managing the area (Natuurpunt) immediately raised the alarm and launched Plan Zeehond (Seal Plan), which was supported by several scientific studies, and served as a statement that it is not necessarily concrete which suits the coast or attracts tourists best.

Every change in designation of the area which would damage the ecological value of one of the last salt marshes in Flanders would be beyond discussion. (Bossu, 1993).

This plan was a U-turn concerning the 'classic' approach of nature conservation organisations. Not only was there a firm 'no' to the yachting port, the 'no' was combined with a positive action plan. The action plan contained suggestions for a sustainable designation of the IJzer Estuary, the only estuary in Belgium, which could see a future

return of a seal population. The proposals in the plan were not only nature-technical (involving demolition of military infrastructure, digging down raised ground areas,...) but also involved the educational value of the area.

From dreams to reality (including tourism)

Thanks to the efforts of the Flemish Community and with support of the LIFE-Nature-project ‘Integral Coastal Conservation Initiative’ and the second LIFE-Nature-project ‘Fossil Estuary of the IJzer Dunes Restoration Action’ the ‘plan seal’ quickly became reality (Herrier *et al.*, 2005).

Now that the nature restauration project has ended, a new challenge for the area immerged: nature-oriented recreational co-usage. The IJzer estuary is one of the spacious tissues in the urban network of the city of Nieuwpoort (and – in a broader perspective – the entire coastal area). From the city’s western riverside magnificent views of the reserve can be enjoyed. The yachts navigating upstream also enjoy sights of the natural estuary which is very rare in Western European ports.

With the arrival of tourists there is also a higher demand for ‘greener’ outings and excursions. The real nature lovers had already discovered the salt marsh area before the nature project, but for many other people nature is also synonymous to resting, vacation, escaping the rat race.... Recreation can also create a broader support for nature conservation projects (Rens, 1993; Staatsbosbeheer, 2004). A new win-win situation was in clear sight.

In 2004, the River IJzer Estuary Nieuwpoort Project, which is supported by the Coast Action Plan 2000-2004 and is coordinated by the regional government’s tourism organisation Westtoer started with elaborating a visitors’ access plan for the Flemish nature reserve ‘De IJzermonding’ (‘IJzer Estuary’). The access plan was realised in cooperation with all parties involved, and includes proposals for improved internal and external access to the reserve, along with better infrastructure for the education of nature and general information. Realisations have not taken long to come into being. Nature-oriented recreational tourists have discovered the reserve for the first time in decades thanks to the construction of hiking and cycling paths. Westtoer organisation and The Flemish Tourism Association have supported the placement of information panels, bicycle ‘parksites’ and sitting benches in the nature reserve.

The nation-spanning interregional IIIB project ‘Frame’ has planned the construction of a bird observatory platform and studies which will investigate the possibility for the reserve to expand. In 2006 a new bicycle and pedestrian boat will cross the river’s estuary and the highest point of the former military dam will become an observation site (Provoost T., 2004).

The IJzer Estuary, a natural port

The project started from a constructive plan by a NGO, supported by scientific reports and kickstarted by the Flemish Community, that made the IJzer Estuary an example for synergy between nature and tourism. Although there might not exist a port for 500 yachts in the estuary at present, the estuary certainly has become a safe haven for many endangered animal and plant species. Not that the project excluded the neighbours of the estuary: they were involved, and conservationists, hotel and bar owners, yachting

ports,... discovered the win-win situations more quickly. This had been different at the time of the Dune Decree, where people involved such as brokers ‘had been made happy against their will’. This time all noses pointed to the same direction.

The coast cycling route: in many aspects a cutting edge project

The coast cycling route symbolises the idea of the coast action plan

Until the mid nineties the sky really seemed to be the limit which resulted in e.g. still increasing numbers of employment in coastal tourism. But this perception was changing rapidly and at the end of the nineties the region was facing an obsolescence of its tourism ‘product’, seasonally strong fluctuations in employment (Westtoer, 2004) and an ongoing deterioration of existing nature (Baeteman, 1995). In order to alter these trends into a more sustainable form of coastal tourism an investment plan was created, called ‘Coast Action Plan’. Several projects could profit from this plan on the condition that each initiative optimally supported the quality and image of the coast as a whole and provided that each initiative optimally supported the quality and image of the coast as a holiday destination. Until that time many initiatives had been running simultaneously without being coordinated, and communal authorities had each implemented their own policies in a relatively separated way. But this time all the different initiatives were rallied behind the same flag (there actually IS a flag!). Support was offered to projects such as a website portal promoting the Flemish coast as an experience or to a sustainable way of public transport ‘De Kusttram’(a tramway along the coast). Another example of this new coordinated approach has been the coastal cycling route which is being realised by Westtoer. The route will run through (practically) all coastal communities and will show the recreational cyclists examples of the best the coast has to offer, at reasonable cycling distances (Gilté, 2004). This includes dunes, typical ‘polders’, beautiful architecture,... This route which leads cyclists across different communities continues to optimise and diversify the tourist-recreational product ‘coast’.

Case study ‘Sint Jans Ader’

Establishing an attractive and safe route along the coastline is a real challenge. Moreover, this route will also have to be an important connection axis between the different coastal towns. The cycling route will also have to serve as a starting point for trips into the ‘back country’. Finally the route will have to be part of and be connected to the international ‘North Sea Cycling Route’. The combination of these factors makes sure a multiple stakeholders project comes into being, involving local councils, road maintenance organisations and many local people involved. A good example of a reached equilibrium between the different parties involved is the elaboration of a part of the coastal cycling route between the towns of Blankenberge and Zeebrugge. Between these two coastal towns there was no attractive route available and this meant a new route had to be found. After thorough discussion the option of expanding the cycling route through the area between the Kustlaan and the Graaf Jansader roads was selected. In addition, the elaboration of the route had not been organised lightly.

The following factors have been taken in account:

- Comfort and safety: the cycle path cannot be constructed next to the Kustlaan avenue but will be constructed on a specially selected new route, three (comfortable) metres wide.
- Attractiveness of the route: next to the cycle path we find the Oudemaarspolder and the Zeebos which are attractive assets for cyclists' eyes. As a consequence, recreation will be promoted by placing three bird watching walls and an observation platform.
- Surplus value for nature. Several visits by the Belgian Institute for Nature Conservation and others have revealed that the ecological value of the area is quite low, but that it has a big potential, which is demonstrated by the presence of certain plant species. The bird population will be able to thrive when elder or sea bucktorn are planted across the area. The neighbouring grassy patches also have potential – if mowed properly – for the development of calcareous grasslands.
- The coastal cycling route serves as a starting point for trips through the back country, and is connected to the cycle network of the Greater Bruges' area.

Again, this has been a (highly tangible) example of the synergy between nature and tourism.

Nature and landscape – surplus value for tourism and the Flemish Coast (and vice versa)

Natuurpunkt and nature-oriented recreation on the Flemish coast

Certainly, the search for equilibrium between nature and tourism continues as we speak. Also for us as a nature conservation organisation this entangles substantial changes. In this last case study we will focus on a nature-tourism project started by our NGO Natuurpunkt.

Natuurpunkt, the Flemish representative of Birdlife International, has many years of field experience in the coastal region. In the eighties the dune workgroup was founded, focussing on government policies, as the natural value of the region was being severely threatened. Actions around the dune decree, drinking water extraction from the dunes,... etc. were being organised in an ever faster pace. At the same time local branches were set up at the coast, which were at first mainly oriented towards policymaking and guiding people through nature.

The last few years nature-oriented recreation has become increasingly important. Although this is not really our core activity, we do have experience in this matter, which is being expressed by one of our slogans 'Natuurpunkt: nature for everybody' which bears a dimension of 'accessibility'.

Nature for everybody: the quest

Throughout Flanders we are being confronted by the gaining importance of this slogan/baseline, since we have been facing several evolutions in recent years.

We will briefly discuss the main evolutions :

At the ‘offering nature’ side we can observe two major evolutions:

- An ever increasing number of visitors’ centres is opening its doors, along with a rise in guided tours through nature reserves. However, this does not necessarily mean the target audience is broadening: Already some years ago (foreign) researchers found that education in nature reserves is too much aimed at those who already have an extensive knowledge of nature (Margadant-van Arcken, 1993). The focus of education is in too many ways sticking to ‘numbers and names’ (Van Martre, 1990). Although we do not have carried out similar research in Flanders we feel from our field experience that this is true.
- More and more groups are getting involved in the debate. This latter trend may seem surprising since Flanders’s nature policy initially was no multi actor policy at all (it was largely directed by a coalition of scientists and nature conservationists – e.g. the elaboration of the Dunes Decree). As the debate proceeded, new actors appeared on the scene (farmers, private land owners,...). In contrast with the first players those new actors belong to challenging coalitions (Bogaert, 2004; Bogaert and Cliquet, 2002).

On the demand side (tourists-recreationists) we obtained new insight thanks to new research.

- We see a great public’s awareness of the environmental problems at the coastal region (Doyen and Bachus, 2003) and an increase in nature-related holidays. Surprisingly, this doesn’t mean that there is a growing public support. Recent research showed us that although we see a discursive renewal on the concept ‘public support’, nature policies on the whole do not pay too much attention to the active dimension on ‘public support’ or to new or additional opportunities for participation (Bogaert, 2004)
- This latter evolution perhaps looks surprising in the context of the newest insight in the field of creating public support for nature conservation and environmental protection: several research projects have shown that positive experience with nature at a young age are fundamental for the development of long-term natural involvement and environmentally friendly behaviour. (Palmer *et al.*, 1999). In addition it is important to realise that people taking part in nature education activities almost always do this out of self-motivation. Most visitors do not come to learn, but to enjoy themselves in nature. As a consequence, the motivation of visitors should be the main axis when creating nature education projects. (Steeghs, 1999).

To conclude we might say that the hardware (*i.e.* nature reserves, visitors’ centres) has enjoyed much attention for nature-oriented recreation, though the software (*i.e.* communication, participation) has not.

LIFE-Nature: communicating with stakeholders and the general public

The European Commission faced the same problems when elaborating Natura 2000. When elaborating this network they broke with the traditional top-down approach of classic nature reserves, where people were tolerated rather than integrated. Natura 2000 is therefore in fact more about saying ‘take note – this is our common heritage’ rather than ‘keep out – this is for wildlife not people’. Natura 2000 therefore puts people at the heart of the process rather than its periphery. This principle of collaboration is enshrined in the Habitats Directive, which requires that conservation measures ‘take account of the economic, social and cultural requirements and the regional and local characteristics of the area’ (European Commission, 2004).

Welcome to the green experience economy

These new trends and insight have also brought about a new view to our slogan ‘nature for everybody’. Thanks to the Coast Action Plan we were allowed to work even more intensively around our slogan and to elaborate new projects which can serve as an example to this perspective. The project was called ‘nature and landscape, a recreational surplus value for the coast (and vice versa). In Dutch: ‘natuur en landschap, een recreatieve meerwaarde voor de kust (en vice versa)’ was started on 1 April, 2004.

We decided to create suitable software, that is, a new methodical approach, since we lacked experience with accessibility plans and tourism projects and were confronted with new tendencies as described above. With the marketing slogan ‘talk the walk and walk the talk’ in mind we decided to adapt ideas in the field of the experience economy, which have quite a (negative) reputation with marketing people (Pine and Gilmore, 1990). Both authors state that a shift is taking place from a service-based economy to an experience-based economy, similar to the shift from the product-oriented economy to the service-oriented economy. Some examples from advertising to prove this: ‘don’t sell a car, sell freedom’, ‘don’t sell make-up, sell hope’. Translated to the world of nature conservation one might say it is all about offering visitors real nature experiences. *Wasn’t it a ‘spark’ or an ‘aha-effect’ which made our own volunteers choose for nature protection? (Chawla, 1998).*

This might seem all too theoretical, but in the practical elaboration of visitor access plans we worked with an interpretive planning process where we focussed on visitors and less on the site itself (Veverka, n.n.), which is the opposite of the habitual procedure (where planners often started from the wishes of the people who paid for the project). In other words, the end product of a successful visitors’ centre would not be the creation of a building, but the activities that take place in and around the building (SNH, 1996). These activities should of course be a mix of entertainment (‘nature should be fun’), education (‘they should learn basic insights on e.g. biodiversity), aesthetic (‘spark-effect’) and escaping daily life (‘nature is one big adventure’). If we apply Natuurpunt’s vision of ‘experience’ to the framework Pine and Gilmore offer us, we can say that ‘experience of nature’ means the following to Natuurpunt:

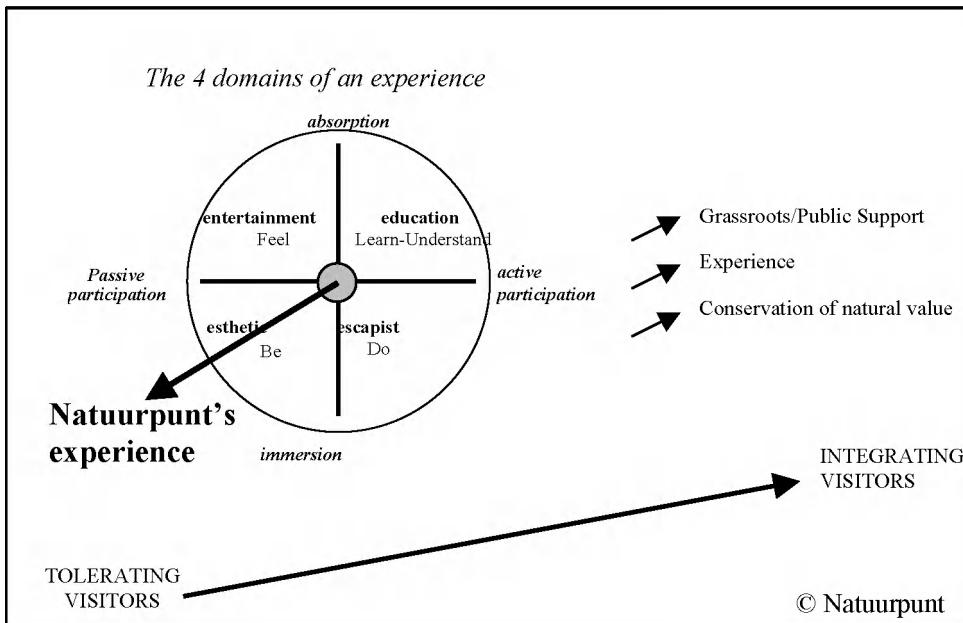


Fig. 1. Natuurpunkt's vision of experience of nature.

In the light of this new working method we have started a coordinated education process for our volunteer force. Below you will find a short description of this process in the nature reserve 'Uitkerkse Polder'.

Case study: Uitkerkse Polder, 'a wide wide world of pasture birds'

The new insights as described above were first tested in nature reserve Uitkerkse Polder. In this nature reserve, we could profit from the LIFE project 'Uitkerkse Polder, for nature and people', which was already running and also included the creation of an array of visitors' infrastructure. We put all the insight gathered as described above into an interpretive planning process and organised a brainstorming session around the central question: 'how can we improve the experience of visitors, guests, customers.... etc.?'. We kicked off by brainstorming about the communication slogan of the Uitkerkse Polder starting from the key elements of the nature reserve:

- 'wide', nature reserve Uitkerkse Polder is a landscape with wide views (which are scarce in Flanders; a highly urbanised region);
- 'pasture – salty plantlife', Uitkerkse Polder boasts several types of salty vegetation types which are selected for the Habitat Directive of the European Union;
- 'birds', Uitkerkse Polder is famous for its pasture birds and its attractiveness as a wintering site for geese and hence selected by the Bird Directive of the EU;
- 'world', Uitkerkse Polder has been included in the Nature 2000-network thanks to its acknowledged value as described above.

The result of this brainstorming session was the slogan: ‘Een weidse wereld vol vogels’ (with the double meaning of the Dutch word ‘weidse’ which bears both the significance of ‘pasture’ and ‘wide’ carried all the aspects as described above). ‘A wide wide world of pasture birds’ is a possible English translation.

This slogan, and its message were used as the basis for the accessibility plan. The slogan was used as a communication tool to make the nature reserve more known with the general public, and also to be used as a strategic compass to create visitors’ infrastructure. In this respect, an observation tower will be constructed to translate the ‘wideness’ into an experience for visitors. We will also present the Nature 2000 project in an exhibition room, which will make visitors realise the nature reserve is indeed a ‘wide wide world of pasture birds’.

This approach does not mean we will not have attention for natural value. Oppositely, we will create a zone plan which we feel is going to create a real win-win situation for nature, tourism and neighbours. To conclude we would like to demonstrate that in the Uitkerkse Polder nature reserve nature can also be a pulling factor for tourism. Several integrated projects have been planned, including the creation of a ‘green tourism arrangement’ (involving local shopkeepers, bars, hotels,...), the planning of a ‘walking route between green stops’ (together with public transportation companies),... etc. In short, a project by which we want to create synergy between nature and tourism.

Conclusion

The title of this paper will have made many people raise their eyebrows: ‘Investments as a lever for ecology?’ Wasn’t it corporate cash that made the Flemish coast into one giant construction site?

In this paper we demonstrated that there was indeed a situation of conflict between nature and tourism. That a long road has indeed been travelled since the dune decree and that we – from the nature conservation point of view – are indeed still seeking for an equilibrium between nature and tourism. We can’t state that all is peace now: conflicts still occur (examples include a media hype around the closure of an illegal campsite in the middle of the dunes) or the conflict of the closure of nature reserve Baai van Heist a few years ago). Nor is everything perfect: many years of work still lay ahead: dismantling illegal campsites, dune recovery by destructing roads as has already been done in nature reserve d’Heye,... etc.).

Nonetheless, we feel that many very important policymaking decisions have been taken during the last 15 years. After many years of non-existing policy concrete results became visible. The mere definitive approval of the Dune Decree has shown a huge U-turn in the official coastal policy. Who could have dreamed the desire for nature would have been stronger than the power of constructors, housing brokers,...?

One of the key factors for success has certainly been the scientific support. The Dune Decree was approved, withstood criticism in the Belgian High Council (Conseil d’Etat) because the founders had foreseen possible criticism by basing the Decree on objective grounds only. In the same time the green urban planning decree ‘Groene Hoofdstructuur’ did not manage to pass the High Council. These examples of mere victory and defeat should be an important lesson for conservationists in Flanders.

Another key factor – which has been increasing in importance in recent years – is public support. The gridlock situation ‘the good, the bad and the ugly’ between private companies, government and NGOs is on its way to becoming history. This thanks to the constructive approach of NGO’s like Natuurpunt (*e.g.* Seal Plan), visionary politicians and the many recent example projects. Time has come for a full-scale creation of integrated coast management, where actions are not taken on the spot nor for just one party’s benefit. Natuurpunt is fully committed to support example projects port and nature, tourism and nature,... actively.

The quest continues ...

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Preserving the beach deposits (high-water driftlines) and the embryo dunes on the coastline of the North Department (France)

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Abstract

The management experiences presented here have been realised since 1994 owing to the 'Conseil Général' of the North district on the upper beaches of the Flemish dunes owned by the 'Conservatoire du Littoral' situated on the Bray-Dunes and Zuydcoote municipalities (France). This experience aims at the restoration of the habitats on the sea frontline of the border dune. The matter is the space that starts from the annual halo-nitrophilic strip on the upper beach, goes on with the embryo dune and finishes with the quick white dune dominated by the European beachgrass (marram). The requirements of beach cleanliness, especially regarding seaside tourism, have led to the destruction of these patrimonial important habitats by the regular and complete mechanical raking of the strand. The first step consisted in limiting this mechanical raking to the rights of sea-side resorts. At the same time, the upper strip of the beach along dunes is managed softly by a selective manual picking up of the biggest trashes. This change of cleaning process rapidly produced the emergence of noticeable habitats that didn't exist before. It concerns water marks mingled with sand and embryonic dunes with sand couch grass. To a reduced extent, these methods of management lead to a reinforcement of the white dune with marram and sand ryegrass and the white dune which is warmer with marram and sea spurge. Some of these habitats are listed as part of the Guideline 'Habitat' and are listed as vulnerable or endangered after the red book of the littoral terrestrial phytocoenoses according to the definitions proposed by the International Union for Nature Preservation. Moreover, the obstacles kept on the upper strip of the beach afford the start of a process of sand accumulation and build the embryonic dune. According to the sedimentary context, this type of operation assists the fertilisation of the upper beach and reduces the retreat phenomenon of the coastline. The cost of operations is much reduced, money is even saved with the reduction of the number of interventions. It was only difficult to convince our partners about modifying their cleaning habits. This successful experience over a 1.5km distance of beach, facing preserved dune massifs, shows the large potentialities of spontaneous restoration of these natural environments. The extreme simplicity of this method and its very small cost, except employment, allow us to envisage and adapt it all along the European coastline.

Keywords: Beach; Strand; Beach deposits; High-water driftlines; Embryo dunes; North Sea coastline; Ecological management.

Introduction

The management experiences presented in this article have been going on for the past 10 years as the result of the ‘Conseil Général du Nord’ (North Department Council- France) initiative. They are placed on the strand (intertidal zone) of the North Department coastline, within immediate proximity of the Franco-Belgian border. They are concerned with beach heights (what we call ‘beach heights’ in this text is the upper part of the beach where it joins the dune) ‘Perroquet’ dunes (250ha) and ‘Marchand’ dunes (110ha), located on Bray-Dunes and Zuydcoote cities territories. They faced the dune ranges that today are owned by the ‘Conservatoire de l’Espace Littoral et des Rivages Lacustres’ (sea and lakeshores lands Conservatory: a national committee for preservation), and are managed by the North Department Council.

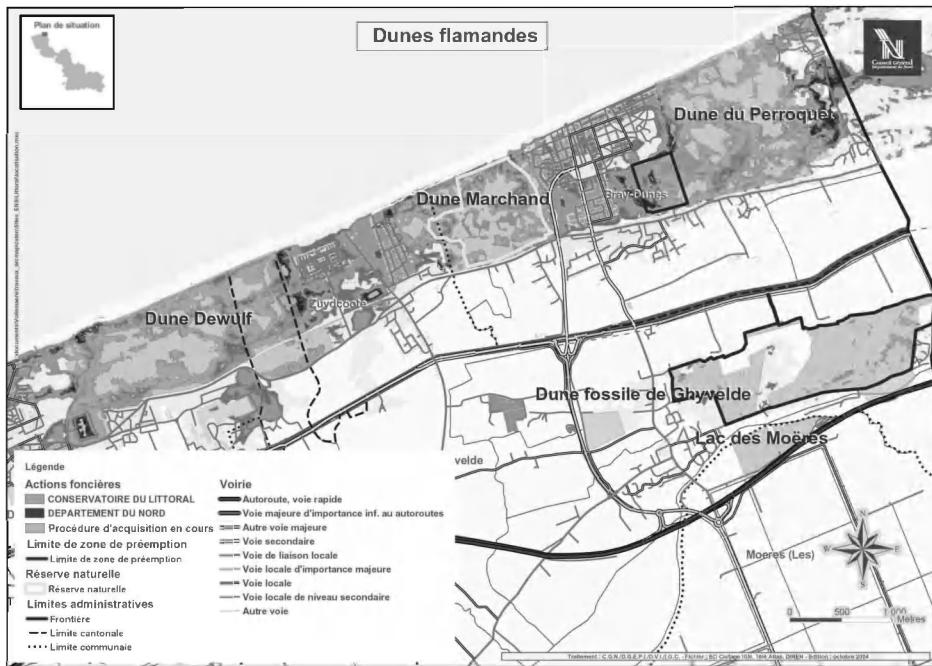


Fig. 1. Localisation of ecological management of beach heights in the north of France.

Presentation

The young dunes are usually found in large beaches, which have a shallow strand and are fed by sediments from the tides. The young dunes can form spots of embryonic dunes that merge, grow higher as vegetation develops (*Elymus*, *Ammophila*); this also occurs because these plants are able to trap in the dunes the sand taken away from the beaches by the wind.

This beach-front vegetation forms groups generally organised perpendicularly to the shore. The regularity of the transaction could be disturbed by the frequent remodelling of the dunes, which are truncated by erosion, or even modified depending on the latitude. In temperate Europe, the big steps of the sequence are usually clear in the dune landscapes, for example:

- the sequence starts at the beach's highest point by the strand of the annual 'halo-nitrophils' (Cakile, Atriplex, Salsola...) grouping (high-water driftlines);
- it continues with the embryonic dunes, where Sand Couch (*Elymus farctus*) starts the construction of the dunes, in lines or in successive islands;
- with the end of the white dune, the domain of the Marram Grass (*Ammophila arenaria*) usually forms the larger and sometimes higher (10-30cm) fringes. It is the dunes construction zone where the European Beaches Grass is resisting to the annual sedimentation of about 80-100cm, thus encouraging the growth of the dunes.

Particularity

The experiences presented will try to restore the different habitats of the maritime front found on the coastal dunes. In fact, bordering the lands of the 'Conservatoire du Littoral' (under departmental management), the three remarkable habitats described could be found. But due to the beaches uncleanliness, especially as a result of seaside tourism, the first two have been systematically destroyed on the entire coastline of the North department and of Belgium. These remarks are equally valid for all European coasts with the same cleaning constraints as a result of human use, even though the vegetal association changes with the latitude.

The restoration undertaken by the North Department Council had to take into consideration several different interests. A collaboration has been restored with the management authority of the beaches, to reduce and stop the regular and radical cleaning of the strand. In fact, from May to September, all strands are raked each week by tractors equipped with claws. The frequency of the raking occurs on a daily basis during summer. It is easily understood that this type of treatment reduces all intentions to install vegetal and animal life on the beaches.

The intervention of the North Department Council, who is in charge of the coastal dunes, has drawn the attention of the SIDF ('Syndicat Intercommunal des Dunes de Flandre') to do the cleaning of the beaches in the patrimony's interest of the beaches heights habitats. Following this first step, the spaces concerned by the intense raking were reduced only to the portions facing the beneficiary seaside communities (a strip of 100 additional meters on each side of the pier is also included in this perimeter).

The other part of the beach (strand) is parallel to the department-managed dune ranges, which have so benefited from a softer management. There is no more raking and only the biggest trash brought in by the sea is picked up every two weeks by the departmental team. In this way the conservation's state of the dunes. Ecoflandres is checked. Ecoflandres, a social insertion association, which is specifically financed by the North Department Council for this work, also regularly helps. At last, some volunteers (associations, schools or general public) help to clean during spring operations organised by the State Ministry of Ecology.



Fig. 2. Ten years ago (1993): all strands were raked each week by tractors equipped with claws.



Fig. 3. Some volunteers help to clean the beach during public actions.



Fig. 4. Trash and waste are evacuated by the departmental team.

This type of operation rapidly allows the habitat to express itself. A pioneer vegetation settles in the beach heights at the high-water driftlines level. Besides, the smallest obstacles to the wind (natural or anthropic) initiate the process of sand accumulation thus recreating embryo dunes.

During the first recorded years, after the vegetation installed in the spring had been checked, cleaning of the beaches started again here and there in the usual way, but the tractor drivers used to avoid raking the formations and vegetations that were newly installed. Later, as a result of the awareness-raising campaigns, the managers of the strand decided to abandon all intruding interventions on the ecologically managed beaches.

Patrimonial interest

The interest in this approach is great: the North Department's action has allowed the return of previously absent remarkable habitats on the beach shores (experience underhand on 1.5km of coastline). These are:

- sea deposits mixed with sand on the beach front (*Beto maritimae - Atriplicetum laciñiatae*), open pioneer vegetation of annual 'halo-nitrophils' plants in scattered groupings, migratory and normally aligned along the great tides deposits on the beach front; this vegetation, characterised by the Sea Rocket (*Cakile maritima*) and the Prickly Salwort (*Salsola kali*), is described as a fragile and rare habitat because of the erosion of the coastline and of the beach raking;



Fig. 5. During the first year of the experiment, the embryo dunes began to reappear after ecological management actions.

- embryonic dunes composed in Sand Couch (*Elymo arenarii* - *Agropyretum juncei* - *formis*) and in hardy social 'graminous' vegetation which is initiating the process of sand accumulation, characterised by the Sand Couch (*Elymus farctus* subsp. *boreo-atlanticus*) accompanied by the Sea Lyme Grass (*Leymus arenarius*) and the Rush-leaved Fescue (*Festuca rubra* subsp. *arenaria*).

In a lesser measure, these experiences will allow to reinforce the following habitats:

- primary white dunes with Beach Grass and Sea Lyme-grass (*Elymo arenarii* - *Ammophiletum arenariae*) composed of a dense plantation of European Beach Grass (*Ammophila arenaria*), poor in species that contribute to the edification of the dunes in which Sea Lyme-grass (*Leymus arenarius*) can be found;
- primary white dunes with European Beach Grass and Sea Spurge (*Euphorbia paralias* - *Ammophiletum arenariae*): that is an habitat close to the previous one, although more thermophile, and also characterised by the presence of the European Beach Sea Grass (*Ammophila arenaria*), the Sea Spurge (*Euphorbia paralias*), the rare Sea Bindweed (*Calystegia soldanella*) and the Sea Holme (*Eryngium maritimum*).

Evaluation of the project

The coming back or the development of these habitats represents a great patrimonial asset. These are in fact recorded in the frame of the 'European habitats directive' under the codes Corine Biotope n°16.211 and 16.212 for the habitats B, C and D. The

embryonic dunes of Sand Couch and the primary white dunes of European Beach Grass and Sea Lyme-grass are also recorded in the red book of terrestrial phytocoenosis of the coastline. They are respectively described as vulnerable and threatened (of which the area or the surface is reduced to a critical level), according to the definitions proposed by the World Conservation Union (IUCN).

The national and regional criteria of evaluation class them as ‘rare’ (for the habitats A and D) and ‘very rare’ (for the habitats B and C) at a national level, ‘fairly rare’ (A and D) and ‘rare’ (B and C) at a regional level. They are equally considered as withdrawing (for the A, B, C) except the D that appears to be stable.

The scientific follow-up consists in phytosociological countings of the concerned zone. Despite the fragmentary side of these habitats, we have witnessed their spatial augmentation as soon as the second year of intervention after their reappearance.

Although difficult to quantify, the habitats cover homogenously a 300m beach front area by 15-20m wide facing the Marchand and Perroquet dunes. On samplings of 100m² realised two years after the implementation of the program, we observed a covering of 10% of the concerned zone. The zone is composed of 25% of Prickly Salwort (*Salsola Kali*), 20% of Sea Rocket, 15% of Sand Couch. Some sea deposits are more sheltered in the Perroquet dune: it has also allowed the installation of wilds Sea Beet and Sea Cabbage (*Beta vulgaris* subsp. *maritima* et *Crambe maritima*) that are protected species in the Nord-Pas-de-Calais or in France, but that had nevertheless disappeared in the meantime.



Fig. 6. Aspect of embryo dunes in 2004. A width of 15m of new dune is gained.

Today, the embryonic dunes of Sand Couch are very important and have a width of 15m. We can also find there the Ovate Sandwort (*Honckenya peploides*) there.

This project is of multiple interests. The cost of the operation is almost nothing. Some savings are even realised with the reduced number of interventions (stopping of the raking). The only difficulty was to convince our partners and to modify the cleaning habits. This type of operation is quite efficient when we leave the spaces potential express themselves. It can be duplicated on all the European coasts at a very low cost. It has also allowed a very important sand accumulation on the beach front, and it is slowing down the generalised retreat of the shore line on this portion of coast.

The return of the embryonic formations over the last 10 years also has a pedagogical interest, allowing to show to a large public during organised guided visits: the formation of the dune ranges, the aeolian sedimentation phenomenon, the coastline geomorphology, and the organisation of the different 'phytocoenos' whose sequences are now present and preserved from the 'estran' (strand) to the wooded dunes.

Table I. List of interesting vegetal species recorded on these habitats

Species	Site (1)	Regional rarity criteria (2)	Protection (3)	Red list
<i>Ammophila arenaria</i>	DD, DM, DP	AR		
<i>Atriplex hastata</i>	DD, DM, DP			
<i>Altriplex lacinata</i>	DM, DP			
<i>Beta maritima</i>	DM			
<i>Cakile maritima</i>	DD, DM, DP	AR		
<i>Calystegia soldanella</i>	DD, DM, DP	R	Belgium	
<i>Corispermum leptopterum</i>	DM, DP			
<i>Crambe maritima</i>	DD		National	National
<i>Elymus farctus</i>	DD, DM, DP	AR		
<i>Eryngium maritimum</i>	DD, DM, DP	R	Regional, national	
<i>Euphorbia paralias</i>	DD, DM, DP	AR		
<i>Festuca juncifolia</i>	DD, DM, DP	AR		
<i>Glaucium flavum</i>	DP	R		
<i>Glaux maritima</i>	DM	AR		
<i>Leymus arenarius</i>	DD, DM	R	National	
<i>Plantago coronopus</i>	DP			
<i>Salsola kali</i>	DD, DM, DP	R		
<i>Honckenya peploides</i>	DP			

Conclusion

Despite the retreat of the shoreline that today seems less and less pronounced, the experiences initiated by the North Department Council have allowed the return of remarkable habitats of the Northern Sea beaches front by an adequate management. The interest of this management approach is also zoological: more than once, Little Ringed Plover (*Charadrius dubius*) and the Kentish Plover (*Charadrius alexandrinus*) were observed during the summer period on the embryonic dunes. The presence of regular

seaweed and vegetal debris at the level of the sea deposits leaves us to hope for the restoration of some beaches invertebrates' habitat. This experience, successful on a strand of 1.5km of beach, facing preserved dune ranges, shows the strong potential for spontaneous restoration of certain natural spaces, and the good health of the existing ranges on the North coastline. The extreme simplicity of the method and its cost efficiency, allow to consider its extension to the whole European coastline.

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NATURE RESTORATION/DEVELOPMENT IN HARBOURS

Plenary session 5 – chair: Frank Neumann

Harbouring nature: port development and dynamic birds provide clues for conservation

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Abstract

During the twentieth century, many coastal areas in Europe changed dramatically due to coastal protection works, human expansion drift and booming beach tourism. As a result the natural area of suitable nesting habitat of many coastal birds has decreased enormously and a large number of species are now listed as threatened. Some species were able to exploit new opportunities offered by human activities, but most coastal birds are now confined to islands, protected areas or artificial sites (nature development projects, restored coastal habitats and even floating rafts). Protection of local resources, as well as further development and management of breeding sites is considered vital in maintaining the populations of threatened coastal breeders. The rationale behind nature restoration and development is often solely based on offering suitable habitat to the birds, while its success is mainly judged from the evolution in the number of birds present. As more and more information becomes available on the reproductive performance of coastal birds, it becomes clear that in some protected areas long-term reproductive success is below self-sustaining levels. Apparently humans are able to create artificial nesting habitats that are highly attractive from the birds' perspective but are in fact pitfalls for the population in the long term. In contrast, the port of Zeebrugge, Belgium, is an excellent example of an artificial nesting habitat of high quality in terms of attraction as well as reproduction. Here, vast sandy areas were raised in a former marine habitat in the 1980s. The works mimicked natural dynamic processes and coastal breeding birds instantly reacted. Within 20 years, the area has developed from open sea to a breeding site of major international importance. Peak population figures by far exceed the 1% of the total biogeographical population. At present, Zeebrugge harbours more than 4% of the total north-west European Common Tern population, thus making it the largest colony in Europe. It is a highly productive population and acts as a major source of recruits for the biogeographical population as a whole. Until recently, the success of the bird populations was based on the ongoing creation of suitable nesting habitats and management measures, like removal of the vegetation and covering areas with shell fragments. Further development of the harbour, the arrival of the fox and competition for nesting habitat with large gulls are major threats for the bird population. Therefore part of the colony was allocated to a peninsula and further steps are now being considered to preserve this valuable population. Apparently feeding conditions are very good and the harbour itself and its direct surroundings function as a major source of small prey fish of which the availability is facilitated by the heavy shipping traffic and the sheltered conditions of the feeding areas.

Keywords: Zeebrugge; Nature development; Coastal breeders.

Introduction

During the twentieth century, increased anthropogenic pressure and the tendency of mankind to protect coastal sites against the unpredictable character of the sea has lead to a decreasing area of dynamic coastal habitats. Throughout Europe, coastal breeders that depend on areas that are subject to processes of erosion and accretion and naturally shifted their location over time are now restricted to remnants of their natural breeding habitat. Only the more opportunistic species were able to adapt to the loss of their original breeding habitat and the increasing pressure of beach tourism. The European populations of many larger European gull species, for example, showed a strong increase during the second half of the twentieth century as their breeding areas were better protected and they learned to exploit new food resources such as fish offal and organic waste on refuse dumps (Del Hoyo *et al.*, 1996; Spaans, 1998; Mitchell *et al.*, 2004). Being true opportunists, they also showed a great plasticity in their habitat choice. In the beginning of the twentieth century Herring and Lesser Black-backed Gulls were restricted to natural coastal habitats, but nowadays they are found breeding far inland and often in the proximity of humans (Del Hoyo *et al.*, 1996; Spaans, 1998; Mitchell *et al.*, 2004). Many urban areas as well as harbours and industrial areas are now harbouring gulls. However, the populations of more specialised coastal birds as well as species that require undisturbed areas for breeding were put under great pressure and many of those species are now listed as threatened on many national Red Lists. At present, they are mainly confined to islands, protected coastal areas or artificial sites (such as nature development projects, restored coastal habitats and even floating rafts). During the twentieth century, it has become a generally accepted principle that threatened birds of dynamic habitats can be helped by managing already established breeding sites or by attracting them to new suitable breeding grounds. This has without any doubt improved the conservation of the species. Here we report on the conservation of a population of coastal breeders in the outer port of Zeebrugge, Belgium.

Evolution of coastal breeders in Zeebrugge

With the development of the outer port of Zeebrugge in the 1980s (Fig. 1) vast areas of sandy, sparsely vegetated and relatively undisturbed land were created. The works mimicked natural dynamic processes in coastal areas and pioneer species instantly reacted to the availability of new suitable nesting habitat. Little Tern *Sterna albifrons* and Kentish Plover *Charadrius alexandrinus* settled in the area in 1985. At first, the vegetation developed slowly and breeding birds reacted reluctantly, but from 1988 onwards the area attracted increasing numbers of plovers, terns and gulls. During the next 16 years the area underwent major changes. Sites of suitable nesting habitats were claimed for the development of buildings, car parks, roads and railways, while ongoing raising of land created new nesting opportunities for coastal birds. In areas that remained more or less undisturbed, Herring Gull *Larus argentatus* and Lesser Black-backed Gull *L. fuscus* displaced pioneer species. To ensure nesting of pioneer species management measures were taken, such as regular removal of the vegetation and covering areas with shell fragments. The radical changes (raising of land, industrial development and nature management) caused strong and sudden fluctuations in the population size of true pioneer species, while slow processes like succession of the vegetation, competition for

nesting habitat and recruitment of young seem to contribute to the population dynamics of gulls and Common Terns *S. hirundo* in a positive (or negative) way. In this paper we will focus on the population development of and future prospective for terns and plovers in the harbour area. The evolution and status of breeding gulls in the Zeebrugge port is described in detail elsewhere (Meininger and Flammant, 1998; Seys *et al.*, 1998; Stienen *et al.*, 2002; Vercruyssse *et al.*, 2002).

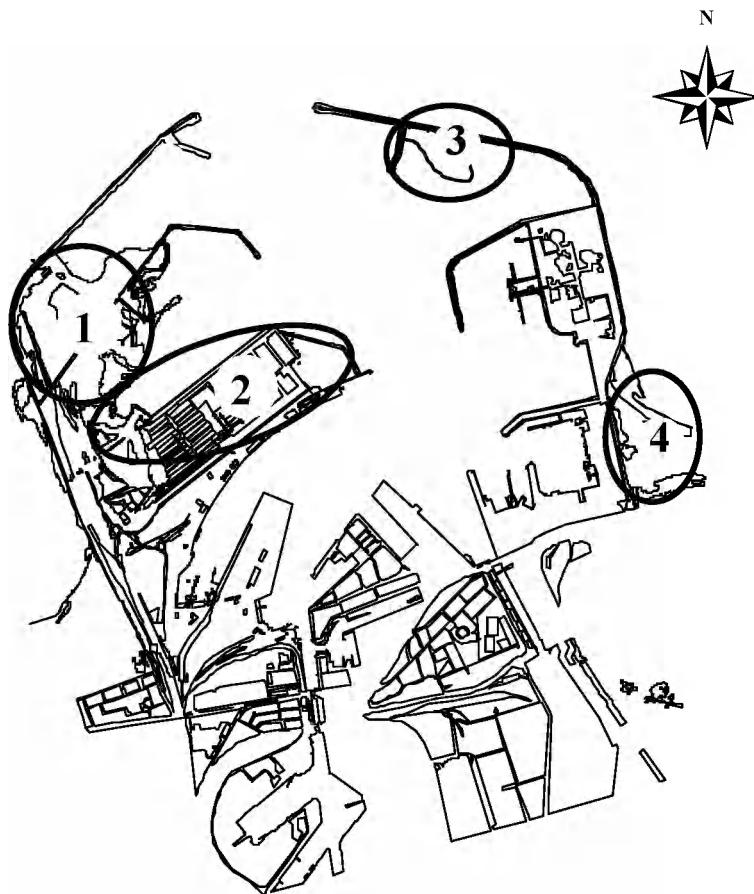


Fig. 1. Map of the outer harbour of Zeebrugge showing (1) the initial nesting site of plovers and terns that is now largely industrialised or taken over by Herring and Lesser Black-backed Gull, (2) the core of the colonies in 1990s, (3) the newly created 'tern peninsula' and (4) the Flemish nature reserve 'Baai van Heist'.

Until 2000, the breeding sites in the harbour were maintained by ad hoc nature management such as mowing of the vegetation, ploughing up the soil and deposition of shell material. Each year, warning signs were put up and the major sites were fenced off

with wire. By the end of the 1990s, a more permanent solution for a part of the ation and in 2000 was sought. A small peninsula (2-3ha) was created along the eastern breakwater of the port of Zeebrugge (Fig. 1). This was the first of a series of measures to compensate for the loss of nesting habitat in the western part of the harbour. During the next five years, the peninsula was further enlarged in four steps and during the breeding season in 2005 it reached about 10ha. The peninsula was intended to attract terns and was therefore named the “tern peninsula”. In order to offer suitable nesting habitats to the different tern species, it had to meet several preset ecological conditions that were extracted from literature (Veen *et al.*, 1997). The lower parts of the peninsula were covered with a 5cm layer of shell material to make them suitable for Little Terns. In order to minimise erosion and to support quick colonisation by Black-headed Gulls *L. ridibundus* the elevated areas were planted with salt-resistant grasses. Most parts of the peninsula, however, were not planted because earlier experience in raised terrain showed that the area would become suitable for Common Terns within a few years anyway. No specific measures were taken to attract plovers because it was determined that the parts developed for Little Terns were also suitable for those species. At about the same time the adjacent Flemish Nature Reserve “Baai van Heist” (Fig. 1) was established and closed for the public during the breeding season from 1998 onwards. This area also attracted coastal breeders for some years.

The different species of coastal breeders that settled in Zeebrugge can be subdivided into four groups that all have different life-history traits and show very specific development of their populations (Fig. 2). The Little Tern and Kentish Plover are true pioneers that require highly dynamic, open habitats. Common Tern and Black-headed Gull are species of the first stage of vegetation succession, whereas the Sandwich Tern *S. sandvicensis* is a more erratic species that depends on the presence of Black-headed Gulls. Finally, there are the larger gull species that show a large overlap in breeding habitat with the Common Tern and Black-headed Gull, but are in fact less critical species. The two pioneer species showed peak numbers during the second half of the 1990s, mainly because the area of sparsely vegetated habitat was then at a maximum. These species instantly reacted whenever new terrains were raised in the harbour or when sandy habitats became available through disturbance of existing terrains. This was also the case when shell material was laid out as a management measure. Similarly, they colonised the new breeding habitat at the “Baai van Heist” in 1989 and they settled on the “tern peninsula” in 2000, the year that the first part of the peninsula was realized. In the following years, they always used the most disturbed soils at the peninsula for their nesting activities. These were either newly raised terrains, parts where the vegetation was removed or parts that were most impacted by the winter storms. In the “Baai van Heist” no specific measures were taken to keep the soil disturbed in order to keep it suitable for pioneer birds. This may very well have contributed to the fact that breeding at the “Baai van Heist” was abandoned after three years.

As representatives of a more evolved habitat, the populations of Common Tern and Black-headed Gull showed a more or less gradual increase and peak numbers were counted in 2004 and 2003. This is directly correlated to the development of the vegetation in the western part of the harbour. For the Black-Headed Gull the increase in numbers was disrupted in 2004 due to disturbance (by human activity or terrestrial predators) in an early stage of egg-laying. Following the abandonment of the western

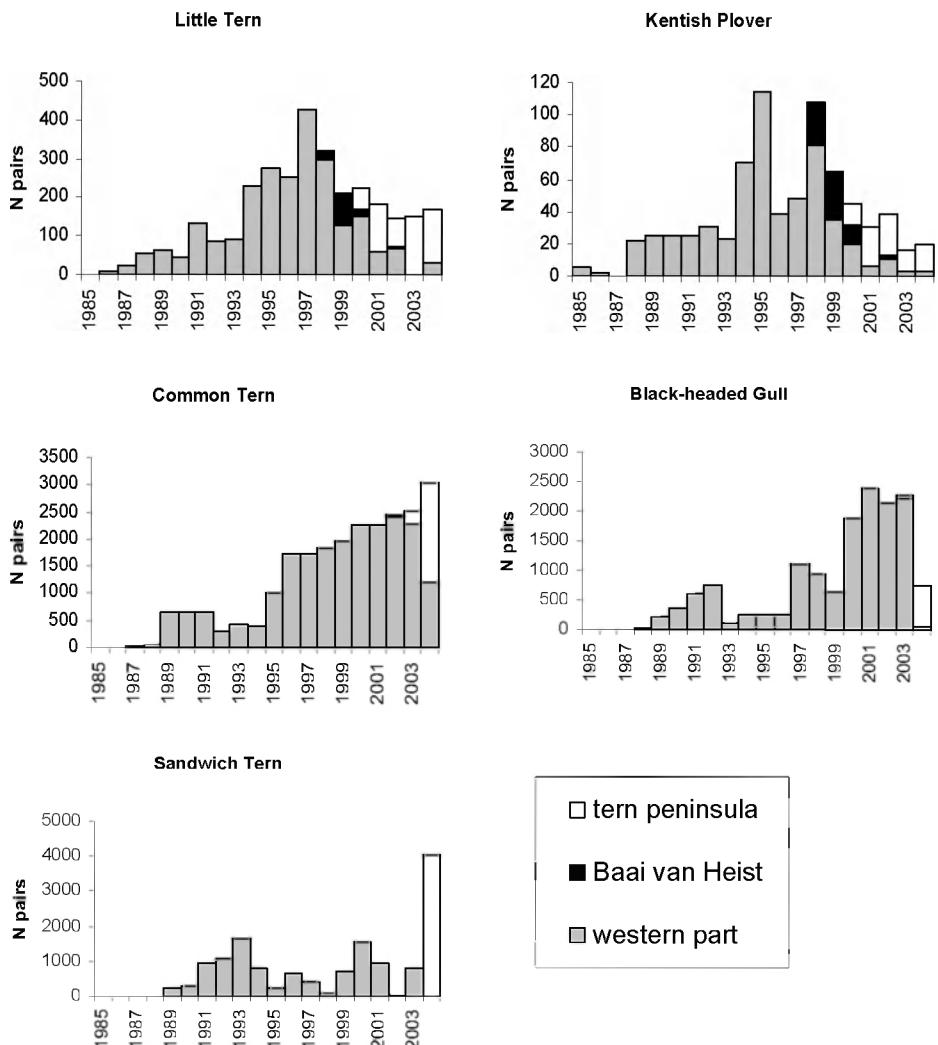


Fig. 2. Evolution of coastal breeders in the outer harbour of Zeebrugge and at the adjacent nature reserve "Baai van Heist" during the period 1985-2004.

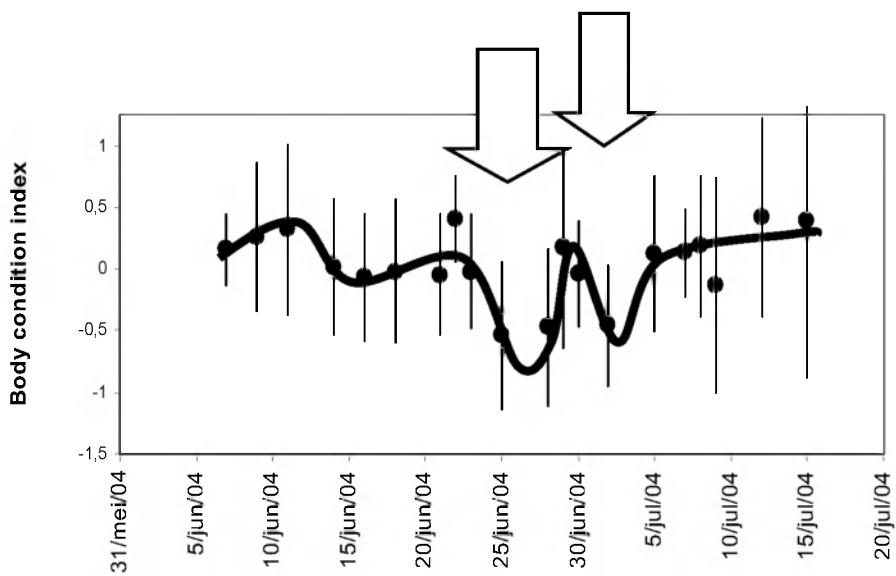


Fig. 3. The development of the body condition (average values \pm standard deviation) of Common Tern chicks in the harbour of Zeebrugge in 2004. The arrows indicate two periods of heavy storm. The drawn line is a visualisation of the development of the chicks' body condition and is drawn by hand.

part of the harbour, a small part of the gull population found a refuge at the "tern peninsula". Common Tern and Black-headed Gull reacted somewhat later to nature management measures than the pioneer species. This is perfectly illustrated by the fact that they only started breeding in Zeebrugge 2-3 years after the first Little Terns and plovers had settled in the harbour. They also occupied the "tern peninsula" two years later than the first pioneers. Judging from the ongoing increase in numbers, at present, there are no signs that Common Tern population of Zeebrugge is reaching its upper limit. Conversely, the Black-headed Gull population fluctuated around a stable number of slightly more than 2000 pairs after 2001 (with the exception of 2004 when only approximately 600 pairs are found).

Sandwich Terns exclusively breed in association with other species and in Europe these are mainly Black-headed Gulls and sometimes Common Terns (Veen, 1977). Since Sandwich Terns are not very aggressive against intruders, they depend on the neighbouring gulls to chase away predators. The gulls also form a buffer against ground predators. In Zeebrugge, the first Sandwich Terns only settled in 1989; the first year a substantial number of Black-headed Gulls nested in the western harbour. Their numbers heavily fluctuated throughout the years and it was not always clear whether intrinsic factors (vegetation, disturbance, food abundance) or external factors (shifts in nearby populations) were the underlying cause.

Preserving dynamic nature

Although mankind has greatly added to the conservation of coastal breeding birds by offering them (semi)artificial breeding grounds or by preserving the original breeding grounds, this practice also has several drawbacks. In the first place it has encouraged a general view that dynamic nature can be manipulated very easily which sometimes led to ill-considered decisions. In the specific case of coastal breeders, nature conservation or nature building is in fact a *contradiccio in terminis* because it assumes that dynamic habitats can be preserved at a fixed location. As a result, there are a growing number of breeding sites that can only be ensured for a longer period by intensive management of the vegetation and/or elimination of terrestrial and avian predators (Meininger and Graveland, 2002). Even many natural sites that harbour historic populations of coastal breeders are now preserved in this way. Europe's largest Sandwich Tern colony, for example, is harboured on an artificially fixated island, Griend, located in the Dutch part of the Wadden Sea (Veen and Van de Kam, 1988). In the 1980s, a dike was built around the island to prevent it from being lost to the sea. Parts of the new island were planted with salt-resistant grasses and each year measures are taken to prevent larger gulls from breeding on the island. In addition a monitoring programme was set up on Griend to measure the health of the population in terms of breeding success. Monitoring the reproductive performance of a population is a vital activity once coastal birds are established on (semi)artificially breeding sites as it can provide valuable clues on the health of the population and may help to guide management decisions.

The excellent scientific knowledge on the habitat preferences of coastal breeders that exists nowadays can be used to create breeding sites of almost supernatural attraction to the birds. Additionally one may put other means, like decoys and sound, into place to lure the birds to a specific place. In fact it is not very difficult to set up a successful nature development project for coastal breeders if its success is merely judged from the number of breeding pairs. However, attracting and maintaining a healthy population in terms of survival is a much more complex task. In this case one should preferably have ecological information beforehand to make sure that the birds are not attracted to an ecological pitfall that merely acts as a sink for adult birds. In addition, one needs a well-considered monitoring programme and a nature management plan must be set up to ensure the health of the population. The latter step becomes particularly important if the site harbours a larger part of the total biogeographical population.

The Zeebrugge example

In the case of Zeebrugge, we had several clues that the population was healthy and self-supporting. A first clue was provided by the number of breeding pairs. At maximum size, the populations of Little, Common and Sandwich Tern represented, respectively 3.8%, 4.8% and 7.2% of the entire geographic population of the species. However, as stated before, the number of breeding pairs is only a poor indicator of the health of a population. Should the Zeebrugge population have low survival probabilities and large dependence on immigration from other colonies then preservation of this may have a negative effect on the geographical population as a whole. A preferable monitoring tool is ring recoveries as these provide better insight into the demographic aspects of a

population. We studied the population dynamics of Zeebrugge's populations and the links with other colonies by trapping ringed adults at the nests and by reading the rings of adults from a hide using a telescope. This resulted in 163 and 113 ring recoveries of Common and Sandwich Tern, respectively. The recoveries show that the Common Tern population entirely consisted of either local birds (85.3% of the recoveries originated from Zeebrugge itself) or immigrants from the nearby Delta area in The Netherlands (14.7%). Recoveries of ringed Sandwich Terns show a similar high proportion of "own" birds (77.9% of 113 recoveries) and again a close connection with the Delta area, although some Sandwich Terns originated from colonies in the Dutch Wadden Sea and in the United Kingdom as well. The most remarkable recovery was of a Sandwich Tern that was ringed in Zeebrugge as a chick in 1989 and successfully raised a chick of its own in 2004. These are indications that the Zeebrugge population is largely self-supporting, although in this light it is not clear what caused the strong fluctuations in the number of Sandwich Terns. Only in 2004, when peak numbers settled at the "tern peninsula", we had an insight as to the origin of these birds. In that year a high flood washed away all the eggs in the nearby colony at the "Hooge Platen" in the Dutch Delta area. Consequently, most terns left the "Hooge Platen" and moved to other colonies to produce a second clutch. That is probably the reason for the peak numbers at the "tern peninsula" in 2004. Indeed we noted several birds wearing Dutch rings, but at present we have not yet received the details on these recoveries.

It goes without saying that the success of the birds in terms of reproductive output is the best indicator for the quality of a breeding site. Monitoring breeding success can provide a very detailed insight into the quality of the breeding habitat and provide clues for future management, in particular if one is able to distinguish between various causes of egg loss and chick mortality. In Zeebrugge, we started measuring the breeding results of the Common Tern population in 1997. Each year, a representative part of the colony was fenced in and the enclosed nests were checked on a regular basis. The monitoring study pinpointed the specific problems of the population in Zeebrugge and enabled us to compare the reproductive output with other colonies.

Clutch size (number of eggs per clutch) and hatching success of the eggs (*i.e.* percentage of the eggs that actually hatched) were rather stable throughout the years (Table I) and close to maximum values reported elsewhere (Stienen and Brenninkmeijer, 1992; Becker *et al.*, 1997; Nisbet, 2002). This indicates low predation rates as well as low concentrations of some specific contaminants that affect hatchability of the eggs. Chick survival as well as productivity (*i.e.* number of fledged chicks per pair) showed much more variation than clutch size and hatching success. Still, compared to adjacent colonies in the Dutch Delta area, Zeebrugge generally scores very highly when it comes to the survival probabilities of the chicks (Meininger *et al.*, 2002). Also compared to Wadden Sea colonies in Germany and The Netherlands – where the same method was used to measure reproductive output – productivity is often higher at Zeebrugge (Table II). The mean productivity at Zeebrugge is comparable to the high values recorded along the Atlantic coast of North America (Nisbet, 2002). This points towards a combination of good feeding opportunities in the surrounding of the colony and low predation rates on chicks. In most years breeding success was well above 1.1 fledglings/pair. Only in 2000, 2002 and 2004 breeding success was below this figure because of either predation or food shortage. In 2000 and 2002, the chicks suffered from predation by Herring and

Lesser Black-backed Gulls. However, in 2002 this was a secondary effect of food shortage among the terns. In that year, chick growth seriously lagged behind the normal pattern. Many chicks died from starvation and the remaining chicks (also in very poor body condition) were preyed upon by the gulls. Also in other colonies along the southern North Sea it was reported that Common Tern chicks suffered from a poor food situation. In 2004, we recorded high levels of predation by mammals (probably ferrets). The predation was restricted to the western part of the harbour where 1220 pairs nested. Here parents only raised 0.1 fledglings per pair, while at the "tern peninsula" in the eastern part of the harbour breeding success amounted to 1.1 fledglings per pair (1832 pairs).

Table I. Parameters of the reproductive performance of Common Terns in Zeebrugge during the period 1997-2004. Each year, the measurements were performed in an enclosed part of the colony that was representative of the entire population

Year	Number of nests	Clutch size	Hatching success	Fledgling success	Productivity (fledglings/pair)
1997	78	2.4	78%	50%	1.2
1998	185	2.5	77%	61%	1.2
1999	90	2.5	78%	67%	1.3
2000	52	2.3	91%	37%	0.8
2001	35	2.3	80%	74%	1.4
2002	34	2.2	79%	8%	0.1
2003	36	2.6	87%	74%	1.7
2004	37	2.1	81%	38%	0.7

Table II. Breeding performance of Common Terns in various northwest European colonies. Information presented is limited to colonies where the same methodology was used. Data from Becker et al. (1997) supplemented with own data for Zeebrugge and data abstracted from Griend reports 1996-2003

Colony (country)	Years (number of years)	Productivity fledglings/pair (overall mean)
Baltrum (Germany)	1993-1995 (3)	0.3-1.8 (1.0)
Griend (Netherlands)	1993-2003 (11)	0.0-1.0 (0.5)
Minsener Oldeog (Germany)	1993-1994 (3)	0.0-1.3 (0.9)
Trischen (Germany)	1993-1995 (3)	0.0-0.0 (0.0)
Zeebrugge (Belgium)	1997-2004 (8)	0.1-1.4 (1.1)

Finally chick growth and body mass of the chicks can provide clues on the local feeding conditions. In this paper, the body mass of the chicks is expressed as a relative difference from the expected body mass (*i.e.* the average body mass of all chicks of similar size), and is forthwith called body condition. A negative value for body condition tells us that the chick's body mass is below average. In Fig. 3 the body condition index of Common Tern chicks in Zeebrugge 2004 is plotted against time. It shows that, except for two

periods of stormy weather, the body condition of the chicks fluctuated around zero, indicating that the chicks grew at an average growth rate and that there were no problems related to food. During the two periods of strong winds the hovering capabilities of the foraging terns were severely affected and the transparency of the water column deteriorated, so that parents could not catch enough fish for their offspring. Consequently growth lagged behind and body condition immediately dropped below zero. As a result of the poor feeding situation some chicks died from starvation, but the surviving chicks quickly recovered after the storm died down (Fig. 3).

By averaging all measurements of body condition over the entire chick rearing season one gets a rather robust parameter that gives insight into the food availability in a specific year. In Fig. 4 this parameter is plotted for Common Tern chicks in Zeebrugge during the period 1991-2004. The figure shows that 2002 was a very deviant year in terms of chick growth. As stated above, in 2002 many chicks died from starvation and the surviving chicks showed very conspicuous begging behaviour each time a parent (whether or not it was their own parent) landed with prey in the colony. This attracted some larger gulls to the colony that were apparently specialised in preying upon tern chicks. When omitting 2002 from the analysis, the graph suggests that the body condition index of the Common Tern chicks in Zeebrugge has slowly decreased over time (Fig. 4). It is not clear whether this decrease reflects changes in the local food situation or is the result of intraspecific competition owing to the growing numbers that breed in Zeebrugge. It might be a first indication that the Zeebrugge population has almost reached its carrying capacity and that the size of the population will ultimately be limited by the amount of food. The evolution of the number of pairs, however, shows no signs yet that the population is reaching an upper limit (Fig. 2).

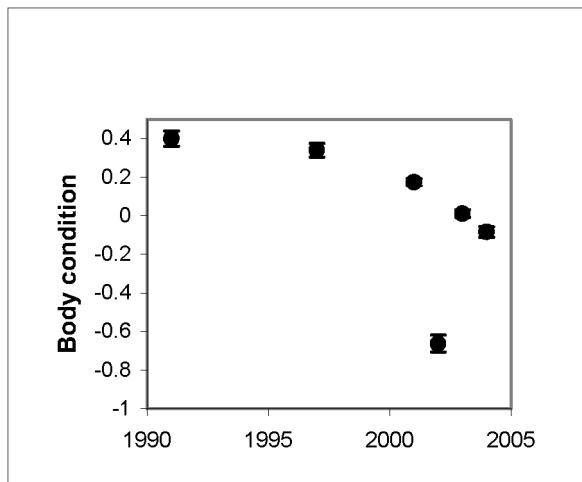


Fig. 4. Averaged yearly body condition index (\pm standard error) of Common Tern chicks in Zeebrugge during the period 1991-2004.

In conclusion, studies revealed that Zeebrugge is an outstanding breeding site for coastal breeders. It serves a very thriving, healthy, self-supporting and internationally important population that is worthwhile to preserve. Increasing pressure of harbour activities and habitat loss in the western part of the harbour created an urgency for the construction of a permanent breeding site in the eastern part of the harbour. The first experiences at this so-called “tern peninsula” show that the population can be successfully relocated. Advanced plans exist to designate the western part of the harbour entirely to economic activities. The harbour’s ecological value will be ensured by further enlarging the “tern peninsula” to a final size of 22ha. The breeding site as well as the foraging areas will soon be designated as Important Bird Area because of the presence of significant numbers of the three tern species. The major challenges in the future will be to maintain the quality of this breeding site so that its important population of coastal breeders will be preserved. Due to the fact that the peninsula lacks sufficient dynamics constant management of the vegetation follows. Predator control, avoidance of competition from Herring and Lesser Black-backed Gulls and minimising collision against windmills, as well as scientific monitoring are required to guarantee the success in the long term.

Zeebrugge is an excellent example of how port development and dynamic birds can go together. It shows that fish-eating birds like terns can be successfully harboured in major ports. The underwater constructions of ports can act as artificial reefs and may enhance fish abundance. The availability of prey fish is further facilitated by the heavy ship traffic (in particular Common Terns often feed in large numbers behind ships) and by the sheltered environment provided by the jetties, so that the terns can find enough food even under adverse weather conditions. In the USA and Canada there are many examples of how major ports (*e.g.* the ports of San Diego, Auckland and Colborne) contribute to the protection of endangered seabirds, but in most European ports this is still a major challenge.

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International legal possibilities and obligations for nature conservation in ports

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Abstract

Ports are often situated in valuable nature areas. In the past, large areas of coastal land and sea were claimed for port development without taking into account the nature values in that area. With the development of international nature conservation law new possibilities for nature conservation and nature development were developed. Although several instruments exist, this article focuses on the Ramsar Convention on the one hand and on the Birds and Habitat Directive on the other. Ramsar sites and protected areas under the Birds and Habitat Directives can be designated in or near port areas. For the designation only scientific criteria are taken into account (and no economic criteria). There are legal requirements for the conservation of these protected sites in both the Ramsar Convention and the directives. Similar provisions exist on the reduction of the size or the deletion of the protected area. Several conditions have to be fulfilled, such as reasons of public interest. Both instruments require compensation matters. The legal requirements are more precise and strict in the EC directives than in the Ramsar Convention. Enforcement is much better organized in the framework of the EC directives. New challenges exist to put the provisions of the directives into practice. If correctly applied these nature conservation instruments can lead to a more sustainable policy in finding a balance between ecology and economy.

Keywords: Nature conservation; ports; Ramsar convention; Birds directive; Habitats directive.

Introduction

Ports are often situated in valuable coastal areas, such as estuaries and mudflats. In the past, large areas of coastal land and sea were claimed for port development without taking into account the nature values in that area. Only economic arguments were taken into consideration. This often resulted in a serious degradation of nature areas and loss of biodiversity (because of large infrastructure works, dredging activities etc.). Sometimes large ecological valuable areas, although not yet in use for port activities, were designated as port areas in spatial planning instruments or strategic port plans. Although these nature areas remain intact, their future is uncertain and they often become degraded due to a lack of appropriate nature management. Occasionally, new opportunities for nature conservation can be created because of port development. This is for instance the case for sand suppletion areas which are not immediately used for port activities, but in the meantime serve as a refuge or breeding ground for seabirds. This is for instance the

case in the port of Zeebrugge in Belgium, in which sand suppletion areas have become major breeding grounds for sterns. Once these areas will effectively be used as port areas, the nature values will be lost.

The lack of a sustainable policy in the past, inevitably led to conflicts with other users in the coastal zone. This sometimes resulted in court cases and even halted further possibilities for port development (for instance port development in Antwerp at Deurganckdok).

In the last years, new insights came into being on nature conservation and nature development. There is more focus on an active offensive nature conservation policy, in which attention is given to restoration of damaged nature areas and to development of new nature areas. If nature cannot be restored, then compensation measures are in order and the loss of nature should be compensated elsewhere. International law now also encompasses the idea of ecological networks. Those networks aim at improving, enlarging and connecting valuable nature areas. These networks can be on a global scale (such as Biosphere reserves, a network of Ramsar sites), or on a regional scale (Natura 2000, the Emerald network, the pan-European ecological network). Specifically for the coastal zone, the concept of integrated coastal zone management has been introduced. Based on sustainable development, this management concept requires that for projects and initiatives in the coastal zone, all aspects have to be taken into account, including economic, social and ecological aspects. These ideas create new possibilities for nature conservation in coastal areas. They might also shift the balance towards a more sustainable port development and to win-win situations for both industry and nature. Conflicts between different user groups in the coastal zone might thus be avoided.

The following questions need to be answered: what are the legal possibilities and obligations for nature conservation and nature development in coastal areas; how can these international instruments be applied in port areas; are these instruments adapted to achieve a sustainable use of the coastal zone and acquire win-win situations for ports and nature? This paper will examine the legal possibilities and obligations for nature conservation and nature development in international treaties and EU legislation and will specifically focus on the application of these instruments in coastal areas. Although there exist several legal possibilities for nature conservation in marine and coastal areas (such as the OSPAR Convention, actions taken in the framework of the Biodiversity convention, etc), this article will be limited to discussion of the Ramsar Convention and the EU Birds and Habitat Directives. An overview of other legal possibilities is given in Cliquet (2000). Specific attention will be given to the legal procedures for conservation and compensation (such as the procedure of article 6 of the Habitats Directive). It will look into the legal possibilities for the establishment of the site's conservation objectives within port areas. As there are often problems with the implementation of the Birds and Habitats Directives in port areas, the paper will look into relevant case law of the European Court of Justice. This article will focus on site protection and management within protected areas. It will not go into species protection or other more general conservational and environmental measures.

Designation of protected areas

A first step towards site protection is the legal designation of a defined area. The procedures will vary according to the legal source.

Designation of Ramsar sites

General

The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat of 1971 (text at http://www.ramsar.org/key_conv_e.htm) is the only global convention that allows for site protection of a specific type of ecosystem. According to the Convention each Contracting Party shall designate suitable wetlands within its territory for inclusion in a List of Wetlands of International Importance. Each Contracting Party shall designate at least one wetland to be included in the List when signing this Convention or when depositing its instrument of ratification or accession. Wetlands should be selected for the List on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology. Criteria for inclusion in the list have been worked out by the conferences of the parties (adopted by the 4th, 6th, and 7th Meetings of the Conference of the Contracting Parties) and can be consulted at http://www.ramsar.org/key_criteria.htm. These criteria form a part of the Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance (adopted by COP7 in 1999). On 31 January 2005 the List included 1421 sites with a total surface of 123.914,362ha.

Application in coastal areas

The Ramsar Convention clearly applies to coastal areas. According to the Convention wetlands are areas of “*marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*”. The boundaries of each wetland shall be precisely described and also delimited on a map and they may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands, especially where these have importance as waterfowl habitat. A large number of sites in the Ramsar list are coastal wetlands. In an inventory made in 1998, 436 sites (from a total of 931) were coastal sites (An Overview of Wetland Types at Coastal Ramsar Sites, 14 July 1998, http://www.ramsar.org/about_coastal_sites.htm). In the Ramsar Classification System for Wetland Type several types of marine and coastal wetlands have been included. Several guidelines and recommendations refer to or apply specifically to coastal wetlands. Very often ports are situated in or near coastal wetlands. The question here is whether Ramsar sites could be designated in existing port areas? Or can the presence of a port area prevent Ramsar sites to be designated? The Ramsar Convention does not require a national protected status of the area. Any area that suits the criteria worked out in the framework of the Convention could thus be designated. If for instance an area regularly supports 20,000 or more water birds or if it regularly supports 1% of the individuals in a population of one species or subspecies of water bird,

then this area could be designated as a Ramsar site. In Belgium, a scientific report of 1999 thus proposed to designate part of the port of Zeebrugge as a Ramsar site (Devos *et al.*, 1999). No policy actions were taken to implement these recommendations.

Designation of Special Protected Areas (SPA's) and Special Areas of Conservation (SAC's)

General

The core legislation on nature conservation in the European Union is formed by the Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds and Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (both texts are found at:

<http://europa.eu.int/comm/environment/nature/home.htm>). Both directives oblige Member States to designate protected areas. The procedure differs for both directives. Once areas have been designated under these directives, they will become part of an ecological network, the Natura 2000 network.

According to article 4 of the Birds Directive, Member States shall classify in particular the most suitable territories in number and size as special protection areas (SPA's) for the conservation of Annex I species and for regularly occurring migratory species not listed in Annex I. For the latter species Member States shall pay particular attention to the protection of wetlands and particularly to wetlands of international importance. The Birds Directive thus links its measures to those of the Ramsar Convention. No further criteria on the designation of SPA's were included in the Birds Directive. However, several rulings by the European Court of Justice narrowed the scope for policymaking of the Member States in designating SPA's. According to the Court of Justice only ornithological criteria should be taken into account for designating SPA's. This was ruled in cases such as the Leybucht Case (Case C-57/89, 28 February 1991, Commission v. Germany), the Marismas de Santoña Case (Case C-3535/90, 2 August 1993, Commission v. Spain) and the Lappel Bank Case (Case C-44/95, 11 July 1996, Regina v. Secretary of State for the Environment, *ex parte* Royal Society for the Protection of Birds). The Court also decided that a sufficient large area has to be designated. Member States can thus be convicted for not designating sufficient large areas (see for instance Case C-166/97, 18 March 1999, Commission vs. France on the Seine Estuary; Case C-96/98, 25 November 1999, Commission vs. France on the Marais Poitevin). Another important decision is that Member States are obliged to classify as SPA's all the sites which, applying ornithological criteria, appear to be the most suitable for conservation of the species in question (Case C-3/96, 19 May 1998, Commission v. the Netherlands). In this case the court ruled that as regards the Member States' margin of discretion in choosing the most suitable territories, that does not concern the appropriateness of classifying as special protected areas the territories which appear the most suitable according to ornithological criteria, but only the application of those criteria for identifying the most suitable territories for conservation of the species in question.

The procedure for the designation of special areas of conservation under the Habitats Directive had been worked out in the directive itself and contains three stages.

According to article 4 of the Habitats Directive each Member State shall propose a list of sites indicating which natural habitat types in Annex I and which species in Annex II that are native to its territory the sites host. The selection of sites should be based on the criteria set out in Annex III (Stage 1) and relevant scientific information. The list shall be transmitted to the Commission. In a second stage, the Commission shall establish, on the basis of the criteria set out in Annex III (Stage 2), in agreement with each Member State, a draft list of sites of Community importance drawn from the Member States' lists identifying those which host one or more priority natural habitat types or priority species. Once a site of Community importance has been adopted, the Member State concerned, shall designate that site as a special area of conservation as soon as possible and within six years at most. The criteria in Annex II do not contain any economic or social criteria. The European Court of Justice in a case on the Severn Estuary, confirmed that no economic or social criteria should be taken into account when proposing the sites (Case C-371/98, 7 November 2000, *The Queen v. Secretary of State for the Environment, Transport and the Regions ex parte First Corporate Shipping Ltd*):

"On a proper construction of Article 4(1) of Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, a Member State may not take account of economic, social and cultural requirements or regional and local characteristics, as mentioned in Article 2(3) of that directive, when selecting and defining the boundaries of the sites to be proposed to the Commission as eligible for identification as sites of Community importance".

Application in coastal areas

Both the Birds and Habitats Directives apply to the coastal zone and apply to the marine environment including the exclusive economic zones of Member States. The Birds Directive mentions the "geographical sea and land area where this directive applies". The Habitats Directive includes terrestrial and aquatic areas in its definition of natural habitats. Both directives include marine and coastal species in their annexes, and the Habitats Directive includes a list of marine and coastal habitat types in Annex I (habitats for which the designation of Special Areas of Conservation is required). Although the directives do not explicitly mention the exclusive economic zone, there is little doubt that these directives extent as far as the exclusive economic zone. This is also the viewpoint of the European Commission (European Commission, 2002a), and has been confirmed in British case law (*Secretary of State for Trade and Industry v. Greenpeace*, 1999) and literature (Backes *et al.*, 2002; Cliquet, 2000).

As a consequence, special protected areas under both directives can be designated in or near port areas. Several ports within the European Union, such as Antwerp, Rotterdam, Hamburg, Bremen, Le Havre, are situated in estuaries. If a port area is an important bird area according to ornithological criteria and qualifies as a most suitable area, the member state has no choice but to designate this area. The presence of a port is no reason for not designating an area. This was confirmed in the Lappel Bank Case for the designation of a special protected area under the Birds Directive. In this case a nature area in the Medway Estuary was designated as special protected area. A part of the area, the Lappel Bank, was however excluded from the designation, as the nearby port of Sheerness wanted to expand in the Lappel Bank area. This exclusion of the Lappel Bank area was

considered by the Court as unlawful, as no economic criteria can be taken into account when designating SPA's. In the meanwhile the nature values in the Lappel Bank area are lost, due to a lack of protection measures.

Also for the designation of protected areas under the Habitats Directive, the presence of a port is not a reason for not designating an area as such. It was also confirmed in the Case on the Severn Estuary (C-371/98) for the special areas of conservation under the Habitats Directive. This last case concerned the port of Bristol in the Severn Estuary. In several Member States areas have been designated in or close to ports (see for instance the areas in Belgium in the port of Antwerp and in the port of Zeebrugge).

Conservation and restoration of protected areas

A second step in the protection of valuable nature areas is taking conservation measures within the designated sites.

Conservation of Ramsar sites

For the sites which have been included in the Ramsar list, the Contracting Parties shall formulate and implement their planning so as to promote the conservation of those wetlands. Each Contracting Party shall arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the List has changed, is changing or is likely to change as the result of technological developments, pollution or other human interference (art. 3 of the Convention). These latter sites will be included in the Montreux Record of sites requiring priority conservation attention. An example is the site "Schorren van de Beneden Schelde" in Belgium, which was included in the Montreux Record in 1990. The reason for including this site in the Montreux Record is the further port development in the port of Antwerp. As a consequence of the construction of a container terminal close to a part of the Ramsar site (Groot Buitenschoor), a change in the ecological character is to be expected. For this site the Ramsar Advisory Mission mechanism was applied, by which the Ramsar Secretariat organizes technical missions to seek solutions and provide advice to the relevant authorities. The Ramsar Convention does not explicitly contain the obligation for member states to prevent any change in the ecological character of the Ramsar sites. However, because of the obligations for conservation and wise use of sites as provided for in the Convention, a state cannot allow such a deleterious ecological change so that the site does not longer fulfil the requirements for inclusion in the Ramsar list (Bowman, 1995).

Any Contracting Party shall have the right to add to the List further wetlands situated within its territory, to extend the boundaries of those wetlands already included by it in the List, or, because of its urgent national interests, to delete or restrict the boundaries of wetlands already included by it in the List and shall, at the earliest possible time, inform the organization of any such changes (art. 5, § 5, Ramsar Convention). Where a Contracting Party in its urgent national interest, deletes or restricts the boundaries of a wetland included in the List, it should as far as possible compensate for any loss of wetland resources, and in particular it should create additional nature reserves for

waterfowl and for the protection, either in the same area or elsewhere, of an adequate portion of the original habitat (art. 4, § 2 Ramsar Convention). In practice, boundary restrictions have occurred on only three occasions (Ramsar Convention Secretariat, 2004.). Parties have invoked the ‘urgent national interest’ clause to restrict the boundaries of a Ramsar site, in Belgium in the 1980s, in Australia in 1997 (although in this case the restriction of boundaries did not in fact occur), and in Germany in 2000. In 1987, the Belgian authorities informed the Ramsar Bureau that 28ha of the Galgenschoor sector of the Lower Scheldt River site (which was then 155ha) had been deleted in Belgium’s urgent national interest (for construction of a container terminal), and that 2200ha of the IJzerbroeken had been designated to the Ramsar List in compensation (according to the provisions of Article 4.2 of the Convention). Although the Belgian government never explicitly used the term ‘urgent national interest’, it can be assumed that the Belgian government was implicitly invoking the urgent national interest clause, as it proposed suitable compensation (Di Leva and Tymowski, 2000).

Conservation of SPA's and SAC's

According to article 4 § 1-2 of the Birds Directive Members States shall take special conservation measures for Annex I species and regularly occurring migratory species concerning their habitat in order to ensure their survival and reproduction in their area of distribution.

In a case before the European Court of Justice of the Commission v. France on the Seine Estuary (Case C-166/97), the Court ruled that the French Republic failed to adopt measures providing the SPA with an adequate legal protection regime for the purposes of Article 4, § 1 and 2 of the Wild Birds Directive. The Commission expressed the view that the protection regime for that SPA, as defined by an agreement entered into on 11 April 1985 by the Ministry of the Environment with the Autonomous Ports of Le Havre and Rouen was inadequate. The protection regime which the Agreement provides for that SPA fails, in the Commission's submission, to meet the conservation requirements defined in Article 4, § 1 and 2 of the Wild Birds Directive. Moreover, no other measure designed to provide the SPA with an adequate legal protection regime has been adopted.

In respect of the special protection areas, Member States shall take appropriate steps to avoid pollution or deterioration of habitats or any disturbances affecting the birds, in so far as these would be significant having regard to the objectives of this article (art. 4, §4 – first sentence). This sentence was given a strict interpretation by the European Court of Justice (in the Leybuch Case and in the Marismas de Santona Case). The Court did not allow a diminishing in the size of the special protected areas for purely economic reasons. According to the Court a change in the protection status is only possible for imperative reasons of overriding public interest. This interpretation by the Court was apparently too strict for Member States and thus this part of the Birds Directive was replaced by the regime provided for in the Habitats Directive (see further). According to the European Court, the old regime of article 4 of the Birds Directive still applies for those sites which were not officially designated as sites, although they fulfil the necessary requirements to be designated as such (Case C-374/98, 7 December 2000, Commission v. France, Basses Corbières).

According to the Birds Directive Member States shall also strive to avoid pollution or deterioration of habitats outside the special protection areas for birds, (art. 4, §4, second sentence).

The conservation measures for special areas of conservation under the Habitats Directive are to be found in article 6 of the Directive. The first two paragraphs include positive measures to be taken by the Member States concerning conservation measures and prevention of deterioration. *“For special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans, and appropriate statutory, administrative or contractual measures which correspond to the ecological requirements of the natural habitat types in Annex I and the species in Annex II present on the sites. Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive”* (art. 6, § 1 and 2).

The next paragraphs of article 6 concern the assessment of new plans or projects: *“Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public. If, in spite of a negative assessment of the implications for the site and in the absence of alternative solutions, a plan or project must nevertheless be carried out for imperative reasons of overriding public interest, including those of a social or economic nature, the Member State shall take all compensatory measures necessary to ensure that the overall coherence of Natura 2000 is protected. It shall inform the Commission of the compensatory measures adopted. Where the site concerned hosts a priority natural habitat type and/or a priority species, the only considerations which may be raised are those relating to human health or public safety, to beneficial consequences of primary importance for the environment or, further to an opinion from the Commission, to other imperative reasons of overriding public interest”* (art. 6, § 3 and 4). Article 6, § 2-4 also applies to the special protected areas under the Birds Directive.

Because of its crucial role in the conservation and management of special protected areas, the European Commission worked out an interpretation guide on art. 6 of the Habitats Directive (European Commission, 2000). In this interpretation guide the Commission elaborates on terms such as ‘significant effect’ and ‘compensatory measures’. Some further step-by-step guidance for the provisions of art. 6, § 3 and 4, was given in a Commission document of 2002 (European Commission, 2002b). Recent case law by the European Court of Justice also interprets some of these provisions, such as ‘significant effect’ and ‘appropriate assessment’ (see Case C-127/02, 7 September

2004, Landelijke Vereniging tot Behoud van de Waddenzee and Nederlandse Vereniging tot Bescherming van Vogels v. Staatssecretaris van Landbouw, Natuurbeheer en Visserij). On the ‘significant effect’ the Court ruled that where a plan or project is likely to undermine the site’s conservation objectives, it must be considered likely to have a significant effect on that site. Thus, the Court links the significant effect to the conservation objectives. It will be very important to define the conservation objectives for the protected sites, in order to be able to make an appropriate assessment.

Although the Habitats Directive is less strict than the interpretation of the Birds Directive given by the Court of Justice, this does not mean that Member States have the unlimited freedom to reduce the conservation status of the special areas of conservation. This will only be possible if the strict requirements of the directive are applied. If Member States disregard these obligations, this can not only lead to the destruction of internationally protected areas, but can also have serious economic consequences. This was clearly demonstrated in the Deurganckdok project in Belgium (port of Antwerp). The extension of the port area which took place in a special protected area, initially took place without taking into account the obligations of the directive. This led to numerous procedures and court cases and a complaint to the European Commission. Because the works could not longer be continued, the state suffered serious economic losses. An ‘emergency’ decree finally legalized the works and saw to it that the requirements as provided for in the Habitats Directive (such as compensation) are being fully implemented.

A second case in a port area in Belgium also led to a complaint to the European Commission. This case concerns a site in the port of Zeebrugge at the coast. Several polder grasslands, such as the Dudzeelse polder, had been designated as a protected site under the Birds Directive by a decision of the Flemish government of 17 October 1988, extended by a decision of 1996. In total an area of 456ha was protected. In view of future port development, 282ha of this protected site was deleted from its protection by a decision of the Flemish government of 17 July 2000 (Fig. 1). Although the decision allowed for a compensation in another area, two NGO’s brought a complaint to the Commission. One of the arguments was that the compensation was not an active compensation, as required in the interpretation guide of the European Commission. Also, there had been no search for alternatives, as required in art. 6 of the Habitats Directive. The remaining part of the Special Protected Area in the port, the Dudzeelse polder, although still under the protection of the directives, has an uncertain future, as it is seen as a strategic reserve area for future port development. The Flemish government is now trying to find a solution in this case. Whether the directives will be fully respected, remains to be seen. If not all the requirements are met, further steps will undoubtedly be taken by the European Commission and Belgium might yet face another conviction by the European Court of Justice.

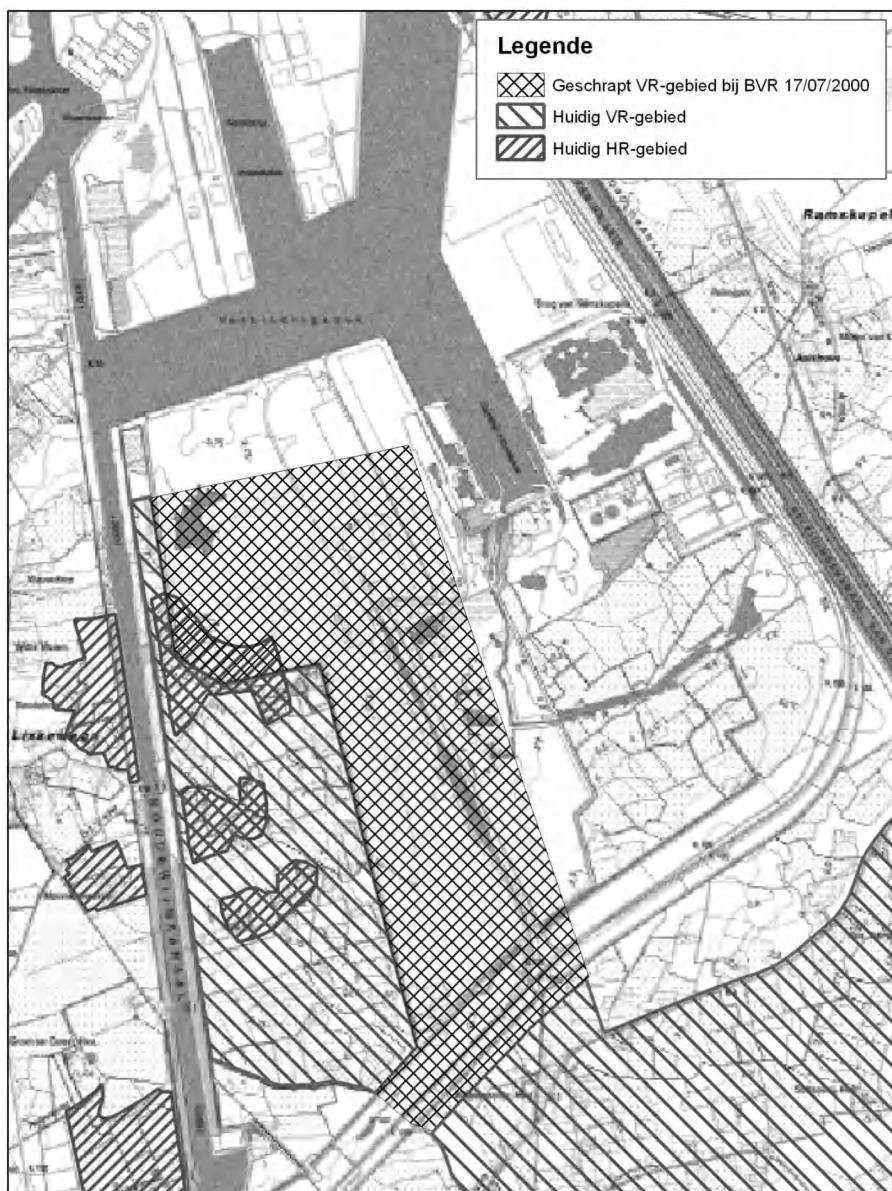


Fig. 1. The Special Protected Area (Birds Directive) in the Port of Zeebrugge.

Conclusions

Notwithstanding the protection regime of international instruments such as the Ramsar Convention and the Birds and Habitats Directives, valuable internationally protected nature areas are destroyed or degraded. In the past, all too often the Member States of the European Union disregarded the obligations under both directives. The Habitats Directive can claim the dubious record of being one of the most litigated environmental instruments in the European Union, as Member States have failed to transpose it correctly into their legal systems and to comply with any of the deadlines established by the Directive (Diaz, 2001). Because of problems such as the Deurganckdok case, it becomes clear that not only nature suffers from this lack of implementation, but that this can also have serious economic consequences. The chance of facing long periods of uncertainties on the future of port development, might yet lead to a better implementation of the directives.

Even though in most cases in the past the international protection regime could not prevent that nature areas were lost in case of port expansion, in future projects the Member States will have to take into account the international obligations, such as the need to demonstrate the urgent national interest. Compensation measures must see to it that there is no net loss in nature values. Compensation is however a last resort. The danger exists that the compensation principle will be abused and that in practice compensation will be a paper compensation only, or in compensations in existing protected areas or areas that should have been designated as protected areas. Also, it will not be easy to find appropriate compensations areas, especially in the crowded areas in Europe. Expansion of ports is usually high space-consuming and thus large compensation areas will be necessary. This might in turn lead to conflicts with other groups, such as farmers. It will be important to include flanking measures for these user groups. A correct implementation of the Ramsar Convention and the Birds and Habitats Directives can contribute to a more sustainable use of valuable areas such as wetland areas.

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SHORELINE MANAGEMENT

Plenary session 6 – chair: James Patrick Doody

Shoreline management – conservation, management or restoration?

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Abstract

The estuarine shoreline forms the margin between the land and the sea. It is composed of a wide variety of habitats with attributes and interests associated with both the marine and terrestrial environment. Saltmarshes are dominated by plants tolerant to saltwater. Sand dunes support essentially terrestrial plant and animal communities. In between these extremes there are other habitats and a suite of transitional and successional features of considerable variety. Sand dunes, shingle shores and estuarine habitats are dynamic and show natural and sometimes rapid changes. Their ability to absorb wave energy or move in response to changing sea levels and storms is a significant feature. Too often in the past humankind has failed to recognise these attributes and sought to control this movement. In areas where socio-economic development has taken place the protection of land from erosion and flooding has become a major preoccupation. Where sea level is rising relative to the land or there is a sediment budget deficit or both a 'coastal squeeze' takes place. This not only threatens the existence of many wildlife habitats and associated species, but also the ability of the coast to protect us from the sea (flooding and erosion). This paper raises the question as to whether traditional approaches to nature conservation in coastal areas are sufficient to sustain habitats for wildlife, coastal defence and other economic uses. Lessons learnt from two European studies will be presented in further papers showing some of the possible ways of 'living with the sea'. These are: the LIFE project 'Living with the Sea'; the EUROSion study funded by the European Commission.

Keywords: Coastal habitats; Conservation; Management and restoration; Coastal dynamics; Coastal squeeze.

Introduction

Coastal habitats, especially those in estuaries, provide the link between the land and the sea. They are dynamic, combine to form ecosystems of great complexity and are often significant areas for wildlife. Their landscapes are treasured by visitors, painters and musicians. They also provide locations for significant economic activity and are intimately bound up with fisheries, providing food and shelter for the young of some species of commercially exploited fish stocks. The habitats themselves provide a buffer to tides and wave action, which may be particularly important in areas where relative sea level is rising and during storm periods. Managing these assets in the face of continuing pressure from human populations on a sustainable basis is a major task.

The most extensive intertidal habitats normally exist within the confines of estuaries, and embayments with macro to meso tidal ranges. They can also be significant in micro tidal areas, where they help to form sometimes extensive deltas. In all cases the shelter afforded by the configuration of the coast or the presence of enclosing sand dunes or shingle spits facilitate the deposition of sediment and form tidal flats and saltmarshes. The interaction between these habitats helps to sustain the system, which is robust in the face of changing environmental conditions.

Too often in the past the value of these areas has been ignored. Human activities have exploited them, taking large areas from the sea by enclosure regardless of the implications for the habitats or the impact on the functioning of the coastal system. This has led to great loss of natural values and in many cases economic values, though the latter is not always recognised. It is not intended in this paper to chronicle these losses.

A key consideration is that the outcome of all this activity, particularly in the estuary environment, has been to 'squeeze' the shoreline into an ever narrowing zone (Fig. 1).

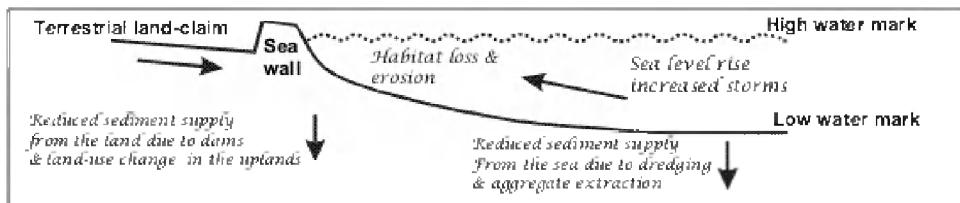


Fig. 1. A simplified picture of 'coastal squeeze'.

In addition to the loss of tidal land, as sediments are removed from functioning coastal systems (for example through nearshore gravel extraction or river damming) the resilience of the remaining habitats is further compromised. This can in turn lead to erosion, which causes further habitat loss and may result in an increased risk of flooding. Where these impacts threaten assets such as industry, housing or high quality agricultural land the response has normally been to erect artificial 'protective' structures.

This exacerbates 'coastal squeeze' and can be especially significant in areas experiencing a relative rise in sea level. The extent to which this results in a loss of economic value and the sustainability of a wide variety of uses, including sea defence and recreational use has only recently been fully appreciated.

This paper will review the role that nature conservation principles have played in conserving nature and the 'natural' environment. It will look beyond these and consider the importance of developing a more sustainable approach, which takes account not only of wildlife, but also coastal defence and other shoreline management issues.

Coastal development

The pressures for economic development and exploitation of biological and non-biological resources for human uses have caused the loss of many coastal areas and the

depletion of some animal populations. For example a review of the situation in Great Britain in the late 1990s showed that in addition to the cumulative loss of some 25% of the natural intertidal areas on 155 estuaries over the previous 100 years or so, in 1989 there were 123 cases of land claim affecting 45 of these sites (Davidson *et al.*, 1991).

Chronicling these losses and their impact elsewhere on the coast of Europe is easy. Papers presented at previous European conferences from 1987 onwards (such as van der Meulen *et al.*, 1989; Doody, 1995) provide examples. It is not intended to give detailed information on these losses here. However, coastal development including land claim (of coastal wetlands) has altered the ‘natural’ coastline especially in the estuaries and deltas of Europe.

These losses reduce the natural, wide and flexibly barrier, which as well as providing important wildlife habitat can help withstand storms and adjust to changes in sea level. This is replaced by a narrow, inflexible, often costly artificial barrier, increasingly vulnerable to attacks from the sea. The EURosion study (DG Environment 2004) suggests that about 7.5% of Europe’s coast is artificially protected in this way (Fig. 2).

This figure only gives an indication of those areas where infrastructure or other ‘land claim’ has resulted in the need for protection from erosion and flooding. The extent of development on other coasts, which are geologically stable (not prone to erosion) or elevated (not prone to flooding) are not reflected in this figure.

Nature conservation

The conservation of species and habitats has long been a major preoccupation of scientists, naturalists and others interested in nature. This has revolved around two principle approaches:

1. protection of sites and species from damaging developments and over-exploitation;
2. the establishment and management of nature reserves.

Protection

The nature conservation lobby, recognising the potentially harmful and often cumulative effects on wildlife of coastal development, has battled against such activities for several decades. This has proved both time consuming and in many cases fruitless, as the losses of habitats and decline in species populations have continued. Faced with this, those concerned with the conservation of nature have fallen back on the tried and tested approach involving the ‘protection’ of individual sites from adverse development as an essential part of their conservation.



Fig. 2. The location of artificial protection around the coast of Europe derived from the recent EUerosion study.

Throughout the last century the identification and designation of sites of special interest for plants and/or animals has become one of the mainstays of the nature conservation movement. In Europe the top sites for habitats and species are included within the Natura 2000 network. Each individual country has developed a series of measures not only to protect these top European sites, but also those with a more local value. These range from national statutory legislation to the management of sites owned by national or local voluntary conservation organisations.

For all these sites, boundaries are agreed and drawn on maps. Their protected status does not necessarily mean that all damaging activities are prevented. Proposals for airports, new roads, buildings, housing and ports continue to be put forward and in many instances these threaten the further destruction of habitats and loss of species. When coupled with other activities such as disturbance caused by tourism, pollution from the sea and depletion of coastal sediments, the damage to coastal wildlife continues.

Management

For sites established as nature reserves it is usual for a management plan to be prepared. This is designed to protect the important wildlife features present within the site at the time of designation. Within these 'protected' areas management is normally based on ecological principles and determined through experience (of management elsewhere), knowledge of the specific requirements of individual habitats and/or species and published guidance (e.g. Packham and Willis, 1997; Doody, 2001).

This approach has proved successful in many areas. However, even where the resources are available and the policies appropriate, unforeseen influences may cause loss of interest. At the same time the act of drawing site boundaries on maps to establish the limit of a particular nature conservation interest, can reinforce a 'protectionist' philosophy. In this case change may be seen as damaging, especially when 'natural'

processes result in one interest being replaced by another. Three examples will be used to illustrate the issues:

Coastal sand dunes and dune dynamics

For centuries coastal sand dunes have been considered to be fragile systems requiring protection from erosion. Sand drift at many sites throughout Europe prompted the planting of trees, mostly of non-native pine. Examples of this abound throughout Europe where extensive areas have been afforested. A considerable part of the Atlantic coastal dunes are covered with woodland (35%), but only a small part of this (4%) is thought to be natural (see the EUCC Coastal Guide on Dune Management at <http://www.coastalguide.org/dune/index.html>, implying 31% has been planted with non-native trees).

In Denmark, as early as 1539, a Royal Decree prohibiting the removal of any vegetation on sand dunes was enacted because of the extent of erosion (Skarregaard, 1989). By the turn of the 20th century some 30,000ha out of a total of approximately 80,000ha (c40%) of open dune had been afforested.

In addition to the direct loss of habitat, monitoring of Danish coastal priority habitats in recent years has shown that for the remaining unafforested fixed grey dunes (2130*) and decalcified fixed dunes with *Empetrum nigrum* (2140*) their conservation status has been further threatened. Three reasons have been identified:

1. invasion of non-native species, especially *Pinus mugo* and *Pinus contorta*, planted to help stabilise the dunes;
2. lack of natural dynamic processes (over-stabilisation of dunes) due to reduction and lack of grazing;
3. ammonium deposition / eutrophication.

This resulted in a LIFE project to help restore ‘favourable condition’ (as defined under the EU Habitats Directive) to the dunes (Ministry of the Environment Danish Forest and Nature Agency, *Restoration of Dune Habitats along the Danish West Coast*, LIFE02/NAT/DK/8584). The restoration methods included the removal of scrub and woodland species and the reintroduction of dune dynamics. This last approach representing a major change in the way dune systems are perceived with a move away from dune protection using sand fences and the like (Fig. 3), which had been practiced at many sites, for many years throughout the world. This change has been accompanied by recognition that a more dynamic approach may fulfil the nature conservation need more readily.



Fig. 3. 'Protected' dunes – gabions and fencing, New Jersey shore, USA.

The need for a change in approach had been highlighted nearly 15 years earlier at a sand dune conference held in Edinburgh. Over-stabilisation of sand dunes, partly due to a reduction in rabbit grazing, was implicated in the loss of open dune vegetation, including sand dune slacks, to invasive scrub. The importance of a more dynamic approach was exemplified by the development of sand dune slacks (Fig. 4). 'It is worth remembering that today's blow-out can be tomorrow's dune slack....' (Doody, 1989).

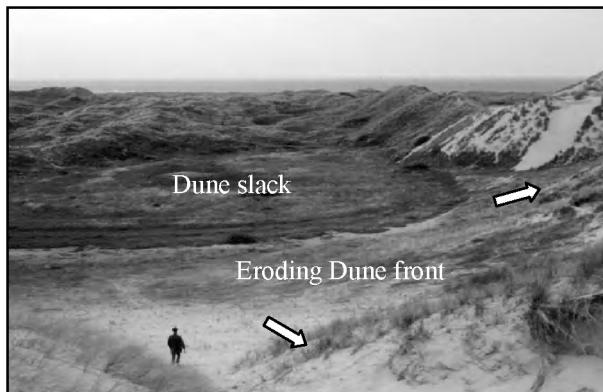


Fig. 4. 'Dynamic' dunes, showing the direction of 'erosion' and the development of a dune slack behind. Braunton Burrows, north Devon, England.

Saltmarsh erosion on the Essex coast

Whilst erosion of sand dunes was recognised as a problem for managers the same was not always true for saltmarshes. If erosion was considered at all, it was more or less seen as an accepted part of the natural processes associated with estuary dynamics. However, in south east England, conservationists became increasingly concerned about the scale of

saltmarsh loss, especially on the Essex coast. These losses became part of what has become known as ‘coastal squeeze’ (Doody, 2004).

Essex estuaries, protection and re-creation

In Essex much of the low-lying coastal farmland is derived from the enclosure of former tidal land, principally saltmarsh and swamp. In the early 1980s the erosion of saltmarshes and the undermining of some of the earth banks protecting the land had already prompted attempts to re-create the habitat. The method adopted involved building polders outside the sea walls (Fig. 5), an approach borrowed from the southern North Sea coast, particularly in the Wadden Sea.



Fig. 5. Groynes built to form polder-like structures on the foreshore as part of an attempt to ‘hold the line’, Cudmore Grove, Mersea Island, Essex (at the time the picture was taken in 2003, some 10 years after construction, there were no obvious signs of mudflat accretion or saltmarsh development).

The increasing cost of maintaining the existing line of defence in this part of the UK, especially in areas of limited agricultural value, led to a growing recognition that simply ‘holding the line’ might not be a cost effective solution. This led to a number of experiments being undertaken in this part of the country to adopt a more flexible approach. Amongst these ‘managed realignment’ is one of a suite of policies promoted by the UK Department of Environment Food and Rural Affairs (DEFRA) for coastal defence (Fig. 6). The method involves realigning sea defences such that new habitat is created by allowing sea water to flow over former tidal land, which has been enclosed. The result is a redistribution of habitats with a general landward movement of intertidal habitats, notably mudflats and saltmarshes. The approach may include identifying a new line of defence landward of the original protective sea wall. This may or may not involve the construction of new sea wall or other barrier inland of the original one.

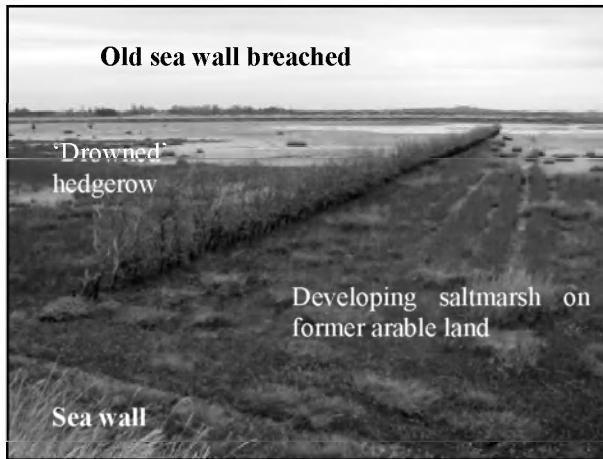


Fig. 6. A managed realignment. Tollesbury, Essex. The outer sea wall was breached in two places in 1995. This picture was taken in 2000, by which time extensive mudflats and some saltmarsh had developed on former agricultural land.

Kessingland shingle shore migration

In areas where there is a net landward movement or longshore drift sand dunes or shingle structures may, over time, move beyond the limits of the original site boundary (Fig. 7). This can result in the nature conservation interest extending beyond the limits of the site as originally designated. This presents a problem for those with the statutory responsibility for 'protecting' the site.

The Kessingland shingle beach was included as part of a larger Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981 in 1989. The northern boundary of the site (Fig. 7) was drawn to coincide with the limit of the shingle beach, the identified feature of importance. The positions of the shingle beach and shoreline in 1991 suggest that the limits of the statutory protection already fell short of the full extent of interest when the statutory protection was confirmed in 1989.

The full extent and rapidity of the change is illustrated by Figs 8 and 9 below. A groyne field is clearly visible in the photograph taken looking south along the coast during a site visit in 1984 (Fig. 8). Their location can also be seen on the 1978 aerial photograph (Fig. 7).

By 2004 the groynes shown in the picture above had completely disappeared and in their place an *Ammophila* dominated sandy foreshore had developed (Fig. 9). This change appears to precede the northward movement of the shingle ness as shown above (Fig. 7).

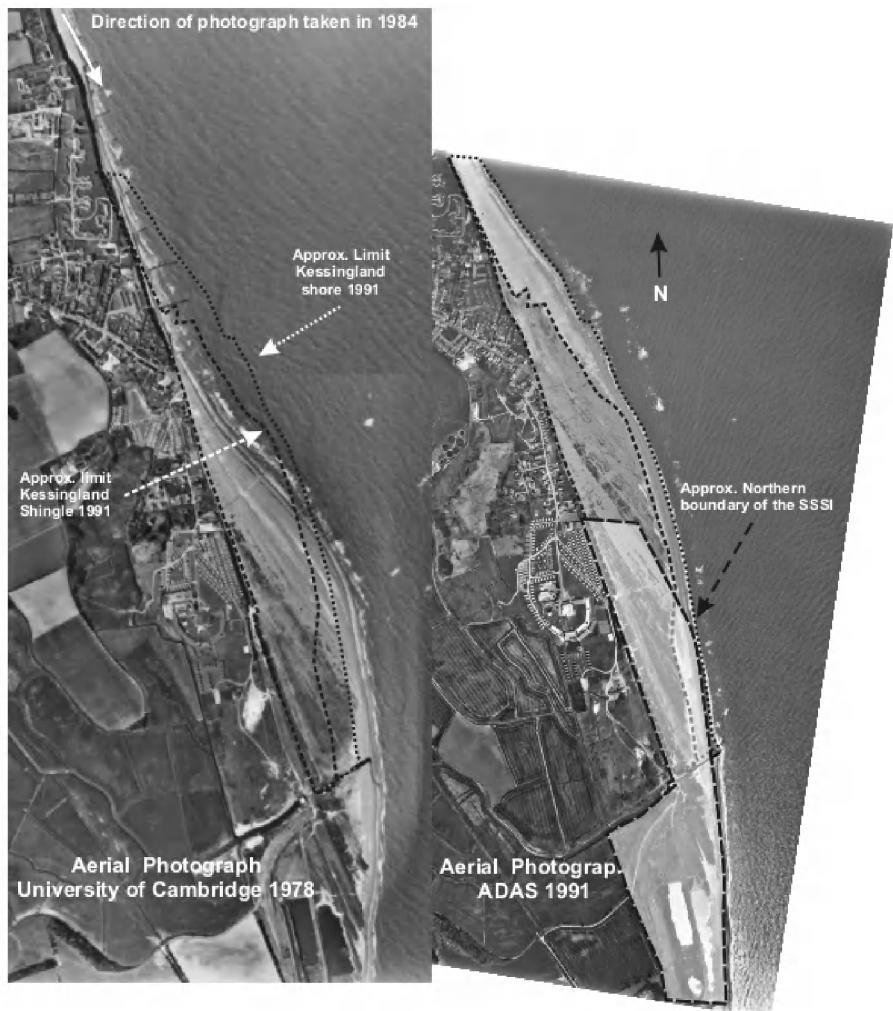


Fig. 7. *Aerial photographs of Kessingland Beach, Suffolk, SE England showing the northward migration of the shingle ness and sandy shore between 1978 and 1991.*



Fig. 8. Kessingland beach looking south from OS Grid. Ref. NR 536870, June 1984. Notice in the foreground how the groynes are showing signs of being covered by shingle.



Fig. 9. Kessingland beach taken looking south east from approximately the same location as in Fig. 7, August 2004. The upper shingle shore, low sand dunes and sandy foreshore (with Ammophila) have replaced the narrow shoreline and groyne field.

Conclusions

This paper effectively poses the question ‘can we rely on the traditional approaches to the conservation of habitats and species’ centred around site protection and management? In the face of increasing demand for coastal land and other resources for human use, the identification of statutorily designated areas, has aided their protection. This has worked for some sites, but not others. The establishment of nature reserves has provided more secure protection and also allows the management of adverse changes.

However, the three examples described above suggest that relying on habitat protection and/or management are not always enough and different approaches are needed.

Coastal dynamics, ‘reintegration’ and habitat migration

At the beginning of this paper it was stated that coastal habitats are dynamic and inter-related. Restraining the dynamic can, as the example of sand dunes suggests, result in over-stabilisation and loss of nature conservation interest. By restoring the dune dynamic, which may include initiating rather than controlling erosion, new habitat can be created. This will restore dune slacks and their associated plants and animals (including the uncommon natterjack toad). It will also help ensure the full range of dune types *e.g.* from yellow dune to dune grassland or heath is represented on an individual site. In addition, by creating open dune habitat it will provide suitable sites for a variety of invertebrates, such as bees and wasps nesting in open sand.

Combating ‘coastal squeeze’ also requires a more proactive approach. Habitat loss may be especially significant in areas where sea level is rising and/or sediment is lost from the coastal system. These losses can also have economic and social consequences, as is the case on the Essex coast where flooding is a key issue. Allowing the sea to flow over land formerly part of the intertidal system provides opportunities for ‘re-integrating’ the land with the sea. This has the combined effect of restoring intertidal habitats and helping to improve sea defences.

The migrating beach at Kessingland may pose problems for those responsible for its protection under national legislation. However, it illustrates another very important aspect of restoration, the ability of natural processes to re-create high quality habitat. In this case, despite intensive recreational pressure the new areas of shingle beach outside the SSSI are as significant as those lost through erosion (Doody 2004). These and other similar issues will be considered more fully in relation to the paper on the EU LIFE project ‘Living with the Sea’ (Worrall, 2005).

Time and space for coastal processes

In the face of ‘coastal squeeze’ habitat restoration, re-creation or creation may be as important to the long term sustainability of our coasts as protecting existing habitats. In this context the role of sand and shingle beaches, mudflats, saltmarshes and sand dunes in the functioning of the wider estuarine ecosystem must not be overlooked.

This wider perspective must also include consideration of the value of coastal areas in relation to human activities, and not always in a negative sense. It can be argued that a wider more dynamic zone, in which coastal habitats are a significant element, will help provide a more sustainable future for our low-lying coastal areas and their economic, recreational and environmental values. Nowhere is this more significant than in relation to areas prone to coastal erosion and flooding. In the past the natural, human response has been to erect bigger and ‘better’ artificial coastal defences. However, the failure of many of these structures, the cost of repair and recognition that they may have exacerbated problems on adjacent coastlines, has led to a reappraisal of their role. At a

European level a study on erosion (EURosion) has resulted in recognition of the need to work within a much wider zone, for example at catchment level (Niesing, 2005). A significant element in this is the importance of allowing time and space for the coast to adjust to external change. This also requires that there is sufficient sediment to allow change to take place without a diminution of the coastal zone.

The above discussion suggests that establishing statutorily designated areas and nature reserves provides only a partial solution to the protection of important habitat and species. Management of these areas can be costly and time-consuming and may not always be optimal. In areas where relative sea level is rising, with or without erosion taking place, 'natural' change may result in habitat loss. In the most dynamic areas coastal habitats will evolve in such a way as to move beyond the limits of 'protected' sites. Taken together, these factors suggest the need for a wider appreciation of the role of natural processes and sediment dynamics in coastal conservation and management. In this context and given the extent of the accumulated losses of coastal habitats Europe-wide, the restoration, re-creation or creation of coastal habitats must be an essential part of any future nature conservation effort.

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EUROSION: Coastal erosion measures, knowledge and results acquired through 60 studies

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Abstract

Approximately twenty percent of the European Union's coast is currently eroding despite the development of a wide range of measures to protect shorelines from eroding and flooding. The prospect of further sea level rise due to climate change and the heritage of mismanagement in the past – such as inappropriate infrastructure – imply that coastal erosion will be a growing concern in the future. This is why DG Environment of the European Commission tendered the EUROSION project, which was realised by a consortium led by the National Institute for Coastal and Marine Management of the Dutch Ministry of Transport, Public Works and Water Management.

A state of the art report was compiled, based on a Europe wide review of successful and unsuccessful strategies, measures and experiments to prevent or manage erosion for different types of coast. This paper presents the main lessons learned from the practical level of coastal erosion management. It aims to provide an overview to coastal managers at the European, national and regional and municipal levels with a state-of-the-art of coastal erosion management solutions in Europe, based on the review of 60 case studies. The case studies along the European coast have been selected on the following criteria: coastal erosion, land use and geographical distribution. The cases, scattered around Europe, are meant to illustrate the different situations on the assessment levels: coastal classification, existing policy, technical measures and socio-economic backgrounds. This paper focuses on the practical lessons learned and their possible utilisation in coastal erosion management. To a lesser extent the relationship between the perspective provided by the European database and the EUROSION policy recommendations is discussed.

Introduction

Coastal erosion is a natural phenomenon, which has always existed and has contributed throughout history to shape European coastal landscapes. Coastal erosion, as well as soil erosion in water catchments, are the main processes which provide terrestrial sediment to the coastal systems including beaches, dunes, reefs, mud flats, and marshes. In turn, coastal systems provide a wide range of functions including absorption of wave energies, nesting and hatching of fauna, protection of fresh water, or places for recreational activities. However, migration of human population towards the coast, together with its ever growing interference in the coastal zone has also turned coastal erosion into a problem of growing intensity.

Coastal erosion is usually the result of a combination of factors – both natural and human induced – that operate on different scales. EUROSION has undertaken a review of factors responsible for coastal erosion in about 60 case studies representative of European coastal diversity (Fig. 1).

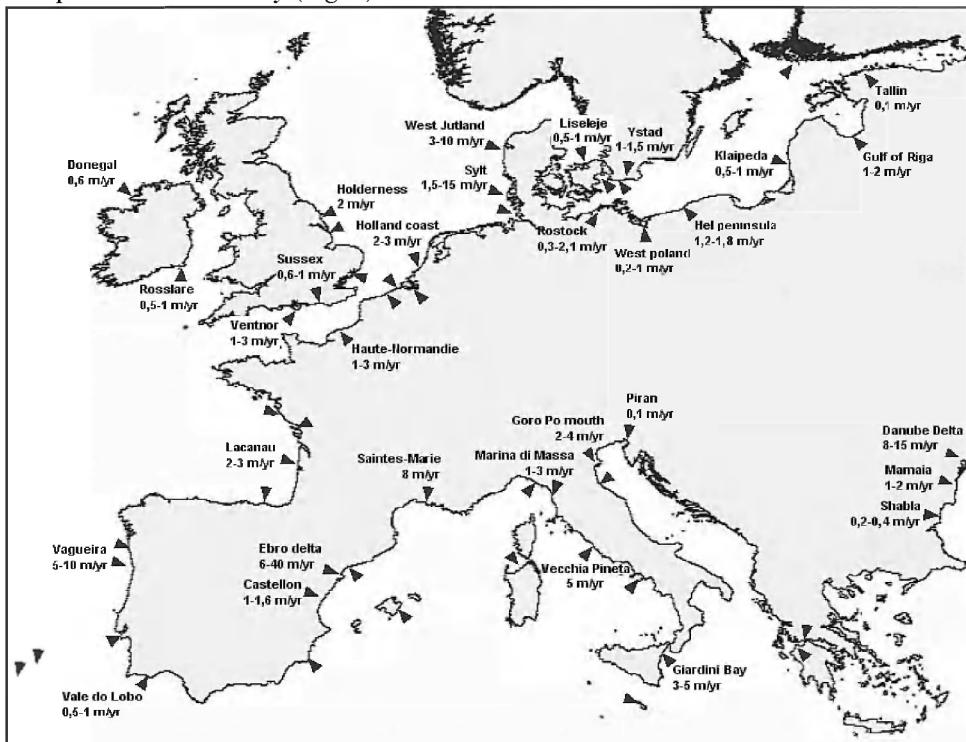


Fig. 1. Location of the 60 case studies reviewed during EUROSION study (with average erosion rate per year for selected cases).

Coastal erosion figures depend on time and spatial scales of observation. The sedimentary coastline exists in an environment that is fluctuating over different timescales with periods relating to waves (seconds), tides (twice daily), seasons and longer timescales, as for example changes in sea level.

The case study review as such does not pass judgement on the success or failure of coastal erosion management solutions implemented. It attempted to highlight those objectives that were initially assigned to such solutions and how far such objectives have been reached.

It is assumed that with such an approach the coastal manager, specialist or non-specialist coastal engineer, would be in a position to understand the major obstacles that may be encountered in deciding which coastal erosion management design is most appropriate for a particular area, bearing in mind the wide range of European experiences.

According to the DPSIR-methodology (Drivers, Pressure, State, Impact, Responses) the review addressed the following issues: the known causes of coastal erosion and their current and anticipated impact on social and economic assets, the technical specifications of the solutions proposed as well as their positive and negative effects from the perspective of local inhabitants. Furthermore, the role of innovative measures, monitoring and modelling prior to the design of measures was studied. The lessons learned that are presented reflect these issues.

Main EUROSION case studies results

The EUROSION case studies have been analysed thoroughly, taking all the influencing factors into account. This has been incorporated into both the EUROSION findings and policy recommendations. An extensive analysis was executed (EUROSION, 2004), including various consortium and international expert meetings. The main lessons drawn are briefly described below:

Erosion types, occurrence and the human driver

Human influence, particularly urbanisation and economic activities in the coastal zone, has turned coastal erosion from a natural phenomenon into a problem of growing intensity. Adverse impacts of coastal erosion most frequently encountered in Europe can be grouped in three categories: (i) coastal flooding as a result of dune erosion, (ii) undermining of sea defence associated with foreshore erosion and coastal squeeze*, and (iii) retreating cliffs, beaches and dunes causing loss of land of economic and ecological values.

*‘Coastal squeeze’. Habitats are lost as a result of a combination of land claim, sea level rise or reduction in sediment availability.

Erosion origins, natural and human-induced

Coastal erosion results from a combination of factors – both natural and human-induced – which have different patterns in time and space (Figs 2 and 3) and can be continuous or incidental, reversible or non-reversible. In addition, uncertainties still remain about the interactions of the forcing agents, as well as on the significance of non-local causes of erosion.

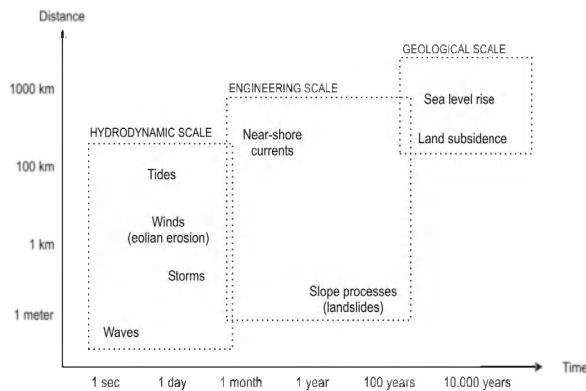


Fig. 2. Time and space patterns of natural factors of coastal erosion (note that 'distance' and 'time' reflect the extents within which the factor occurs and causes erosion).

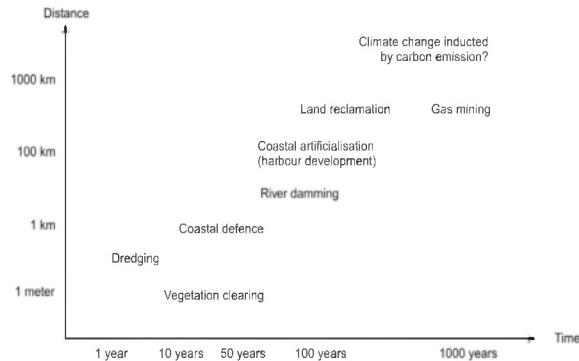


Fig. 3. Time and space patterns of human induced factors of coastal erosion.

Environmental Impact Assessment and coastal erosion

Coastal erosion induced by human activities in Europe has surpassed coastal erosion driven by natural factors. Human-induced coastal erosion mainly proceeds from the cumulative and indirect impacts of small and medium size projects, as well as from river damming. However, little attention is paid to these impacts by project developers, Environmental Impact Assessment (EIA) practitioners and competent authorities.

Knowledge of erosion processes

Knowledge on the forcing agents of coastal erosion and their complex interaction tends to increase over time. However, this knowledge is fragmented and empirical as reflected by the many different models commonly used throughout Europe to anticipate coastal morphological changes. Secondly the usage of knowledge in the decision making

process is lacking, resulting in inadequate decisions and sometimes huge adaptation and compensation costs.

Local management action in broader perspective

Past measures to manage coastal erosion have generally been designed from a local perspective: they have ignored the influence of non-local forcing agents and have disregarded the sediment transport processes within the larger coastal system. As a consequence, they have locally aggravated coastal erosion problems, and triggered new erosion problems in other places. They still influence the design of present measures.

The coastal sediment cell

In an attempt to respond more effectively locally to non-local causes of coastal erosion and to anticipate the impact of erosion management measures a number of cases, mainly in northern Europe, have built their coastal erosion management strategies upon the concept of “sediment cell”. This has been accompanied by a better understanding of sediment transport patterns within the sediment cell (Fig. 4). Such approaches require a strong cooperation between regions, which share a same sediment cell.

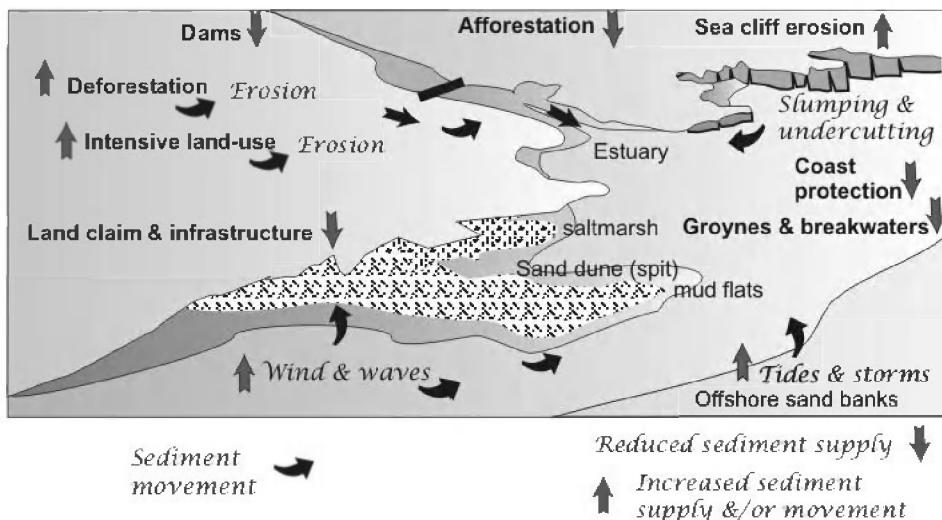


Fig. 4. Some of the principal causes of change in sediment movement in a 'sediment system' (Doody 2001). In this diagram the coast is taken to include the sea cliffs and sand dunes, tidal saltmarshes and mud/sand flats. Nearshore marine waters (blue) and the hinterland (green) make up the 'sediment system'. In the diagram sediment movement is tending towards 'sediment sinks' associated with a coastal embayment, such as an estuary.

No miracle solutions, but learning through experience and applying multi-functional design and acceptability

Experience has shown that, at the present time, there is no miracle solution to counteract the adverse effects of coastal erosion. Best results have been achieved by combining different types of coastal defence including hard and soft solutions, taking advantage of their respective benefits though mitigating their respective drawbacks. Multi-functional technical designs, *i.e.* which fulfils social and economic functions in addition to coastal protection, are more easily accepted by local population and more viable economically.

The setting of clear objectives, towards accountability through cost-benefit analysis

Assignment of clear and measurable objectives to coastal erosion management solutions – expressed for example in terms of accepted level of risk, tolerated loss of land, or beach/dune carrying capacity – optimises their long-term cost-effectiveness and their social acceptability. This has been facilitated by the decrease of costs related to monitoring tools.

Though critical for decision-making, the balance of coastal defence costs and their associated benefits is – in general – poorly addressed in Europe. This may lead to expenses, which are at the long run unacceptable for the society compared to the benefits.

The EUROSION database and natural assets

The European dimension of sediments and soils: sediments that are important for future coastal resilience are sealed within water catchments that in many instances extend over several Member States. River regulation works can also have impacts on coastal zones of other Member States. The Water Framework Directive is an important instrument in which this can be addressed. In addition, sediments also cross borders in the coastal zone; coastal management actions can easily have cross-border impacts, not only along dunes and beaches but also in estuaries (*e.g.* dredging works in transboundary zones).

Current coastal erosion management practice tends to use Natura 2000 sites as Strategic sediment reservoirs. This will have long term and possibly irreversible implications for the Natura 2000 Network. EUROSION suggests that designated natural habitats should not be the source of sediments to compensate for chronic deficits of sediment due to human interventions, because this would undermine coastal resilience and community environmental policy objectives. At the EU-level this can be approached through the Habitats Directive.

Within EUROSION a Europe wide database has been realized assessing the European magnitude of coastal erosion. This assessment included both the sensitivity and impact analysis of coastal erosion and flooding events. Approximately 40.000 km² wetlands under the influence of coastal erosion are considered to be at risk. Studies for the UN-IPCC estimate that the number of people subject to an actual coastal erosion or flood risk

in 2020 would exceed 158,000, while half of Europe's coastal wetlands are expected to disappear as a result of sea level rise (Salman *et al.*, 2002).

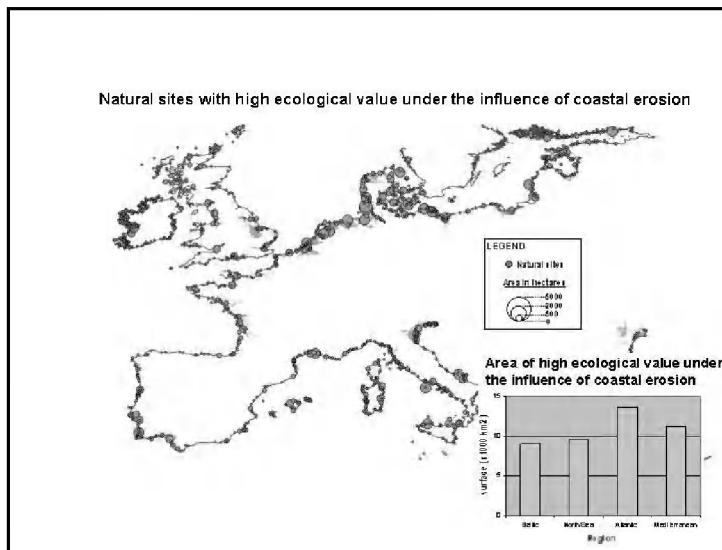


Fig. 5. Natural sites with high ecological value under the influence of coastal erosion.

Major concerns: what is at stake?

For the next 50 years, EUROSION is particularly concerned with the following trends:

- Loss of sediment: the amount of sediments will continue to be at risk due to ongoing trends, especially in river regulation works and coastal urbanisation;
- Loss of dynamic coastlines and natural habitats;
- Loss of resilience;
- The impacts of climate change.

Apart from hazards and risks that tend to be unpredictable, coastal erosion will result in an increasing cost to society involving:

- Increasing risk to lives and economic assets;
- More habitat loss;
- Greater mitigation and management cost.

EUROSION major findings

With regard to the underlying mechanisms responsible for the problems in the field of coastal erosion EUROSION has identified the following major findings:

Finding 1: on coastal squeeze and the loss of sediment

Urbanisation of the coast has turned coastal erosion from a natural phenomenon into a problem of growing intensity. The majority of coastal erosion problems are now induced by human activities and artificially stabilised seafronts are progressively encroaching on sedimentary coastlines and cliffs. Dynamic ecosystems and their undeveloped coastal landscapes are gradually disappearing, due to a lack of sediment. In many places the process of 'coastal squeeze' is responsible for this phenomenon.

Finding 2: on environmental and economic assessment

Environmental Impact Assessment (EIA) procedures – as implemented under the terms of the directive 85/337/EEC – have been insufficient in addressing the impact of human activities, such as development, on the wider coastal environment. Subsequently, the cost of attempting to reduce coastal erosion has increased considerably in relation to the assets requiring protection. Consequently it has resulted in a need to transfer the cost of coastal erosion mitigation measures to such activities.

Finding 3: on coastal erosion risk

The cost of reducing coastal erosion risk is mainly supported by national or regional budgets, hardly ever by the local community and almost never by the owners of assets at risk or by the party responsible for coastal erosion. This is emphasized by the fact that coastal erosion risk assessment has not been incorporated in decision-making processes at the local level and risk information to the public remains poor.

Finding 4: on the mitigation of coastal erosion

Over the past hundred years the limited knowledge of coastal sediment transport processes at the local authority level has resulted in inappropriate measures of coastal erosion mitigation. In a considerable number of cases, measures may have solved coastal erosion locally but have exacerbated coastal erosion problems at other locations – up to tens of kilometres away – or have generated other environmental problems.

Finding 5: on information management

In spite of the availability of tremendous amounts of data, information gaps continue to exist. Practices of coastal information management – from raw data acquisition to aggregated information dissemination - suffer from major shortcomings, which result in inadequate decisions. Surprisingly, sharing and dissemination of coastal data, information, knowledge and experiences are hardly ever considered by regional and local stakeholders. The use of a better knowledge base when coastal development is proposed provides an opportunity, which could help reduce technical and environmental costs of human activities (including measures for coastal erosion mitigation) and could help anticipate future trends and risks.

Coastal resilience

Understanding the dynamic nature of the coastal margin is a key factor in managing coastal erosion. In the past development has encroached upon coastlines, resulting in a sometimes dramatic loss of habitats and with them a reduction in their natural dynamic characteristics. EUROSION has shown that whilst protection is possible, extreme events undermine and/or overtop coastal defences. Long term trends and knock-on effects from the structures themselves also often result in negative effects on the resilience of much larger coastal units. It is anticipated that this situation will be aggravated by climate change, resulting in an increase in sea levels and a more unpredictable and extreme storm climate. This will result in a long term threat to the safety of people, to the sustainability of many coastal activities, to coastal biodiversity and to the ability of the coast to provide a ‘natural’ coastal defence.

EUROSION recognises the sustainable development of coastal zones and the conservation of dynamic habitats, especially on the remaining undeveloped coast, as important long term goals for European coastal zones. This requires a respect for, and in many cases restoration of, the natural functioning of the coastal system and hence its natural resilience to erosion. EUROSION defines coastal resilience as the inherent ability of the coast to accommodate changes induced by sea level rise, extreme events and occasional human impacts, whilst maintaining the functions fulfilled by the coastal system in the longer term. The concept of resilience is particularly important in the light of the predictions for climate change.

Resilience depends on two key factors: *sediments* and *space for coastal processes*.

Coastal resilience will decrease as a result of:

- Chronic losses of sediments and
- Limitations set to the space that is required to accommodate:
 - natural retreat of cliffs and sedimentary systems
 - redistribution of sediments as a result of this retreat.

These aspects need to be recognised as most fundamental conditions for sustainable coastal planning in general and shoreline management in particular. In order to make link the elements ‘sediments’ and ‘space’ EUROSION proposes the concept of ‘strategic sediment reservoirs’.

Strategic sediment reservoirs

The need to counteract a negative sediment balance in a particular coastal zone will require a source of sediment to be identified. To facilitate the future availability of such an ‘appropriate’ sediment supply, EUROSION proposes the concept of ‘strategic sediment reservoirs’. These are defined as: supplies of sediment of ‘appropriate’ characteristics that are available for replenishment of the coastal zone, either temporarily (to compensate for losses due to extreme storms) or in the long term (at least 100 years). They can be identified offshore, in the coastal zone (both above and below low water) and in the hinterland. After designation of strategic sediment reservoirs their availability should be ensured by leaving them undeveloped.

EUROSION policy recommendations

On the basis of the findings and the EUROSION vision four key recommendations are proposed that, once implemented as a package, will make coastal erosion problems and risks in Europe manageable. For each recommendation an indication is given of its implications at the level of the European Union, Member States and coastal regions (local government).

Recommendation No. 1: Increase coastal resilience by restoring the sediment balance and providing space for coastal processes

A more strategic and proactive approach to coastal erosion is needed for a sustainable development of vulnerable coastal zones and for the conservation of coastal biodiversity. In the light of climate change it is recommended that coastal resilience is enhanced by: (a) restoring the sediment balance; (b) allocating space necessary to accommodate natural erosion and coastal sediment processes and (c) the designation of strategic sediment reservoirs. In view of the importance of the availability of sediments and space for sediment transport (from rivers, along the shore and between coastal system and seabed) EUROSION proposes the concept of a 'favourable sediment status' for coastal systems. This concept can help form the basis for shoreline and water catchment management. Favourable sediment status may be defined as the situation of 'coastal sediments' that will permit or facilitate meeting the objective of supporting coastal resilience in general and of preserving dynamic coastlines in particular.

Recommendation No. 2: Internalise coastal erosion cost and risk in planning and investment decisions

The impact, cost and risk of human induced coastal erosion should be controlled through better internalization of coastal erosion concerns in planning and investment decisions. Public responsibility for coastal erosion risk (through the taxation system) should be limited and an appropriate part of the risk should be transferred to direct beneficiaries and investors. Environmental Assessment instruments should be applied to achieve this. Risks should be monitored and mapped, evaluated and incorporated into planning and investment policies.

Recommendation No. 3: Make responses to coastal erosion accountable

Coastal erosion management should move away from piecemeal solutions to a planned approach based upon accountability principles. These would help optimise investment costs against values at risk, increase the social acceptability of actions and keep options open for the future. EUROSION proposes a more proactive approach based on planning and accountability of achievements in the fields of coastal erosion management.

Recommendation No. 4: Strengthen the knowledge base of coastal erosion management and planning

The knowledge base of coastal erosion management and planning should be strengthened through the development of information governance strategies. These should be the starting point with information on ‘best practice’ (including learning from failures), for a proactive approach to data and information management and for an institutional leadership at the regional level.

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Windows in the dunes – the creation of sea inlets in the nature reserve de Westhoek in De Panne

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Abstract

The Flemish Nature Reserve 'De Westhoek' constitutes together with the French public domain 'La Dune du Perroquet' a transborder coastal dune area of 700ha, situated between De Panne (Belgium) and Bray-Dunes (France). From high-tide mark to polders, the range of dunes has a width of nearly 2km. In the 1950s heavy storms beat a breach through the foredunes of 'La Dune du Perroquet'. Consequently, the seawater could penetrate through the breach into a dune slack during high high tides. This phenomenon is called a 'sea inlet', or a 'slufter'. The seawater could also top over the foredunes of the Belgian 'Westhoek' in those days (during storm tides), but at the end of the 1970s a concrete dunefoot revetment was built in front of the foredunes to prevent further coastal erosion. Sea inlets in the dunes are a rare phenomenon along the sandy coasts of the southern North Sea. They usually harbour a highly specialised bird life and salt-tolerant flora. The management plan for the Nature Reserve 'De Westhoek' that was approved in 1996, includes the creation of sea inlets by locally removing the concrete dunefoot revetment. As the coastal protection policy of the Flemish Regional Authority has evolved to a more dynamic and risk-based approach, the Coastal Division decided to create two sea inlets. Projects that have an influence on the hydrological system of natural areas are however subject to an Environmental Impact Assessment, so that an EIA had to be drawn up for the creation of two sea inlets. After the approval of the EIA by the competent authority and the delivery of a building permit, the works were carried out between January 2004 and June 2004. The two new sea inlets' surface totals approximately 1ha. The deflation zones where the sea inlets were created consisted originally of sandy plains that were thickly strewn with debris from demolished blockhouses and had a scarce Marram-grass (*Ammophila arenaria*) vegetation. The creation of sea inlets should allow the development of the natural habitats of the annex I of the European Habitat-directive '1310 (15.11) Salicornia and other annuals colonising mud and sand' and '2110 (16.211) Embryonic shifting dunes', and also offer breeding opportunity to at least Kentish Plover (*Charadrius alexandrinus*) and Great Ringed Plover (*Charadrius hiaticula*). The results and effects of the sea inlets on the salinity of the groundwater is being meticulously monitored.

Keywords: Sea inlet; Slufter; Dynamic coastline; Risk-based coastal safety.

Introduction

The Flemish Nature Reserve 'De Westhoek' is the largest area of natural coastal dunes area along the Flemish coast. It is situated near the border with France. Together with the French public domain 'La Dune du Perroquet' it forms a transborder coastal dune reserve of 700ha. From high tide mark to polders, the range of dunes has a width of approximately 2km (*cf.* Fig. 1).

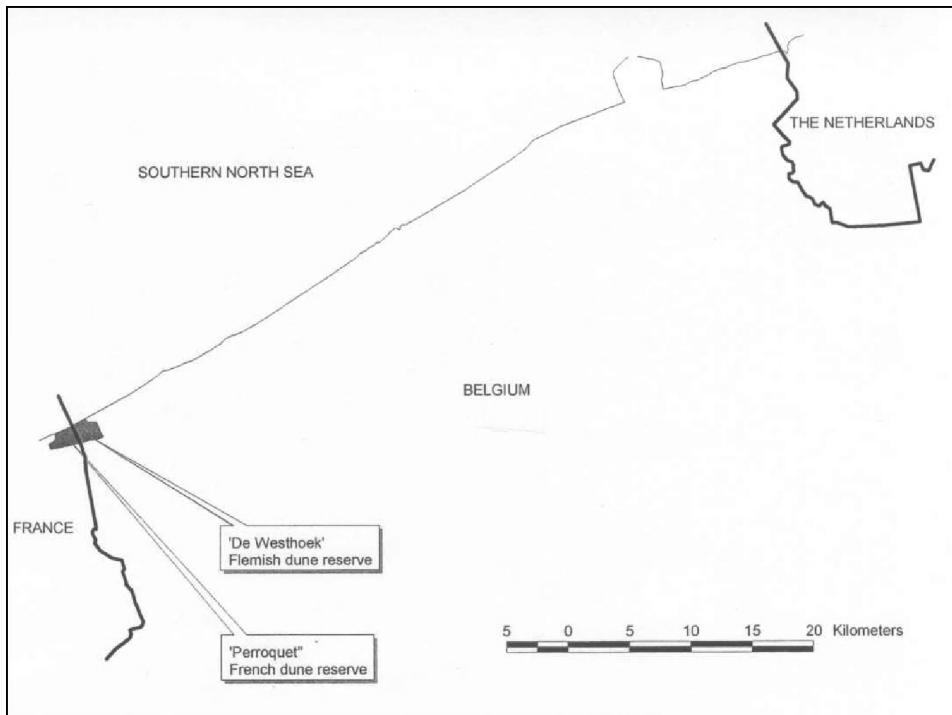


Fig. 1. Location.

In the 1950s heavy storms beat a breach through the foredunes of 'La Dune du Perroquet'. Consequently, during high high tides the seawater could penetrate through the breach into the lowlying areas behind the foredunes. This phenomenon is called a 'sea inlet', or a 'slufter'. A sea inlet has a limited lifespan. Eventually a sea inlet will close when natural accretion by sand that is transported from its surroundings by wind and water blocks its mouth. A closed sea inlet can reopen again by erosion during stormy weather. A sea inlet is a feature of a dynamic sandy coastline. Sea inlets in the dunes are a rare phenomenon along the sandy coasts of the southern North Sea. They usually harbour a highly specialised bird life and salt tolerant flora.

At the end of the 1970s a concrete dunefoot revetment was built in front of 'De Westhoek' dunes in order to prevent further coastal erosion of these dunes. Back then the

shoreline management in Belgium consisted very much of fixing the coastline wherever erosion was taking place. Meanwhile the coastal resort of De Panne was expanding. Dune areas were built up with apartment blocks and villas. These buildings further necessitated the protection against erosion of the dunes.

Development of the project

Nowadays, a quarter of a century later, the shoreline management of the Flemish Regional Authority has changed and it is now forbidden by law to build inside the dunes. The concept of fixing the coastline has been replaced by the concept of a dynamic coastline, meaning that the natural processes of sand transport along the coastline are being re-established wherever possible. According to these new shoreline management principles a project has been developed for the artificial creation of sea inlets in the dunes of the 'Westhoek'.

The project idea is presented by Figs. 2 and 3. Essentially the idea was to remove the first line of dunes and the dunefoot revetment at two locations, to build two bridges at those locations, and to remove sand from the slufter areas and transport it to the second line of dunes.

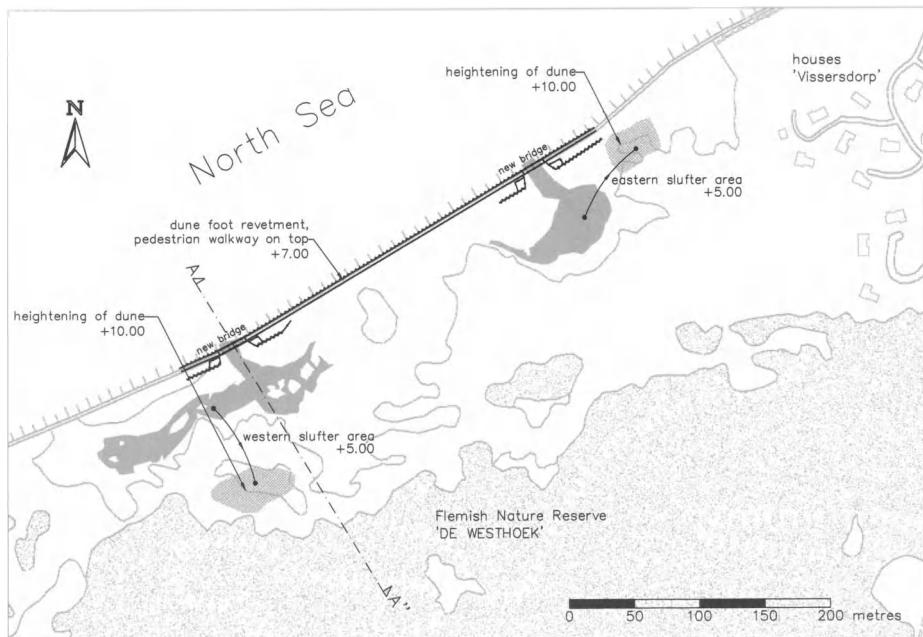


Fig. 2. Project idea - plan view.

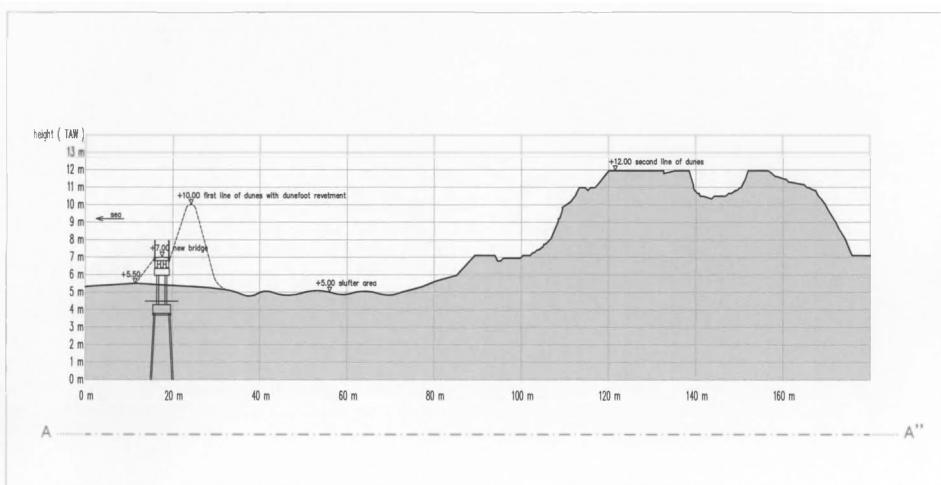


Fig. 3. Project idea – cross section.

Finding common goals

It has been very difficult to agree on common goals during the development of the project. Different stakeholders emphasised different view points. Many aspects had to be taken into consideration. The most important aspects were nature development, coastal safety, recreation, landscape conservation and protection of the fresh groundwater.

During the elaboration of the management plan for the Nature Reserve 'De Westhoek' between 1994-1996, the possibility of developing one or more sea inlets behind the frontdunes came into view. The feasibility of such a measure from the point of view of coastal protection was then thoroughly examined by a contracted coastal engineering consultant.

The management plan for the Nature Reserve 'De Westhoek', that was approved in 1996, suggested to create sea inlets by locally removing the concrete dunefoot revetment. The creation of sea inlets allows the development of the natural habitats of the annex I of the European Habitat-directive '1310 (15.11) Salicornia and other annuals colonising mud and sand' and '2110 (16.211) Embryonic shifting dunes', and also offer breeding opportunity to at least Kentish Plover (*Charadrius alexandrinus*) and Great Ringed Plover (*Charadrius hiaticula*).

The coastal protection policy aims at minimising the possible damage by the sea during storm periods. The creation of sea inlets in the foredunes had to be combined with strengthening the dunes behind the sea inlets. Thus, the risk of storm damage for the local residents as well as for the hinterland does not increase.

On top of the dunefoot revetment is a very popular path for walkers. It is part of the signposted footpaths across the 'Westhoek' dune reserve. Breaching the foredunes and

the dunefoot revetment had to be combined with the building of bridges over the mouths of the sea inlets. In that way the continuity of the walkways is preserved.

In the first concept, wooden arch bridges were proposed, but this concept turned out to be conflicting with the landscape protection regulations. Therefore a new concept of the bridges has been worked out in which the bridges have the least possible visual impact on the landscape.

A large layer of fresh groundwater exists underneath the 'Westhoek' dunes. Part of it is pumped up as drinking water. The creation of the sea inlets is not expected to cause major salinisation of this fresh water reserve.

Detailed design of the mouths of the sea inlets

The width and the height of the mouths of the sea inlets determine how much water can flow into the sea inlets. Larger mouths need more expensive bridges. Therefore the width of the mouths has been set at approximately 20m. To guarantee the stability of the bridges under stormy conditions erosion protection of the mouths was necessary. The top level of these stone revetments is situated at approximately the level of mean high water. On top of these stone revetments a layer of sand was placed with a thickness of ca. 1m, in order to establish sandy, dynamic mouths of the sea inlets. Because of the height of the mouths, well above mean high water level, flooding of the sea inlets can occur only occasionally, namely when water level setup caused by stormy weather is high enough (in combination with the amplitude of the astronomical tide).

Procedural issues

Projects that have an influence on the hydrological system of natural areas are subject to an Environmental Impact Assessment, so for the creation of two sea inlets an EIA had to be drawn up. After the approval of the EIA by the competent authority a procedure for getting a building permit had to be followed, which includes a public enquiry on the project.

Although these procedures are time-consuming they generated broad discussions about all aspects of the project. Finally this resulted in a public acceptance of the project.

Description of the works

The works were executed in the spring of 2004.

The works consisted of:

- lowering the bottom of two deflation zones behind the foredunes and partly the foredunes themselves to a level that is lower than the high tide level;
- strengthening the dunes that surround those lowered deflation zones to prevent the sea-water from penetrating the dune area further than is considered desirable; this

reinforcement was carried out with the sand that was excavated from the deflation zones and the foredunes;

- removing the concrete dunefoot revetment at two locations over a distance of 20m and 15m respectively to allow the seawater to penetrate the deflation zones;
- building two bridges over the breaches in the dunefoot revetment to allow pedestrians to continue their walk uninterrupted.

The result is shown on Fig. 4 based on a photograph taken during a flooding of the western slufter area from on top of the second line of dunes.



Fig. 4. View on the western slufter area during flooding on 13 November 2004 (photograph by Thierry Delrue from De Haan).

Monitoring

Measurements of the morphological changes during the first months after completion of the works reveal that especially the mouths of the sea inlets are very dynamic. Wind blown sand accumulates in the mouths but is eroded again by the sea when flooding occurs. Also a thin layer of silt and mud has already formed a deposit in the slufter areas' gullies, together with the deposition of organic debris such as seaweed at the floodmark.

A large number of borings with open pipe piezometers have been installed to monitor the evolution of the groundwater salinity in the immediate surroundings of the slufter areas and also at a larger distance from the slufter areas in the direction of the drinking water wells. Conductivity measurements in the boreholes (EM 39 technique) show that on 13

January 2005 salt water has infiltrated underground not farther than ca. 10m from the slufter areas, and not deeper than ca. 10m beneath ground level.

Monitoring of the different environmental and natural characteristics will be continued in the coming years.

Conclusions and recommendations

Shoreline management projects must be executed according to the principles of Integrated Management of Coastal Areas. Multidisciplinary studies and consultation between the different competent administrations and other involved parties take a lot of time and effort, but they result in better projects.

The legally necessary procedures, such as EIAs and building permits, embed the broad social consultation on shoreline management projects. Nevertheless during the period before these procedures, when the project was still being outlined, ample consultation between the different competent administrations and other involved parties was also needed. With a view to prevent discussions from lasting endlessly, mediation by a neutral, authoritative coordinator is very useful.

Due to the complexity of shoreline management projects, there is an increasing need to pay extra attention to the project management. Many years pass between the preparation of the project and its realisation. Numerous organisations each give their input in the success of the project. A multidisciplinary team with representatives of all parties involved is needed to finally realise a successful project.

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Coastal dune evolution on a shoreline subject to strong human pressure: the Dunkirk area, northern France

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Abstract

The extreme northern coast of France from Dunkirk to the Belgian border is bounded by coastal dunes that have been massively transformed by urban and port development. The only stretch of preserved dune barrier, less than 8km long, is located east of the port of Dunkirk. The foredune ridge was seriously damaged at the beginning of the 20th century by urban development and almost completely destroyed during World War II. In the 1980s, the foredune, 10 to 20m high, was affected by breaches and blowouts, and by erosional scarps cut during storm events. The dunes are presently in a state of meso-scale (decadal) stability. This stability is attributed in part to human intervention. In the early 1990s, active restoration was carried out by the Departmental Authority of the North (Conseil Général du Nord) in charge of the management of these coastal dunes. These measures have resulted in incipient foredune development along accreting sectors. Collaborative work involving beach and foredune surveys carried by the *Coastal Geomorphology and Shoreline Management Unit* of the Université du Littoral Côte d’Opale and the Conseil Général du Nord over the past years has enabled better insight into beach and foredune sediment dynamics. Aeolian sand transport measurements enable quantification of sand exchanges within the dune front. The influence of sand fences and brushwood barriers on incipient foredune growth is presently studied along an experimental sector. These surveys highlight the current stability of this coast. Much of the foredune foreslope is now stabilized by vegetation and only episodic dune scarping occurs during winter, with recovery in summer. There is, however, a need to address more precisely the exact role of human interventions in the present status of shoreline stability. The restoration practices mentioned above have significantly encouraged foredune stability and incipient foredune development. However, no major storms have occurred since 1990 and a context of net sediment supply from foreshore to dune has certainly been a factor in enhancing shoreline stability and dune development.

Keywords: Coastal dunes; Shoreline evolution; Detailed monitoring; Management practices.

Introduction

The importance of coastal dunes as natural sea defences, sites of ecological interest and recreational areas is now well recognized. Beaches and coastal foredune systems in many parts of the world have experienced erosion in recent decades (Bird, 1985), and coastal dune retreat is a major concern along developed coastlines. Coastal dunes act as sand reservoirs, which may supply sediment to adjacent beaches (Psuty, 1988; Pye, 1991; Sherman and Bauer, 1993), and therefore can delay coastal retreat and protect low-lying backshore areas against marine invasion. This is particularly the case along the southwestern coast of the North Sea where a large proportion of the coastal plain consists of densely populated reclaimed land. The extreme northern coastline of France, bordered by the southern North Sea has been massively transformed by urban and port development and the only stretch of preserved dune barrier, less than 8km long, is located east of the port of Dunkirk (Fig. 1). Along this coastline, coastal dunes are not only a protective natural barrier against marine invasion, but also are a much appreciated recreational area and a 'natural' landscape of biological and geomorphological interests. This paper presents coastal dune evolution along this coastline, with particular attention to natural processes and management practices that resulted in the recent (last decade) stabilisation of this shoreline characterized by erosion since at least the beginning of the 20th century. Such an understanding of the factors which influence the present dune morphology is essential in order to make accurate assessments of the effects of natural processes and human activities within the dune system.

Study area

Macrotidal beaches of the northern coast of France are characterised by a wide beach/surfzone consisting of parallel bars and troughs (Sipka and Anthony, 1999; Masselink and Anthony, 2001). These ridge and runnel beaches are associated with extensive coastal dune fields (Battiau-Queney *et al.*, 2000). The development of these dunes has been related to massive sediment supplies from a sand-rich nearshore zone consisting of tidal banks, the Flemish Banks (Anthony, 2000). From Dunkirk to the Belgian border, inland parabolic dunes fronted by a foredune ridge form a well-developed coastal dune system, 5 to 30m high and 700 to 1100m wide (Clabaut *et al.*, 2000). This coastal dune field, known as Dewulf, Marchand and Perroquet dunes (Fig. 1), is interrupted by the coastal resorts of Zuydcoote and Bray-Dunes (Fig. 1).

Along this coastline the beach is subject to a macrotidal range that increases from 3.5m during mean neap conditions to 5.6m during mean spring conditions. At low tide, the beach is 400 to 500m wide and has a very gentle gradient (0.01). The beach consists of fine homogeneous well-sorted sands and is characterised by irregular ridge and runnel morphology (Sipka and Anthony, 1999; Reichmuth and Anthony, 2002). A gently sloping terrace, flooded only during high spring tides and by storm setup, links the intertidal ridge and runnel system to the incipient foredune front. The beach is backed by an established foredune ridge 15 to 150m wide and 10 to 20m high. This coastline is dominantly exposed to offshore to shore parallel winds from a south to southwesterly window. Northerly onshore winds, the most important in terms of potential dune

accretion, are less frequent, but they occur in winter and can induce storm surges responsible for upper beach/dune erosion (Vasseur and Héquette, 2000).

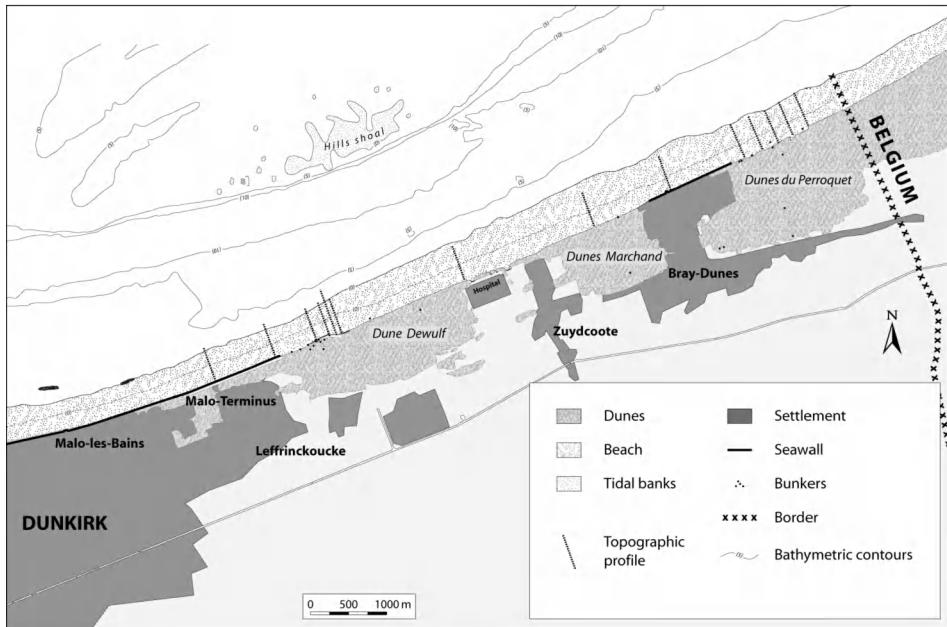


Fig. 1. Location map.

Medium-term coastal dune evolution (20th century)

The very high population density of the « Département du Nord » has resulted in strong human pressure on these coastal environments. East of Dunkirk, the shoreline evolution during the 20th century is dominated by coastal retreat. This evolution is related to both human pressure and natural erosional processes under storm conditions. Coastal erosion however varied through time and was not spatially uniform. The foredune was seriously damaged at the beginning of the 20th century by urban development. The extension of the seawall, east of Malo-les-Bains (Fig. 1), around 1906, resulted in the destruction of the adjacent foredune and the formation of active parabolic dunes, migrating eastward in response to the dominant south westerly winds (Fauchois, 1998). From 1894 to 1939 the erosion rate was estimated at up to 2.5m.yr^{-1} east of Bray-Dunes (Fauchois, 1998). Coastal dunes were also badly damaged during World War II. On the upper beach, as well as on the foredune ridge, several German bunkers (Fig. 2) and an anti-gunfire defence wall illustrate the strong impact of these buildings on the shoreline morphology. From 1947 to 1977 erosion still prevailed along the eastern and western part of the study area while in the central part, foredune development occurred (Clabaut *et al.*, 2000). From 1971 to 1994, erosion rates were of the order of 1.7 to 2.9m.yr^{-1} in the western part

of the Dune Marchand (Fig. 1) while in the western part of the dune Dewulf the mean retreat rate was less than 1m.yr^{-1} . Along the Dune du Perroquet close to the Belgian border, stability prevailed (Clabaut *et al.*, 2000). In these fairly stable sectors, the foredune was progressively rebuilt and stabilized by vegetation. In the 1980s, the foredune was affected by breaches and blowouts, mainly due to human disturbance, and by erosional scarping during storms. Erosion was related to storm intensity and frequency. Analysis of storm at Dunkirk from 1962 to 1995 revealed an increase in intensity and duration from 1971 to 1977 (Clabaut *et al.* 2000; Vasseur and Héquette, 2000). Over the last few decades shoreline retreat was counterbalanced by sand accumulation at the top of the dune crest and on the backslope, resulting in a widening of the foredune. The refilling of dune blowouts and the development of a vegetation cover suggest a relatively balanced sand budget (Clabaut *et al.*, 2000).



Fig. 2. German bunkers on the upper beach, Leffrinckoucke.

Recent (10 yr) dune evolution

The foredune is presently in a state of meso-scale (decadal) stability (Vanhée *et al.*, 2002). The seaward slope of the foredune, which was cut into an erosional scarp (Clabaut, *et al.*, 2000; Vasseur and Héquette, 2000) up to 1998, is now stabilised by vegetation. This stability is attributed in part to human intervention. In the early 1990s, measures to combat degradation of the dunes and reduce the threat of marine erosion were implemented by the Departmental Authority of the North (Conseil Général du Nord) in charge of the management of these coastal dunes. Wooden and brushwood fences were erected in order to encourage sand accumulation in the most sensitive areas. Wooden fences were erected across major blowouts and bare sand patches were fenced off and plants artificially introduced (Fig. 3a). Attempts have also been made to improve the effectiveness of the frontal dunes as sea defences by encouraging artificial accumulation of blown sand along parts of the backshore. Access to the public was restricted and panels showing information aimed at increasing people's understanding of

the area were put up at the entrance of the pathways. In order to promote the recovery of natural habitats, these rehabilitation measures have involved, since 1994, manual collection of detritus and debris accumulating at the high tide lines at the Perroquet and Marchand dunes (Lemoine *et al.*, 1999). These measures have resulted in incipient foredune development along accreting sectors (Fig. 3b).

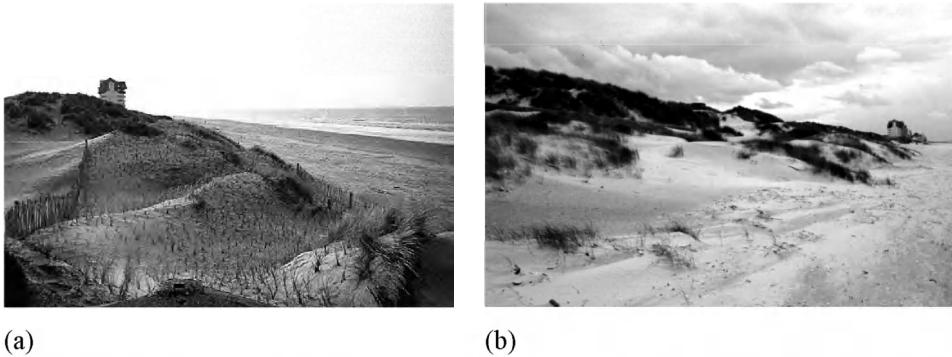


Fig. 3. Coastal dunes evolution east of Bray-Dunes: (a) wooden fences and marram planting along in a deflation hollow; (b) development of incipient foredunes.

Detailed beach and dune topographic surveys and hydrodynamic measurements have been carried out along this coast by the Coastal Geomorphology and Shoreline Management Unit of the Université du Littoral since 1996, in order to gain a better understanding of morphological variations and beach sediment budgets on a short time-scale. Several beach profiles, extending from the foredune crest to the low tide level (Fig. 1) were regularly levelled from 1994 to 2004 (Sipka, 1997; Triquet, 1998; Vanhée, 2002; Reichmüth, 2003; Brulez, 2004). The study of spatial and temporal beach variability along this coastal sector revealed equilibrium sediment budget conditions (Reichmüth, 2003). Short-term (< 2 months) ridge mobility is only triggered when successive storm events occur, especially when they coincide with large spring tides. However, volumetric changes in the profiles over the period 1996-2000 were insignificant (Reichmüth and Anthony, 2002). Under fair weather conditions (usually during summer) the bar formed in the upper beach welds onto the extreme upper beach and forms a low terrace which acts as a sediment source for the incipient and established foredune zone (Vanhée, 2002; Brulez, 2004; Quesnel, 2004). Much of the foredune foreslope is now stabilised by vegetation and only episodic dune scarping occurs during winter, with recovery in summer (Valet, 2002; Visayze, 2004).

East of Leffrinckoucke (Fig. 1) a study of the effects of ridge and runnel morphology on aeolian sand transport was carried out between 1999 and 2002 (Vanhée, 2002). Experiments involved short (30 mn) deployments of anemometers, weather stations and sand traps along systematically surveyed beach profiles along which ground surface moisture was measured. The results show that, along this macrotidal beach, in spite of potentially large wind fetch with onshore winds, the effective fetch is generally limited to the upper beach terrace and to the first ridge on the upper beach. The fetch is

especially segmented by the runnels, which may act as efficient sand traps (Vanhée *et al.*, 2002).

Collaborative work involving beach and foredune surveys carried by the Coastal Geomorphology and Shoreline Management Unit and the Conseil Général du Nord over the past years has enabled better insight into beach and foredune sediment dynamics. Aeolian sand transport measurements enable quantification of sand exchanges within the dune front in a coastal sector where brushwood barriers and sand fences were erected and where marram was planted in order to favour the formation of a protective incipient foredune. This study permitted a detailed quantification, through differential contour maps, of aeolian sand volume trapped by brushwood barriers and sand fences. An accumulation of about 1.75m was recorded between September 1999 and May 2001 on the developing incipient foredune foreslope, demonstrating the efficiency of these management structures (Vanhée *et al.*, 2001). Sand transfer from the upper beach to the backshore through aeolian processes has resulted in sand accumulation that put the dune toe out of reach of the highest tides. Furthermore, the absence of major storm events since the early 1990s reinforced this natural accumulation trend.

A detailed measurement of the elevation of the dune toe, from Leffrinckoucke to Bray-Dunes (Fig. 1) was carried out in spring 2004 (Visayze, 2004) in order to determine the sensitivity of this shoreline to erosion and submersion in case of extreme storm events (storm surges combined with spring tide). The elevation of the highest annual water levels recorded at Dunkirk harbour for the period 1956 to 2003 were coupled with the present-day dune toe elevation. Dune sectors below the uppermost limit of high water levels were identified and mapped. Results show that the central part (Dunes Marchand) of the area is still at risk while the eastern and western parts are presently out of danger. Such a map is a useful tool for managers in charge of the dunes as it indicates the locations of the most sensitive sectors.

The influence of sand fences and brushwood barriers on incipient foredune growth is presently studied along an experimental sector at Leffrinckoucke (Fig. 1). Brushwood barriers and fences perpendicular to the dominant southwesterly winds have been erected on the bare upper beach, above the highest high-tide levels (Quesnel, 2004). The aim of this experiment is to evaluate the efficiency of these two types of dune-rehabilitation structures.

Near the Belgian border, east of Bray-Dunes, accumulation in the backshore zone has prevailed since at least 1995 (Clabaut *et al.*, 2000; Valet, 2002; Brulez, 2004) and is emphasized by incipient foredune development. This coastal sector, less than 150m long, is of particular interest as recent shoreline evolution can be studied along a ‘managed’ sector and a natural one located a few metres apart. The eastern part of this sector was subject to sand deflation and the dune was an irregular assemblage of poorly vegetated hummocks (Fig. 4a) while the western sector was characterized by a breach opened by waves during a storm in the early 1980s (Fig. 4c). Erection of wooden fences and marram planting were completed in the eastern sector (Fig. 4a) while the western one evolved naturally. From 1998 to 2004 an ‘artificial’ foredune developed along the eastern sector, well behind the uppermost water levels (Fig. 4b). Along the western sector, the former breach was naturally closed by wind blown sand, and incipient

foredunes, up to 2m, high have recently developed on the upper beach (Fig. 4d). Such an evolution shows that along a coastal sector with a positive sediment budget, deployment of dune rehabilitation structures is not always necessary.



(a)



(b)



(c)



(d)

Fig. 4. Recent evolution of a 'managed' and a 'natural' sector at the Belgian border between 1998 and 2003: (a) erection of wooden fences on poorly vegetated chaotic dunes; (b) development of an 'artificial' foredune; (c) morphology of the breach in 1998; (d) natural formation of incipient foredunes.

Conclusion

These surveys highlight the current stability of this coast. Detailed monitoring shows that coastal erosion has slowed down since dune protection schemes were implemented, but this trend has been favoured by the non-occurrence of major storm events in conjunction with large spring tides since the early 1990s. There is, however, a need to address more precisely the exact role of human interventions in the present status of shoreline stability. The restoration practices mentioned above have significantly encouraged foredune stability and incipient foredune development. Nevertheless, a context of net sediment supply from foreshore to dune has certainly been a factor in enhancing shoreline stability and dune development. This present-day state of stability is spatially limited, however, and likely to be temporary. Along the northern coast of France, several beaches are presently experiencing rapid coastal retreat, a remarkable example being Wissant Bay located south of Calais (Ruz and Meur-Férec, 2004).

Reactivation of coastal retreat can occur at any time, after a stormy winter, for instance. The evolution of the coastline east of Dunkirk therefore still needs to be carefully observed through detailed monitoring and cautious management.

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The UK LIFE project on shoreline management: 'Living with the Sea'

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Abstract

Climate change and sea level rise is posing ever-greater challenges to the sustainable management of our coasts. 'Living with the Sea' was a four-year partnership project benefiting from European Commission LIFE Nature funding. The project focused on coastal areas of England, in particular on coastlines with complexes of sites designated under European Habitats and Birds Directives. Research has indicated that climate change and sea level rise will drive significant habitat change on these coastlines, with implications for how we deliver flood risk management. This paper provides information about the overall project aims and successes, the Coastal Habitat Management Plan concept, and other specific elements of the study including the review of how we have incorporated the Habitats and Birds Directives into UK law. The paper also considers the recommendation's arising from this visionary project in the wider context of how we need to manage our coastlines, the communities, natural features and wider land use, so that we can survive climate change and sea level rise in the long term. We must anticipate change, plan for it and provide space within our coastal zones; zones that will become more extensive and influential with the continued rise in sea levels and pressures to find new development opportunities.

Keywords: Sea level rise; Habitats and birds directives; Flood risk management; Coastal zones;
Long-term planning.

Introduction

The last six centuries have seen massive changes to the UK coastline through coastal defence works and land management. Local communities have become more demanding of the environment, exploiting the natural resources to provide food, wealth and now leisure.

This human intervention has also changed the natural biodiversity. Ironically it is the last century growth in leisure activities that has highlighted the seriousness of this loss of biodiversity. If it was not for the growing human interest in watching birds, the first private nature reserves would not have been established, and in turn the first environmental legislation would not have been passed! We now have extensive national and international legislation and agreements to conserve our natural environment, but at times this only seems to make it more difficult to do!

Legislation

The Habitats Directive was transposed into United Kingdom law under The Conservation (Natural Habitats, & c.) Regulations 1994. These regulations establish procedures for selection of Special Areas of Conservation [SAC] and make provision for establishing ‘management agreements’ to protect the European sites (including Special Protection Areas [SPA]) and regulate potentially damaging activities. The regulations also require an appropriate assessment to be carried out on projects or plans that are likely to have a significant effect on a European site. A project or plan can only go ahead if it can be ascertained that it will not adversely affect the integrity of the European site, unless there are no reasonable alternatives and there are imperative reasons of overriding public interest (OPI). In the latter situation, compensatory measures will be secured.

In the UK, Natura 2000 sites are generally underpinned by designation as ‘Sites of Special Scientific Interest’ (SSSIs). Because the roots of UK conservation started on ‘terra firma’, site delineation and selection criteria have in the past tended to reflect the more predictable behaviour of terrestrial features. For example site boundaries are drawn tightly around the habitat or species interest; measures such as existing area or numbers of species are set at time of designation; and natural change is not defined.

This has presented some interesting situations when coastal intertidal and freshwater sites are incorporated in the UK Natura 2000 series. Intertidal habitats do not conform to set boundaries or conventional condition measures. Because of their dynamic nature wind, tide and wave drive and form intertidal ecosystems.

Flood risk management

The single most intrusive human activity in this intertidal zone is sea defence and coastal protection. Because the UK is an island, keeping the sea back has been a preoccupation since the 15th century. Engineering works traditionally aim to fix the coastline, prevent erosion and claim land where possible. This has caused a phenomenon known as coastal squeeze. This is where the intertidal Natura 2000 sites are caught in an eroding environment, with the forces of nature (tide, wind and wave) driving in from the seaward side and man’s coastal defences (seawalls or high ground) fixed on the landward side. This leaves intertidal habitats nowhere to retreat in the face of sea level rise.

How can the United Kingdom, or any other coastal member state, meet its obligations to protect habitats under the Habitats Directive whilst also protecting from the sea its important urban and freshwater coastal areas? This is the subject that has been studied through the ‘Living with the Sea’ project.

The ‘Living with the Sea’ project

In 1998 the UK successfully submitted a project to the European Commission, under the LIFE Nature fund, to trial a number of solutions to these challenges. The ‘Living with the Sea’ project started in December 1999 and produced its final report in July 2003. Four UK partners supported it: English Nature, the Environment Agency, the

Department for Environment, Food and Rural Affairs (DEFRA) and the Natural Environment Research Council. The key European partner was the European Commission. The project aims were as follows:

To promote:

- understanding of long-term coastal change resulting from sea level rise;
- sustainable integrated coastal management policies;
- ownership of shared issues and common solutions.

To develop:

- mechanisms for delivering Habitats Directive compliant flood and coastal defence schemes;
- practical ways of demonstrating habitat creation at work;
- working partnerships between engineers, conservationists and landowners.

Four aspects of coastal planning and management were studied and developed:

Coastal Habitat Management Plans (CHaMPs)

CHaMPs support the UK's strategic approach to flood and coastal defence management by informing Shoreline Management Plans (SMPs) which decide flood defence policy for coastal cells. Lets consider the past, present and future context for this approach:

Past

The first SMPs were completed approximately eight years ago, and are now approaching their first review. These early plans did not fully address the requirements of the Habitats Directive, in many cases recommending a 'hold the line' policy until further research is completed on the effects of this option. They continued to promote 'hard engineering' solutions in the face of growing understanding that this was not a sustainable defence option. To resolve this issue the concept of a CHaMP was developed from experiences on the North Norfolk coast where coastal squeeze was threatening important SPA and SAC features. The first project objective was therefore to publish guidance, 'Coastal Habitat Management Plans: An Interim Guide to Content and Structure' with a foreword by Elliot Morley, then Minister for Fisheries and the Countryside.

CHaMPs help where the conservation of all the existing interests in situ is not possible due to changing coastlines. Their two primary functions are to act as an accounting system to record and predict losses and gains to habitat from flood management works, and to set the direction for habitat compensation measures to address these net losses. This ensures that damage to Natura 2000 sites from the coastal defence response to sealevel rise is avoided or compensated for. The plans therefore contribute to maintaining the overall coherence of the Natura 2000 network.

Present

The project developed seven CHaMPs covering the east and south east of England. Using an analysis of coastal geomorphology, over an entire coastal process cell. CHaMPs evaluate the combined effect of the existing defence policies over the next 30 to 100 years. Where there is a damaging impact, then, unless there are assets of overriding public interest, the CHaMP suggests alternative options such as ‘managed realignment’ of the defence or removal of the existing structure, to promote more natural coastal process and habitat response. Where it is an urban defence, which must be defended, ways of creating compensatory habitat are considered. These plans rely on understanding and forecasting coastal geomorphology. They recognise and promote the great effectiveness of mudflats, saltmarsh and sand dunes in providing a natural coastal defence. These features take the energy out of winter storms and surge tides, recovering their form and capacity through the summer. They are more effective in this than concrete and steel, and are self sustaining, provided we do not cut off sediment supplies by preventing erosion or arresting transport pathways. CHaMPs support the principle that we must plan our coastlines to work with nature, not to fight her!

CHaMPs also consider situations where both intertidal SACs and freshwater SPAs occupy an eroding coastline. Build or maintain a seawall to protect a coastal freshwater SPA from saltwater flooding and you can damage the integrity of the adjacent intertidal SAC. Remove a sea defence to allow the intertidal SAC to evolve and you destroy the freshwater SPA interest. Either option presents problems under the Conservation Regulations, and possibly under the Habitats Directive. The UK government has also given an undertaking to protect Natura 2000 features *in situ* where it is sustainable to do so.

The solution to this conundrum needs to be site specific because some SPAs contain habitats or species that are unique on the coast, for example brackish features. However, in principle we should be following nature’s own steer. Intertidal features cannot exist anywhere other than the land/sea interface. Freshwater features may develop in this zone but they will naturally be transitory. Stable freshwater habitats occur in the river flood plains, but often these have also been drained to facilitate intensive farming practices, preventing the natural development of new fluvial wetlands. Where can these habitats go?

Future

It is clear that the solutions to coastal squeeze are not easy. The principles of integrated coastal zone management will need to be enshrined into the wider local planning and land use framework if we are to meet our international obligations for habitats and birds, provide sustainable flood and coastal defences and achieve best value from tax payer’s investment in our coastlines. SMPs and their resultant strategies, will use CHaMPs as part of their decision making process when reviewing the current sea defence and coastal protection policy. CHaMPs alone cannot decide on policy, they are evaluating the potential to comply with the Habitats and Birds Directive and advice on how to work with nature, to restore the natural form and function of our coastlines. However to ignore their guidance will compromise delivery of UK and European environmental law.

Failing to work with nature will also mean we are stepping back into the past, when we thought concrete and steel could do a better job of defending our island, and we could preserve our natural environment artificially, within a line on a map!

Practical habitat creation on the North Norfolk coast

To examine practical solutions to the SPA/SAC conundrum, two Environment Agency schemes were promoted at Brancaster and the Cley Salthouse frontages. Both sites rely on a SAC feature as the formal sea defence structure. At Brancaster the sand dune was stabilised and revetted to form the sea defence, and between Cley and Salthouse the shingle ridge is regularly dozed into an unnatural steep bank to form a sea defence. Both structures were unsustainable in engineering, financial and environmental terms. The constant engineering management prevented them from being effective energy absorbers, and from naturally recovering their capacity after storms. The pressure of coastal change forced a flood defence review, the simplest solution would have been to abandon managing the existing defence, but both defences directly protect important freshwater or brackish marshes and reed beds designated SPA; to abandon the defence would therefore have an impact on the SPA interest.

One solution was to construct a new set back seawall through ‘managed realignment’, adopting a ‘non intervention’ policy for the sand dune or shingle ridge. This would protect part of the SPA and any properties at flood risk for a limited time. The SAC features can then be restored to a natural form where they can continue to roll landward in response to coastal processes.

But this approach does not provide a once-and-for-all solution; it will not be long before coastal squeeze is forcing a further critical rethink of the new seawall position due to unstoppable coastal processes. At Brancaster we have constructed a set back wall and continue to monitor the effectiveness of the solution; at Cley/Salthouse the preferred scheme is still under review. If the criteria for sustainability in coastal planning solutions are applied it is clear we should be realigning back to rising ground and compensating for the loss of freshwater interest by recreating this within fluvial flood plains. In these rural locations this represents the best value for money for tax payer’s investment, and the best outcome for nature conservation. Natural habitats arise and are sustained by natural processes. This applies to freshwater sites as much as intertidal sites. The criteria for sustaining SPAs are therefore the same as for SACs, support form and function and not isolate the site by artificial walls and boundaries! In reviewing these North Norfolk schemes, we must consider how effective they have been in meeting the requirements of flood risk reduction, the Habitats and Birds Directive and furthering wider biodiversity targets.

Good Practice Guide to Habitat Replacement and Restoration

To help engineers, conservationists and landowners create compensatory habitat where it is necessary, the project prepared a guide to the existing case studies on good practice habitat creation and restoration, (including studies carried out by the project) with links

or directions to the original author's material. Dr Pat Doody developed and produced the model under contract to the Project, and researched the extensive material that he has included.

It is an interactive guide that helps you identify your habitat creation objectives based upon various 'habitat condition states'. This novel approach is essential in a dynamic environment. Habitats evolve and mature, supporting different species at different times. It is therefore essential to understand what you are trying to achieve by your management, and to predict how successful you are likely to be! The guide provides links to practical examples and authoritative case studies and manuals.

The Good Practice Guide is published on the Internet so that it is available to anyone, and can be kept up to date by English Nature. Where limited knowledge exists on a particular feature, interim guidance will be given until new research data is available and the guide can be updated. You can access the guide via the project website address given below.

European framework: options for maintaining features of European importance in dynamic situations

The development of CHaMPs in the UK was a direct response to challenges arising from trying to plan for compliance with the Habitats and Birds Directives. This work has highlighted many practical conservation issues arising from the UK's interpretation of the Directives and the way this is applied to dynamic sites.

Through an analysis of the circumstances of these issues, close examination of the objectives of the Habitats Directive, and discussions with other coastal member states, the project prepared a framework report and guidance towards addressing coastal squeeze in the UK, and shared this with practitioners throughout the EU.

Three key themes were developed which addressed the issues arising in the UK and which are of relevance to other member states when reviewing their own procedures:

Favourable conservation status

Favourable conservation status is all about the health of natural features across the Natura 2000 network of sites, and the wider environment, not just the individual site condition. To gain this understanding we must in future measure the natural form and function of habitats, the effects of dynamic change on features, as well as the existing individual site based qualitative assessment of habitats. This will require new site management objectives to be set, and extended long-term strategic condition monitoring, systematically applied.

An ecologically coherent network

To achieve favourable conservation status we must manage the European Natura 2000 sites as an ecologically 'coherent network' ... this is one of the key aims of the Directive. To understand this we must effectively monitor how the entire network is operating, covering the interaction of habitats and species, and the ecological and physical factors affecting them. Where necessary we may have to update the designated sites to ensure the network retains its capacity to respond to climate change. This may require a new UK approach to how we identify and designate and manage sites in future.

Designated site boundaries

Currently we have benefited from using the existing UK legislation covering Sites of Special Scientific Interest and their boundaries to quickly establish the Natura 2000 series in the UK. However this process establishes fixed site boundaries which are too cumbersome to respond to the evolution of a dynamic network on rapidly changing coastlines. We need to consider including buffer zones, wildlife corridors and transition zones where habitats need to migrate over time. Many of these sites are also covered by other national and international designations. Maybe we do not need multi-tier designations in the UK; the highest single tier of designation should be enough!

More detail on the specific studies covered by the project, and downloads for the reports can be obtained from the website: www.english-nature.org.uk/livingwiththesea

An action plan

Encapsulating all of the learning and experience gained over the four years the project prepared an England Action Plan. This identifies the future actions required by project partners to realise the long-term potential of the studies, and to deliver certain future actions that were beyond the remit of the project. Now 18 months on from project completion, the partners have incorporated the actions in their individual corporate strategies. CHaMPs are included in DEFRA guidance on shoreline management planning; the principles of an ecologically coherent network are included in English Nature's Maritime Strategy; and the Environment Agency is establishing a National Habitat Replacement Framework to deliver strategic compensation where required as part of Shoreline Management Plans and coastal strategies. Maintaining the momentum is vital when a project is completed. A successful project produces future actions, and should fuel future debate, leading to better understanding by all.

An integrated vision for the 21st century

It is clear to the author, that future sustainable coastal management can only be built around a long-term integrated vision. This vision must be based upon realism in the face of coastal change and must work with natural geomorphologic processes. We should seek to develop only in areas not subject to flood risk. We must restore the natural operation of flood plains, wash lands and intertidal areas to reduce the flood risk to

existing development, and we must focus on an vision three generations ahead, but deliver the actions now!

This vision must embrace the developed and natural environment. There must be a place for people and communities, wildlife and ecosystems. It should be about creating space as much as it is about using that space. With increasing extremes in weather we must ‘make space for water’, a theme adopted by DEFRA in the 2004/5 review of their flood risk management strategy. Coastal (and riverine) zones will develop more extensive wash lands to dissipate the increased natural energies of the 21st century climate, and beyond. These will be new areas of wilderness, but not wasteland. We will better understand the value of these dynamic and exciting areas to our own rural communities and livelihoods, as to the natural environment. We must actively promote this outcome and not try and restrain change; these areas will provide the natural breath of life for our future generations!

Conclusions

Coastlines have been and will continue to be places of change, driven by nature. Man settled on the coast, built ports and claimed land for farming and industry. Future human expansion will place even greater pressure on what is now a fragile environment. If we do not understand the future effects of our policies on the natural environment we stand to lose the last of our coastal wildernesses. Coastal planning decisions can no longer be taken in isolation, without thought for the long-term consequences. An integrated coastal vision is essential for the 21st century, where we stand side by side with nature and learn to live with the sea.

Through our partners, the ‘Living with the Sea’ project delivered practical tools for engineers, conservationists and government agencies. It demonstrated that by adopting a pragmatic approach to coastal form and function it is possible to deliver cost effective and sustainable flood risk management whilst conserving the natural environment. Now each of us must look to the future, share our vision and act now; we decide the next generation’s environment!

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PARALLEL THEMATIC WORKSHOP SESSIONS

*Workshop ‘Tourism/recreation and nature
restoration’
chair: Haim Tsoar and Albert Salman*

Herrier J.-L., J. Mees, A. Salman, J. Seys, H. Van Nieuwenhuyse and I. Dobbelaere (Eds). 2005. p. 463-474
Proceedings 'Dunes and Estuaries 2005' – International Conference on Nature Restoration
Practices in European Coastal Habitats, Koksijde, Belgium, 19-23 September 2005
VLIZ Special Publication 19, xiv + 685 pp.

The Abbey of the Dunes (Koksijde) and Noordduinen: the environmental link restored

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Abstract

The Abbey of the Dunes (Ten Duinen) at Koksijde, founded in the 12th century and abandoned around 1600, forms the subject of a land use planning project realized by the Flemish Land Agency (Vlaamse Landmaatschappij). Initially the project focussed on the museum and the integration of the abbey ruins in an open-air museum. However the site presented an opportunity to involve the Noordduinen, bordering on the abbey park, in a nature restoration project. The key intention was to restore the landscape connection between the abbey and the dunes, as it was in the Middle Ages. The proposed actions consist of breaking up a road, deviation of the traffic, upgrading the abbey park and start of a nature restoration project in the Noordduinen. The main bottlenecks were deviation of the traffic, excavation and preservation of archaeological finds and intensive recreational use of the Noordduinen. Continuous consultation and deliberation with all involved authorities and with the local inhabitants of Koksijde resulted in a plan supported by the majority of the community.

Keywords: Koksijde; Nature restoration; Recreation; Archaeology; Spatial consolidation.

Introduction

The site of the Abbey of the Dunes (Ten Duinen) including ruins of the abbey, museum and park and the dunes of the Noordduinen cover 115ha between the urbanization of Koksijde-dorp, Koksijde-Bad and Sint-Idesbald. Military infrastructure of the Belgian air forces (Kwartier Basis Adjudant Vlieger F. Allaeyns) is located in the south. The area is also criss-crossed by three busy roads (Van Buggenhoutlaan, Leopold III laan, Robert Van Dammestraat) (Fig. 1).

The Noordduinen and the Abbey of the Dunes have exceptional historical, ecological and recreational values, therefore they enjoy protection under different legislations. More than 90% of the area is designated as nature area by the Law on the Organization of Town and Country Planning (1962). The decree of Monuments and Landscapes of Cities and Villages (1986) protects the archaeological site of the Abbey of the Dunes. The non-built-up area within the military domain is protected by the Decree on

Protection of the Coastal dunes (1993). Furthermore the dunes are designated as SAC (Spatial Area of Conservation) under the EEC Habitat directive (92/43/EEG).

Since 1999 a plan was conceived to upgrade and re-integrate the ruins of the Abbey of the Dunes and its surroundings. The realization of the plan involved different aspects, such as history and culture, ecology and recreation. This paper elaborates on the start and the course of the plan and the encountered difficulties.

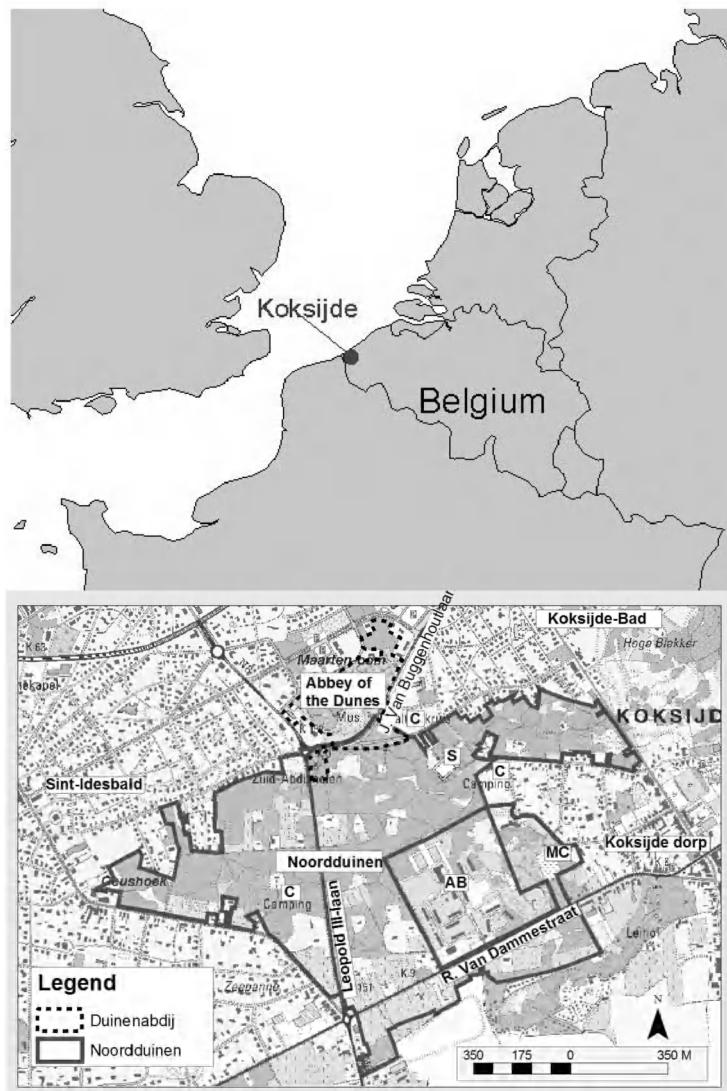


Fig. 1. Localisation of the Abbey of the Dunes and Noordduinen (C: Camping; S: School; AB: Army Base; MC: Military Cemetery).

Historical review of the abbey site

In 1107, Ligurius, a French hermit settled in the dunes northwest of the modern community of Koksijde-dorp. He was soon joined by congenials and they organised themselves according to the rules of Benedictus. In 1128 they established a first abbey in wood amidst the dunes on land, which was a gift from the earl of Flanders. In 1138 the abbey sought association with the Cistercian order (De Boer *et al.*, 1989). The abbey played a leading role in the development of the region, but the agricultural–economical strategies of the abbey deviated substantially from tradition and rules of the Cistercian order. During the following 150 years acquisitions, gifts and exchanges of land lead to the establishment of vast *grangiae*. Besides the Abbey of the Dunes, many farms were leased to and managed by civilians (Termote, 1992).

At Koksijde the construction of a new abbey started in 1214. This was the first complex of brick buildings constructed in Flanders. The gothic church measured 117m long. At circa 1300 the abbey is at the height of its power with 120 monks and 248 lay brothers and the estate of the abbey amounted up to 10,000ha (Van Royen, 2003).

From 1400 onwards a gradual decline started: unfavourable political circumstances, large debts and a decrease of vocations were the main causes. Because of its localisation amidst the dunes, the abbey suffered problems from an increasing mobility of parabolic dunes and rising groundwater. At first it was possible to slow down the progression of the parabolic dunes by plantation. Soon however a large mobile dune developed which became very difficult to control.

From the end of the 15th century onwards plans were made to relocate the abbey. The map of Pieter Pourbus (Fig. 2a) from 1560 shows the abbey and its environment, its aim was to depict the abbey as exact as possible in order to reconstruct it elsewhere. The threatening dunes are clearly visible on the northwestern side. The position of the abbey was weakened by the ‘War of Religions’ (between Protestants and Catholics 1566 – 1648) and the problems with the mobile dune could not be counteracted anymore. The dune, “Hoge Blekker”, covered the ruins of the abbey completely in the 17th century. The monks finally founded a new abbey in Bruges in 1627, partially constructed with recuperated materials from the Abbey of the Dunes (Termote, 1992).

In 1949 excavations started on the site and the discoveries were remarkable: the church, cloister arcade, lavatory and refectory were recovered. The foundations of the buildings were still intact. The discoveries were consolidated with the techniques available at the time and put on display for the public.

During the same period, part of the abbey disappeared under a newly constructed road (Van Buggenhoutlaan). This road severed the historical link between the abbey site and the dunes. An archaeological park and a very attractive and modern museum was constructed. However, by lack of new investments, the exhibition became outdated, the ruins of the abbey and the park fell into decay and eventually the museum closed its doors in 1998.



Fig. 2a. Painting of Pourbus (1580).

The Noordduinen

Until the end of the 19th century an uninterrupted sequence of parabolic dunes extended from Dunkerque (N-France) till Nieuwpoort (De Ceuninck, 1992). Due to increasing urbanization especially since the Second World War, the dunes become strongly fragmented and active parabolic dunes and mobile dunes only remain in the larger nature reserves such as the Westhoek, Ter Yde and Karthuizerduinen. In the smaller dune areas such as the Noordduinen active deflation is limited to small surfaces, often induced by intensive recreation.

The coastal dunes are an important reservoir of fresh water replenished by precipitation surplus. The lower limit of the groundwater reservoir is formed by impermeable clayey tertiary deposits at approximately 32m from the surface. Groundwater flows are influenced by the presence of the polder south and water extraction east of the Noordduinen. At the archaeological site, the water table is artificially kept low, resulting in a change of groundwater flow and a lower water table south of the abbey site.

Soils develop in aeolian sand with modus of the particle size between 175 and 208 μ m and carbonate content between 2 and 6%. The main soil forming processes are production and alteration of organic matter often resulting in the property of hydrophobia, oido-reduction, leaching of carbonates, micropodzolisation. Profile development in dune soils is limited. Soils are young with often only a thin A-horizon overlying the parent material. In stable soil conditions – not disturbed by anthropogenic activities or bioturbation – decalcification proceeds till 25cm deep and micropodzols develop. Soils on former small agricultural plots are characterised by a 20 to 60cm thick light greyish A.p-horizon in which a new A-horizon in accordance with the new vegetation cover has developed.

The main habitats are ‘grey dune’ (moss dunes and dune grasslands), humid dune slacks, dunes with *Salix repens*, dunes with *Hippophae rhamnoides* and dune forest. Open dunes with *Ammophila arenaria* (‘white dunes’) cover small scattered areas. Grey dunes are designated as priority habitat in the Annex I of the EU Habitat Directive and deserve special conservation attention (Provoost *et al.*, 2004). For the Flemish west coast, the species richness of the dune grasslands is one of the highest in the Noordduinen (Janssens, 2000 in Provoost and Bonte, 2004): rare chalk grassland species, such as *Thesium humifusum*, *Asperula cynanchica*, *Polygala vulgaris*, also included in the Red List, are well represented within the Noordduinen.

Land-use planning and nature restoration by the Flemish Land Agency (FLA - Vlaamse Landmaatschappij) at Koksijde

The municipality of Koksijde counts about 20,000 inhabitants and as a coastal community its economic activities are mainly geared towards tourism. Summer months are usually very busy and weekend tourism is on the increase. So-called “all-weather-activities” become more important as an attraction pool for tourists. Koksijde became conscious of the tourist value of the dune abbey site and requested the FLA to cooperate with the project to restore the site of the Abbey of the Dunes.

Within the FLA a team was established to study the site of the Abbey of the Dunes and its wider spatial context. It is a multi-disciplinary group, which studies the different aspects such as environment (fauna and flora, hydrology, pedology and geomorphology), recreation and archaeology. For each aspect an inventory, an analysis of the bottlenecks and a view was formulated. Next a comprehensive strategy was determined in which the different disciplines fit. In a first phase a land use planning project for the abbey site, aiming at the integration and sustainable development of different land-use aspects such as culture, history, environment and recreation was established. Such projects are characterised by a holistic approach based on in-depth studies of all aspects, which shape the area. Because of its spatial position, bordering on the Noordduinen and caught between the urbanization of Koksijde-Dorp, Koksijde-Bad and St-Idesbald, it was soon decided to involve the surrounding Noordduinen in a nature restoration project. This approach would ensure a consolidation of the fragmented dune area and an integration of the abbey in its original landscape.

The project of the dune abbey

Analysis of the area

In the past the abbey was a very important agricultural and economic centre in the area. Through the archaeological excavations one can imagine the grandeur and significance of the Medieval abbey. In Medieval times the use of the dunes as grazing area contributed to the prosperity of the Abbey of the Dunes, but later on the dunes formed one of the causes of the decline of the abbey.

Superimposition of the ground-plan of the abbey by Pourbus (1560) on the recent cadastral map (Fig. 2b) shows that an important part of the abbey is buried by and situated on the other side of the road (Van Buggenhoutlaan) (Fig. 2c). Because of fragmentation of the site it is difficult to envisage the link between the abbey site and the dunes. Nowadays enclaves of residences, a military cemetery and an army base, a school and a camping within the Noordduinen and urbanization around the abbey site and Noordduinen contribute to the fragmentation of the Noordduinen.

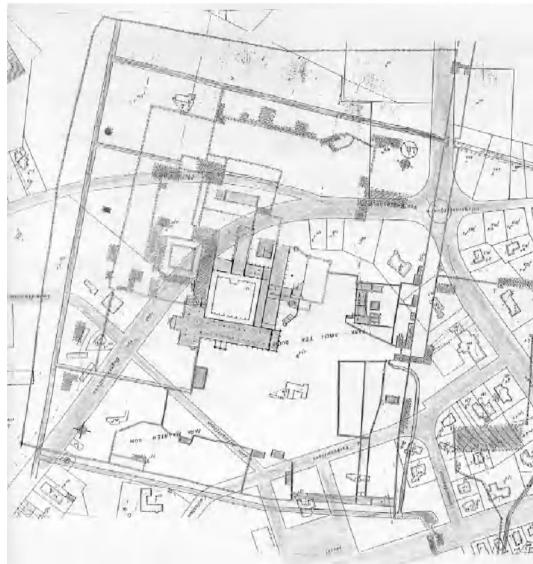


Fig. 2b. Groundplan of Abbey of the dunes.



Fig. 2c. Orthophotograph of the Abbey site.

Fragmentation of the Flemish coastal dunes leads to smaller and more isolated areas and obstructs dynamic geomorphological processes typical for the dune environment. Habitat fragmentation decreases survival chances of rare populations as dispersal of seeds and migration of fauna become difficult. The Noordduinen located between Belvedere (dune-polder transition) and Houtsaegerduinen nature reserves in the west and the dune complex of the Hoge Blekker – Doornpanne nature reserve in the east, form an indispensable spatial link (Econnection, 2000) between remaining dune areas.

The absence of any form of nature management causes a degradation of the moss dunes and the dune grasslands suffer from shrub invasion. Several ‘exotic’ species cause the deterioration of the typical vegetations. Locally strong wood expansion occurs due to seedlings of Poplars (*Populus x euramericana*) planted for dune fixation and of Maple tree (*Acer pseudoplatanus*). Migration from gardens and deposition of green waste result in the spreading of aggressive plant species such as Mahonia (*Mahonia aquifolium*) and White poplar (*Populus alba*) which replace indigenous plant species. In addition internal degradation of the grey dunes occurs through grass encroachment. These processes result in a decrease of the quality of the grey dunes and an evolution towards a less specific flora resulting in a decline in biodiversity (Provoost *et al.*, 2004). The disappearance of moss dune vegetation and dune grasslands has a negative effect on the bird species (*Saxicola torquata*), insects of open spaces (*Oedipoda caerulescens*) and butterflies (*Issoria lathonia*).

A special landscape element typical for the Noordduinen are the old fisherman’s houses and their small fields. These originate from the 18th century when fishermen supplemented their income by growing potatoes and rye. The fields were often laid out in levelled dune slacks and enclosed by wooded banks. Nowadays, many of these small pastures are intensively used as horse paddocks. They are overgrazed, heavily trampled and manured and of poor botanical quality. The horses cause severe damage to the wooded banks grown with Common alder (*Alnus glutinosa*).

Recreation is an important activity within the Noordduinen. Although no quantitative data on recreational use of the area are available, it is clear that the present recreation in the Noordduinen leads to disturbance and treading. Especially moss dune, pioneer vegetation of dune slacks and dune grassland are very sensible to treading. Horse riding, mountain biking, cyclo-cross cause a lot of damage to vegetation and soil. Walking trails and horse routes are often not well indicated and many paths occur. Stray dogs disturb wildlife and littering (paper, refuse, garden waste, building materials,...) is a problem throughout the area. Last but not least there is the annual Belgian cyclo-cross Championship which causes soil and vegetation damage, not so much by the cyclists but mainly by the many spectators and ‘wannabe champions’.

Finally there is a lack of a scientifically founded management plan that takes into account the actual bearing capacity of the land and the objectives of nature restoration.

Objectives for restoration of the abbey site and Noordduinen

The bottlenecks described above indicate that the problems require adequate and swift solutions. The actions to be taken, should concentrate on the conservation and restoration of historical and ecological values of the area. Recreational use and educational facilities can be developed as well.

The abbey site, completely run down by the end of the nineties, could be developed by a land-use planning project. Its main objective is the development of abbey site as an attraction point for the inhabitants of Koksijde and the many tourists. The removal of the road Van Buggenhoutlaan will allow archaeological research on the additional part of the abbey. The interdisciplinary approach will improve the knowledge on the monastic living environment from the 13th to 16th century. The extension of the abbey site towards the Noordduinen will restore the original glory of the Medieval abbey and the link between the abbey and the dunes will be re-established.

The development of the Noordduinen forms the subject of the nature restoration project Noordduinen. The policy of the Flemish government is to safeguard all remaining dune areas. It aims at conservation and restoration of specific environmental dune environments, to stimulate biodiversity by conservation of typical dune flora and fauna communities (De Pue *et al.*, 2002). The ecosystem vision on coastal dunes of the Flemish government (Provoost and Hoffmann, 1996) proposes for the Noordduinen a semi-natural landscape. In such areas preservation and/or expansion of specific succession stages on rather small scale is the main purpose. The project wants to strengthen the nature values especially the moss dunes and dune grasslands.

The biggest challenge is to find a balance between ecological potentials, historical values and recreational use. The planning and realization of a project whereby very diverse interests and different pressure groups agree on a common strategy will be the main task. Obtaining wide support by all parties involved and by the general public will be a major achievement.

At the moment the land-use planning project is under implementation. The project "I rise again from beneath the sand" launched by the municipality, aimed at a cultural-historical valorisation of the entire former abbey site. An integrated concept of museum, park and dunes was designed. The very attractive museum uses a new concept with modern presentation techniques. An ecological park-forest, in which the structure of the abbey is visualized, incorporates a remnant of dune grassland situated to the north of the site. The excavations and reconstruction of historical elements of the ruins take into account the recommendations of the Charter of Venice (1964). As such, the foundations of the church were reconstructed by using an uniformity of building materials.

The next phase of the project concerns the removal of the Van Buggenhoutlaan. Not only the breaking up of the road is investigated but a multi-modal traffic study had to formulate solutions for the future traffic flows. From the study it was clear that most of the traffic could be deviated along the Ter Duinenlaan. Because this road runs through a residential area it is necessary to rebuild the road. Thereafter the Van Buggenhoutlaan can be broken up and the extension of the park can proceed.

Reconciliation of nature, history and recreation in the Noordduinen nature restoration project

Nature restoration projects put the main emphasis on nature development. In the Noordduinen the actions involve habitat restoration as well as the introduction of different management regimes. Habitat restoration activities are very diverse and include removal of poplar plantations, removal of shrubs, removal of exotic plant species such as *Mahonia aquifolium*, strengthening of small landscape elements e.g. making drinking pools and restoration of wooded banks bordering the 19th century agricultural fields, removal of the nutrient rich surface horizon, clearing of a dune slack to set back the succession, reshape the microrelief on former intensively used fields, introduction of mowing and grazing.

Recreation in Noordduinen occurs under many different forms such as the pure experience of the natural environment with specific interests for flora and fauna to very active sports with little affinity for nature and landscape. In the first case nature stands at the centre of the activity, in the latter case the action itself is the main objective e.g. jogging, mountain biking, geocaching, quad riding, cyclo-cross... and although the scene is very agreeable the activity could be easily relocated to e.g. recreational areas with proper facilities. In between these two types of activities, an intermediate group of dune users enjoy walking (whether or not accompanied by dog), pick-nicking, horse riding... For them, the main attraction of the dunes are landscape qualities such as scenery, attractiveness and tranquillity.

Activities such as walking are perfectly reconciliatory with the aims of nature restoration. Other activities such as sun bathing which are not at all nature-oriented, do little harm to the ecological values of the area. Indeed, it has now been recognized that light recreation pressure can be beneficial in dune areas by supplementing rabbit grazing (Rooney and Houston, 1998). As it happens in Noordduinen some rare plant species such as Large thyme (*Thymus pulegioides*), Common milkwort (*Polygala vulgaris*), Common rock-rose (*Helianthemum nummularium*) occur along stray paths. The more active forms of recreation, like mountain biking, are much more difficult to reconcile with the aims of nature conservation, especially when they occur very dispersed over the area (Provoost and Hoffmann, 1996).

In spite of the protection of the largest part of the Noordduinen under the Law on the Organization of Town and Country Planning (1962) and the designation as SAC (Spatial Area of Conservation) under the EEC Habitat directive (1992) no management plan nor a code of conduct has been drawn up for the area. This has led to an intensive recreational use of the dunes and many activities have obtained the status of 'acquired rights'. As such it was not an option nor desirable to exclude recreation in the Noordduinen. The proposals of the nature restoration project took into account the carrying capacity of the dunes and the compatibility with future management. The choice was made to canalize and/or to relocate as much as possible the different recreational users. As a consequence some restrictions on recreational use had to be introduced. This has been a deliberate choice as it is not obvious that part of the 'nature' budget is used for recreation.

Nature restoration sometimes involves ground-works. These types of works are not at all appreciated by archaeologists who fear the damage or destruction of archaeological features in the soil archive. Especially ground-works which cover large areas such as the removal of a nutrient rich surface horizon or changing the microrelief on former agricultural fields form a very sensitive point for archaeologists and they wish to reduce these types of works as much as possible. Although in land use planning and nature restoration projects the FLA often implements a culture-historical study of the project area, budgets are often too limited to allow detailed archaeological prospecting, not to mention the financing of a complete archaeological excavation. So even nature restoration can destroy valuable sites and it is important to take this risk into account from the planning phase onwards. In most cases archaeologists can predict these chances, but they can never be totally sure, except when the soil has been disturbed before. In spite of these dangers, contemporary archaeological administration is not actively involved in the different phases of spatial planning. They prefer to focus their attention on ongoing ground-works but a certain involvement in the planning phase would be desirable.

Consultation process

In the restoration project of the abbey site the break up of the ‘Van Buggenhoutlaan’ road formed the most important bottleneck. It was necessary to convince the different authorities, in particular the municipality of Koksijde. Once the municipality agreed to remove the road, consultancy meetings were organised with the Roads department, Nature division, division of Monuments and Landscapes of the Ministry of the Flemish community, the Institute for the Archaeological Heritage of the Flemish Community (VIOE). Furthermore there are different advisory authorities with a say in the matter. Finally the members of the public are also involved and during a public hearing objections on the plan can be raised. If relevant these suggestions are incorporated into the plan. On advice of the committee of the project and on request, emerging from the public inquiry, a bicycle path between the extended abbey park and Noordduinen was taken up in the plan.

The procedure of nature restoration project Noordduinen provides for different ways of public’s participation through representatives in a commission and a committee but most importantly through public hearings. However to formulate a well founded nature restoration plan in which some facilities for recreation had to be accommodated, the project team had to identify representative spokespersons. In the case of horse riding, consultation with the three riding schools of Koksijde resulted in an acceptable compromise. For mountain biking or cyclo-cross (except for the annual race) the lack of any organisational structure makes consultation very difficult. Especially in winter the entire area is used on a frequent basis by individual bikers. Finally cooperation was sought with the sports official of the community of Koksijde to work out an acceptable track for both parties. Other activities such as squad riding and motor biking have been banned from the dunes.

Conflicts with archaeologists are not always easy to resolve. In the case of the Noordduinen, we know exactly where the abbey is situated. For the other historical

periods, there is a gap in our knowledge about the past and it is more difficult to locate potential archaeological sites. Archaeologists question if groundwork is the only option to reach specific habitat requirements because they wish to conserve the soil archive as intact as possible. So far the agreement reached is that the archaeologists will follow up the ground-works reaching deeper than the plough-layer (or deeper than the A-horizon in young sandy soils in this case). When any archaeological finds are exposed by ground-works, one should evaluate their importance and decide whether or not to excavate before allowing the works to continue or to halt the ground-works altogether.

Conclusions

The project of the Abbey of the Dunes has proven that it can be important to include larger parts of the environment than the historical site only. Such an approach needs a more comprehensive strategy but leads to a better integration of the different interests. Due to a smooth cooperation between the different study fields it was possible to develop a plan that all parties could agree upon. As the plan is the result of much deliberation and consultation with many different disciplines and the public, it is supported by the majority of the community. The realization of the three phases of the project Abbey of the Dunes increases the quality of the environment and integrates an archaeological monument into the present situation.

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The opening to the French public of 'natural' sites of coastal dunes: the choice between 'over-visiting' and 'over-protection' of a shared natural heritage

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Abstract

This paper proposes some thoughts on the stakes of opening to the visiting public natural sites with particular reference to coastal dunes.

In France the visiting public readily enjoys access to sites and particularly those situated along the coasts where this social activity forms part of the vocation of the Conservatoire du Littoral, the *Office National des Forêts* and the *Conseils Généraux (Départements)* (Meur-Férec, 1997). At ground level the diversity of each site together with the variable policies adopted by owners and managers, together with their differing geographical locations and social and economic pressures, produces an infinite variety of particular situations. The range of the degree of liberty of access to coastal sites varies greatly from the extremes of severely protected "*Réserve Biologique Domaniale*" only open to guided tours to free access peri-urban sea-side parks. Although most coastal zones readily admit the public, the inherent damage caused to sand dunes by "over-visiting" is sometimes badly accepted in scientific and ecological circles as constituting a real menace to our shared natural heritage.

Reasoning in terms of risk we have to consider stakes of opening, or closing, of sites to the public. The reasons for this are multiple and the protection of the biodiversity for future generations is certainly one of them (the protection of human lives against the risk of sea water flooding is of course another prime aspect but, fortunately, this is a limited risk along the coasts of France). However, one can also consider the amenities acquired through site visits and the awareness of ecological issues that hopefully will be transmitted to future generations. To what degree the opening of sites will conciliate the major issues of conservation of the biodiversity / public access?

These questions lead to a reflection concerning the evolution of the relation between Man and Nature (Kalaora, 1998; Miossec, 1998). The coastal dune environment has moved on over recent centuries from the "frightening desert" (Brémontier, 1797) to a precious spatial resource destined often for short term unbridled economic development, and nowadays sometimes evolves to a "sanctuary" precluding public access. In a reaction against development excess the current thought in sites management tends to privilege the conservation of the ecosystems in the name of biodiversity. However the best interests of Humanity as a whole cannot only be translated into

terms of biodiversity which is, after all, only one of the several factors of good husbandry concerned by the protection of our shared heritage of Nature. The access accorded to a public, as a function of the nature of the sites, well informed, marshalled, limited in number and reasonably behaved, can also through an acquired awareness of our heritage become a guarantee of sustainable preservation.

Keywords: Coastal dunes; Natural heritage; Opening to the public; biodiversity; Visitors access; France.

Introduction

In France most protected natural sites are public property, owned by the State or local communities, and open normally to public access under more or less stringent conditions. This situation has two objectives: nature conservation and at the same time allowing as many people as possible to enjoy the countryside and our "natural" environment. In other countries other choices have been made. As an example in the United Kingdom the two notions of nature conservation and the enjoyment of the countryside are considered separately. The first being restricted to private sites, largely unknown to the public, destined to preserve the existing ecosystem termed "Sites of Special Scientific Interest" and the second, within the framework of enjoying the national heritage, to the popular public enjoyment of the countryside termed "Areas of Outstanding Beauty, Heritage Coasts" (Meur-Ferec, 1997).

On the 5,500km of the coasts of metropolitan France, about 1,250km are as of today public property: about 800km are shared between the *Départements* - ENS (*Espaces Naturels Sensibles*) and the Conservatoire du Littoral ; 370 km of the coasts are managed by the ONF (*Office National des Forêts*) ; about 50km depend on local communes and others which are also managed by the ONF (excluding those lands managed by the Conservatoire) and about 30km which are public property managed by other bodies (Regional and Communal). This extraordinary heritage, made up of about 75% of sand dunes, has been extracted from the forever mounting economic pressures which bear down on private land and is presently being enjoyed by an ever increasing public. It has always been difficult to assess the number of visitors who avail themselves of sites due to their very nature of being open to all-comers who may enter them from all directions. However we are witnessing, through reports both by local officials and quantitative surveys of particular sites, that the number of visitors has increased considerably over the last 20 years (the *Conservatoire du Littoral* has undertaken an extensive survey of the frequency of visitors in order to better appreciate the phenomena, the results should be available in 2005).

This enthusiasm for sea board natural sites brings up questions of management connected with the double objective of nature conversation and public access. To what measure are these two objectives opposed? Our natural heritage represented by the local ecological systems may perhaps be severely menaced by "over-visiting" by an irresponsible public having no respect for nature and motivated by a thirst for free access to natural sites readily available? On the other hand there exists a risk that the "over protection" of sites for their own sakes which conflicts with narrow ecological views, which appear to be largely immune to a more open spirit of public governance, such that

we may well question that this may perhaps constitute a danger to the principles of the “humanist” view-point?

The reply to these questions cannot be sought through a strictly academic discipline or through a vested interested approach; the reply must come from a philosophical reflection of the relations between man and nature together with the multitude of points of view surrounding the issues of our humanities’ shared heritage constituted by our natural surroundings (the authors are aware that this adjective of “natural” cannot be applied to its undisturbed status which has today disappeared but rather an “orientation” where considerations of “nature” command a high place in the occupation and the management of sites). This short paper proposes some elements of thoughts on what is at stake in opening sites to the public and their management within the context of coastal areas and particularly that of sand dunes.

A large variety of both sites and types of visitors

In France, especially following the Second World War, part of the sea-board sand dunes had been occupied and subsequently destroyed by both urbanisation and industrial activity. The process continues today, in spite of the stringent legislation laid down in the “*Loi Littoral*” of 1986, to attract numerous property developers. The State has intervened through the powers invested in the *Conservatoire du Littoral* together with the *Départements* through the legislation concerning the “*Espaces Naturels Sensibles*” and the ONF (*Office National des Forêts*). This natural heritage of about 180,000ha, acquired and managed by public funds is, with some minor exceptions (Marquenterre) largely freely open to visitors as a public service. However the degree of free access is tempered according to the nature of the different sites according to their characteristics, their particular status, owners and managers.

The varied degrees of open access

All the sites of the *Conservatoire du Littoral*, the *Départements* and the ONF are open to the public within the limits of a due respect to an ecological balance. Visitors are generally directed along pathways and are advised by informative panels. The rules of expected behaviours are indicated at the entry-points and concern generally the prohibited use of motor vehicles, the picking of plants, camping, lighting fires, waste disposal, letting dogs run wild, etc. Some areas may at times be prohibited from access to allow for the regeneration of areas suffering from over-frequentation. Free access is proposed at numerous entry points and the guards provide both information and advice as well as supervising behaviour. Repression for misdemeanours is not excluded. The ONF guards are endowed with an historical authority handed down from the judicial police force which empowers them to establish contraventions on evidence of a lack of compliance with the site rules. Since the Law of 27 February 2002 concerning local democracy the guard of the *Conservatoire du Littoral* have the same power.

Some statutes place very strict limits on the degree of access by the public. This is the case for the RBD’s (*Réserves Biologiques Domaniales*) and parts of National Parks which are classified as “protection zones”. These sites privilege an ecological ambition rather than one of welcoming visitors. This is the case of the RBD in the *Departement* of

the Pas-de-Calais at Merlimont, on the Côte d'Opale, where only guided visits by representatives of the ONF are authorised. However the coastal sites are extensively open to the public throughout their length bordering the coastline and access is not absolutely forbidden; it is however not encouraged with formal pathways and car parking areas etc. Only the île de Port Cros benefits from the statute of a "National Park" on the national coastline of France. Again the designation of the zone is an ecological sanctuary, open to the public, with strict limitations. Occasionally national parks may contain small areas of limited access, termed "*Réserve Intégrale*", an example is the zone called "Bonelli eagle" on the île de Port Cros. These restrictions remain very limited in number and extent throughout the littoral and only concern sites having an ambition of conservation of local ecological systems.

At the other hand of the scale some coastal dune sites managed by local Communes in largely urbanised areas have a truly open access and are managed as such as leisure zones (*Parc du Vent* in Dunkirk). In this case the play areas have the priority. It is more a question of a public recreation field than a nature zone. Nevertheless environmental education is present through informative posters and animated games based on the flora and fauna. This type of site responds to a very real social demand and it does possess the inherent advantage of exposing to a very large public the notions of "nature protection".

In fact, the very ecological diversity of each site, and their "providers" varying designations and their management team's status together with their geographic context, social and economic aspirations, are all at the very heart of the wide variety of natural sites along the sea coasts harbouring sand dunes.

A large diversity of public requirements, practices and objectives

The profusion of freely accessible nature reserves is well received by a varied public whose multiple demands are ever increasing. Following surveys made during guided tours organised in the natural sites in the dunes to the east of Dunkirk (Meur-Férec *et al.*, 2001; Baron-Yelles and Meur Férec, 1999) we can attempt to classify the various visitors into categories as a function of their practices and objectives. Initially we find that the majority of visitors fall into the category of families, often **parents with their young children**, not particularly familiar with the aspirations of "nature lovers", and in search of a structured welcome and a playful learning experience. Secondly we find a **youthful adventurous** group seeking to "discover" and "have surprises", keen on sporting activities like hiking, together with a motivation to "learn something" during their visit. Young urban couples fall typically into this category. Finally a **public of specialists** make up a third group. They are composed of both national and international visitors having made the trip for the specific reason of visiting nature reserves. These visitors possess specific fields of ecological interest: bird-watching, botany, insect life,... Often middle aged and members of an educated sector of society they are frequently members of several organisations concerned with the protection of nature.

To these groups keen on guided visits should be added all those, perhaps making up the majority, of people with no affirmed interest in nature but are simply on their way to the beach to sun bathe, play, jog, get some fresh air or get away from things.

Confronted by this interest in nature, largely encouraged by local communities endeavouring to promote their sites, and by the State Education Ministry within their environmental vocation, also the *Conservatoire du Littoral* within its remit of encouraging open access, together with Tourist Boards for whom the attraction of Nature is an economic resource, not forgetting the media who thrive on popular aspirations, etc. The management teams responsible for nature reserves are often concerned and at times positively alarmed. How can they protect the ecosystem under such conditions? Why protect rare plant species if they are only to be trampled under-foot by families on picnic somewhat insensible to the future of *Parnassia palustris* or *Liparis loeselii*?

Managers and the public at large – the face to face of often divergent values

Biodiversity and the protection of species: a management priority?

It is easy to understand how management teams are concerned with the future of seaboard nature sites especially considering their stated objectives and the background of the people employed to achieve them.

These objectives are incorporated into a “**Management Plan**” which constitutes the basis which orientates the mission entrusted to its members. Generally set up for the sites of the Conservatoire du Littoral and the *Départements* they are generally updated every five years. They stipulate, following an ecological assessment of each site, the management objectives to be obtained, the strategies to be persuaded, the ways and means to be employed, the time-scale planning, and the monitoring and evaluation of the results. These documents are generally written by the senior staff of the management organisation (*Départements* and Regional Authorities for example) and at times consultant organisations specialising in ecosystems. The main objectives laid down in the plans are the stability and the increase of the **biodiversity** and the conservation of **protected species** through national and international legislation. The nature reserves managed by the ONF benefit from “*Plans d’Aménagement*” based on the same principles; their ambition is to seek to reconcile the economic, ecological and social functions; in the coastal sites the function of wood production gives way to the considerations of conservation and sustainable public amenity (Favennec, 1999).

In accordance with the Management Plans the actions are organised in order to respect the objectives which appear to obtain a large consensus within the management team responsible for the Nature Site. Welcoming the public and the limitation of access to certain areas are usually planned around the cited conservation objectives.

Biodiversity is effectively accepted worldwide as a guarantee of the quality and the “sustainability” of our planets ecosystem. *The biological diversity, or biodiversity, concerns the variety and the variability of all living organisms. This includes the genetic variability within species and their populations, the variability of species and their forms of life, the diversity of the ecological complexes of which they are part, and those of the ecological processes in which they act* (XVIIIth UICN meeting, Costa Rica, 1988). The conservation of the biodiversity involves the protection of certain species set down in

reference lists which refer to statutes (Red List of the UICN, annexes of European Directives “Birds” and “Habitats”, National Directives...). The main criteria for the protection of species are their rarity and/or the importance of the risk of extinction which is often directly connected with the destruction of their natural habitat by Man (Bellan-Santini, 2002).

Without denying the usefulness of these lists we may however express some reservations. The statutes (Protected Species on a national and international level, Key Species, Heritage Species...) and qualification criteria are not always clearly defined and supported. Such “*is said to be representative of our heritage any species which becomes the subject of interest whatever the nature of this interest*” (Delavigne, 2000). One could therefore imagine a scientist developing a passionate interest for a particular plant or insect for personal reasons and the species thus becomes protected or even a symbol. Additionally the rarity of a species is a function of space and time. As an example we may well consider a species to be rare considering its historic attachment to a defined space (like *Elymus arenarius* in France), which is quite common in other regions generally situated at high latitudes. In this case rarity is a function of a specific space of reference and there is no risk of extinction of the species as a whole. We should also consider that rarity is an evolutionary function which varies in time and at such speeds that the lists, despite of their capacity to be updated, are often notably by their nature, slow in being revised. The lists are a simple and efficient means to combat the disappearance or the reduction of certain species and so protect Man’s natural heritage. However they are too “fixed” and are tied directly to a function of space and time together with a direct link to the sensitivity of those who set them up. They are thus useful but incomplete in their use to establish the objectives of natural site management criteria.

Notwithstanding the objectives of site management plans, **the sensitivity of managers** towards the conservation of ecosystems is also connected with their professional backgrounds. The large majority of senior staff members have been trained through a syllabus concerned with biology, ecology, forestry and agriculture. These courses do assure a certain level of knowledge of the natural sciences required to perform as a manager in the field of our natural living heritage. They do also orientate manager’s sensibilities towards certain species (rather than spaces) both animal and vegetal (rather than human). These fields rather preclude managers who have a geographic education together with both sociologists and philosophers in the field of nature in spite of the fact that these backgrounds are represented in the scientific committee of the *Conservatoire du Littoral*. These orientations, often firmly anchored in natural sciences, tend to produce managers who at times consider Man, and thus the public at large, as elements that upset the natural equilibrium and act destructively towards the efforts made in favour of the conservation of species, or at the very least they represent attitudes which ignore the values of conservation.

Tagging, rubbish disposal and bulldozers: a doubting public

On the other hand, the various types of visitors, generally satisfied with the preservation efforts in hand (Meur-Férec *et al.*, 2001) have, because their motivations differ so widely, another set of objectives (Kalaora, 1998).

For some, nature sites are owned by us all and are therefore owned by nobody. They tend to use sites as playgrounds, for moto-cross, parking, meeting and picnic areas and camping grounds and have no perception of their value to the community as sites of our natural biological and landscape heritage. This category of user tends to degrade sites through negligence or even wilfully as a manifestation of their refusal of a form of society which they reject (brush fires, tagged panels, etc.). They constitute the most difficult type of visitor to manage and educate and certainly the most provocative and depressing to the guards. These problems with vandals are not specific to nature sites and affect all facets of public life.

For other types of visitors, fortunately in the vast majority, very largely holding in respect the facilities, there are some areas of incomprehension with the authorities. From recent surveys of the degree of satisfaction held by visitors after their visit it does appear that people do expect to find a higher degree of urban facilities at sites. It is noted that a number of visitors to sites in northern France expect to find benches, dustbins, toilets and, why not, snack bars! People seem to be looking for "nature" as a back-drop to their activities without the inconvenience of not having "creature comforts". The level of "naturality" accepted amongst visitors appears often to be very low. This ambiguity shown by numerous visitors has already been underlined in the review "Cahiers du Conservatoire du Littoral" (1995). These situations often leave managers perplexed in view of their unfailing efforts to restore natural habitats.

On the other hand some visitors readily understand and react negatively to the artificialisation introduced by some managers themselves and the curbs placed on their personal liberties. For some it is difficult to accept being channelled into paths so to avoid trampling on protected species or to give up cross country cycling or using trial motor-bikes to avoid tearing up humus when at the same time large areas are over-turned in order to "rejuvenate" the vegetation of the established dunes and new wet lands are formed to foster *Triturus cristatus* and Natterjack toad (*Bufo calamita*). How to understand the restrictions on picking up plants when the site managers cut down areas of natural long grasses (*Calmagrostis*) or tear out Sea buckthorn (*Hippophae rhamnoides*) or cut down trees (Pines at Sefton Coast, UK)? Also why do bird watching in silence and prohibit dogs to go near newly laid eggs while hunters shoot water fowl on protected nature sites?... Of course all these situations have rational explanations, more or less well founded, connected with a local context and a choice which has been made, but how to appeal to the public for respect and understanding in view of these apparent contradictions. Efforts may be made to educate and alleviate some of these contradictions (displayed information should be permanent and in several different forms; the information displayed by the guard as mediator is certainly the most efficient; no fixed information board can replace the indispensable human presence).

However the main question remains open: how to lay down rules which are “good for Nature”? Are the doctrines in this field open to discussion and consensus, or are they arbitrarily laid down by some “enlightened despots” (Thiébaut, 1988)? Is there sense in protecting Nature for its own sake (Berque, 1996)? What are the objectives and what is at stake in preserving what we have left of “Nature”? These questions bring us to face the ambiguities of the evolution of the relation between Man and Nature.

Replies (or questions) to be looked for in the relations between Man and Nature

Even though the relations between Man and Nature have fluctuated over the centuries between one social group to another, one can identify certain currents of thought chronologically.

Up to the XVIIIth century our coasts were not intensively occupied by Man and retained a certain atmosphere of fear mixed with a fascination in view of the immensity of space and violence displayed by the elements. The dunes were described as a “horrific desert” (Brémontier, 1797); Nature being often considered to be hostile towards Man.

During the XIXth century the dominant tendency was towards “domestication” of nature by Man in order to master the elements and if possible to render them “productive”. At this time the dunes were calibrated and managed using different techniques of stabilisation and notably by the planting of pines used for the production of timber and resin. At the same time society was becoming more democratic and rural life was giving way to a more urban society, the rising attraction of the pleasures of the seaside radically changed the relationship between Man and the sea-board. At the same time as the coast became the object of long walks and the doctors subscribed to the benefits of sea bathing at the end of the XVIIIth century, the dunes revealed themselves to be a **useful space to be exploited** for the needs of the construction industry.

During the XXth century the sparse aristocratic villas which had been built gave way to more dense constructions including housing developments and flats and often, after the Second World War to a “boom” in mass tourism. At the same time the rapid increase of industrial activity, especially the localisation of steel production on the sea boards and the need for generating power, encouraged the construction of industrial plants near ports located on flat sites near the sea and using principally the dunes and the estuaries. In view of this increasing need these sea board sites once numerous and of low cost became rare and sought after. During the 1950’s to 1970’s the sensibility towards the protection of our natural heritage had not yet affected the rapid rate of consumption of the space remaining in its natural state. In fact at this time the dunes were the site of a rapid developing part of the economy and their being used was considered acceptable without any consideration towards the well being of the environment. The only dunes that were totally saved were managed by the Forestry Commission (*Eaux et Forêts*).

Even though the first organisations concerned with protecting Nature appeared early in the 20th century, like the Society for the Protection of Birds which was founded in France in 1912, it was not until the 1970’s that the ecological movement really made a break-

through in forming a powerful counter movement to denounce the exploitation of Nature by Man without any notion of the importance of sustainability. This movement took the stand against unlimited economic development at any price and promoted the notions of a **common natural heritage** together with the menace to certain species and the ecological heritage. It was Man who became over time the **intrusive figure** who “disturbed” and destroyed nature. He stigmatised power and profit in the face of a fragile, delicate defenceless Nature. The excesses of this line of thinking both in the form of sentimentality or hard core beliefs of “deep ecology” are reflected in the development aberrations that they have brought about.

Today, the context has changed from that of the “30 glorious years” because the economic exploitation of nature reserves is governed by strict legislation is spite of some abuses, and deviations are present (Becet, 2002).

The protection of Nature in the western world remains in the forefront of media preoccupations and has been adopted, and sometimes used, for political ends. The current **main line thought** for most people is “Nature is not in the service of Man, neither for his needs nor for his pleasures; it is Man who is in the service of Nature” (Delbos and Jorion, 1988). Political ecology refers more and more to science that supplies its foundation and justification which is forever increasing; in depth quantified studies of fauna and flora supply full justification for the awareness of the importance of **biodiversity**. The term, used by the political classes concerned with their public image, has become the panacea of the protection of Nature, its ultimate objective, the very future of Humanity. Largely relayed and amplified by the media “biodiversity” and “future generations” are the leitmotif of all programmes concerning Nature often leaving aside present generations (often including elements of humanity suffering both here and elsewhere) and the considerations of landscapes.

The results of a poll carried out in March 2004 amongst 400 walkers on the beaches and dunes of the *Départements* Nord and Pas-de-Calais reflect the strong influence of the media and the thought patterns which are dominant amongst the general public (Meur-Férec *et al.*, 2004). In response to the question “in your opinion should we combat erosion?” almost everyone chose the reply: “yes, always” in order “to protect nature”, and “not at any price” in order to “protect homes”. From this should we understand that we should build erosion defences around all Nature reserves and allow sea erosion to wear away the coastline and thus menace our sea side towns? This interpretation would certainly not reflect the beliefs of those questioned who may have attached undue importance to the words “protect” and “Nature” in the question to the degree that our question was badly formulated. However these surprising results reveal the weight of current thought patterns and the answers considered to be “politically correct” which directly connect “Nature” and “protect at any price” – it is as if one precipitated to press the “Yes” buzzer on a TV Game Show without really thinking about the question.

But if biodiversity becomes the only objective, constructed by intangible and universal faiths, does not nature risk becoming a field for “specialists only”, a sanctuary for scientists which excludes the common man, punished for his excesses, suspected of having dangerous intentions towards destruction or, at least, living in dangerous ignorance. One may well ask oneself if the protection of diversity allows for a similar

diversity in both the approaches as in the points of view. One could apply to Nature management a principle advanced by Arnould and Miossec (2000) in discussing geography: "if diversity constitutes a richness, then one single line of thought can never become an eternal philosophy".

What is really at stake in the preservation of Nature may perhaps involve its being made part of our building of **our sustainable heritage**, that is to say an appropriation by everyone of this common resource? A heritage to remain such must be protected, safeguarded but it has no value unless it is fully appreciated, that is to say shared, shown and accessible. One may risk the presumption of making a parallel between a Nature site and an emblematic historical site. It is difficult to imagine the closure of the castles of the Loire Valley or the Palace of Versailles closed to visitors to protect them and reserve their enjoyment for future generations. The public knows and respects this heritage because it has been appropriated and would not dream of organising a picnic in the crystal gallery or to jump on the beds... Of course Nature is not managed in the same way as castles; it is free alive and dynamic; the species are unnumbered, the space involved unlimited and the guards are outnumbered. However the process of heritage passes through the acquisition of the notion of true appropriation of a common wealth and that's true for Nature as well as manmade objects (Audrerie, 1997). After all is not **Nature an object of society?** "Nature exists for Man in so far as Man is concerned with it" (Delbos and Jorion, 1988). In this case should not its management respond to the principle of governance associating the ordinary common people in the debate?

Conclusion

The double objective of trying to conciliate the conservation of ecosystems on one hand, and welcoming the public and their environmental education on the other hand is ambitious and entails some difficulties. It does seem however very important that these two objectives remain associated if we search a real consideration for Nature as our heritage. A compromise can be found and adjusted as a function of the various sites and what is at stake and may well require that one or the other of the options will prevail. The balance and thresholds of the capacity to absorb visitors have to be found, probably on a case-by-case basis. In any event the choices made in managing our common heritage must be explained and justified within the spirit of public service to the public at large. The undertaking is well worthwhile because opening up sites to the public, with some restrictions, is a means of conserving them for the long term through their appropriation by the public at large. It is an investment in the future even if some species and plants suffer from time to time and as long as none are eradicated completely. But the ecosystems, and in particular those in the dunes, have a natural resilience which allows for manmade errors in their management. Through their natural mobility the dune systems have an immense in-built capacity to heal themselves. It is a system which is adaptable providing that it is not wiped out by the advances of urbanisation or industrial development and is quite capable of surmounting changes in management choices and therefore adapt itself to current ways of thinking: development, stabilisation, forestation during the XIXth century, then deforestation and burning, scavenging, excavating, remobilisation; eradicate the rabbits then reintroduce them; open them up to the public, then close them, then reopen them...

The main difficulty in the management of dunes seems not to be connected to their intrinsic fragility but to the definition of the objectives and as such the reflection and aspirations we are looking for in our efforts to protect them. These considerations cannot be left up to only naturalists or even scientists in general; they need in addition to be informed by public opinion.

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Ecological aspects of vegetation removal from the coastal sand dunes of Israel

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Abstract

Coastal sand dunes are known to be (*i*) free of vegetation and active (*ii*) partly vegetated and active (*iii*) fully vegetated and fixed. Some of the dunes are vegetated naturally while others were artificially stabilised for the purpose of controlling sand movement or because of biological invasion of alien species. The vegetation that covers two parabolic coastal sand dunes south of Ashdod, Israel, was removed as part of a study of dunes management. This inventive and not so well known method of management was used despite the common idea that active sand dunes are an undesirable nuisance which are a threat to arable land and infrastructure elements. The aims of the research are (i) to study the geomorphological and dynamic responses of the dunes to removal of vegetation (ii) to monitor the rate of vegetation recovery, its pattern and effect on dune morphology and dynamics. Coastal dunes provide us with examples of dynamic natural processes and the nature of the ecosystems that they support depends on this dynamism. Re-mobility of stabilised dunes is an important technique of ecological restoration. The parabolic dunes of the research area were formed during the last 30 years and are characterised by phytogenic mounds, known as nebkhlas, composed of windborne sand that was trapped within or around shrub canopies. The nebkhlas were formed mostly on the crest of the dunes because the crest is the area of no erosion and no deposition.

Two methods of vegetation removal were employed. First, removal by hand with no disturbance to the dune shape. By this method the nebkhla mounds were sticking out at the dune crest. These exposed nebkhlas turned the dune into a bluff body (a non-streamlined shape) that produces considerable resistance to the wind. The wind acts on the projecting mounds as an eroding force. After one year the nebkhlas were not eroded. Artificial sand mounds near the nebkhlas were eroded quickly after a couple of storms. The resistance of the nebkhlas to the wind is due to the weave of the roots. In the second method, the nebkhlas were flattened by a tractor shovel that reinstated the form of active transverse dunes. In both methods the roots of the shrubs started to sprout and grow, particularly in the dune that was exposed by the first method.

Keywords: Coastal sand dunes; Vegetation; Aeolian processes; Mobilisation.

Introduction

The coastal sand dunes of Israel occupy about 460 km², most of them south of Tel Aviv. All these dunes were formed within the last 1000 years (Tsoar, 1990) and during most or part of this period human agricultural and pastoral activities resulted in extermination of natural vegetation. The area south of Ashdod is preserved as Sand Park.

According to aerial photographs from 1944, the dunes were of transverse/barchan type with no vegetation cover. The stable interdune areas were used for agriculture. As a result of relocation of the population of the area in 1949, agricultural land-use stopped and grazing was drastically reduced. Vegetation recovered first in the interdune areas (the agricultural plots) during the 1950s and on the dune crests during the 1960s. Vegetation sprang up rapidly during the 1980s and even more so in the early 1990s and 2000s, covering the slip-faces and changing the transverse dunes into parabolic forms (Tsoar and Blumberg, 2002).

GIS analyses of the aerial photography show an increase in vegetation cover from 4.3% in 1944 (most of it in the agricultural plots in the interdunes areas) to 8.4% in 1974 and 17% in 1995 (most of it on the crest and lee sides of the dunes). All of the increase in vegetation, which is clearly discerned from the aerial photographs, is a result of the abatement of human impact. The quick change from mobile sand to vegetated sand required management interference in order to keep the free mobility of sand. We have tried two ways to remove vegetation from the dunes and to change the stabilizing sand dunes landscape back to active dunes landscape as it was in the past. We question whether we can form a sub-environment that will have ecological values together with recreation values. We assumed from the very beginning that vegetation may recover once our interference is curtailed. All sand dunes in Israel, including those that are in the extremely arid climate, are vegetated. The reason for that is the low wind strength in Israel compared to the high wind strength in NW Europe (Tsoar, 2001).

The removal of vegetation and subsequent monitoring may answer some of these management questions:

1. Can we turn parts of the Park into mobile sand systems?
2. What are the processes that would act on the system after the removal of vegetation?
3. How can we manage and preserve a system of active free sand in the Sand Park?

Should we be afraid of shifting sand?

For many years, dune sand was erroneously considered as a substance with no economic or ecological value except for mining. Sand is easily blown by wind and as such is a threat to arable land and infrastructure elements. Because sand retains little moisture for plants, it is useless for agriculture. Many planners consider the coastal dunes as an undesirable nuisance and consequently, they designate the dune sand for quarrying or for building and industry. In the last twenty years, it has become abundantly clear that man is a greater threat to sand dunes than sand dunes are a nuisance to man. Coastal dunes provide us with examples of dynamic natural processes and the nature of the ecosystems that they support. Like many other landforms, coastal sand dunes and their ecosystems

have an intrinsic value. Their unique changing form and the specialized plants, animals and other organisms, which inhabit them, increase our understanding of the diversity that exists in this environment (Nordstrom and Lotstein, 1989; Van Zoest, 1992; Heslenfeld *et al.*, 2004; Martinez *et al.*, 2004).

Based on the above, there is an increasing awareness among scientists and managers in recent years of the importance of sand dunes as an active system. There were some attempts to remove vegetation and soil from the coastal sand dunes of Western Europe which had been artificially stabilised in the past mostly by planting trees (for stabilisation and wood production) and Marram grass (Arens *et al.*, 2004). Many ecologists and managers claim that dune stabilisation is not necessary because it changes the dunes' dynamics and the aeolian processes, with an impact downwind. Stabilisation is responsible for a less diverse landscape and a decrease in biodiversity. Mobile sand is considered as part of the natural successional landscape while stabilisation prevents normal function of the system (Heslenfeld *et al.*, 2004; Martinez *et al.*, 2004).

Removal of vegetation

The coastal sand dunes of the Ashdod – Nizzanim Sand Park are covered mostly by *Artemisia monosperma* and some other shrub species (Fig. 1). Because of the sparseness of the vegetation (15%–17%), most of these shrubs trap sand to form phytogenic mounds known as nebkhas which are an important patch on the dunes. The nekha has its own dynamics and its size and amount of trapped sand depends on the location of the shrub on the dune. Shrubs that are formed close to the crest where the maximum sand transport occurs are the biggest. Shrubs at the lower windward side of the dunes are subjected to erosion and degeneration (Fig. 2).

The removal of vegetation was first done by hand on one parabolic dune. In that case the nekha mounds were left intact containing the roots of the plants (Fig. 3). Our assumption that these mounds of sand would be eroded very quickly after a couple of sand storms was refuted. The nekha's mounds had not eroded after a year. Artificial mounds of sand of identical size were built near the exposed nebkhas and the rate of erosion was measured by erosion pins. Fig. 4 shows the results of the rate of erosion from the artificial mounds, the nebkhas without vegetation and the nekhas with vegetation. The artificial nebkhas were eroded very quickly and disappeared after two storms. The rate of erosion of the artificial mounds was on average 7 times higher than the rate of erosion of the exposed nebkhas. The intact nekhas continued to trap sand and slowly increased in height.

The removal of vegetation by hand did not eradicate the plants. The removal was done in November 2001. Sprouts of *Artemisia monosperma* gave off shoots by February 2002 and most of the plants recovered. In autumn 2002 we decided to remove the vegetation from another parabolic dune with a tractor shovel which levelled the nebkhas. After a short time of adjustment the dune restored the slip face on the lee side in winter 2002/03 and the dune advanced about 4 metres per year. A similar rate of advance took place in the following winter of 2003/04. Very few sprouts appeared from the roots but the sand

erosion had exposed the roots of the *Artemisia monosperma* and that formed some resistance to the wind erosion. The monitoring of this active dune is continuing.

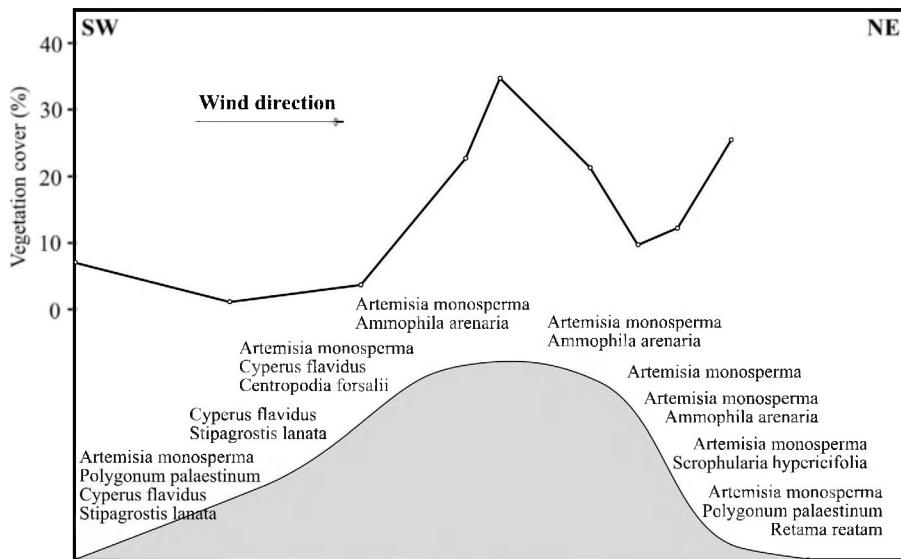


Fig. 1. Perennial vegetation cover on parabolic dunes in the Ashdod - Nizzanim Sand Park. The percentage of vegetation cover increases from zero at the mid-windward slope to 34 at the crest.



Fig. 2. The eroded windward side of a nebkhah that exposes the roots of *Artemisia monosperma*.



Fig. 3. The exposed nebkhlas on the crest of the parabolic dune.

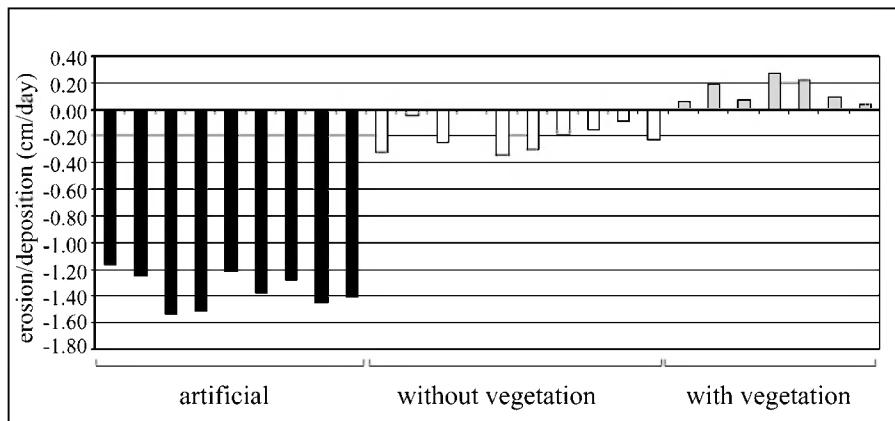


Fig. 4. The rate of erosion/deposition of the nebkhlas (artificial, without vegetation with vegetation) during the storms of winter 2002-03.

The increase in sand flux after the removal of vegetation

The sand flux was measured at each of the treated dunes by comparing it with the sand flux in a nearby dune (control dune). The flux was measured with a 'Sensit', which is a sensor composed of a ring-shaped piezoelectric crystal mounted on a 2.5cm diameter post (Stockton and Gillette, 1990). This ring reacts to impacting particles and registers every impact in a data-logger. The flux was measured in the treated dunes (research dunes) and the nearby control dune, on the lower windward slope and near the crest during four storms that occurred in winter 2002/03. Results are shown in Table I.

Table I. The average sand flux ratio between the treated dunes (research) and the nearby untreated dune (control) during four storms that occurred during winter 2002/03. The vegetation was removed from dune 1 by hand in November 2001 and from dune 2 in October 2002 by tractor shovel

Dune	Sand flux ratio (research/control) at the lower windward slope	Sand flux ratio (research/control) near the crest
1	130/1	1.5/1
2	573/1	77/1

It is obvious that dune 2 is more active than dune 1 because of the flattening out of the nebkhlas. However, the nebkhlas near the crest are bigger and more developed. For that reason the ratio of the sand flux near the crest is much lower than that at the lower windward slope particularly on dune 1 where the nebka mounds persist. The wind magnitude increases towards the crest. For that reason there were cases in which the wind speed at the lower windward slope of the controlled dune was below the threshold velocity needed to move sand. That brought about a higher ratio of sand flux at the lower windward slope.

It was also found that during rain there was a drastic decrease in the sand flux of the research dune while the control dune showed very little decrease. We assume that this is because of the process of precipitation landing on the leaves of the shrubs being intercepted and held in temporary storage (interception).

Conclusions

1. Removal of vegetation from a coastal sand dune for the purpose of formation of a dynamic dune landscape is much more effective when a tractor shovel is used to take off the shrubs and their roots and to level the nebka mounds.
2. The nebka mounds are resistant to wind erosion after removal of the vegetation. This is probably due to the roots of the shrubs which can make the sand more cohesive. According to the rate of exposed nebka mound's erosion we assume that it would take a nebka mound 6 to 7 years to become completely level.
3. The vegetation on an exposed nebka recovers quickly during the rainy season. Taking into account the low rate of erosion, the exposed nebka mound will turn from erosional mode into accumulation mode within a year or two.

4. The sand flux of a vegetated dune is less affected by the rain because of the processes of interception. For that reason the ratio of the sand flux between research and the control dunes is reduced during a sand storm that is accompanied by rainfall.

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PARALLEL THEMATIC WORKSHOP SESSIONS

*Workshop ‘Nature restoration/development in
harbours’
chair: Jaap Graveland*

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Management Plans in perspective of article 6.1 of the Habitats Directive: a common interest binding fishers, ecologists, hunters, port planners and recreationists

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Abstract

In this paper the development of management plans for estuaries and coasts in NW Europe is explored, based upon experiences with a European co-operation project on Natura 2000 and based on a limited literature study. Management plans become more important, now the European Commission has accepted the list of designated sites for the Atlantic Region (EC, 2004). Based on the review of a number of aspects: conservation objectives, stakeholder consultation and management structure, some of the main experiences with the development of management plans are described. The focus of this paper is particularly on the organisational and managerial aspects of management plans. It does not aim to develop statements that can be generalised for a larger number of management plans, but instead intends to form an impression of relevant experiences in two EU countries, the UK and France, that early-on started with the development of management plans for large aquatic surfaces in terms of the Habitats Directive. A number of observations are described and recommendations for further discussion at European level are presented. Designation issues are not dealt with in-depth in this article, apart from their relevance in relation to the delay of the development of management plans.

Keywords: Habitats Directive; Birds Directive; Natura 2000; Management plans; Coastal zones; Estuaries; Paralia Nature.

Introduction: management plans for estuaries in development

The development of management plans for zones designated as SACs or SPAs under the Birds Directive 79/404 EEC (BD) and the Habitats Directive 92/43 EEC (HD) is not an obligation, but an option according to article 6.1 HD. However, in all larger estuaries in NWE management plans are considered as a solution for integrating various forms of use such as, fishery, maritime transport, agriculture and hunting. Further to this, the European Commission enhances the development of such a plan, when in particular, it includes co-operation of the different stakeholders. The El Teide Declaration of the European Union, made under the Spanish presidency, encourages the involvement of a broad range of stakeholders in the management of protected nature (EC, 2002b).

Management plans for safeguarding protected nature on land are not a new issue of course. However, the initiatives for the rather holistic management plans that aim to integrate management of fishery, port activities, agriculture and recreation with the protection of nature in large estuary systems are fairly unexplored and relatively new. Such management plans are complex, not only due to a broad range of actors that are involved, but also due to the uncertainty about the functioning of the aquatic eco-system, compared to land-based systems. Moreover, coastal zones and particularly estuaries are dense accumulations of intensive economic functions. Therefore, measures regulating and managing functions such as maritime transport and fisheries may be a painful matter for individual stakeholders, what makes stakeholder management a crucial but also difficult factor in the development of a management plan.

This article aims to review some of these developments in France and the UK.

From a series of European workshops on the different aspects of management plans, amongst others in the perspective of the Paralia Nature Project (Poykko *et al.*, 2005; Petersen and Neumann, 2004), the following elements of management plans come out as particularly relevant for their development:

Conservation objectives

The setting of conservation objectives is the first essential step for the development of a management plan. Much discussion is going on here currently in particularly in the Netherlands, Germany and France, as the European Court Decision on the Dutch Shell Fisheries (Case C 127/02) underlined the importance of conservation objectives as a criterion for determining significance of effects. This court decision further sharpened the criterion for conducting an appropriate assessment. Only when it is absolutely sure that there will be no significant effects whatsoever, an appropriate assessment does not need to be carried out – this will rarely be the case however–. Prior to the court decision the criterion for carrying out an appropriate assessment used to be the likeliness of significance effects.

According to the court decision, the conservation objectives should be the main reference points to judge whether an effect is significant or not. When a certain process or action affects a conservation objective of a site, the label 'significant' can be assigned. When the conservation objectives are not affected at all, and also the ecological requirements for a site are not affected, in such a case this effect can be considered as 'not significant'. This places conservation objectives at the centre of the appropriate assessment in terms of article 6.3 HD and makes them an important determinant of the content of a management plan. Although it is strictly not obligatory to set conservation objectives for a site, it is nearly impossible to develop efficient management measures for SACs and SPAs without proper conservation objectives. If they are lacking it is difficult to measure significance or to take proper protective measures as there is no clear reference point. If only the occurrence of certain species or habitats is used as a reference point, any effect will be significant and it will be also difficult to measure the effectiveness of protective measures. Conservation objectives thus are the starting point for the development of a management plan. This is even more so as they determine for a

large part the type of measures that are taken, for example recovery measures vs. conservation measures. Fig. 1 shows they are the central part of the planning operation.

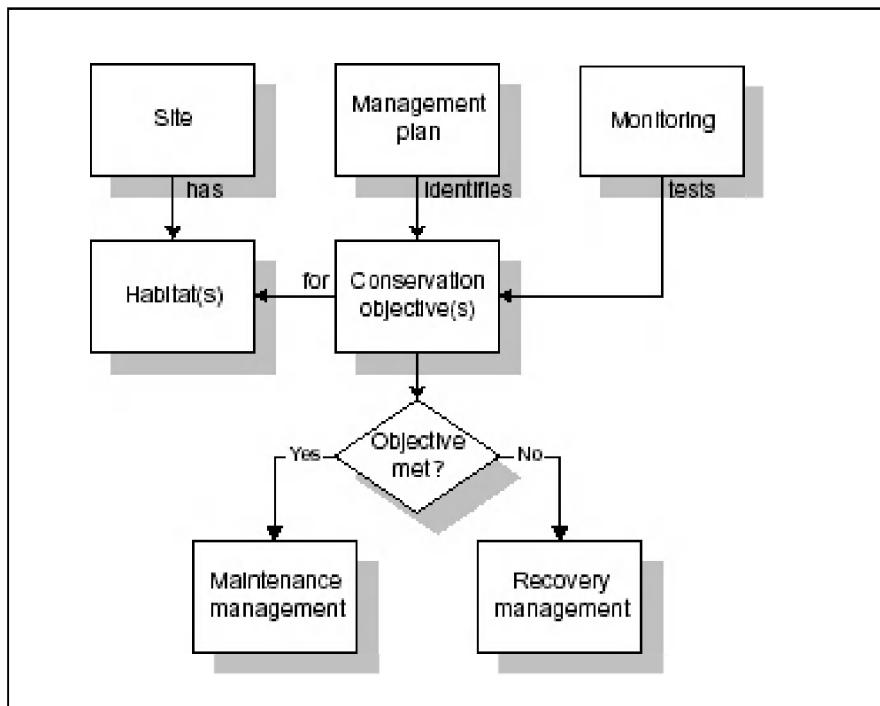


Fig. 1. Positioning conservation objectives (CCW, 2000).

Stakeholder consultation

One of the next great challenges in the development of a management plan is to have societal support and at least some consensus among the main stakeholders.

Although strictly spoken, the authorities would not have to consult all the stakeholders, keeping the group for stakeholder consultation limited may seem to speed up the process in the beginning but in the end means losing valuable time in legal procedures and delays to societal discussions in the implementation time of measures. This is a risky situation for restoration or infrastructure projects with tight planning as these may be delayed when certain measures cannot be implemented in time (Neumann and Woldendorp, 2003).

In order to prevent conflicts with stakeholders at a later stage it is very important to involve them at an early stage – the basic research and the setting of conservation objectives –. Even if some stakeholders may not agree at all with the management plan this is at least already known in advance, so attention can be paid to their positions and input. Experience European wide is that in any case, the introduction of a Management

Plan makes the issue of designation more tangible and practical, while a misunderstanding of the designation issue can greatly delay the development of management plans (see also Box 1).

Box 1. Designation discussions – a liability to development of projects and management plans but in another way than commonly thought... (a box that administrators should definitely read prior to taking decisions to dispute – or continue to dispute - designation)

Commonly thought is that designation would hinder the decision-making regarding port expansion projects, or other types of development projects, and that by designating an area, economic development projects would be slowed down. Such a perspective is seen in several Member States, where there are conflicts between the wishes of the Commission of which areas to designate and which not (European Commission, 12/1/2005).

The contrary however seems to be true: a simple first impression shows that in fact, by disputing designation administrations and decision-makers put a firm brake on any economic development; disputing designation costs years of extra discussion, running obsolete the implementation plans for any project.

Non-designation, while ecological values are in place stops or temporarily hinders much more projects for sure. This leads to long trajectories for litigation, whereby discussion on project interests and their limited time frame, are replaced by discussions on Member State interests and an unlimited time-frame.

A completely different perspective may be helpful in such discussions, namely to introduce a proper scenario of the consequences of non-designation, and to compare that with a scenario of the consequences of designation. The following list of consequences of non-designation may be helpful:

1. Any development project will be stopped or delayed, particularly in BD areas, due to EU court decision of 7 December 2000 Case 734/98: only nature protection can be a motivation for development projects in BD areas that should have been designated, but are unjustly not. In such case article 6 HD cannot apply so that economic grounds cannot be used to decide positively on a project.
2. Still having to carry out an appropriate assessment, even if the area is not designated: moving the border couple 100 of meters doesn't change procedural requirements; also external effects of activities in non-designated sites on designated sites need to be taken into account and can be the reasons for carrying out an appropriate assessment.
3. Lengthy litigation, year's long procedure holding up everything and disturbing development of societal support will start immediately. Factual information shows that when designation discussions are started between various public bodies, this can take for at least three years, which means three years delay for any project or activity planned that needs permission.
4. No management plan can be developed that would allow peaceful co-existence of economic and environmental restoration activities, that would may be solve lengthy discussions about the consequences of designation.
5. Risk of losing societal support for solutions found earlier. Particularly due to designation discussions, earlier found compromises may be rediscussed.
6. Capital loss due to standstill of project development, risk of projects coming too late to meet market demands. In case of disputing designation, business economic planning rhythms that motivate projects are replaced through governmental planning rhythms where political interests are at stake and not project interests.

Management structure

In an EU seminar held in 1996 (EUC, 1997) under the Irish Presidency – also referred to as the Galway seminar – a number of common elements were identified to be relevant as elements in a management plan:

- 1) a policy statement;
- 2) site description;
- 3) a statement of objectives;
- 4) a statement of constraints;
- 5) a list of actions to be implemented, including timing and financial planning;
- 6) a proper consultation process;
- 7) a system for monitoring and evaluation.

These elements were also described in the annex to the guidance manual on Article 6 of the Habitats Directive (European Commission, 2000).

The most common structure seen arising in the UK and France include the institution of a management group that takes decisions and agrees on the planning and selection of measures, upon the basis of conservation objectives set for a site.

The difference notably seems to be the way that there is control over the work of the management group by the competent authorities and the way that conservation objectives are set.

Exploration of two initiatives

From the perspective of the aforementioned three aspects: conservation objectives, stakeholder consultation and management structure, observations regarding the organisational and conceptual approaches towards management plans in the UK and France are discussed, and issues for further discussion at European level identified.

The UK and France are taken as examples as in several European workshops in perspective of the Paralia Nature project (Poykko *et al.*, 2005; Petersen, 2004), as well as from the EU interim report on the Habitats Directive (EUC, 2003) it seems that these Member States have started relatively early-on to systematically explore the development of Management Plans according to article 6.1 HD for large aquatic sites.

The development of management plans in the UK

As one of the Member States where the site protection of the Habitats Directive was early-on transposed into national regulation with the Conservation Regulations (also referred to as Habitats Regulations) in 1994, the UK also started early with the development plans for Estuaries with the Estuaries initiative in 1993 (Morris and Reach, 2005; English Nature, 1993).

Conservation objectives and ‘Regulation 33 Advice’

The conservation objectives for sites are described according to article number 33 of the Habitats regulation in a ‘Regulation 33 Advice’ from English Nature, the UK agency that is in charge of amongst others, advising other governmental agencies on nature protection issues. A ‘regulation 33 advice’ includes:

- a description of the site features, the protected values of the site for which it was designated;
- a description of the sub-features of the site;
- the conservation objectives for the site;
- advice how to maintain the favourable condition of the site.

Looking at how the conservation objectives emerge in practice, it can be noted that the kind of objectives formulated for estuaries in the UK are not so much of a quantitative nature but particularly qualitative: they focus on the kind of ecological value to conserve.

An example of a conservation objective for the Stour and Orwell estuaries (in South-West UK):

Subject to natural change, maintain in favourable condition the habitats for the internationally important populations of regulatory occurring Annex 1/ migratory bird species, under the Birds directive, in particular:

- intertidal mudflat;
- salt marsh (Stour and Orwell/Suffolk Coast and Heaths Unit, 2003).

These goals were set by the Management Group of the Estuary at local level, upon advice of the regulation 33 advice of English Nature (Reach, 2005), and also discussed with the Advisory Board, the two groups involved in the development of the Management Scheme.

Also most goals of other management plans for sites in development, *e.g.* the ones of the Twyni/Anglesey coast – a Dune site – or the Gower Commons – wet heaths – and others in development are mostly of a qualitative nature and focus on ‘reaching a favourable status of’ ... or on ‘conserving ...’.

In order to be able to evaluate, in regular management scheme reports, such goals are accompanied by a description of measures and in regular monitoring reports, the effects are evaluated. Although the objectives themselves are of a qualitative nature, their monitoring is particularly quantitative.

Management structure and stakeholder consultation

The regulatory basis for the Management Scheme itself can be found in the conservation regulations of 1994, article 33 up to 36. A Management Scheme in principle is voluntary; however the Secretary of State for Environment can ask to initiate the development of a management plan at sites where this was not done before.

The crucial function of the Management Plan (see also Fig. 2 – Morris and Reach, 2005) is carried out by the Management Group that consists of all authorities involved. This is the group that is responsible for the day-to-day-management and that also sets up the conservation objectives. The Management group is composed of:

- 1) Relevant Authorities (authorities exercising managerial, functional tasks in relation to the estuary);
- 2) Competent Authorities (authorities that have a legislative power, *i.e.* the granting of permits);
- 3) NGOs that have interests at the protected sites.

The stakeholders are all operating in the Management Group at the same level, they are not hierarchically organised. There also is the freedom to establish an advisory group, an even wider group of stakeholders that usually meets once yearly.

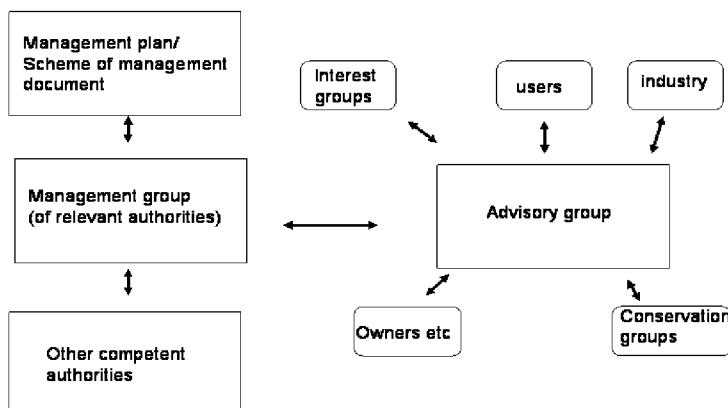


Fig. 2. Management plan structure (Morris and Reach, 2005).

A standard format for Management Plans in the UK and further work-out of the above structure is featured in the UK Marine SACs life project, ‘Living with the Sea’ (English Nature, 2003). This includes:

1. description of the site;
2. description of legal aspects of site protection;
3. an advice on measures with reference to regulation 33;
4. description of measures;
5. summary of on-going activities on the site (*i.e.* economic activities);

6. a summary of an action plan;
7. description of a scheme for monitoring and evaluation of regulatory compliance;
8. description of monitoring of compliance;
9. appendices:
 - list of relevant authorities
 - glossary
 - information on Bird Species

This standard format matches the format for management plans of the Galway seminar.

Morris and Reach (2005) evaluated some of the initial experiences with the management plans at UK marine sites. They come amongst others to the following conclusions:

- The Management Plan is working as a platform to discuss Natura 2000 management with the authorities and main stakeholders. According to Morris and Reach it has helped a great deal that one of the requirements within the Article 33 regulations for European Marine Sites was that there should be only one management plan for a site, also where overlap with other management plans exists. This has brought more uniformity in the management of areas.
- General organisational aspects of the plan can be crucial for implementing measures and for the actual success of the plan. These aspects relate to the fact that many of the management plan organisations consist of staff of other agencies. This brings management issues with such as *e.g.* often staff assigned to working on the management plan for part of the time, spend time working on other tasks of the mother organisation in the time originally planned for the management plan. In order to be a success for the kind of sites designated in the UK in any case at least one full-time staff needs to be appointed in order to be a success. If the plan only works by all staff working on it as an additional activity, the chance of succeeding is low. Even if there is one appointed staff member this is already quite limited.
- One item being particularly problematic has turned out to be the operation of management plans across administrative borders. Also the UK is organised into regions (Wales, Scotland, etc.), which have administrations of their own, that in the designation process did not always have the opportunity in time to coordinate their designation process due to differences in administrative cycles and planning. This may lead to difficulty where species or habitats run across borders and on the one side are more protected than on the other side.
- In some cases, there were discussions regarding the appropriateness of presumed cause-effect relations. Morris and Reach advise here that in such cases the competent authorities should take actions to firmly clarify such discussions.

One general experience that turned out to be very important for the flexibility of a management plan, is proper systems for an adaptive management, in case situations change, or initiatives are taken for development outside the ear that affect plans.

In order to improve the management of Marine sites, it is proposed by Morris and Reach to consider and possibly adapt current schemes, on the basis of past experiences and a more systematic review by a guidance development by IUCN (Pomeroy *et al.*, 2004). Over-all the progress of the action plans of some schemes is found to be slow. Management schemes are supposed to be reviewed each five years.

The development of management plans in France

In France, the Habitats Directive has been transposed through the ordinance ‘Natura 2000’, number 2001-321 (Official Bulletin of 14/04/2001). This ordinance is worked out in further detail by the interministerial memorandum – circulaire interministériel – of 3 May 2002, published on 26 September 2002 in the Official Bulletin of the Environment Ministry, No. 02/6.

Methodology for developing conservation objectives

Conservation objectives for Natura 2000 at the site level are set in the perspective of the ‘Document de Objectifs’, DOCOB – the conservation objectives document – (Senat, 2004). This approach has been developed since 2000, when France was awarded a LIFE-project on the improvement of management of natural sites (Jensen, 2003). In this project 37 Natura 2000 sites featured as pilot for the development of a management plan, based on the ideas regarding the establishment of a ‘conservation objectives document’ – Document de Objectifs – in the form of a contract between the central administration, the local authority and the relevant stakeholders and users of the site.

The composing elements of a DOCOB include:

- a diagnosis of the situation the site is in;
- a description of challenges, stakes and objectives;
- a plan of action.

The kind of conservation objectives in these DOCOBs resemble the ones in the UK in that they are mostly qualitative.

The difference is the way the objectives are defined: the conservation objectives are not advised by one authority, but instead are decided upon in discussion by the members of the steering committee, in the end with the approval of the prefect – who considers the compliance with Natura 2000 –. At the national level, the compliance of the collective DOCOBs and plans is overseen by a national ‘Natura 2000 Monitoring Committee’.

A good example of conservation objectives of a DOCOB are the ones worked for Port Cros, a small island in the South of France that knows hardly any development, where tourism and fishery is strictly regulated and motorised transportation is not allowed. One of the conservation objectives there is for example:

‘To conserve the herbier Posidonia and support its development’ (Jensen, 2003) or
‘To further study and control the presence of exotic species – e.g. the eucalyptus – on the island of Porquerolles (Parc National Port Cros, 2004)’.

These goals for Port Cros were set in the framework of the DOCOB, after deliberation with the main stakeholders of the ‘comité de pilotage’, also based on a prior diagnosis of the island, that is in a relatively good state but particularly suffering from the effects of tourism and recreational sailing as other parts of the coast in the South of France (Adreani, 2005). The goals are yearly monitored in a quantitative way and reported to the steering committee. The monitoring is carried out by staff of the site.

Management structure and stakeholder consultation

Main elements composing the managerial structure of the DOCOB are as follows:

- The central function exercised by the ‘Comité de Pilotage’ – the steering committee – that includes the relevant governmental and non-governmental stakeholders related to the site, including four groups:
 - 1)environmental NGOs;
 - 2)user and owners;
 - 3)representatives of the local administration;
 - 4)the prefect, as representative of the national government.

The steering committee is in charge of producing the state of the art of the site, describing the main challenges and proposing an action plan as well as providing a structure for its monitoring and evaluation. This committee also is conducting a regular progress report to the relevant authorities.

- The chairman of the steering committee is initially selected by the local authorities. Upon demand of the local authorities the state can also appoint the chairman of the steering committee. There was much discussion on this point. Upon proposition of the Senat, the prior proposal that left the choice of the chairman partly to the central government, was amended to let the authority for this choice lie at the local level, more in line with the policy to decentralise. Now it is up to the local level to choose a chairman for the steering committee or to ask the state to make this choice. The DOCOBs are meant to allow more freedom for the regional level, although there is still control exercised by the prefect.
- The third important element is the role of the prefect and the central state. Ultimately, the prefect has to approve and sign the DOCOB. Furthermore he is also responsible to check whether the measures taken in the DOCOB are sufficient to meet the Natura 2000 requirements. The DOCOBs are evaluated each six years by the prefect to check conformity with the directive. Also the prefect can take action if it is signalised that the measures implemented are not sufficient or that the situation of the site is deteriorating.

The plans are meant to be evaluated regularly, but at least each six years by the Prefect, who has to approve the evaluation report.

Initial experiences

The experiences so far with the development of DOCOBs have in any case been positive, in that fears of a designation to lead to a zone where no activity can take place at all are unfounded; the discussion about the different DOCOBs have led to a better understanding about designation at local level (Palos and Bertrand, 2004).

According to Palos and Bertrand, who carried out a preliminary assessment of the DOCOB and of water management plans in France, the DOCOB has structured the involvement of a broad range of stakeholders. A difficulty Palos and Bertrand found in the development of the DOCOB and the designation of sites is the countervailing interests of the 'ecological arena' of NGOs and the administration responsible for the environment on one hand and the 'rural and local groups' in charge of managing agriculture on the other hand.

In addition to the development of the DOCOB there was much discussion between the local and central administration regarding their roles in the steering committee. In the current structure, much authority is left to the local level. However, a strong role of the prefect remains, particularly regarding the control of compliance with European regulations.

In some conflicting cases the DOCOB according to Palos and Bertrand have however created much clarity about the meaning and practical implications of Natura 2000, easing some of the designation discussions.

An example of interest is the earlier mentioned management plan for the protection of Port Cros, a small SCI and SAC in front of the coast of Hyères in the south of France. Particularly the close co-operation of the different parties at Port Cros has led to better understanding among the different stakeholders, allowing even to take measures for some stakeholders to temporarily cease activities in number of areas. An interesting experience was that small scale companies fishing around the island, came over time to the insight that the regular closing of areas for all fisheries turned out to be beneficial for their harvest and its quality in the long run (Jensen, 2003).

There is still some way to go with the implementation of the DOCOBs as for many of the DOCOBs, an official approval has not been granted yet. The Prefect can only approve the DOCOB formally if the designation process has been completed. This administrative process sometimes delays the implementation of measures. Meanwhile however the initiatives for the DOCOB in the country, in particular also in the South and South-East have started extensive discussions on how to better regulate activities for tourism and industrial activities at protected sites.

Some illustrative examples of management plans in development and some relevant outcomes of the Paralia Workshops

Apart from activities in France and the UK, of course also efforts are on-going in other Member States. One of particular interest is PROSES 2010. This is an initiative carried out by an organisation especially created by two Member States, the Netherlands and

Belgium/Flanders, for a special purpose. With PROSES the first steps have been made to develop a common managerial approach towards the Scheldt Estuary shared between the Netherlands and Flanders. The initiative for this plan is now being worked out further and waiting on the setting of conservation objectives, that will be set at each side individually, also because the designations have been a Member State issue on both sides. At the Dutch side the conservation objectives will be set by the Ministry of Agriculture, at the Flemish side by the Nature Protection Department of the Ministry of the Flemish Community.

The PROSES approach (PROSES, 2005) right away shows what may be a difficulty for other Management Plans in border areas as well: the co-ordination of the protection of sites in border zones where the same species and habitats are protected, while there are different protection regimes, due to Member State individual characteristics. The way the EU functions in this case is that the Member State is the designating entity, so that it can happen that in border zones, different goals, borders, measures are set, even when they concern the same biological biotope. Such situations are not always beneficial for Natura 2000 that notably has a goal to ensure a European system and tight network for the protection of Nature.

Informally, at Paralia Workshops the European Commission has mentioned that it is up to the Member States to initiate co-operation in such cases. In the case of Flanders and the Netherlands this has worked quite well with PROSES. Both sides are very satisfied with it. There may also be cases, where this has worked less well, or where one Member State does not agree with another one on the goals or measures to protect species. In such cases, there are no or only formal instruments for an individual Member State to take action, other than informal initiatives. In case one Member State would wait too long to take action, creating a disadvantage for a protected site in a Member State that has reacted faster, there are little instruments available for the latter to make the first take action. This issue, also recognized by Morris and Reach, would be useful to discuss further on some of the EU expert groups, e.g. the one on conservation objectives. That would be increasingly relevant, as many of the countries in NWE and also the new Member States are currently setting up their structures and debating on measures for Natura 2000 sites, and there are many bordering sites.

One other issue which turned to be relevant from the various Paralia Workshops is the issue of stakeholder involvement and management. In projects, where this is done badly, or in a very limited way, in the end there are many formal procedures and much litigation as parties not involved turn to more formal modes of interaction. In projects, where much attention is given to stakeholder management, of course still also legal procedures can arise, but the chance is minimised and usually any procedural damage is repairable.

Conclusions and recommendations

This limited review shows that considerable development both in France and the UK has taken place regarding the development of management plans focussed on integrating

nature protection and the management of other activities as *e.g.* maritime transport and fisheries. From this review the following can be concluded:

- In all developments stakeholder willingness and their early involvement and an early setting of conservation objectives are essential in coming to management plans. From the UK experience amongst others it has showed that one relatively simple element is very important: having fixed staff working full time is a must for a truly operating management plan. Furthermore, the UK experience shows it is useful for Marine sites to start from the principle that there is only one management plan for a site.
- The French experience shows that instituting a contractual system is very useful in order to shed the light on what designation exactly means for the stakeholders involved. This can be particularly helpful in cases where designation is not properly understood or in cases where it is thought that designation means standstill.
- For both the UK and France it shows that the structural development of management plans for Natura 2000 sites is very useful in order to be able to create structure to efficiently manage and take decisions regarding the sites and involve stakeholders. Without the presence of the differently created advisory and working groups, the involvement of for example NGOs and other groups would need each time the creation of temporary structures in case conflicts or discussions arise. In case well worked out Management Plans are not present, local and national administrations would continuously run from one to other incident while the presence of a Management Plan systemises the information queries and stakeholder management necessary for running the proper and efficient procedures and societal processes.
- Over-all looking at how Management Plans are discussed in literature and documentation, so far it seems little attention has been given to actual organisational aspects and processes – in contrast to the legal aspects –, while that is just what keeps the schemes running. It seems this aspect deserves more attention as also mentioned by the European Commission in her progress report on the implementation of the BD and HD (EUC, 2003). Particularly such attention could be also very beneficial to learn from for New Member States, who in some cases, are in the process of designating considerable marine sites? *e.g* Poland (EC, 2003). Also some of the existing Member States as Portugal, Spain, Greece and Finland have designated considerable Marine Sites and could perhaps learn from the long-term experiences in the UK and France. Particularly for the new states such learning is useful, as they are suffering from drawbacks due to the large capacity that is required to adapt to all new EU legislation. Knowing more about how to efficiently set up management plans could help them greatly in the management of these sites and also limit the number of infringement procedures.
- A topic very relevant for the New Members states – as well as for the old ones – is the issue of cross-border management of coastal zone sites. This is a question playing in fact at two levels: between Member States, but also between regions or states within federally organised states – where the designation process is done by regional governments –. A better mechanism should be found for such cases, as their frequency will increase with the new states that have joined. The case of the Scheldt River is

definitely not unique in this case, as there are also other estuaries that are divided by bordering states. For example the Oder River that separates Germany and Poland, with the port of Szczecin on one side. Also here the issue of cross-border management of sites becomes important (Bundesministerium für Bildung und Wissenschaft, 2005). All Member States and regions dealing with this issue could benefit from the identification of a mechanism or guidance – or even prototype example – of how to proceed in such cases in an efficient way.

Finally, regarding the concept of Natura 2000, one can wonder whether the adjective ‘2000’ is still applicable. Maybe European institutions and actors/stakeholders should think also of a Natura 2010 or 2020 – particularly considering some states only became member after 2000?

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Maintenance of the favourable conservation status in two Special Protection Areas in co-habitation with development of the Antwerp harbour

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Abstract

The growing Antwerp harbour on the left bank of the River Schelde has a considerable overlap with designated Birds and Habitats Directive areas (SPA and SAC). Harbour development projects threaten the favourable conservation status of the protected habitats and species. On the other hand the international conservation commitment hampers the harbour development. ‘Co-habitation’, the aim of the Flemish Government to maintain a balance between industrial and ecological needs is a key word in the present-day management of the region. The Deurganckdock case exemplifies possible problems and solutions for Natura 2000 in harbour development areas. Compliance with article 6 of the Habitats directive is the most complex issue. In this case it failed with respect to the assessment of adverse effects and several aspects of the compensation policy. Well defined conservation objectives and performance criteria are essential to the process and should be defined as soon as possible for any Natura 2000 site. Habitat creation/development as compensatory measure should start prior to and not simultaneously or after habitat destruction. Temporary compensations are no sustainable solutions and are only acceptable when an existing habitat is involved; temporary habitat creation is both an economic and ecological loss. Monitoring Natura 2000 sites is essential to successful adaptive management and the maintenance of a favourable conservation status, especially in highly dynamic areas such as harbour development areas.

Keywords: Natura 2000; Favourable conservation status; Harbour development; Co-habitation; Compensation.

Introduction

The growing Antwerp harbour on the left bank of the River Schelde has a considerable overlap with the Birds and Habitats Directive areas ‘Schorren en polders van de Beneden-Schelde’(SPA) and ‘Schelde- en Durme estuarium van de Nederlandse grens tot Gent’ (SAC). Harbour development projects are continuously potential threats to the favourable conservation status of the protected habitats and species. On the other hand the international conservation commitment laid on these sites hampers the economic

expansion of the harbour. A key word in the management of this region is 'co-habitation', the aim of the Flemish Government to maintain a balance between both industrial and ecological needs.

With the construction of the Deurganckdock the reciprocal pressure led to a conflict situation. Construction works had to be interrupted following a complaint from the EC because Article 6 of the Habitats directive was not well complied with. The EC commented that the alternative selection was erroneously guided by economic motives rather than Natura 2000 values, that the overriding public interest was not convincing, that compensation measures should be a very last resort, like for like and effective prior to habitat destruction. The principal complaints were the lack of a proper assessment of the adverse effects on the protected habitats and species with specific reference to conservation goals and objectives, including cumulative effects with previous developments and of a well substantiated 'like for like' nature compensation plan, integrated in the cost-benefit analysis and time-table of the construction project.

In response a new environmental impact assessment (EIA Linkerscheldeoever – Deurganckdock 2001) was compiled, taking into account cumulative effects with previous projects. It includes a substantiated compensation plan which is linked in time to the Deurganckdock construction works: each compensation measure is linked to a specified aspect of the Deurganckdock works in a 'compensation matrix'. In the absence of specific conservation objectives, every adverse effect was considered as significant and was to be compensated for.

The compensation matrix is an important tool for the management committee which was installed to coordinate and control the nature compensation works and to report on its progress to the EC. Parallel to the planning and development process, a long-term monitoring program is set up to evaluate the effectiveness of the compensation measures and the evolution of the conservation status of the special protection areas in the harbour. The monitoring results are an input for the management committee's annual report to the EC and are an important aid for the adaptive management of the area.

The Compensation Matrix

The completion and exploitation of the Deurganckdock are linked to the realisation of specified compensation measures. The Compensation Matrix (Table I) contains all the information needed for the planning of the process. In the EIA the loss of each habitat type and the need for compensation were quantified; potential zones for compensation were proposed. The matrix contains information on the required habitat types, the surface area needed, potential localities for their creation, the Deurganckdock construction permit it is linked to and the responsible authorities for implementation and financing. In chronological order four different tasks are determined: acquisition of land, acquiring permits, development of the habitats and conservation of the area. The principle of contemporaneity prevails: Deurganckdock construction permits can only be granted if the works for the corresponding compensation measures are started simultaneously with the start of the works granted by the corresponding construction permit. Simultaneously with the loss of a habitat type, creation of the same type has to

start in a compensation zone. The matrix makes a distinction between permanent and temporary compensation zones. Temporary compensation zones are undeveloped areas with a future economic destination. They can develop into specific habitat types until they will be claimed for harbour development, whereupon another nature compensation zone will have to be developed in exchange.

Table I. Simplified version of the Compensation Matrix for the Deurganckdock

Habitat type	Surface needed (ha)	No. of potential zones	Total surface of potential zones (ha)	Type of compensation (ha)
Bare sandplanes with water	200	3	204	temporary
Reedland and water	25	2	27.8	17.8 temporary 10 permanent
Tidal mudflats and marshes, shallow water	25	2	50.5	permanent
Meadows	250	3	273	221 permanent 52 temporary
Deep water with natural shores	35	2	116.7	80 temporary 36.7 permanent
Polder with high ecological value	45	large perimeter	undet.	temporary

A specific section of the Matrix (Table II) deals with historical, uncompensated habitat losses due to harbour development activities (phase I of the Verrebroekdok). For ‘reedland and water’ existing habitat within the perimeter of the harbour was permanently changed from industrial area to nature reserve. ‘Mudflats, tidal marshes and shallow water’ will be realised in the polders of Kruibeke-Bazel-Rupelmonde, where 50% of Flanders biggest flood control area will be subjected to a controlled and reduced tidal regime.

Table II. Simplified version of the Compensation Matrix for historical losses

Habitat type	No. of potential zones	Total surface of potential zones (ha)	Type of compensation (ha)
Reedland and water	2	101.5 + 82.4	permanent
Tidal mudflats and marshes, shallow water	1	300	permanent

Conservation goals and objectives

Quantified and well defined conservation goals for species and habitats, in accordance with the Habitats Directive art. 6(1), are an essential asset to good management and land use planning in Natura 2000 sites, especially in very dynamically evolving environments like the Antwerp harbour region, where several actors (harbour authorities, industry, agriculture, nature, ...) claim the land. Such objectives did not exist for the study area and were recently set. In a study by the University of Antwerp, commissioned by the Administration for Nature of the Flemish government (AMINAL, section Nature) (Van Hove *et al.*, 2004) conservation goals for the Birds and Habitats Directive were integrated for the port of Antwerp and defined in terms of required surface area for each type of habitat.

A list of bird species of special interest was set, following several criteria such as Annex I of the Birds Directive, the Ramsar international 1% standard for migrating water birds, the Flemish Red list for breeding birds and the 5% level of the Flemish breeding population. For each species of special interest the minimum required population size was set. In combination with the species' habitat needs and its population densities in the specific habitat types these target numbers were translated into target surface areas of different habitat types. These were integrated with the habitat conservation objectives for the Habitats Directive.

Theoretically a minimum required population should be based upon a minimum viable population size, calculated from a population ecological approach, but for most species good knowledge on life history parameters is lacking. Moreover local populations should be considered as a functional part of the metapopulation and do not always need to be sustainable by themselves. As an alternative strategy minimum required populations were calculated based on historical time series for the region.

For waterbirds a systematic counting program existed, but for breeding birds no systematic long-term monitoring program has been run in the past. Only data from volunteers were available. The quality of such information can differ much from region to region, depending on the local observers. Sometimes very good and detailed information is gathered, but in other cases time series are more or less biased by the observers interest, focussing on rarer species or areas with high densities. Nevertheless

this type of information is of crucial importance as a guideline for expert judgement if interpreted with caution. International literature was a first input for the translation of bird number into habitat surface areas. However, this is not always the most appropriate method because of the high regional variability in specific bird densities and the influence of habitat quality and characteristics. Field data from comparable nearby regions are an important additional input source. Since the monitoring program of the Antwerp left bank harbour region had been started in the meantime, the present field data could be used for comparison.

As a next step the conservation objectives for the different habitat types serve as an input to design different scenarios for Natura 2000 in the regional planning.

Monitoring

At the end of 2002 a systematic monitoring program for compensation works on the Antwerp left bank harbour region was started by the Institute of Nature Conservation, commissioned by the Flemish government (AMINAL, section Nature). The main goal of this monitoring program is to gather data to evaluate the effectiveness of the compensation measures for the Deurganckdock and the general management of the Natura 2000 network in the harbour. The program includes census of breeding, migrating and wintering birds of special interest, according to the criteria which were set in the conservation objectives, availability and quality of habitat types of special interest and hydrology of the region. In addition, some other animal groups are monitored for their indicator value (specific insect groups) or because they are listed as Annex IV species in the Habitats directive (Natterjack toad and bats).

The ultimate goal is to get a complete picture on the evolution of the conservation status of the special protection areas. With the monitoring results deviations from the conservation objectives can become apparent and the management can be adjusted accordingly. It can also reveal slow but steady and continuous deteriorations of the SPA, e.g. due to changing agricultural practices.

Another important advantage of the monitoring program is the generation of data, needed for environmental impact assessments and/or appropriate assessments in compliance with article 6(3) of the Habitats directive for infrastructure projects and changes in land use.

Assessments of the favourable conservation status, the impact of harbour development projects and the mitigating effects of compensation measures can only be reliable if they were based on long enough time series, hence the importance of long term monitoring programs.

The Institute of Nature conservation, is responsible for the monitoring program, but it works as much as possible in cooperation with the local nature conservation association 'Natuurpunt WAL'. Monitoring is very time consuming, all extra information from volunteers can be very helpful and essential to appropriate evaluation. Moreover volunteers are very familiar with the area, have profound knowledge of its history and

are very motivated. On the other hand they often don't use standardised methods or lack the time or scientific background. Good cooperation and agreements between professionals and volunteers are very important to optimise the quality and comparability of the results. In this monitoring plan all inland waterbird counts are organised by the volunteers while they only participate for a small part in the breeding bird census as this is far more time consuming. Additionally volunteer involvement is an important asset to the societal base for nature conservation policies .

Results and discussion

The first year's results (2003) revealed a problematic situation for breeding birds which rely on one of the three specified habitat types: bare sandplanes with water, meadows in the polder with high ecological value and deep water with natural shores (*cf.* Table I) (Spanoghe *et al.*, 2003). The breeding numbers for almost all of these species were below the stated target numbers in the conservation objectives (*cf.* Table III). Species like Avocet, Redshank, Black-tailed Godwit, plovers and Shoveler revealed the greatest decline in comparison to previously known records. This was clearly related to substantial losses of these habitats in the developing zone. In 2003 these species could not settle in permanent compensation zones; these were still under planning or construction. In the meantime there was a gap in the habitat balance and consequently breeding bird numbers decreased. The necessary works were started in accordance with the compensation matrix, but as long as they have not been finished the habitat needs will not be fulfilled. Moreover the development to full functional habitat can take several years. The simultaneous creation of habitats parallel to the infrastructure works will always cause a dip in the populations for a number of years. Therefore compensation measures should be taken in advance. This proactive way of working is now embedded in the future strategic planning process for the Antwerp harbour, when conservation objectives will be translated into spatial scenarios.

The importance of the temporary compensation zones in the study area was dual. Temporary compensation zones that already existed as appropriate habitat, accommodating already important numbers of breeding birds and where only some management actions such as reduction of accessibility were needed, were successful. However, temporary compensation zones where the appropriate habitat type was still to be created were generally unsuccessful. The habitats were not yet functional and did not meet the required quality, or development works were simply not finished, due to time loss for the finalisation of the development plans and the acquisition of legal permits. In general habitat creation for temporary compensation is probably not very cost-effective because the habitats will hardly be fully functional before they will be destroyed to fill in their final destination (Fig. 1).



Fig. 1. Left: Target habitat type wet meadows (photo F. Piesschaert). Right: Farmland that has to be converted into wet meadow by excavation. According to the matrix this compensation measure is temporary, since the area is foreseen for further harbour expansion.

Table III. Numbers of some breeding birds in the SPA Left bank compared to the Conservation Objectives (Van Hove *et al.*, 2004)

Habitat type	Conservation objectives (Van Hove <i>et al.</i> , 2004)	2001	2003
Black-tailed Godwit	80-100	84	32-39
Redshank	100-130	138	58-59
Avocet	350-450	447	70-100
Shoveler	100	109	App. 31
Little Ringed Plover	50-60	45	13
Ringed Plover	4-5	5	1

Conclusions

Conservation objectives for species and habitats of special interest are essential assets to the maintenance of the favourable conservation status of Natura 2000 sites. They should be considered in the process of regional planning and land use.

Compensatory habitat should be created and be functional prior to and not simultaneously with habitat destruction.

Temporary habitat compensation is not sustainable and should be avoided.

To avoid unnecessary delays the necessity of compensation projects and their planning should be included in the planning process, the environmental impact assessment and cost-benefit analysis of the development projects.

Long term monitoring results are essential to set conservation objectives, to assess the favourable state of conservation of the site, to evaluate its management, for appropriate

assessments of planned projects, to plan compensation measures if necessary and to evaluate their effectiveness. For optimisation monitoring programs should as much as possible be set up as a cooperation between professionals and volunteers.

Acknowledgements

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Tidal wetland restoration at Ketenisse polder (Schelde Estuary, Belgium): developments in the first year

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Abstract

Ketenisse polder is a former intertidal brackish marsh (30ha) situated in the mesohaline part of the Schelde Estuary. In the 19th century its central part was embanked as a polder. In the mid 1980's the area was raised above intertidal level when it was used as a dumping site for the excavated soil from the Liefkenshoek tunnel. In 2002 the area was restored, it was levelled with a weak slope below mean high water level, creating the optimal starting conditions for the development of intertidal mudflats and marshes. Geomorphological changes, sediment characteristics and colonisation by phytobenthos, vegetation, zoobenthos, water birds and breeding birds at the restored site are monitored. The monitoring results of the first year after tidal restoration are presented. Sedimentation as well as erosion between 0 and 30cm was observed in the first year. Local changes in stream current patterns caused erosion on parts of the former mudflats; sheltered depressions filled up relatively fast. Median grain size showed large variation. Organic carbon content of the sediment varied between 0.5 and 15% and was closely related to sediment medium grain size. Chlorophyll a concentrations were negatively correlated with median grain size and tended to increase from the low water line to the shore. They were comparable to nearby intertidal areas and displayed similar seasonal variability with a maximum in spring. The large surface covered with *Vaucheria* was indicator of initiated succession towards tidal marsh. *Scirpus maritimus* and transitional vegetations to *Chenopodiaceae*-vegetations established with increasing altitude. The *Chenopodiaceae*-vegetations were relicts of earlier vegetations before the tidal restoration, and will probably disappear. The macrobenthos community was dominated by Oligochaetes, which were present in 73% of all samples and attained an average density of about $40 \cdot 10^3$ ind. m⁻². Other macrobenthos species found were nematods, copepods and Corophium. On the sheltered sampling stations macrobenthic densities were high compared to those on nearby intertidal areas. In the first season, 15 breeding bird species were recorded, the most common species being the Pied Avocet (*Recurvirostra avosetta*). The most common waterbirds were Common Shelduck (*Tadorna tadorna*), Greylag Goose (*Anser anser*), Pied Avocet (*Recurvirostra avosetta*) and Lapwing (*Vanellus vanellus*), typical species for the mesohaline part of the estuary.

The first year's results suggest that Ketenisse polder has the potential to develop towards a varied and normal functional intertidal area.

Keywords: Tidal wetland restoration; Ketenisse polder; Monitoring results; Schelde Estuary; Belgium.

Introduction

Reclamation of intertidal habitat has been a major feature of coastal management for the past 500 years. Growing awareness of the ecological and economic damage caused by this large scale habitat destruction and the general concern about possible consequences of sea level rise have led to the recognition of the need to alleviate some of this damage. The concept of habitat creation and restoration was conceived in the USA some decades ago. More recently it was also adopted in the other continents. Initially the main incentive for tidal wetland restoration was compensation for habitat loss elsewhere. However, with the growing appreciation of tidal wetland functions, new imperatives have developed with a wider range of objectives, including coastal defence, flood alleviation, water quality improvement, fisheries production, groundwater recharge and tourism and recreation. Due to the relatively recent interest in habitat creation, few evaluations have been made of the long-term outcome of schemes, particularly with regard to the ecological value of the newly created habitat.

Tidal restoration is a radical estuarine restoration measure; prior to large-scale execution its effects should be estimated within an acceptable range of accuracy. Multidisciplinary monitoring of small scale projects can help to identify key forcing factors and to infer general patterns in processes after tidal restoration. In this paper the first year monitoring results of a 30ha tidal restoration project are presented.

The study area

Ketenisse polder is a former intertidal brackish marsh (30ha) situated in the mesohaline (3g Chl.l^{-1}) part of the Schelde Estuary. Mean tidal amplitude in this part of the estuary is about 5.1m, between 0.04 and 5.14 mTAW (Belgian ordnance level). The site borders a bend in the river and has the shape of a boomerang. In the 19th century its central part was embanked as a polder. In the mid 1980's the area around this central polder was raised above intertidal level when it was used as a dumping site for the excavated soil from the Liefkenshoek tunnel. The marsh was restored in 2002 as compensation for the construction of the North Sea container terminal on an intertidal mudflat near an internationally protected site (Ramsar, Birds and Habitats directive). The plan was to remove the rubble of the summer dike and the dumped material and to level the area with a weak slope below mean high water level, creating the optimal starting conditions for new intertidal mudflats and marshes. However, removed soil was to be used for dike construction works and only suitable construction material was taken and the dike was not completely smoothed. As a result the starting slope and level in the tidal frame differed along the site, leaving supratidal vegetated parts, lower bare mud and a rather steep slope along the summer dike remnants (Fig. 1; Table I). For safety reasons the most upstream part near the Liefkenshoektunnel (LHT) was left at its supratidal level.

Sections a, b, c and g were levelled according to the plan except for some hard exposed peat layers, which also created a differentiated resistance to wave action along the slope. The central polder (section d) was left at its original level, almost 1m below MHW; the summer dike around it was only partly removed and breached, leaving a relatively sheltered intertidal area. Its upstream part contained some pipelines and was defended by surrounding dikes (Fig. 1; polder). Section e, the widest part, was levelled to almost 0.5m below MHW; a greater part of section f, remained untouched and supratidal.

Geomorphological changes, sediment characteristics and colonisation by phytobenthos, vegetation, zoobenthos, water birds and breeding birds at the restored site are monitored in a multidisciplinary project. Monitoring of all aspects is done near 20 sampling stations along 6 transects perpendicular to the shoreline (Fig. 1a: in a given transect sampling station numbers increase from the dike towards the river). These stations were established and referenced gradually as the works proceeded in a downstream-upstream-direction (Table I). For the bird counts the area was divided in sections around these transects (Fig. 1b). The first year's results are summarised in Table I.

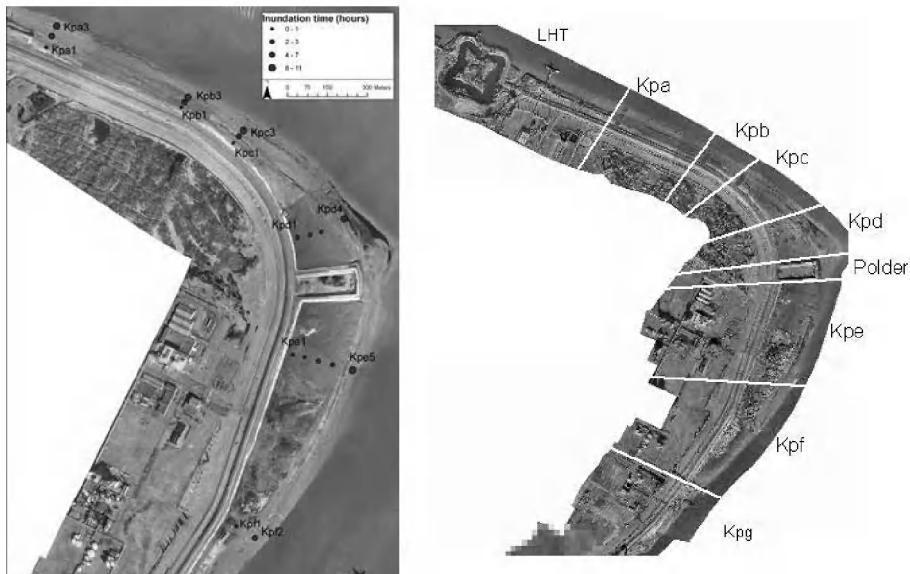


Table I. Abiotic and biotic characterization of the sampling stations (2002-2003): date of completion, initial altitude, net sedimentation/erosion, 25 and 75% medium grain size (MGS), 25 and 75% organic matter % of sediment (OM%), chlorophyll a mean annual and maximum concentrations (g/g dry weight). Vegetation type: (1) Pioneer vegetation of *Enteromorpha* sp., (2) Pioneer vegetation of *Vaucheria* sp.-*Enteromorpha* sp., (3) Pioneer vegetation of *Vaucheria* sp., (4) *Vaucheria-Sciurus maritimus* vegetation (5), *Phragmites australis* vegetation, / no vegetation, ? unknown vegetation; total number of benthic organisms in samples and Oligochaeta densities (ind.m⁻²; 2002 and 2003)

Com pletion dates	Altitude (mTAW)	Inun- dation time	Net sed/eros (cm)	MGS (um) (25%-75%)	% OM (25%-75%)	Chla (μ g.gDW ⁻¹) Mean (Max)	Vegeta- tion types Aug(2003)	Benthos Oct2002 #spec	Benthos Oct2003 #spec	Oligochaeta Oct2002 ind.m ⁻²	Oligochaeta Oct2003 ind.m ⁻²	
Kpal	June 02	5.07	1	-15.82	190 - 272	0.86 - 1.50	1.71 (4.49)	2	13	23	981	17,658
Kp2	June 02	2.51	6	1	32 - 60	2.65 - 5.30	16.61 (98.86)	/	149	134	418.887	299,205
Kp3	June 02	0.52	11	12.46	37 - 51	4.16 - 6.66	8.08 (19.09)	/	19	11	62,784	54,936
KPb1	Aug 02	4.90	1	-0.9	166 - 281	0.99 - 1.90	3.48 (12.74)	?	1	79	6,867	981
KPb2	Aug 02	3.40	5	-31.53	63 - 206	1.02 - 3.19	5.20 (19.91)	3	2	139	6,867	11,722
KPb3	Aug 02	1.32	9	7.37	56 - 220	2.14 - 2.84	6.41 (22.16)	/	37	19	202,086	56,898
KPc1	Aug 02	5.15	0	13.28	168 - 246	1.17 - 1.86	5.91 (12.22)	1	0	58	3,924	981
KPc2	Aug 02	2.92	6	-15.73	191 - 279	0.95 - 1.50	2.47 (4.19)	3	3	8	1,962	0
KPc3	Aug 02	1.31	9	-2.85	25 - 38	7.40 - 9.50	5.76 (17.72)	/	2	12	2,943	30,411
KPd1	June 02	?	2	33.95	16 - 25	8.91 - 12.65	34.81 (93.85)	/	177	239	235,440	513,063
KPd2	June 02	4.59	3	0.35	38 - 54	4.01 - 6.17	13.72 (30.23)	3	214	306	186,390	134,397
KPd3	June 02	4.30	3	20.11	36 - 62	3.97 - 6.23	16.03 (41.48)	3	138	132	118,701	537,588
KPd4	June 02	1.72	9	-10.9	25 - 45	7.37 - 10.58	6.25 (17.94)	/	0	5	1,962	10,791
KPe1	Nov 02	5.40	0	-1.52	117 - 131	1.81 - 2.39	6.75 (15.04)	4		2		3,924
KPe2	Nov 02	4.94	1	3.19	40 - 71	2.95 - 6.00	19.64 (55.76)	3		28		44,145
KPe3	Nov 02	4.52	2	19.23	27 - 52	4.88 - 6.25	24.71 (57.91)	3		93		324,711
KPe4	Nov 02	4.60	2	11	38 - 54	3.31 - 5.80	9.25 (19.29)	/		64		239,364
KPe5	Nov 02	0.60	11	-17.65	57 - 105	2.78 - 5.15	2.95 (13.51)	/		0		0
KPf1	Jan 03	5.42	0	0	19 - 30	10.78 - 13.11	12.87 (27.50)	5		23		11,772
KPf2	Jan 03	2.22	7	-10.62	40 - 69	3.60 - 6.29	8.54 (10.07)	/		6		6,867

Geomorphological changes

When the works where finished (January 2003) a topographic levee of the situation at that moment was made by means of a total station, with a cover of 12 points per hectare. Full topographic levees by means of aerial photography and laser altimetry were taken after 8 months and 11 months. Elevation changes along transects were monitored with seasonal topographic levees every 10m. At each sampling station sedimentation-erosion was measured every fortnight in sedimentation-erosion plots. In each plot three level metal tubes are anchored in the mudflat in an equilateral triangle of 1.5m. The tubes are connected by a measuring rule and the distance between the rule and the mudflat is measured every 20cm.

Sedimentation-erosion processes

The combination of the shape index, the presence of peat layers and the very varied topography of the site along its length resulted in varied exposure and resistance to wave action (tidal, wind and from ships) across the site and consequently in very local specific sedimentation-erosion processes. Net sedimentation and erosion both varied between 0 and 30cm in the first year after restoration; both processes were also observed along each transect. Minimal changes were noticed at the supratidal stations Kpf1 and Kpe1. The more exposed intertidal stations clearly eroded (Kpa1, Kpb2, Kpc2, Kpd4 and Kpe5). The lower and sheltered stations (Kpd1-3 and Kpe2-4) showed a clear net sedimentation; at these stations some depressions filled up relatively quickly. Sedimentation and erosion generally occurred gradually, however some ‘sudden’ net erosion of more than 10cm between two consecutive measurements was observed in the very low and exposed sampling stations.

Topographical changes

The onset for a creek network system established relatively quickly in the wider and sheltered d and e sections where sedimentation was observed. Once established the main channels did not alter their position very much but the sinuosity seemed to increase very gradually. This process, together with the formation of smaller channels and the transition from sedimentation to erosion channels will eventually become apparent in the coming years as they were observed by French (1996) in some UK abandoned reclamations and in several US tidal wetland restoration projects (van Oevelen *et al.*, 2000).

Due to the levelling of the site stream current patterns along the area changed. As a result Kpd4 and Kpe5, sampling stations on previously rather stable mudflats started to erode.

In the more upstream g section a steep cliff, with a height between 0.3 and 1.5m developed over a length of 100m. In less than 6 months it eroded up to 2m landwards.

Sediment characteristics

Sediment cores (diameter 2cm) were taken monthly at each station. Three replicate samples were taken from the top cm and one from the top ten centimetres. Sediment composition was analysed with laser diffraction in a Malvern Mastersizer.

The more sheltered stations along the d and e transects with the highest net sedimentation rates were also the muddiest, with a lower median grain size (MGS). At the f stations, which were not levelled merely because of the high mud content, MGS was also relatively low. The erosive sampling stations were generally sandier. Along the more narrow upstream part (sections a-c) MGS increases with elevation.

Sediment composition along the b-transect showed large variations, changing from fine to rather sandy sediments in a few weeks time. These changes were probably related to occasional dredging activities on the nearby ‘plaat van Lillo’.

A close relationship was found between MGS and organic matter content of the sediment ($\%OM = 108.89MGS^{-0.8081}$; $R^2 = 0.8398$). No relationship was found between mean %OM and net sedimentation/erosion over the first year.

Microphytobenthos

Microphytobenthos on the Ketenisse mudflat was monitored monthly in 2003 by quantifying chlorophyll a concentrations in the upper cm of the sediment. Sediment samples were freeze-dried and pigments were extracted by sonication in 90% acetone. Chlorophyll a was measured fluorometrically according to Welschmeyer (1994). Chlorophyll a concentrations varied between 0.3 and 118 $\mu\text{g.g}$ sediment dry weight $^{-1}$ with the highest values found on sections d and e. They were comparable concentrations found on Groot Buitenschoor, a mudflat situated nearby (M. Lionard, unpublished data). Chlorophyll a concentration generally peaked in the period March to July. This is in agreement with previous studies in the Schelde Estuary (De Jong and De Jonge, 1995). The timing of the chlorophyll maximum varied between sampling stations.

As often observed in estuarine mudflats (*e.g.* Lucas and Holligan, 1999), chlorophyll a concentration increased with decreasing sediment MGS. Chlorophyll a concentration also increased with intertidal elevation. In turbid conditions sediments higher in the tidal frame have a shorter submersion period and therefore have higher temperatures, are subjected to a lesser degree to hydrodynamic disturbance and receive on average more light (Fig. 2). Although transects e and f were only levelled between November 2002 and January 2003, chlorophyll a concentrations were not significantly lower than in the other transects. This indicates that microphytobenthos populations can rapidly colonize newly constructed mudflats.

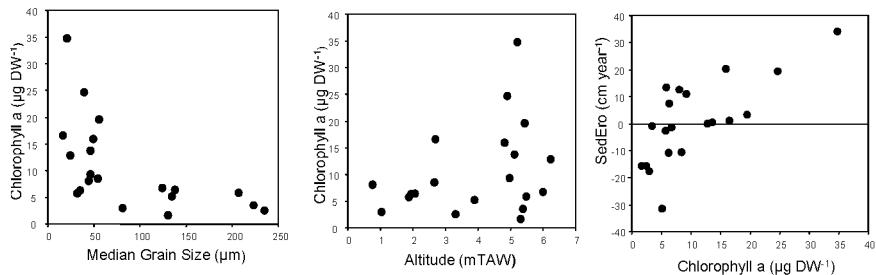


Fig. 2. Relation between annual average chlorophyll a concentration and sediment median grain size, position above mean low water level and net sedimentation-erosion rates in 2003.

Microphytobenthos is known to play an important role in the stabilisation of intertidal sediments (review in Stal, 2003). A close relationship was found between chlorophyll a concentrations and sedimentation-erosion rates (Fig. 2). Chlorophyll a concentration might therefore be a potential indicator for sedimentation and erosion in newly created marshes.

Vegetation

Successional changes in vegetations are best observed by the combined use of permanent plots and vegetation maps (Smits *et al.*, 2002). Four transects were added between the six originals; along the 10 transects 38 permanent plots were established. In September 2003 vegetation relevés of these permanent plots were made according to the decimal scale of Londo (1976). In addition a detailed vegetation map was made of an 8.6ha section near transect e. This section was selected because its width (230m), elevation and gentle slope allowed geomorphological and ecological processes to take place over a large gradient. The boundaries and elevation (mTAW) of the different vegetation types were measured using a theodolite Wild Leitz TC 1600. A digital elevation model of the study area was computed by converting point altitude measurements into a continuous grid (4x4m) by Kriging interpolation. For each grid cell of the elevation model the occurring vegetation type was identified.

The sector contained seven vegetation types (Fig. 3), corresponding to the results of a Twinspan (Two-way Indicator Species Analysis) on the 38 vegetation relevés of the permanent plots (Hill, 1979). Spatial distribution of the different vegetation types was closely related to intertidal elevation, which sets the tidal inundation regime in a given place (Fig. 4). Tidal inundation regime is indeed one of the major determining parameters for the distribution of tidal marsh vegetation (Adam, 1990, Olff *et al.*, 1997, Sánchez *et al.*, 1996). Vegetation types of vascular plants grew between 4.73 and 6.15mTAW. *Vaucheria* vegetations, terrestrial algae which are considered as the initial stage in tidal marsh colonisation, already established as low as 3.86mTAW. The high proportion of tidal mudflat and *Vaucheria* area was indicator of the very early stages of the brackish tidal marsh succession. Next stages consisted of *Scirpus maritimus* vegetation and subsequently *Chenopodium* sp. and tall herb vegetation, with transitional types in between. The *Chenopodium* sp. vegetation types on the study site were more typical for non-tidal situations, they were remnants of the existing vegetations before

tidal restoration and will probably disappear under tidal influence. Further monitoring results will confirm or disprove this hypothesis.

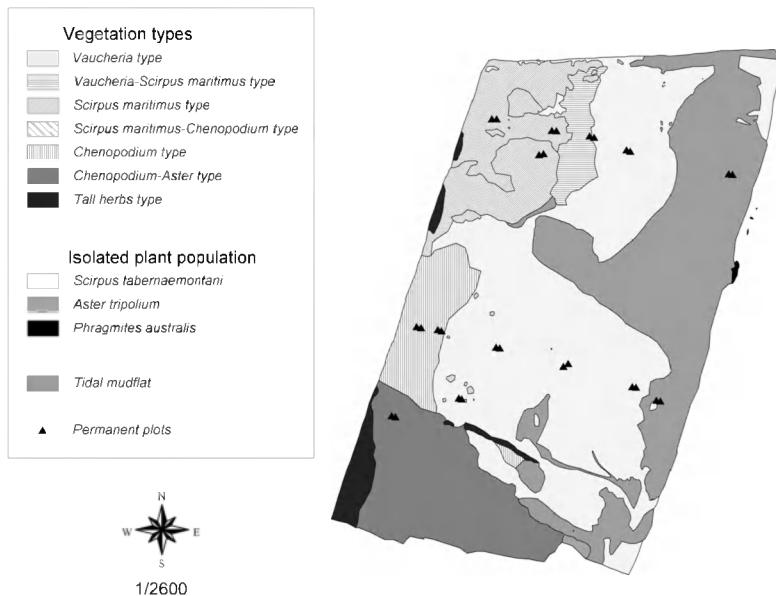


Fig. 3. Detailed vegetation map (anno 2003) of a part of section Kpe.

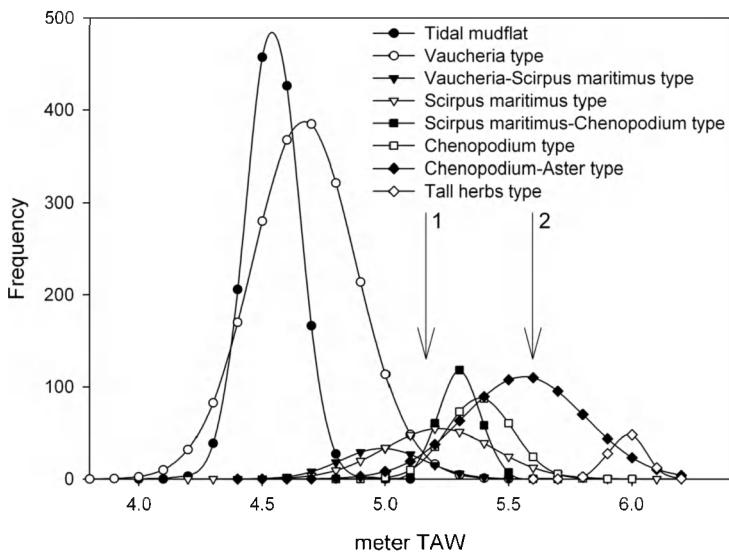


Fig. 4. Distribution (fitted curves) of the seven appearing vegetation types and the tidal mudflats along the elevation gradient at the study site (1: mean high tide; 2: mean spring high tide).

Macrobenthos

Five replicate samples were taken at each station with a small core (3.5cm) to a depth of 10cm. In the laboratory the samples were preserved with a 4% formaldehyde solution after sieving over a 1mm and a 250 μ m mesh-size sieve. Both fractions were sorted under a dissecting microscope and the animals were counted.

In 2002, Oligochaeta were found at all stations, with generally more organisms found in the smaller fraction. Maximum abundance was found at the first restored station Kpa2 (418,887 ind.m⁻²), minimum at station Kpa1 (981 ind.m⁻²). Also high densities were found on the sheltered Kpd and Kpe stations and were relatively high compared to nearby brackish mudflats; the low densities and the species composition corresponded to what was found on the existing intertidal mudflats at Ketenisse in 1999 (Van den Bergh et al., 2003). *Tubificoides heterochaetus* and *Paranais litoralis* were by far the most common species. On the muddy Kpd-transect, relative abundance of *Paranais litoralis* decreased with intertidal elevation in favour of *T. heterochaetus*. In 2003 densities were lower in most of the exposed stations; at the d-transect an increase was noticed (Fig. 5).

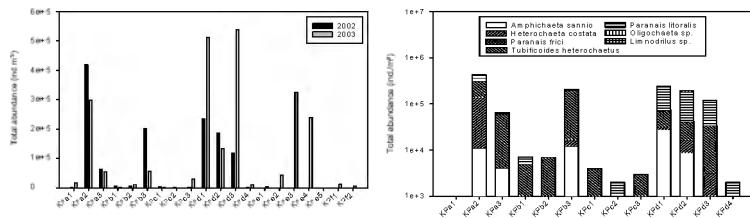


Fig. 5. Total abundance (2002 and 2003) and species composition of Oligochaeta (2002).

Other macrobenthic species present in the Oligochaeta samples were also examined. In 2002, most macrobenthic organisms were found at stations Kpa2 (149), Kpd1(177), Kpd2 (214) and Kpd3 (138). Nematoda and Copepoda were the two most common taxa. Acari, Corophium and Nereis were rarer. In 2003 the total number of macrobenthic species on the Kpd-transect increased and Corophium became relatively more important. The importance of Nematoda decreased in favour of Corophium. Kpa2 showed a slight decrease in total number of macrobenthic organisms (134), all other stations (except Kpd4) showed an increase. The macrobenthic species composition on the e-transect, which was levelled later, was most comparable to the d-transect. Stations with relatively higher densities were mostly stations with a low median grain size, high organic matter content and high chlorophyll concentrations. All probably related to inundation regime. The presence of vegetation negatively affects benthic densities. A relationship was found between macrobenthos abundance and chlorophyll a concentrations (Fig. 6). Higher chlorophyll concentrations possibly indicate higher food availability. Macrofauna abundance and sediment composition were not statistically related in a similar way.

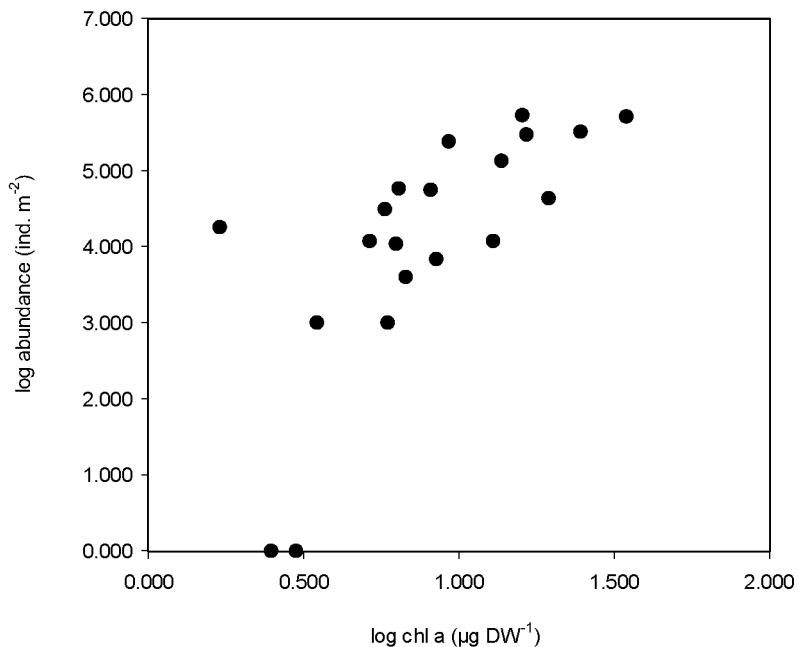


Fig. 6. Logarithm of the abundance of Oligochaeta versus the logarithm of chlorophyll a concentration.

Water birds and breeding birds

In total 43 water bird species were observed. Season maximum was in summer with 12,600 bird days in June (Fig. 7). Common Shelduck (*Tadorna tadorna*), Greylag Goose (*Anser anser*) and Pied Avocet (*Recurvirostra avosetta*) were the most numerous species, responsible for 31%, 18% and 9% of the total number of bird days. Geese are typical winter guests, Common Shelduck and Pied Avocet are especially abundant in summer. Common Shelduck and Pied Avocet (*Recurvirostra avosetta*) feed on the more sheltered, low dynamic mudflats in Kpd and Kpe and breed on their highest parts. Greylag Goose feed on the *Scirpus maritimus* vegetations in these sections and rest on the mudflats. Lapwing (*Vanellus vanellus*), Gadwall (*Anas strepera*) and the migrating waders are more common on the sandier sections (kpa, kpb, kpc, kpf en kpg). Curlew (*Numenius arquata*) was found in all sections (Fig. 8). In total 15 species of breeding birds were observed; Pied Avocet was by far the most common breeding bird.

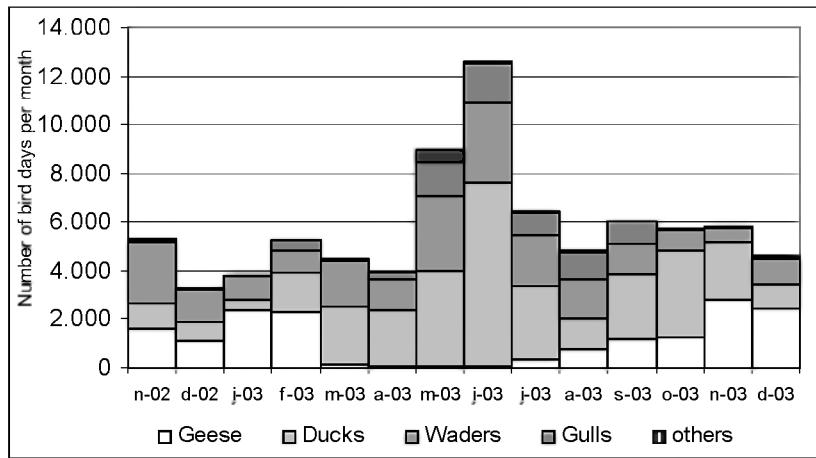


Fig. 7. Seasonal variation for the different species groups of water birds (bird days/month).

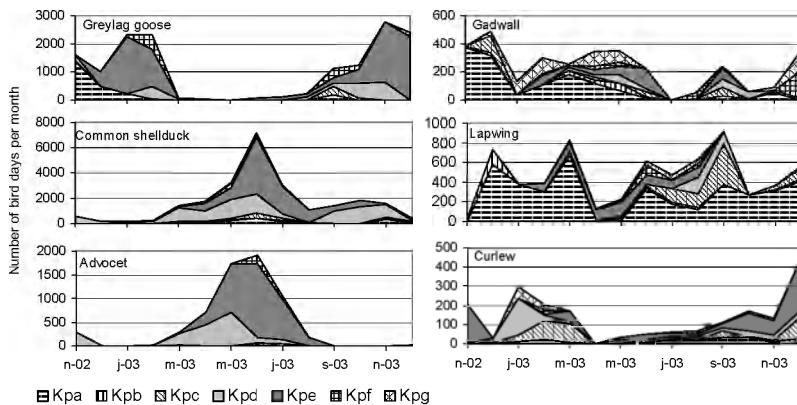


Fig. 8. Seasonal distribution of the most common waterbird species on the muddier (plain) and sandier (striped and chequered) sections of Ketenisse polder (bird days per month).

Conclusions

One year after tidal restoration Ketenisse polder was developing into a varied and functional intertidal area. Colonisation by microphytobenthos, macrobenthos, vegetation and birds started soon after levelling. The onset for a creek network system was seen in the wider and sheltered d and e sections. Once established, the pattern of this network doesn't seem to change. Unexpected was the remarkable development and erosion of a steep cliff in the most upstream part of the study area, caused by the changed stream current patterns.

The differences in the starting conditions were reflected in the differences in evolution across the site. On the sheltered and wider Kpd and Kpe sections in general net sedimentation was observed with sediments of low MGS, high OM content and chlorophyll a concentrations. These areas also contain relative high macrobenthos densities and are selected by typical species such as Common Shelduck and Pied Avocet for foraging. The other, more dynamic sections also show erosion in some parts, generally have higher MGS, lower OM content, Chlorophyll a concentrations and macrobenthic densities. They attract other bird species. Succession stages of tidal marsh vegetation were observed and most apparent on the sections with a weak slope.

The applied monitoring scheme seems to be adequate to monitor the developments on the new site, even though it is rather labour-intensive. Developments on levelled sites start shortly after the end of the works, therefore it is important to monitor intensively in the early stages. The monitoring frequency is evaluated yearly and, if necessary, adjusted to the developments on the site.

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PARALLEL THEMATIC WORKSHOP SESSIONS

*Workshop ‘Shoreline management’
chair: Helena Granja*

Herrier J.-L., J. Mees, A. Salman, J. Seys, H. Van Nieuwenhuyse and I. Dobbelaere (Eds). 2005. p. 537-545
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Morphological evolution and management proposals in the Authie Estuary, northern France

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Abstract

The Authie is a small macrotidal estuary largely infilled by marine sand and affected by flood dominant tides and waves. The shallow estuary mouth exhibits a relatively large intertidal zone of about 2.2km² with saltmarshes and on the south bank a massive sand spit platform. It confines the main Authie channel towards the north bank, threatening the dune barrier and the health and seaside-resort of Berck. The localized erosion and the generalized sedimentation have been focussed for a long time. It poses a number of severe management problems, notably estuarine shoreline protection, and call into question the very survival of the estuary itself. The Regional authority have been aware of these problems and undertook a study on estuary restoration. The first stage consisted in understanding the morphological changes within the estuary. They were deduced from analyses of historical documents, bathymetric charts and from the analysis of successive series of scale-rectified aerial photographs covering the last five decades. The main hydrodynamic processes and transport trends involved in these changes are analysed from observations and measurements of currents and waves. The results show that the width of the estuary mouth has decreased over the centuries. Moreover, the trends observed suggest that morphological changes have been linked to empoldering and the progressive construction of defence structures. The aim of the second stage is to develop predictive scenarios on future evolution of the estuary. Therefore, engineering models have been computed in order to simulate sediment dynamics and several defence schemes and a relocation of the sand platform are proposed. They were also complemented by biological studies on potential impacts of the operation on fauna and flora. The long term objective of the Regional authority is to define the best strategy, fighting the north bank erosion and the generalized sedimentation. But the heightened awareness of the socio-economic and the environmental values of intertidal zone give rise to recommendations on an integrated management of the Authie, notably the interaction between the environment and the shellfish farming ecosystems.

Keywords: Macrotidal estuary; Erosion; Sedimentation; Management proposals.

Introduction

Estuarine coastlines make up a significant part of coasts, and at the same time, estuaries are important for many human activities such as provision of sheltered sites for harbours, navigation and nature conservation. Often these interests are conflicting, and managers frequently have to attempt compromises that entail economic constraints.

Infilling in macrotidal estuaries may be favoured by flood-dominant tidal currents. The wave input may occur through recycling of sand drifting alongshore into the estuary mouth, often derived from dune reworking. Understanding these patterns of estuarine development is important to a variety of management issues such as conservation, shoreline protection and embanking. Good examples of macrotidal estuaries exposed to significant storm-wave activity are found on the dune-bound coast of northern France. One of these estuaries is the Authie, an estuary that embodies the paradox of significant overall accretion but severe erosion of its north bank (Fig. 1). Moreover, the evolution of the Authie Estuary morphology results from changes in sediment transport patterns determined by several factors operating at various temporal and spatial scales, as result of morphodynamic adjustments (Anthony and Dobroniak, 2000).

The aim of the present paper is to describe the morphological change that has occurred from the analysis of successive series of aerial photographs covering the last five decades. The main hydrodynamic processes and transport trends involved in these changes are briefly analysed from observations and measurements of currents and waves. In a second time, some predictive scenarios on future evolution of the estuary are developed by the Regional authority to define the best strategy for the estuary sustainable development.

General description of the estuary

The Authie Estuary is located on a low-lying dune coast in northern France (Fig. 1). It forms the terminus of a 98 km-long and straight coastal river that drains a low-gradient Mesozoic limestone plateau catchment covering an area of 989 km². However, the mouth of this estuary exhibits a relatively large intertidal zone of about 2.2 km². Another 2km² of former tidal lands have been transformed into polders (Fig. 1). Large portions of the south bank and parts of the inner estuary have been empoldered since the 12th century and this empoldering accelerated in the 18th century.

River discharge data are relatively sparse but show regular flow, characteristic of a small temperate catchment. The mean liquid discharge of the Authie is moderate ($10\text{m}^3.\text{s}^{-1}$) and is relatively constant throughout the year, fluctuating between $4\text{m}^3.\text{s}^{-1}$ (August) and $13\text{m}^3.\text{s}^{-1}$ (March) (Service Hydrologique, 1992). Catchment erosion provides the only sediment brought down to the sea by the Authie. This is exclusively fine-grained suspension load. The mean spring and mean neap tidal ranges at the mouth of the estuary are respectively 8.54m and 4.89m. These ranges decrease to around 4m and 1.8m, respectively, 7km up the estuary. The spring tidal influence on water level goes up to 16km inland. This large tidal range causes rapid tidal currents of up to 1m.s^{-1} at the mouth (Dobroniak, 2000).

Like all the other estuaries on this coast between the Somme (Fig. 1) and Belgium, the Authie is a shallow estuary that shows advanced sandy infill. The shallow estuary mouth exhibits a massive sand deposit covered only during high spring tide stages (Fig. 1), comprising a spit platform. The tip of the platform exhibits a massive dune barrier that extends northwards up the coast. The platform stretches across the shallow estuary

mouth, confining the main Authie channel towards the north bank. Mudflats and salt marshes occur in the inner estuary.

Historical reconstructions of estuarine evolution over the last three centuries show significant northward extension of the south bank dunes, and concomitant erosion of the north bank dunes (Briquet, 1930; Dallery, 1955). By progressively prograding across the shallow estuary mouth, the south bank confines the main Authie channel towards the north bank, threatening the dune barrier and the health and seaside-resort of Berck (Fig. 1) which developed in the 18th century. To keep the Authie channel from moving and eroding, several groynes and major embankments were constructed from the beginning of the 19th century to the early 1960^s (Dobroniak, 2000).



Fig. 1. The Authie Estuary, northern France. Aerial photograph is from the French Geographic Institute, the "Institut Géographique National" (IGN), carried out in 1991.

Morphological trends

Bathymetric charts show a clear pattern of erosion and sedimentation at the estuary mouth. These documents highlight systematic erosional and depositional trends, respectively of the north and south banks of the estuary. The superposition of shorelines on these documents shows that the width of the estuary mouth has decreased over the centuries. Dallery (1955) showed that the width between the Pointe de Routhiauville and

the Bec du Perroquet, decreased from an initial 3.5km in 1671 to 1.8km in 1953. It suggests that the progradation rate of the south bank is superior to the rate of erosion of the north bank, the ultimate fate of this rapidly accreting is complete silting up.

On the north bank, scale-rectified aerial photographs covering the last five decades show marked changes (Fig. 2). Their analysis documents progressive dune erosion and the migration of this erosional sector towards the inner estuary. The superposition of the photographs highlights important spatial and temporal variability with successive zones of erosion and accretion, the positions of which change in time. It has been linked to the progressively construction of defence structures (Dobroniak, 2004). The shoreline retreat from 1947 to 2000 has not been constant (Fig. 2). It has been estimated at 395m northward (about 7.5m.y^{-1}) and 230m inwards (about 4.5m.y^{-1}), reducing the width of the dune barrier and threatening the human constructions on the Pointe du Haut Banc. In contrast, the shoreline has been accreting further south (about 11m.y^{-1}), leading to the formation of the inner estuarine spit of Bec du Perroquet (Fig. 2). This accretional zone is characterised by successive longitudinal dune ridges that highlight progressive extension of this inner estuarine shoreline.

The trends observed from the aerial photographs are corroborated by topographic survey (profile and DEMs). It shows the importance of human defence structure to limit wave attack of the dune cliff face (Dobroniak and Anthony, 2002).

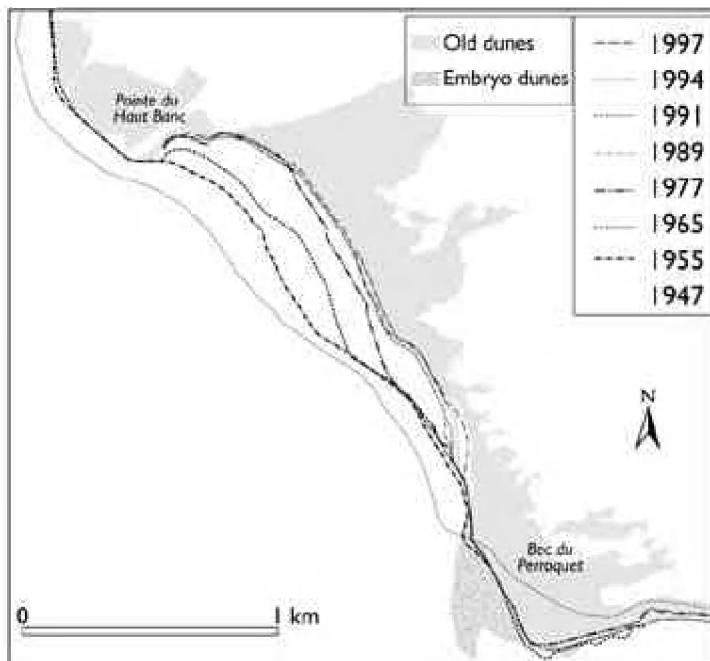


Fig. 2. Changes in the position of the dune-bound northern shore from scale-rectified aerial photographs. Photographs were chosen covering the last fifty years from the French Geographic Institute, the "Institut Géographique National" (IGN).

Sediments transport

Patterns of sedimentation and erosion of the Authie mouth were suggested by currents measurements inner the estuary and offshore. Records highlight a strong northward longshore drift attributed to combined tidal and waves currents. At the mouth of the Authie, a counteractive drift to the south is manifested by sediment movement, confirmed by the orientation of major morphological features, notably dune spits, at the north bank approaches to the estuary, and by preferential entrapment of sand on the northern updrift sides of groynes on the Berck seafront (Fig. 3A). This wave-induced drift is overwhelmed and strongly reinforced by flood tidal currents directed towards the inner estuary (Fig. 3B).

Along the north bank, all currents are parallel to the coast towards the inner estuary, jammed between the massive sand platform and the dune barrier. They confirmed the residual inward transport pattern (Fig. 3C). This hydrodynamic circulation involves both a wave energy gradient from the exposed outer estuary to the more sheltered inner estuary and a residual shore-parallel flood current. Much of the sand released by storm erosion of the dunes is transported alongshore and inwards towards the Bec du Perroquet spit, within this sediment drift cell driven by combined wave and flood-tidal currents. It suggests a southward transfer of sand characterised by an updrift erosional sector that feeds a depositional one further downdrift.

Moreover, Dobroniak and Anthony (2002), by the interpretation of profile survey, highlighted the dominant role of the estuarine beach. The sand is temporarily stored on the intertidal beach by storm-wave erosion of the dunes. Then it is transferred onto longitudinal dune ridges further inside the estuary, by both wave-current reworking and winds, although limited backcycling may occur into dune blowouts. This sand finally ends up its recycle in estuarine deposits, building up mudflats and saltmarsh substrates (Fig. 3D). Dobroniak (2004) points that recycling of this sand, eroded from coastal dunes lining the estuary and transported by tidal drifts into the intertidal inner estuarine sink, transforms the saltmarsh vegetation into embryo dunes vegetation.

This important input of dune sand into the intertidal estuarine sink, and the enhanced mud accumulation and saltmarsh development it causes, accelerate the silting up of this estuary.

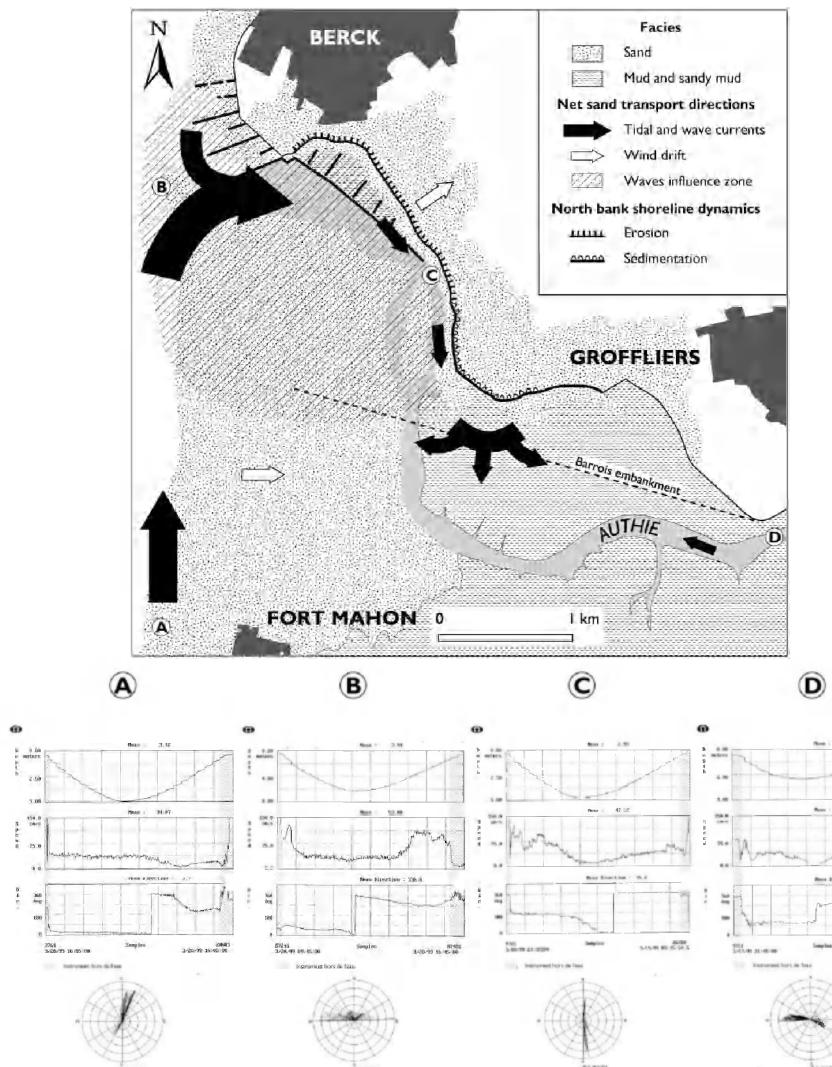


Fig. 3. Tidal current and sand transport patterns in the Authie Estuary. Arrows size indicates relative importance of sand transport.

Management proposals

The localized erosion and the generalized sedimentation of the estuary pose a number of severe management problems, notably estuarine shoreline protection and call into question the very survival of the estuary itself. To oppose these trends, the Regional authority is responsible for the operation and management of the Authie Estuary. The SOGREAH has been appointed to develop predictive scenarios on future evolution of the estuary. Engineering models have been computed in order to simulate sediment

dynamics, using a number of studies about coastal processes, notably those of Coastal Geomorphology and Shoreline Management Unit. Managers bring to propose several defence schemes and a relocation of the sand platform. In the past, they showed a marked preference for using hard structures to protect the north bank. But today, they know the acceleration of erosion and sedimentation patterns are linked to the progressive construction of defence structures along the bank. They prefer to adopt a comprehensive conception of soft management with a long term objective. Proposals are also complemented by biological studies on potential impacts of the operation on fauna and flora. Dynamism and physical characteristics of the landforms and sediments, highlighted by the study, play a relatively greater role in the evolution of the benthos and salt-marshes communities.

As a result the Regional authority prefers to choose a relocation of the sand platform, less harmful than groynes and embankments. Engineering models show the performance of sea defences along the north bank to protect the dunes and the Berck-resort. But they highlight an amplification of accretion inner estuary. On the contrary, the possibility of a relocation of the Authie channel by the excavation of a new channel, removes the threat further the north bank and has less sedimentation effects. But, the location of this new channel induces hydrodynamic changes and disturbs saltmarshes and embryo dunes development (Fig. 4). The heightened awareness of the socio-economic and the environmental values of intertidal zone give rise to recommendations on an integrated management of the Authie, notably the interaction between the environment and the shellfish farming ecosystems. By another way, to keep the estuary in this new configuration, post-relocation maintenance dredging of the new channel is necessary.

Conclusion

Authie Estuary provides a good example to highlight the contribution of erosion in the infill of an estuary. It shows also that the sand, released during storm wave attack of the dune on both banks by currents, is recycled successively as beach, dune, and finally, estuarine deposits. As a result, the north bank shoreline transport pathway probably constitutes the major infill pathway of the inner estuary. Erosion of the north bank and estuary-ward recycling of the eroded dune sand is thus largely a reflection of estuarine morphodynamic adjustment to massive sedimentation constraining the tidal flux towards the bank. Understanding such patterns of erosion and sedimentation and their driving mechanisms is important to estuarine management issues such as shoreline protection, estuarine infill and embanking.

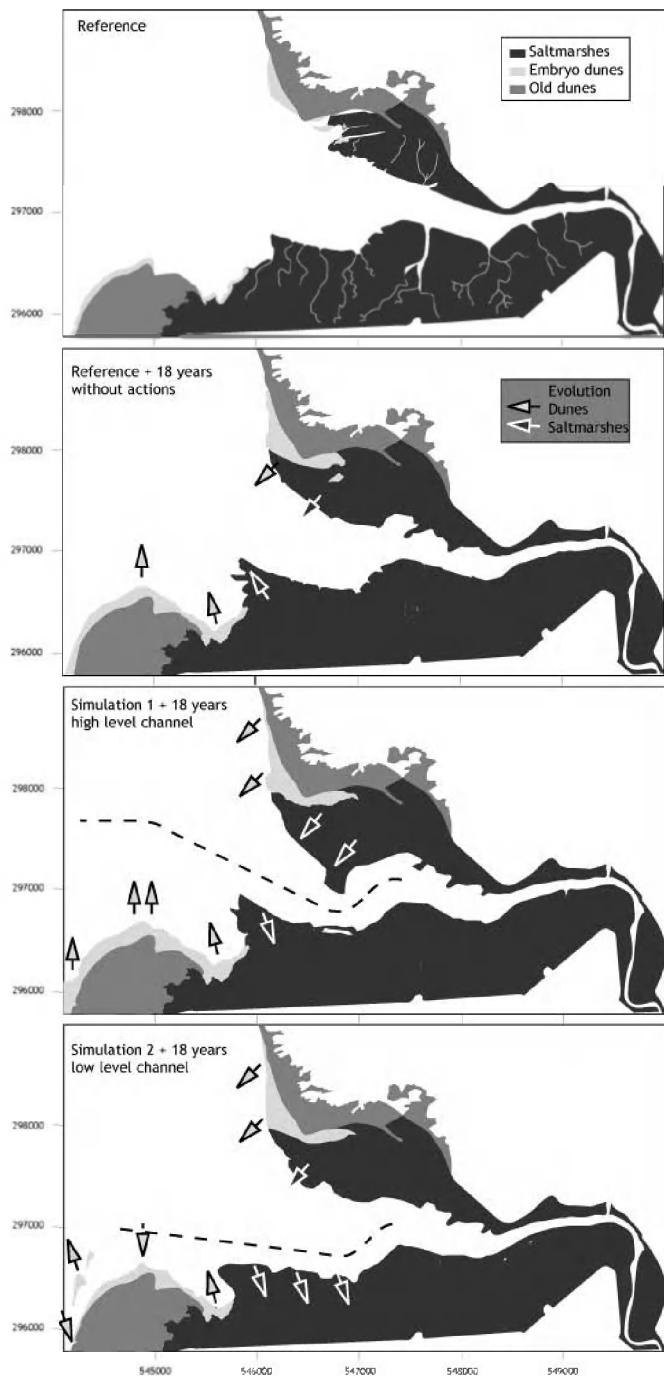


Fig. 4. Dynamics of dunes and salt marshes after predictive models, with (two simulations) and without coastal management. Morphological reference is 1998 data.

In the past, no actions have been taken against accretion. All the actions taken against erosion were hard engineered solutions. Traditionally, action has only ever been taken with regard to erosion, because it is seen as a problem and accretion is not. But, today, Regional authority, knowing sediment processes, prefers soft defences structures and a relocation of the channel. She accepts responsibility of a potential modification of the estuary ecosystem. Finally, the hypothetic modification of the platform will be the focus of considerable debate due to the environmentally sensitive nature of the issues. Studies about human impacts on intertidal ecosystems are essential for the Authie Estuary sustainable development.

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Restoration of intertidal habitats by the managed realignment of coastal defences, UK

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Abstract

In the United Kingdom, coastal defence has been the primary driver of intertidal habitat restoration. Rising sea levels, coupled with the high cost of maintaining coastal defences, have led coastal managers to look for more cost effective and sustainable methods of coastal protection. Managed realignment, the landward retreat of coastal defences and subsequent tidal inundation of formally reclaimed land, has since the early 1990's, been increasingly used to fulfil these requirements.

Results from several managed realignment schemes have shown that with fairly minimal pre-treatment and management, by allowing tidal ingress through a simple relatively small breach, the landward realignment of coastal defences will quickly produce intertidal mudflats on low-lying agricultural land which are colonised by invertebrates and, given the appropriate elevation, saltmarsh plants. What is unclear, however, is the time scale needed to produce intertidal habitats that are equivalent to reference conditions or if equivalency can indeed ever be reached.

To date, most research effort has concentrated on monitoring the biological and physical development of realignment sites. This paper presents the results of a survey of saltmarshes that have developed on formally reclaimed land as a result of an accidental breach in the embankment. These marshes are used as analogues for managed realignment and may give an indication of the future trajectories of current saltmarsh creation efforts.

Keywords: Managed realignment; Saltmarsh; Restoration; Chronosequence.

Introduction

Replacing coastal habitats where they are eroded, inundated or otherwise impacted upon is particularly important given the high level of ecosystem service they provide. Saltmarsh creeks provide spawning and nursery areas for many fish species and the vegetation provides roosting, nesting and feeding sites for birds. In addition to the specialist flora and fauna directly associated with tidal saltmarshes they are areas of high productivity providing a source of organic matter and nutrients for adjacent marine habitats. Their biodiversity and functional value is recognized in law under the European Union Habitats Directive (CEG, 1992). The directive seeks to maintain 'no-net-loss' in

total habitat area. The UK's Biodiversity Action Plan (BAP) commits the Government to develop strategies to conserve and, where possible, enhance biodiversity (UK Biodiversity group, 1999). Managed realignment (the setting back of coastal defences inland) is viewed as an important and viable technique in meeting BAP objectives for the creation of intertidal habitats.

In addition to their high biodiversity value it is widely accepted that coastal wetlands, and saltmarshes in particular, play an important part in ameliorating the effect of wave action on coastal defences (Moller *et al.*, 2001; Toft and Maddrell, 1995; Pethick, 1992). Moller *et al.* (1999) showed that wave attenuation over saltmarsh was 50% higher than over sand flat, even under similar water depths. As saltmarsh width decreases an almost linear increase in the height of the sea wall is necessitated to offer comparable protection, adding considerably to capital wall building and maintenance costs (Dixon *et al.*, 1998; King and Lester, 1995). By setting back coastal defences and creating saltmarsh in the intervening area considerable savings could be made.

Since the early 1990's the managed realignment of coastal defences is increasingly being used in the United Kingdom as a cost effective and sustainable response to biodiversity loss and flood management. Results from several managed realignment schemes have shown that with fairly minimal pre-treatment and management by allowing tidal ingress through a simple, relatively small breach the landward realignment of coastal defences will quickly produce intertidal mudflats on low-lying agricultural land which are colonised by saltmarsh plants and invertebrates. In addition it has been shown that the tidal curve within the de-embanked area quickly reflects that of the adjacent marshes and wave attenuation is considerably reduced (Rawson *et al.*, 2004), (although this is not reported for the majority of sites). What is unclear however is how long it will take for saltmarsh vegetation, representative of semi-natural communities to develop, if at all.

Sites of historic sea defence failure

The UK has a long history of saltmarsh reclamation for agricultural use. Marshes were embanked, drained and used initially for grazing livestock and in many cases, when salinities had reduced, ploughed for the production of crops. The response of the fronting intertidal areas was to adapt to the change in shore profile with the seaward extension of the saltmarsh, which, over time would again be at an appropriate elevation for reclamation. This process was piecemeal, with no specific design criteria, and the speed of reclamation often reflected the economic climate of the period. Conversely, at certain periods through time large storm events led to breaches in embankments, some of which were not repaired, usually because it was uneconomical to do so. These historic breach sites provide an analogue for modern day managed realignment and present us with a chronosequence of saltmarsh development on formally enclosed land.

In the late 1980's, as the concept of managed realignment was evolving, Burd (1992; 1994) studied these historic breach sites in an attempt to determine the physical variables which may have determined the fate of the de-embanked marshes when they were re-flooded, together with the observed characteristics at the time of the survey. Results from the project were used to inform on the construction of sites for saltmarsh creation

by managed realignment. Burd (1994) identified 23 historic breach sites in the English county of Essex that had been fully enclosed and then subsequently breached. The majority of sites were originally enclosed before 1774, with further sites being added in the period to 1840 and only 4 enclosed after 1840. Although many of the sites were breached a number of times in their history the storms of 1897 caused the final breach in 10 sites with three further sites being breached and repaired at this time. The 1921 storms accounted for several more of the final breaches, and the 1953 floods caused the most present round of permanent loss to the sea.

A chronosequence survey of saltmarsh vegetation

Of the 23 historic breach sites identified by Burd (1994) in Essex, 20 were visited along with four managed realignment sites, in a survey to determine how closely the vegetation of those sites resembled that of adjacent semi-natural saltmarshes. The survey was carried out during the summer of 2004. Sites were rejected that did not have directly adjacent saltmarsh. In two cases the sites no longer contained any saltmarsh at all. This gave a total of 18 sites with adjacent reference saltmarsh over four estuaries or embayments (Hamford Water, the Colne, the Blackwater and the Crouch), including the managed realignment sites. This gave a space for time view of saltmarsh development from 2 to 107 years old (as of 2004).

Five 2x2m quadrats were located along a 100m transect at equivalent elevations within the de-embanked sites and adjacent saltmarsh. Transects were stratified into five 20m lengths, with one quadrat placed at random within each 20m length. This method ensured good coverage along the 100m transect but avoided any periodicity that might be found in the vegetation (e.g. ridges and runnels that reflected old agricultural systems). Elevation was used as a surrogate for tidal inundation to ensure that at each site vegetation communities on both the reference saltmarsh and de-embanked site received equivalent tidal inundation frequencies. Checks were made at several sites by watching the incoming tide to ensure this was in fact the case. Species presence and an estimate of percentage cover were recorded for each quadrat. Mean percentage covers for species recorded within each transect were calculated. The difference in percentage cover between the de-embanked sites and the reference marshes was calculated as “historic –reference”, where negative values indicate lower percentage covers in the de-embanked sites and positive values, a greater cover (Table I).

Atriplex portulacoides occurred at significantly lower mean percentage covers (-12.9%) in the de-embanked sites than the reference marshes along with *Spergularia media* and *Triglochin maritima*. Conversely, *Spartina anglica* occurred at significantly higher percentage covers (+10.6%) within the de-embanked sites than the reference marshes.

Table I. Mean percentage cover (s.e.) for species recorded in quadrats within the historic sites (and managed realignment sites) and adjacent reference marshes

Reference marsh	s.e.	Historic/ MR sites	s.e.	Hist/M R – Ref	s.e.	p_diff
<i>Armeria maritima</i>	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
<i>Aster tripolium</i>	8.8	(3.0)	9.6	(2.7)	0.8	(1.9)
<i>Atriplex portulacoides</i>	28.5	(4.1)	15.6	(4.7)	-12.9	(4.6)
<i>Atriplex prostrata</i>	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
<i>Bostrychia scorpioides</i>	1.8	(0.6)	1.8	(1.1)	0.0	(1.2)
<i>Cochlearia anglica</i>	0.2	(0.1)	0.1	(0.1)	-0.1	(0.1)
<i>Limonium vulgare</i>	10.3	(3.0)	6.2	(2.6)	-4.1	(4.2)
<i>Plantago maritima</i>	0.3	(0.2)	0.0	(0.0)	-0.3	(0.2)
<i>Puccinellia maritima</i>	29.4	(3.9)	31.6	(5.7)	2.1	(4.8)
<i>Salicornia agg.</i>	7.2	(2.2)	11.6	(3.3)	4.3	(2.5)
<i>Sarcocornia perennis</i>	0.8	(0.2)	0.4	(0.1)	-0.5	(0.2)
<i>Spartina anglica</i>	2.8	(1.5)	13.4	(4.6)	10.6	(3.6)
<i>Spartina maritima</i>	0.01	(0.0)	0.0	(0.0)	0.0	(0.0)
<i>Spergularia marina</i>	0.01	(0.0)	0.0	(0.0)	0.0	(0.0)
<i>Spergularia media</i>	1.0	(0.3)	0.5	(0.2)	-0.5	(0.2)
<i>Suaeda maritima</i>	1.9	(0.5)	3.7	(1.2)	1.8	(1.2)
<i>Triglochin maritima</i>	6.2	(1.7)	0.7	(0.6)	-5.5	(1.8)
Algal	0.5	(0.5)	0.4	(0.4)	-0.1	(0.1)
Bare mud	6.6	(2.1)	8.8	(2.0)	2.2	(2.2)
Water	0.2	(0.1)	0.0	(0.0)	-0.2	(0.1)

The successful establishment and spread of *Spartina* throughout the UK during the twentieth century was largely due to the species perennial life history and the existence of a zone of mud flat formally unoccupied by saltmarsh plants – a vacant niche (Gray *et al.*, 1990). The sparsely vegetated mudflats in the early phases of saltmarsh development would provide ideal conditions for the invasion of *Spartina* within the de-embanked sites, at least by the time of the 1953 floods by which time the species was wide spread.

Rauss (2003) describes the invasion of *Spartina* in the Bay de Veys in northern France from when it was first recorded in 1906 (also France's first record) through an invasive stage to becoming the dominant species by 1963. Rauss (2003) reports the present situation where *Spartina* is now confined to the pioneer zone and the saltmarshes of the Bay de Veys are again dominated by typical *Atriplex portulacoides/Puccinellia maritima* communities. This transition from invasion through stabilisation and regressive phases, where *Spartina* is now a stable component of the community, comes as a result of interspecific competition between saltmarsh plants. It remains to be seen whether the

saltmarshes that have developed within the de-embanked sites in the UK can follow the same trajectory over time or if a lack of adequate drainage or sediment supply produces relatively static vegetation.

The lower mean percentage cover of *Atriplex portulacoides* may be a reflection of a higher water content in the soils of the de-embanked marshes, of which *Spartina* is more tolerant. There is a significant inverse relationship between water saturation in the root zone and abundance of *Atriplex portulacoides* (Crooks *et al.*, 2002). Watts *et al.* (2003) found that newly accreted marine sediments at the Tollesbury realignment site on the Blackwater Estuary in Essex were characterised by high water content, low bulk density and low resistance to erosion. This may be due, in part, to the formation in reclaimed agricultural soils of an over consolidated horizon with low hydraulic conductivity, forming an aquaclude or barrier to water that restricts sub-surface drainage within the developing marsh sediments (Crooks, 1999).

Figure 1 shows the difference in cover values for *Suaeda maritima* between de-embanked (historic plus managed realignment sites) and reference marshes over time. As would be expected for a pioneer species cover values are highest in the de-embanked sites initially and over time, the cover falls. Conversely, the perennial species *Limonium vulgare* has considerably lower cover values in the early years in the de-embanked sites and shows an increase in cover over time (Figure 2).

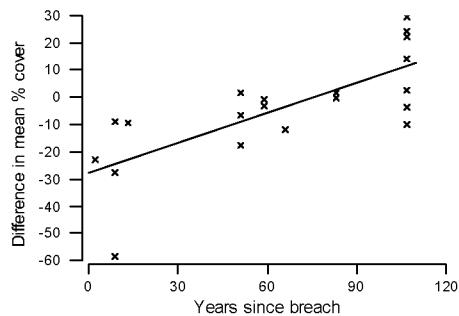


Fig. 1. Difference in percentage cover (historic – reference) over time for *Suaeda maritima*, with fitted linear regression ($p=<0.05$).

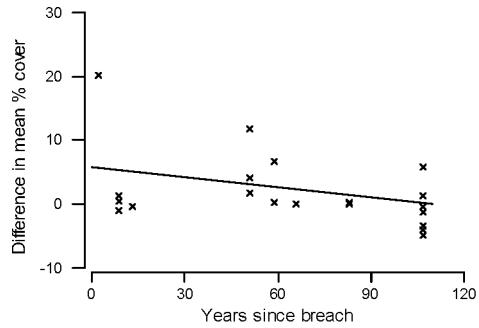


Fig. 2. Difference in percentage cover (historic – reference) over time for *Limonium vulgare*, with fitted linear regression ($p=<0.001$).

In addition to differences in mean percentage cover between de-embanked and reference marshes, there were also differences in the number of species recorded with the de-embanked sites showing lower species richness than their adjacent reference marshes

(Fig. 3). The mean number of species recorded in the reference marshes was 10.1 with a mean of 7.9 species recorded in the de-embanked sites. It is estimated that the fitted linear regression line will pass through 0 at 126 years. That is to say it will take an average of 126 years for species richness within the de-embanked sites to accumulate an equivalent number of species to that of their adjacent reference marshes (it may not be the same species however).

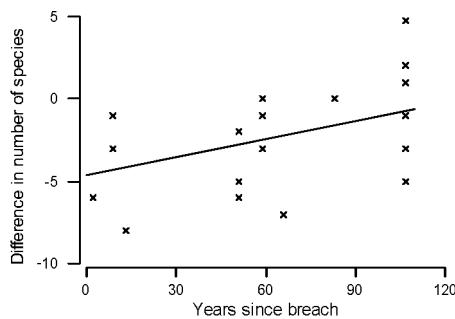


Fig. 3. Difference in species richness (historic – reference) over time, with fitted linear regression, $p < 0.05$. $spp_hist - ref = -4.57 + 0.0362 \text{ years since breach}$.

Choosing the right reference to measure restoration success

There has been considerable debate on how to define success in tidal wetland creation (Zedler, 2001). The choice of reference to measure the success of a scheme will strongly affect the outcome.

In the county of Essex, saltmarsh losses have been rapid with 974ha being lost between 1973 and 1998 (Cooper *et al.*, 2001), mainly caused by human activities and a continuous rise of high and extreme water levels (Van der Wal and Pye, 2004). By 1998 there were only 2878ha of saltmarsh remaining. The majority of marshes are clifffed on the seaward edge and backed by sea walls giving a truncated saltmarsh profile. This is reflected in the limited number of mid and upper marsh species recorded in the chronosequence survey (Table I). The truncated nature of the Essex saltmarshes may make it difficult to identify reference conditions by which success can be measured, particularly in situations where the elevation of de-embanked sites are outside the range of those observed in the reference sites. Wolters *et al.* (in press) have suggested a diversity score to measure success, where plant species present within the restoration site are given as a proportion of those present in a regional target species pool. In this way success can be measured as a continuum towards the goal of 100% fit with the target species pool in addition to allowing comparisons between sites. At present many of the schemes in the UK are unlikely to reach a complete fit, due to their small size and lack of elevational range. Measures of success must be realistic and adapted to take into account the physical characteristics of individual sites.

Even though there may be problems using existing saltmarshes as a bench mark for reference conditions, it may still be the most appropriate template to measure the development of a site in the absence of other quantifiable data. Reference conditions must however, be chosen to reflect the variation inherent in natural processes. Caution should be taken not to use 'one-off' surveys to identify target conditions; rather a long term and wide scale approach to monitoring should be used. Monitoring of saltmarshes adjacent to the Tollesbury managed realignment site, in Essex has shown that there has been a large change in the vegetation composition. Between 1994 and 2001 there was a 25% loss of *Atriplex portulacoides* leading to a complete change in vegetation community classification in 28% of permanent plots. Using the plant data collected from 1994 or 2001 as a baseline would have very different outcomes by which the success of a scheme could be measured against. It is therefore important that methodologies used to identify reference conditions are robust enough to reflect the variation in hydrodynamics, ecology and geomorphology found in the natural environment.

The contemporary view of restoration ecology emphasises process and function and the modern paradigm is the restoration not of a species assemblage or community but of a functioning ecosystem which can evolve and change. Measures of success should take account of this and include, for example, nutrient exchanges between created marsh and the adjacent estuary, the ability to adapt to disturbance (natural and/or anthropogenic) and the contribution of a scheme to overall estuarine processes.

Implications for saltmarsh creation

Experience over the last decade has shown that, where elevations are suitable, managed realignment can quickly produce intertidal flats that are colonised by saltmarsh vegetation. Realignment sites low in the tidal frame have developed large stands of *Salicornia* spp., rare in the south east of England where saltmarshes are predominantly clifffed, excluding pioneer communities. Nationally scarce plants such as *Inula crithmoides*, *Suaeda vera* and *Spartina maritima* have all been recorded within realignment sites and transitional species such as *Trifolium squamosum* and *Bupleurum tenuissimum* (also nationally scarce) have been recorded growing on the now abandoned embankments. Where sites are at present too low for the development of saltmarsh, mudflats have been colonised by intertidal invertebrates providing additional feeding areas for wading birds (Atkinson *et al.*, 2004). Fish have also been recorded using realignment sites for feeding and refuge.

The results of the chronosequence survey should not be interpreted as the inevitable failure of saltmarsh creation schemes in matching reference conditions, rather a cautionary note that habitat creation efforts rarely create an exact replica of a semi-natural system. Neither should saltmarsh developed on managed realignment sites be seen as a like-for-like replacement for losses elsewhere. Emphasis should continue to be placed on the protection and sustainable management of existing marshes.

Created saltmarshes should ideally function within the normal variation found in semi-natural marshes and retain key features (Atkinson, 2004). It is essential that pre-breach monitoring of existing habitats, at a local or regional scale, is part of any intertidal

habitat restoration scheme to take into account variation so that specific and realistic success criteria can be prescribed. Post breach monitoring should be designed to measure such success criteria. The survey of the historic breach sites has shown that differences between existing saltmarshes and those developed on previously agricultural land can exist for long periods. It is therefore difficult to assign time scales for saltmarsh restoration. Success should be measured on a continuum towards a desired goal. In this way, whilst the achievement of the goal may be beyond the life span of most projects, the trajectory of a site towards that goal may be measured.

A longer term, geographically wider, more flexible approach to coastal zone management has been developed in the UK whereby both intertidal habitats and coastal defence can both be accommodated. As Morris *et al.* (2004) emphasise, the benefits of managed realignment schemes should not be looked at in isolation but in the broader context of coastal management. Ultimately the success of any managed realignment should be measured in terms of the contribution the scheme makes to coastal processes at the landscape scale.

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How may beach nourishment affect the sandy beach ecosystem? The case of Belgian beaches

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Abstract

Though often regarded as biological deserts, sandy beaches provide a unique habitat for several species. Research was conducted by a consortium of experts with as a first objective to provide an integrated overview of the Belgian beach ecosystem and all its major components. A second objective comprised a review of available literature on the ecological impact of beach nourishment. To meet the first objective, an integrated overview of the Belgian sandy beach ecosystem based on spatial and temporal variation of fauna and flora of 11 sandy beaches is provided. The presented results corroborate the overlooked ecological significance of sandy beaches as a habitat. Besides sedimentology and hydrodynamics, five ecosystem components were taken into account: microphytobenthos, vascular plants, terrestrial arthropods, zoobenthos and avifauna. Nourishment of beaches is a large scale anthropogenic influence on sandy beach ecosystem. Sandy beaches are regarded as systems with a strong resilience towards such impacts. Nevertheless serious (short term) ecological effects can be expected. A review of prior studies indicates that the impact of nourishment is rather case-specific and that it is difficult to draw general conclusions. Short term impact is mostly large due to total mortality of benthic life. It seems very likely that potential recovery from the impact of nourishment will be limited to two essential, species specific pathways: (1) survival by resident organisms and (2) re-colonisation by immigrating individuals, the latter depending on both the dispersal capacities and habitat demands of the organisms. Further research is needed to explore possibilities for reducing detrimental

ecological effects. Specific studies are needed towards the survival options, the dispersal capacities and habitat demands of the species present. These should allow for management guidelines to be drawn in terms of preferable nourishment sediment characteristics, timing and practice of the deposition of the sand.

Keywords: Sandy beaches; Belgium; Beach nourishment; Beach ecosystem.

Introduction

Sandy beaches are often regarded as biological deserts, mainly in contrast with rocky shores. Yet, while they do not exhibit the same level of biodiversity as their hard substrate counterparts, sandy beaches possess a clear functional role. Besides providing a habitat for a number of beach-specific organisms, sandy beach ecosystems play an important role in providing food and serving as breeding grounds, resting area and nursery for several plants and animals. This is illustrated by *e.g.* the importance of macrobenthic intertidal fauna as a food source for wading birds (Smit and Wolff, 1981; Glutz von Blotzheim *et al.*, 1984; Hulscher, 1996; Cramp, 1998) and intertidal juvenile flatfish (Lasiak, 1983; McLachlan, 1983; Nicolaisen and Kanneworff, 1983; Gibson and Robb, 1996; Beyst *et al.*, 1999; Van der Veer *et al.*, 2001). In a first part of this paper, we will demonstrate that sandy beaches are valuable ecosystems, using 11 Belgian sandy beaches as an example. Instead of investigating a single ecosystem component, we aim at providing an integrated ecosystem perspective. Therefore, five important beach ecosystem components have been taken into account: microphytobenthos (benthic micro-algae), vascular plants, terrestrial arthropods, marine zoobenthos and avifauna.

Many beach users (managers and recreational beach users) consider sandy beaches as “unbreakable”. As long as the beach sand stays in place, it is often assumed the beach is in good health and – if taken into consideration – so is the beach ecosystem. The numerous anthropogenic influences on sandy beaches, like beach cleaning, beach nourishment, beach fisheries, spraying against wrack associated bugs etc., do however pose possible threats on the ecology of sandy beaches. Within this paper our attention goes specifically to beach nourishment.

Beach nourishment is defined as ‘the process of mechanically or hydraulically placing sand directly on an eroding shore to restore or form, and subsequently maintain, an adequate protective or desired recreational beach’ (Greene, 2002) or as ‘deliberately placing an amount of sand on an eroding beach or creating a beach where no beach or only a narrow beach was present before’ (National Research Council, 1995). It is a rather recent phenomenon (*e.g.* National Research Council, 1995; Hamm *et al.*, 2002; Hanson *et al.*, 2002; Basco, 1999) and the overall awareness and attention towards problems of coastal erosion in general and towards beach nourishment and physical and biological monitoring in particular has grown during the last decades. As an alternative for “hard” coastal protection both positive and negative aspects of beach nourishment are mentioned. The higher chance of erosion as a consequence of “hard” coastal protection, often at other (nearby) locations than where the actual nourishment took place (through long shore transport of the sediment) is mitigated if nourishment is applied (Peterson *et al.*, 2000a). Beach nourishment gives rise to smaller changes in the dynamics of both

sediment and water, thus a natural equilibrium is reached sooner, more easily and stays in effect for a longer time (Peterson *et al.*, 2000a). Negative aspects are the higher costs as a consequence of the need of replenishment every few years and the lower applicability on beaches with high wave energy (Esteves and Finkl, 1998). Some cost efficiency options are discussed by Raudkivi and Dette (2002).

Nourishment is widely considered as a better alternative for coastal protection than the construction of hard structures to mitigate detrimental erosive effects (e.g. Dankers *et al.*, 1983; Adriaanse and Coosen, 1991; Charlier *et al.*, 1998; Basco, 1999; Brown and McLachlan, 2002; Finkl, 2002; Greene, 2002; Hanson *et al.*, 2002; Hamm *et al.*, 2002). Even though beach nourishment is considered as the more ecology friendly option, this form of beach restoration too brings about sizable changes in the sandy beach ecosystem. Due to the highly dynamic nature of the beach environment, the benthic organisms inhabiting the littoral zone of sandy beaches are limited to those species with a high tolerance towards several forms of environmental stress. Therefore, according to many authors, nourishment should cause only minor damage to the ecosystem (e.g. USACE, 2002b; Löffler and Coosen, 1995; Miller *et al.*, 2002). This high tolerance is however not unlimited (Moffet *et al.*, 1998; Jaramillo *et al.*, 1996). On short terms, a large part of the beach inhabiting flora and fauna is destroyed by covering the resident sediment with a thick layer of nourishment sand. Changes in the beach habitat after nourishment like altered beach profile and sedimentology will influence the rate of recovery of the ecosystem's natural equilibrium. An impact of such magnitude can be expected to impact the entire beach ecosystem. Nevertheless, most research has been carried out on the intertidal benthic macrofauna (e.g. Rakocinski *et al.*, 1996; Peterson *et al.*, 2000a) and other ecosystem components remain mostly out of consideration. Most studies are short term investigations of the benthic macrofauna, little is known on the long term effects or the effects of repeated replenishment at the same site (cumulative impact). The biological focus of this paper is to provide an ecosystem perspective. Whereas the majority of past research focused on macrobenthic infauna, we feel a functional ecosystem approach has a much higher scientific value. Therefore here too, the same five beach ecosystem components have been taken into account: microphytobenthos (benthic micro-algae), vascular plants, terrestrial arthropods, marine zoobenthos and avifauna.

In the specific case of beach nourishment, no environmental impact studies are available from Belgian beaches. Yet, some lessons can already be drawn from available literature. In a second part of this paper, we will briefly review what is known on the ecological effects of beach nourishment from the available literature. Combined with the knowledge obtained from the first part, this will allow scientific assessment of future nourishment effects on the Belgian beach ecosystem.

Aims

The aims of this research are twofold and can be summarized as (1) demonstrating the biological value of sandy beaches through an integrated ecosystem approach using 11 Belgian beaches as an example and (2) reviewing what is known from available literature on the ecological effects of beach nourishment to provide a baseline for future research.

Material and methods

The results presented here are the final output of two different research projects, financed by different branches of the Flemish government. Within the framework of the BEST project (financed by AMINAL-Nature – file number AN.GKB/2002/nr.2) an inventory of the five aforementioned ecosystem components was made for 11 selected beaches along the Belgian coastline. Samples and observations were gathered from all 11 beaches, for most components both spatial and temporal (seasonal). A theoretical study on beach nourishment (financed by the Flemish Coastal Waterways Division – file number 202.165) compiled from literature all available knowledge on (1) the Belgian beach ecosystem and (2) the ecological impact of beach nourishment (on a global scale). Additional funding was provided by Ghent University (GOA2005).

Sandy beaches do have ecological importance: a case study from Belgian beaches

Briefly presenting the results of the BEST project, some details of the Belgian beach ecosystem will be discussed next, dividing the beach into three conventional zones.

Supralittoral zone

Terrestrial arthropods, vascular plants and birds are the most important ecosystem components present on the supralittoral zone, considered here from strandline to the foot of the dunes.

Many (semi-)terrestrial arthropods living on the strandline and on the dry part of the beach play a crucial role in the natural decomposition of stranded seaweeds (mainly kelps and brown algae), while others feed on those decomposers. Especially the strandline harbors a diverse community, as demonstrated by a total number of 236 species encountered in the samples of the BEST project.

Within the BEST project research, 27 species of vascular plants were found on the 11 investigated beaches. Most of these species form the first steps in the fixation of beach sand and the formation of coastal dunes. Four species comprised 94% of the mapped plant populations, while all remaining species are classified as “very rare” to “extremely rare”.

How may beach nourishment affect the sandy beach ecosystem?

Birds use the dry part of the beach to rest (mainly at high tide) or the nest. Nesting of birds is at the moment however non-existent on Belgian beaches.

Littoral zone

The intertidal part of the beach is inhabited by microphytobenthos and benthic infauna (macro- and meiobenthos) but it is also important for foraging birds and tidal migrating hyper- en epibenthic animals.

Sediment related differences between different beaches were among others apparent from the BEST results on microphytobenthos. This component is largely dominated by Bacillariophyta (diatoms).

The BEST results on macrobenthos are concordant with prior research (Degraer *et al.*, 2003), showing an increasing number of species from high water level towards low water level and with the flat, ultra-dissipative beaches reaching highest values for both number of species and densities. Conclusions for meio-, epi- and hyperbenthos are less apparent but it is clear that all these components have a specific use of beaches, albeit regarding specific communities (meiobenthos, Gheskire *et al.*, 2004) or the use of beaches as a nursery (epibenthos and to a lesser extent also hyperbenthos - Beyst *et al.*, 2001ab).

Feeding largely on intertidal macrobenthos, a number of birds (e.g. Sanderling *Calidris alba*) use sandy beaches for foraging while others feed on stranded dead animals or just use the beach to rest (gulls). BEST results showed the littoral zone being much more used by birds than the supralittoral zone, with more than 90% of the observed birds (mainly gulls) being present in the intertidal zone.

Infralittoral zone

The nearshore infralittoral zone can be equally affected by beach nourishment (especially with foreshore nourishment).

Benthic organisms occupying more stable nearshore habitats are said to be more vulnerable towards changes in their environment than animals living in the littoral zone (Thompson, 1973). Prior research demonstrated the importance of this zone for e.g. macrobenthos, with a number of diverse communities being encountered (Degraer *et al.*, 2002) and their role as food for seabirds like *Melanitta nigra* feeding on bivalves like different *Spisula* species (e.g. Durinck *et al.*, 1993; Leopold, 1995).

The information gathered within the BEST project on the flora and fauna of these 11 beaches provides a tentative, yet valuable overview of the Belgian beach ecosystem and this case substantiates the often overlooked ecological importance of sandy beaches.

Beach nourishment affects the sandy beach ecosystem: a review

The ecological effects of nourishment can be classified into three main groups (Fig. 1): (1) effects related directly to aspects of the nourishment project – the construction, (2) effects related to quality characteristics of the nourishment sediment and (3) effects related to quantity characteristics of the nourishment sediment. Furthermore, the size of

the effects can be classified by (1) place, time and size of the nourishment project and (2) the chosen nourishment technique and strategy. As they can regulate at the level of several aspects, these are not included in Fig. 1.

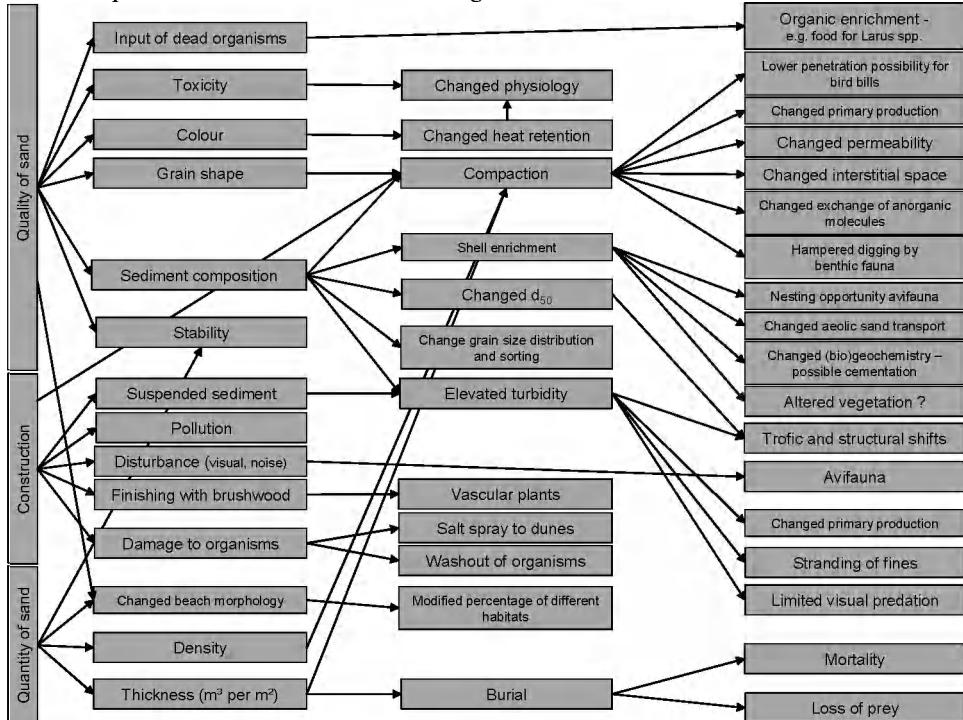


Fig. 1. Integrated network of the ecological effects of beach nourishment. The scheme is a tentative summary resulting from the compiled literature data and consultation of all authors, each of them expert in a specific ecosystem component.

From all effect pathways demonstrated in Fig. 1, some selected aspects (stressing options for impact reduction) are discussed below.

- From the available literature it can be deduced that sediment characteristics play a very important role in the impact of beach nourishment on the ecosystem sediment composition and beach morphology. Beetles of the genus *Bledius* do not live in sand too rich in shells due to their digging behaviour (Den Hollander and Van Etten, 1974) and a slower recovery of a *Donax* (intertidal clam) population after nourishment with sediment containing a high percentage of shell fragments has been noted (Peterson *et al.*, 2000a). A high level of fines in the fill sediment can result in slow recovery of macrobenthic organisms (Saloman and Naughton, 1984; Gorzelany and Nelson, 1987; Rakocinski *et al.*, 1996), because of e.g. limited juvenile survival (*Donax*, *Scolelepis squamata* ~ Reilly and Bellis, 1983). McLachlan (1996) studied a beach on which grain size was artificially increased while tidal range, wave energy and turbidity remained constant. The beach's morphodynamic state evolved from dissipative to intermediate. The changes in grain size and slope could both separately be correlated with a decreasing species richness and macrobenthic abundance. Eventually, the local

Donax species disappeared. Yet, some scientists question the importance of grain size distribution of the nourishment sand for ecological recovery and state that the grain size distribution will be restored very fast by physical conditions like currents and storms (J. Cleveringa, pers. comm. in: Harte *et al.*, 2002). A gradual shift towards a morphological equilibrium (depending on the current hydrodynamic conditions) can indeed be expected but it is crucial to understand that an ecological recovery can only be expected after this equilibrium is established. Thus, to limit the ecological impact, it is sensible to choose nourishment sands with a comparable sediment composition to that of the original sediment. If the sediment composition (grain size distribution and organic matter content) of the nourished sand matches the original sediment, the benthic fauna is least impacted and will recover fastest (Parr *et al.*, 1978; Nelson, 1993; Löffler and Coosen, 1995). Apart from these ecological arguments some geologists are also in favour of retaining the original grain size to avoid a sharp transition from dissipative to reflective beaches (Anfuso *et al.*, 2001).

- Compaction of the sediment after nourishment may be three or four times higher than on the original beach and increases sometimes (Ryder, 1991). Effects of compaction are manifested through changes in the interstitial space, the capillarity, the water retention, the permeability and the exchange of gasses and nutrients (USACE, 1989). Apart from the penetration of bills of wading birds also vertical locomotion of the infauna is inhibited when grain size and composition of the fill sediment differ too much from the original beach sediment and compaction is enhanced (Maurer *et al.*, 1978). This can be solved by ploughing or ‘tilling’ the beach (Dean, 2002) but it is mainly a short-term problem, as wave action will soften the beach, especially during storms.
- While the impact of sediment colour is largely unknown it seems precautionary to apply again the same colour as the original sediment. Toxic substances should also be absent from the fill sediment (USACE, 1989; Adriaanse and Coosen, 1991; USACE, 2002a).
- When aiming at a minimal ecological impact, nourishment should be completed within a single winter, starting after October and ending around March (USACE, 1989). This timing is optimal for nesting birds (MMS, 1999), while summer is better to avoid an impact on resting and foraging birds. A swift recovery of the macrobenthic fauna has been observed when timing was chosen accurately (Saloman and Naughton, 1984). If nourishment activities continue until May, recovery can be postponed until the next recruitment, macrobenthic animals can become smaller sized and average biomass may drop gradually (Peterson *et al.*, 2000a). Yet, as a number of organisms spend the winter months in the shallow infralittoral zone, it is possible that the reduced impact due to accurate timing becomes undone with foreshore nourishment (Grober, 1992).
- In general it is stated that a number of smaller projects (< 800m) should be preferred over a single large nourishment project (Adriaanse and Coosen, 1991; Löffler and Coosen, 1995; Peterson *et al.*, 2000b). The small distance between nourished and unnourished beach strips allows swift re-colonisation, depending on species-specific dispersal capacities. This may very well be the case for infauna but may be only to a lower degree true for birds.
- No clear choice can be made among the three currently used nourishment strategies (classic, profile nourishment, foreshore nourishment and backshore nourishment). It seems advisable to decide on this point in view of the local natural value of each ecosystem component on the nourishment site.

- For all further aspects, the reader is referred to Speybroeck *et al.* (submitted).

Options for future research

The biological processes, relevant for assessing nourishment effects, comprise (1) the process of disturbance and survival during nourishment (in short terms) and (2) the process of re-colonisation after nourishment (in medium to long terms) (van Dalsen and Essink, 2001). Disturbance and survival are mainly determined by species specific tolerances, while re-colonisation is determined by (1) species specific dispersal and migration capacities and (2) species specific habitat demands and tolerances, including physical and biological elements. If the necessary scientific attention is paid to these processes for some key species within the beach ecosystem, it will allow beach managers to execute an ecosystem directed evaluation of scheduled nourishment.

Conclusions

Though sandy beaches are often regarded as biological deserts *e.g.* in contrast with rocky shores, they form a habitat for a number of specific species of vascular plants, terrestrial arthropods, microphytobenthos, zoobenthos and birds. These components display a number of biological interactions (*e.g.* through grazing and predation), stressing the need for an integrated ecosystem approach. The obtained results from 11 Belgian sandy beaches support this.

In an ecological comparison, beach nourishment turns out to be the least damaging option for coastal protection. In a few cases beach nourishment is even applied to offer protection to threatened or protected species like turtles or nesting birds (Ryder, 1991). From the presented review it may be concluded that on short and medium term negative ecological effects of beach nourishment dominate. After restoration of the physical equilibrium, the degree of recovery of the beach ecosystem largely depends on the physical characteristics of the equilibrium, shaping the habitat.

An overall ecosystem approach of nourishment effects is always lacking: each study is limited to a certain ecosystem component, omitting to draw an overall image. As the effects of nourishment may differ largely depending on the considered ecosystem component, it is today impossible to obtain an objective general image of the ecosystem effects.

The referred studies in this overview all picture the ecological effects (on mostly just one ecosystem component) of a specific nourishment project (*i.e.* monitoring). Thus, it remains hard to estimate the effects of future nourishment projects. These studies describe the effects rather than investigating the biological processes which are causing these effects and thus are relevant for assessing the ecological effects of beach nourishment. Only by approaching these processes, effects of future projects can be anticipated scientifically and thus ecological adjustments in nourishment practice can be suggested.

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Sustainable estuary management for the 21st century

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Abstract

In England, many estuaries have been effectively canalised, or so constrained that natural energy attenuation provided by saltmarsh and mudflat has been severely impaired. In this paper, it is argued that there is a need for a change in the management of estuary form, flood defence design and the maintenance of other coastal structures that influence morphological evolution. This needs a radical departure from popular thinking that existing structures should be maintained *in situ*. Such an approach, whilst defying the popular view of flood and coastal management, is likely to lead to sustainable form, and lower maintenance and capital investment costs in the long-term. In many cases, positive measures to widen the mouth of many estuaries will be needed and reversal of canalisation should be an objective where saltmarsh extent is too limited for effective sustainable flood management.

Keywords: Sea level rise; Coastal squeeze; Morphological evolution; Flood and ebb dominance; Estuary mouth; Canalisation; Saltmarshes; Sandflats; Mudflats; Sustainability.

Introduction

The English coastline is very varied, reflecting the wide age range of bedrocks, with older harder rocks to the west and north, and softer sands and clays to the south and east. This, together with the distribution of periglacial material strongly influences the form and function of many estuaries. For example, the estuaries of south-western England such as the Fal and Helford (Cornwall) and Tamar (Devon) are deep, relatively sediment free and form natural deepwater harbours. In the north-west, estuaries such as the Solway and Duddon (Cumbria) have wide mouths, extensive sandflats and saltmarshes, and are shallow with shifting sandbanks. In southern and eastern England, much of the sediment is derived from eroding clay and sand cliffs and leads to the formation of muddy estuaries such as the Humber (East Yorkshire/Lincolnshire), Stour-Orwell (Essex/Suffolk) and Blackwater (Essex).

A brief evaluation of English sites designated for their nature conservation importance shows that a high proportion of our coastline is designated under UK and international legislation. Foremost amongst such designated sites are our estuaries. At a rough glance at least 48 English estuaries are designated, most of which have European designations in addition to domestic status as Sites of Scientific Interest (SSSI). This level of

protection reflects the importance of English estuaries as wildlife sites, especially as overwintering grounds for migratory waterfowl and as breeding sites for an array of birds including marsh harrier *Circus aeruginosus*, bittern *Botaurus stellaris*, bearded tit *Panurus biarmicus*, wildfowl and waders. Habitats of importance associated with estuaries include saltmarshes (Atlantic salt meadows), mudflats and sandflats, subtidal sandflats, *Zostera* beds, biogenic and rocky reefs. Estuaries are the conduit for migratory fish, especially salmonids, lampreys and shads, whilst mudflats and saltmarshes are important nursery grounds for fish such as bass *Dicentrarchus labrax*. Behind sea walls, saline lagoons and brackish grazing marshes are particularly important for their invertebrate assemblages (Drake, 2004).

Historic influences on estuary morphology

Where estuaries support extensive saltmarshes there has been an historic tendency to build counter-walls to limit the degree to which the land was flooded. Such walls would have been sufficient to allow grazing by livestock, but more recent designs have changed. There are two obvious drivers for the change in sea wall design. Firstly the great storm of 1953 led to widespread flooding and fatalities in eastern England (and the Netherlands etc.): it changed forever the public perception of flood defence. The public memory is long, and the perceived solution is to build bigger armoured walls. Secondly, agriculture behind the flood defences has changed. Post-1945, the political direction for agriculture centred upon self-sufficiency for our food supply. This combined with the UK's entry into the Common Market and more effective mechanisation led to a major shift from coastal grazing marshes to arable prairies. As a consequence, some 85% of coastal grazing marshes in the Thames Estuary were converted to arable (Thornton and Kite, 1990), the value of which was considered much greater in relation to cost-benefit analysis. In the north-west, however, coastal marshes continue to be grazed and are not subjected to the same agricultural pressures.

A further factor behind the construction of sea walls and the canalisation of some estuaries was the nature of coastal shipping and the location of ports. Historically, commercial navigation went many miles inland, linking up with the canal system and carrying goods to and from a final destination far inland. This meant that some estuaries were much-modified to allow favourable navigation conditions, minimise the costs of maintenance of the navigation channel and to deliver particular economic benefits to communities that were to a large extent self-contained.

Today, coastal shipping has changed dramatically, with bigger ships calling at fewer ports. In addition, road and rail transport have led to the gradual loss of inland water-borne transport and the fracturing of communities that are now pleasant dormitories rather than the focus for local commerce. The past infrastructure has slipped into disuse and decay. In places, former floodbanks and training walls have breached (often as a result of the 1953 flood) leading to unusual estuary forms with narrow, hardened entrances and extensive inland mudflats. Classic examples include the Blythe and Alde Estuaries in Suffolk, but others with close similarities include the Crouch and Roach in Essex and the Deben in Suffolk.

In some parts of England, the morphological evolution of estuaries has led to the development of bars or spits that have subsequently been consolidated by hard defences and structures such as quays or hard-standing that make natural evolution in response to changing tidal prisms difficult. Extreme examples include Portsmouth Harbour (Hampshire) and the Mersey (Lancashire) but there are many variants ranging from the Deben (Suffolk) to the Medina (Isle of Wight) and Langstone Harbour (Hampshire). In some cases the scale of infrastructure investment is such that it is inconceivable that changes can be made to the mouth (*e.g.* Portsmouth harbour, the Medina and Mersey Estuaries), but in others the cost/benefit in the long-term may favour such an approach.

Prior to the 1980's, saltmarshes and mudflats were seen as a resource, as new agricultural land and of course for commercial development. This became more pronounced as land prices rose, and development land became more expensive. Thus, the principal ingredients for coast squeeze were in place, but their effects had yet to be recognised. However, by the late 1980's it became apparent that there was a developing problem as east-coast saltmarshes showed signs of erosion (Burd, 1992). More recent studies have confirmed these findings and for example show net losses of nearly 30% of saltmarsh in Hamford Water, and nearly 80% loss in the Stour Estuary between 1973 and 1998 (Coastal Geomorphology Partnership, 2000). Flood defences have become more exposed, requiring strengthening, raising and the placing of energy absorbing rock-armour (also to protect the exposed toes of sea walls). The natural energy attenuation provided by saltmarshes has been substantially lost and engineering solutions have been sought.

The reasons for the accelerating saltmarsh loss first recognised in the late 1980's (Burd, 1992) arise from a number of combined factors. Two of these are largely beyond our control in the immediate future. Firstly, isostatic adjustment whereby south-eastern England is gradually sinking as the north-west rises in response to the loss of the ice-sheet that covered much of the UK during the last glaciation. Secondly, the rising spectre of climate change accompanied by sea level rise and increased storminess. In an unmodified environment these twin factors would simply mean that saltmarshes, reedbeds and mudflats migrated inland, but where there are hard defences this is not possible and the only part of the process that can progress is the erosion of the outermost mudflats and saltmarshes.

The width of the estuary channel along its length, but perhaps especially at its mouth, is particularly important in the process of morphological evolution and responses to sea level rise. O'Brien (1931, 1969) argued that there was a close relationship between the width of the mouth of an estuary and the tidal prism, whereby the mouth width would adjust in accordance with increasing or decreasing flow arising from volumes of water moving in and out of the estuary. Above a particular threshold, the mouth would narrow and below that threshold the mouth would tend to widen. Similar responses can be modelled along the length of an estuary, so a pinch-point within an estuary may lead to localised or more extensive changes to the flood-ebb regime accompanied by erosion or accretion. This relationship has since been refined and forms the basis for much of the top-down and hybrid modelling for estuary form and function including Regime Theory (Pethick and Lowe, 2000) and Dronkers gamma asymmetry ratio (Dronkers, 1969).

These various influences set the scene for today's estuary management issues and possibly offer clues as to how solutions could be delivered. To recap, the problems of sea level rise, erosion of natural energy attenuation features, long-term flood management economics have got to be addressed regardless of other important drivers. For English Nature a major driver is the need to ensure that nature conservation is properly accommodated within the equation. England's estuaries offer some of the best wildlife and wilderness experiences. Many estuaries, including all those quoted above are designated for their international wildlife interest: migratory and breeding birds under the Birds Directive (EEC, 1979), habitats and species under the Habitats Directive (EEC, 1992) and for other wetland communities under the Ramsar Convention (UNESCO, 1994). Sea level rise, coastal squeeze and accompanying loss of intertidal habitat have profound implications for the maintenance of these sites in favourable condition and as a consequence there are huge implications for the coherence of the Natura 2000 series. Unfortunately, the solutions are not simple, and may in themselves involve a degree of loss of existing habitat to create functionally sustainable estuaries.

The nature conservation and flood management dilemma

In many estuaries, nature conservation interest lies both to the front of, and behind sea walls or coastal structures. Since 1945, once extensive grazing marshes with networks of freshwater and brackish ditches favoured by specialist plants and invertebrates, and open grassland supporting breeding and roosting waterfowl, have been reduced to a fraction of their pre-war extent. Saline lagoons, naturally rare habitats that are in many cases transitory in a dynamic coastal environment, are often represented by artificial structures behind sea walls, or are squeezed between mobile barrier beaches and hard defences to their rear. In addition, upstream reedbeds and wetlands that represent natural transitions between the open coast and fluvial systems are non-existent in many estuaries as a result of widespread land-claim and drainage. These, combined with cases where active habitat creation and management has led to important wildlife resources in pools and wetlands behind flood defences, mean that we have a multitude of problems that require innovative solutions.

In the past ten years, there have been important changes in flood management policy, and in the process of planning for future flood management programmes. Morphological evaluation drawing on a variety of top-down and bottom-up models now features prominently in the development of estuary-wide flood management strategies in the UK. However, there are significant obstacles to the delivery of sustainable estuary form that delivers improved flood management standards utilising natural energy attenuation and reversing past intervention that prevents the development of sustainable form. Inevitably, the most challenging problem is that of public opinion and the ways in which local communities wish to maintain the status-quo. This can often lead to the flood management authorities and their consultants concluding that the most appropriate way of addressing sea level rise is to prioritise realignments of flood banks to new defendable locations, and to target nature conservation sites for such realignment in the first instance.

Whilst it is accepted that there will be a need for realignment over some nature conservation sites, such as grazing marsh and lagoons behind sea walls, there is a problem in so far as their loss needs to be accompanied by compensatory habitat creation. That in turn arouses concern amongst the public and flood managers; firstly because it often involves reversion of agricultural land and secondly because it is costly. Delays arising are frequently blamed on nature conservation being unreasonable and on the Habitats Directive being too restrictive.

Case studies

The Blyth Estuary

The Blyth Estuary (Fig. 1) in Suffolk was once canalised along its entire length. Today, there are extensive mudflats upstream as a result of breaches during the 1953 flood, but the mouth extends inland as a canal. This leads to a highly ebb dominant system that does not allow the import of sediment to feed mudflats and sandbanks, and means that flood banks are left in an unsound condition through erosion and foreshore lowering. A major proportion of the flood banks defends arable or nature conservation sites and could be retreated by adopting to high ground or to localised new defences to form new intertidal; but this would further push the estuary into ebb dominance. Meanwhile, the canalised mouth of the estuary is such that navigation is extremely difficult and existing structures will require major investment to maintain further.

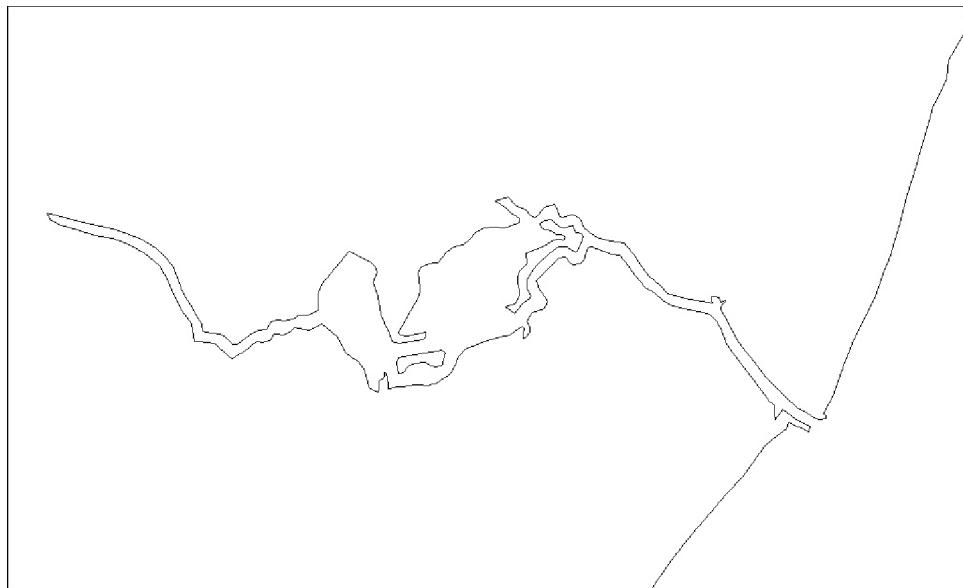


Fig. 1. The Blyth Estuary, Suffolk, UK.

The Alde-Ore Estuary

The Alde-Ore Estuary (Fig. 2) cSAC, SPA and Ramsar Site lies behind the spit of shingle forming the Orfordness to Shingle Street cSAC. Again, it is highly canalised for much of its length, with open mudflats upstream as a result of breaches in the 1953 flood. There have been ongoing possibilities of a breach forming at the northern end of Orfordness (towards Aldborough) in keeping with the overall evolution of such shingle structures exhibited by, for example, the cuspatate foreland at Dungeness. In the face of sea level rise and increased storminess, such a breach is probably inevitable, especially as bathymetric data indicate that the foreshore is steepening. There is therefore an argument in favour of managing the change rather than trying to maintain the existing state for as long as possible. Morphologically, a breach would have important implications for the flood/ebb regime on the estuary and modelling suggests that this would push the estuary into ebb dominance rather than mild flood dominance in its current state. As a consequence additional morphological changes would be needed to widen the currently canalised sections of the Alde Estuary northwards.



Fig. 2. The Alde-Ore Estuary, Suffolk, UK.

The Crouch and Roach Estuary

The Crouch and Roach Estuary (Fig. 3) SPA and Ramsar Site (part of the Essex Estuaries cSAC) is effectively canalised for much of its length, with few natural locations for evolution of saltmarsh and mudflats. In this case, there are a number of pinch-points that affect the ability of flood managers to deliver a sustainable estuary form based on natural energy attenuation of mudflat and saltmarsh. Without widening of

these pinch-points, it is unlikely that additional measures can be widely undertaken to create new saltmarsh and mudflats other than in some restricted areas.

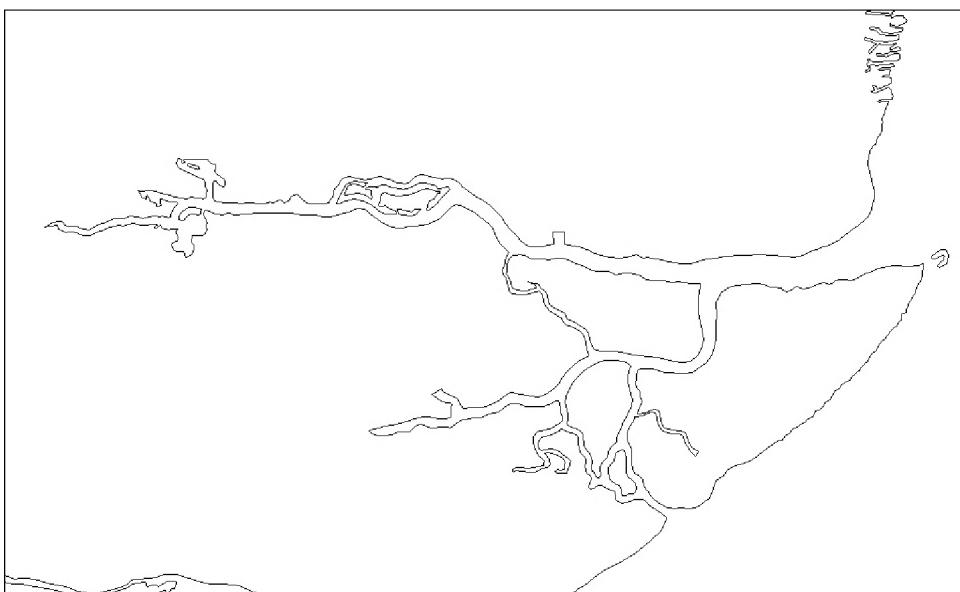


Fig. 3. The Crouch and Roach Estuary, Essex, UK.

Some wider considerations

In many estuaries, the natural transition from saline to freshwater through various levels of brackishness has been lost or confined to a narrow channel constrained by flood banks. Reed-swamp and brackish swamps have to a large extent been lost completely, and the plants and animals they formerly supported are now confined to artificial habitats such as ditches, borrow-dykes and fleets in grazing marshes. The ability of these assemblages to move, adjust to losses or to colonise newly created habitat is poorly understood; this needs much further investigation if we are to ensure that losses associated with the development of a strategic approach to flood management can be compensated for elsewhere.

Plants and invertebrates are relatively obscure, however, and do not evoke the emotions that are expressed over the loss of bird habitat. Therefore much recent debate has centred on the ways in which compensatory habitat for breeding birds can be secured. Such habitat does not necessarily require a coastal location but a whole-estuary approach to flood management, compensatory habitat creation and sustainable use of the tidally influenced environment therefore seems to offer a solution.

A sustainable solution

Sustainable management of our coasts and estuaries relies on the adoption of a long-term vision that provides sufficient time for adaptation and evolution. In particular, it is important to undertake cost-benefit analysis over a sufficient time-frame to recognise the real costs of holding the line, or to realise the front-loaded costs of implementing radical change. The processes of defining a way forward must be founded on sound morphological principles in relation to the effects of sea level rise and increased storminess. There are a number of obvious components, largely associated with the natural environment:

- Sea level rise will inevitably lead to increased tidal prisms, which will push many estuaries closer to or deeper into ebb dominance, whereby the currents on the ebb tide are of greater strength than the shear-stress of newly accreted sediment. In these circumstances, ebb dominance for fine sediments will affect the ability of an estuary to accrete sediment and for saltmarshes and mudflats to keep pace with sea level rise.
- Estuary sensitivity to change is a key driver to find a more stable morphological solution. Removal of pinch-points along the length of the estuary wherever possible will be necessary if soft engineering techniques such as realignment are to be used. Erosion of soft sediments at the estuary mouth must be expected as a natural component of stratigraphic rollover in which erosion at the mouth of an estuary is countered by upstream transgression of tidal influence accompanied by sediment deposition further upstream (Allen, 1990).
- The importance of eroding soft coastlines as a sediment resource must be safeguarded. This is highlighted in the final report of the Erosion Project (2004). In broader terms, sediment such as material removed through maintenance dredging must be seen as a resource and not as a waste product. Even when disposed of at sea, it forms part of the background of suspended marine sediment.
- In defining programmes for sustainable flood management within estuaries, there is a need to give serious consideration to the removal of structures that currently constrain the mouths of estuaries or which canalise sections and make them morphologically incapable of accommodating realignment to create sustainable soft defences.
- Managed realignment should not be confined to the wholly saline end of an estuary. There is a need for programmes of realignment to take place as far upstream as possible within the tidal influence. This way, it should be possible to create sustainable freshwater and brackish habitats to offset losses where grazing marshes have to be sacrificed in the best interests of a sustainable estuarine form and to accommodate stratigraphic rollover.
- There is a need to embark on a programme of grazing marsh re-creation based on prior research into the mobility and restoration potential of brackish water invertebrate and plant communities.

Our vision for English estuaries is the restoration of a morphologically functional system capable of accommodating stratigraphic rollover, and exhibiting all of the features that would normally be associated with such a system including brackish-freshwater transitions to the limits of the saline wedge and beyond. Such a vision is unlikely to be achieved completely in many estuaries, but there are a number where such aspirations could be met.

Estuary sustainability in a human and economic context

Radical changes to flood management provisions inevitably provoke the expression of many concerns by the communities they serve. Inevitably there is a tendency to resist change and to argue in favour of further investment in existing defences. In one important case, a small group of residents adjacent to the Cuckmere Estuary (Sussex) have applied for consent to reinforce flood defences on land owned by third parties who are in favour of realignment. In another, the scale of public opposition to a major realignment scheme was such that it had to be dropped; and in further cases there have been objections from other parts of the nature conservation movement to the loss of freshwater habitat and to realignments that in any way change the current form of an estuary! There is no consensus.

So far, the messages over managed realignment and sustainable estuary form have been championed by the nature conservation community, especially by English Nature. As a consequence, sustainable flood management is largely perceived as a nature conservation management tool. In England, there have been a relatively small number of realignments to date; nearly all of which have been promoted largely for nature conservation benefits. Some examples include Orplands, Old Hall Farm, Northey Island and Tollesbury (Essex), North Sea Camp (South Lincolnshire) and Paull Holme Strays and Alkborough (Humbershire). All of these have joint flood management and nature conservation benefits, either as trials for the technique or as measures to offset flood management works elsewhere. In reality, there is a need for a shift towards sustainable flood management based on sustainable estuarine morphology to deliver a social benefit in the first instance and wider nature conservation benefits as an ancillary outcome. That shift can only be achieved by the emphasis on some key messages:

- Flood management costs will spiral in the next 100 years and will not be affordable in the light of demographic changes leading to increased pressure on social welfare budgets such as old age pensions.
- The technical feasibility of maintaining the existing line of defence will diminish as foreshores steepen and wave exposure increases. The longer the delay, the more costly the solution; especially as improved defences encourage inappropriate development that makes longer-term options less practicable.
- Evaluation of possible uses of newly created intertidal habitats that would positively add to the rural economy. For example it would not be an impossibility to allocate some new intertidal as moorings or even as more formal marina facilities. Samphire *Salicornia* harvesting is another obvious possibility that has been undertaken on one

realignment site. The key issue is to manage change and to look for opportunities that replace lost employment or perceived attractions.

- There must be a shift towards flood management programmes taking forward realignment projects without nature conservation benefits as a principal objective: such soft engineering is needed for very real flood management and social benefits and needs to be promoted as such.

Conclusions

Climate change and accompanying sea level rise sit towards the top of the issues that will most profoundly affect the human and natural environments in forthcoming years. Continuation of current flood management practices does not appear to be sustainable in the long-term, and there is an urgent need for flood management planning to adopt radical new approaches. Without such approaches, the risks and costs for coastal communities will rise as foreshores steepen, mudflats and saltmarshes erode, and natural wave energy attenuation declines.

The solutions need to be radical, and require a degree of foresight and bravery as decisions may have to be made in the face of serious local opposition. To make such decisions more socially and economically viable, solutions must not focus solely on nature conservation outcomes, but must seek to deliver the most morphologically sustainable form from the mouth of the estuary to the tidal limits and beyond. This may mean that some estuaries will look very different in years to come.

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POSTER PRESENTATIONS

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Sediment characterization in the ‘IJzermonding’ using empirical orthogonal functions: application to CASI

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Abstract

The erodability of mudflats is strongly determined by biophysical characteristics of sediments, such as silt, sand, benthic microalgae and water content. Mudflats are often large and inaccessible areas, leading to dangerous and time-consuming in situ measurement campaigns. Furthermore the collected point samples are unrepresentative for the spatial variability of these coastal systems. Airborne hyperspectral remote sensing is identified to be effective for the collection of a synoptic overview of biophysical characteristics of sediments in mudflats. An automated method for the classification of hyperspectral images acquired by the Compact Airborne Spectrographic Imager (CASI) is proposed. The method is based on a linear transformation of each spectrum in the hyperspectral cube. Comparable classification results are obtained using a standard classification method employed in hyperspectral image processing. The superiority of the proposed method lies in its robustness, computational requirements, repeatability, interpretability and objectiveness.

Keywords: Mudflats; Biophysical characteristics; Hyperspectral image classification; Linear transformation.

Introduction

The process of mudflat sediment entrainment, transport and deposition is dependent upon the biophysical characteristics of the sediment. Hyperspectral airborne images are promising for the study of intertidal zones because of the global coverage, the superior spectral and spatial resolution, and operational flexibility. Two classification methods will be applied to hyperspectral images of a Belgian mudflat acquired in 2001 and 2003.

Methodology

The principal component transformation (PCT) is a powerful technique to decorrelate the bands of hyperspectral images so that the largest amount of information can be explained in few bands. For the intertidal zone, the number of PCs did not exceed two to explain more than 99.2% of the data variation. The first two PCs explain the variability

in the near infrared (NIR) and the red reflectance. The most important classes present in an intertidal zone are vegetation (on the stabilized dunes), silt, sand and mixed sediment (mixture of sand and silt). These classes show distinct properties in the NIR reflectance and red absorption. The combination of the two PCs will enable us to separate these four classes. If more than four classes are present, a cluster of pixels consisting of more than one class will appear. The pixels of the mixed class are isolated, and the PCT followed by the classification is performed on these pixels.

The standard method of hyperspectral image classification consists of several steps: i) the minimum noise fraction transformation to reduce the dimensionality of the data; ii) the collection of the spectra of pure materials (endmembers); iii) the classification based on spectral angles between pixel spectra and endmembers.

Results and discussion

Both images were classified using the principal component transformation. The spectral characteristics of the classes and field knowledge are used as basis for the identification and labeling of the clusters of pixels.

The same classes were identified using the standard method, but large differences were observed in the classification results. An accuracy assessment of both methods could not be made due to lack of ground data.

However there are large differences in the procedures. The standard method is time-consuming and very subjective. It is mainly based on expert knowledge of the terrain and the image and on trial and error. The results are not reproducible. On the other hand, the classification method using PCT is objective and robust (no interference of image interpreter necessary) and it can be automated in a few steps. The procedure is fast and easy to perform. The results are physically interpretable.

Conclusion

A classification method for intertidal mudflats based on empirical orthogonal functions was developed. The proposed method is superior to the standard classification method of hyperspectral images with regard to user-friendliness, repeatability, ground truth requirements and physical interpretability.

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Contribution to the methodology for the evaluation of the habitats conservation state

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Abstract

With this work we propose a method for the evaluation of the habitats conservation state in their natural sites. This methodology considers different criteria to evaluate the plant communities (= habitats following the phytosociology). These criteria are as objective as possible in order to define 3 conservation states : 1. favourable state, 2. not representative yet not deteriorated state, 3. unfavourable and deteriorated state.

Keywords: Conservation state; Phytosociology ; Relevés; Habitats evaluation.

Introduction

The evaluation of the conditions (state of conservation) of habitats (plants communities) is fundamental for inventory and preliminary vegetation maps and for the setting up of the "Documents d'Objectifs" for the pSIC (proposal of site of Community importance) of the future European natural sites network, Natura 2000.

The evolution of the managements of these sites is analysed through the changes of the habitats conservation state (especially the plants communities belonging to the Annex 1 of the Habitats Directive): it is therefore essential that the evaluation is founded on objective bases.

However, the notion of "state of conservation" of a habitat – as well as the term "habitat" - remains very complex and needs a better definition both from a conceptual and a methodological point of view. Several institutions, among which some Conservatoires Botaniques Nationaux (National Botanic Conservatories) in France, made proposals for the assessment of the state of conservation (see "Cahiers des charges" for vegetation mapping) but there is no common methodology.

Other indications are given in European technical papers. Nevertheless, all different information and approaches are rather dispersive, and the evaluation of the state of the habitats gives a large place to the subjectivity.

With this paper we would like to introduce our approach and suggest a methodology for the evaluation of the habitats conservation state in a natural site. Such a method distinguishes some objective criteria (*e.g.* structure or floristic composition typical or not typical, changes such as eutrophication, encroachment of shrubs,...) from others referring to the subjective appreciation (*e.g.* environmental conditions,...).

Methodology

The first group of criteria (called "objectivable" criteria) depends on the analysis of the phytosociological tables of relevés concerning and describing a vegetal association. The second group ("non objectivable" criteria) combines conditions such as threats, flood, drying.

Each "objectivable" criterion has a numerical value (levels):

- Floristic composition typical: 1
 not typical: 2
- Eutrophication no: 0
 low: 1
 high: 2
- Encroachment of shrubs no: 0
 low: 1
 high: 2

After attributing different values to each phytocoenosis and summing them up, it is possible to establish one of the three following conservation levels (states) for each habitat:

1. favourable state;
2. not representative yet not deteriorated state;
3. unfavourable and deteriorated state.

The definition of the habitat state is a particularly important phase to define the stakes and the reasons for the conservation and the management of a natural site.

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Morphological and sedimentological monitoring of a man-induced accretionary beach – dune system (Ca’ Roman, Venice, Italy)

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Abstract

A detailed morphodynamic and sedimentological survey has been carried on one of the few sites along the barrier islands of the Venice lagoon where a complete coastal dune system still survives, recently included in pSIC. The high aeolian transport potential, as well as the accretionary trend caused by the shoreline advance updrift to the northern Chioggia jetty, gave rise to the formation of a large dune assemblage during the last Century. The collected data, together with the historical documentation analysis, have allowed to the reconstruction of the evolutionary history, and a better knowledge of the processes regulating the formation and the development of coastal dunes in this geographical area.

Keywords: Foredune; Accretionary beach; Dune monitoring; Management; Venice lagoon.

Introduction

For a long time the barrier islands bordering the Venice Lagoon have been subjected to man-made huge modifications. Despite the systematic coastal dune destruction occurred along the most part of the northern Adriatic sea after World War II, some complete foredune systems still survive, as rare witness of an ancient and significant morphogenetic activity. These small areas are biotopes identified as pSIC (IT3250023) “Venice barriers: littoral biotopes (Lidi di Venezia: biotopi litoranei)”. One of these areas has been selected, due to its particular interest, for a detailed morphological and sedimentological study. The aim was either to improve our knowledge on the processes controlling the formation and the development of coastal dunes in this geographical area, and to consider possible management strategies in the framework of recent beach and dune nourishment interventions, carried out without any local specific study.

Study area

The Ca’Roman beach is located at the southern tip of Pellestrina island, Venice, and is characterized by a parallel series of dune ridges, with a vegetation succession of a certain

importance for the geographical context (Gehu *et al.*, 1984). The present morphological structure is the result of a continuous beach accretion, documented since the end of the first phase of the construction of the jetties of the Chioggia inlet, in 1911 (Zunica, 1971).

The wind regime appears particularly favourable as the exposure is practically onshore with respect to the dominant ENE wind, locally known as "Bora". The direct human impact is considerably reduced, above all because of the natural isolation of the area. The beach area and the dunes have been subject to a monitoring field survey during one year, including a detailed topographical and morphological survey along four transects, the sediment samples collection, the anemological data analysis, the comparison of historical maps and aerial photographs.

Results

The data collection and analysis have allowed to outline the conditions for the present development of the beach-dune system, and to reconstruct the evolutionary history related to the foredune morphology and beach-dune sedimentary budget (Psuty, 1988).

The present beach state is still accretionary, and the incipient foredune consists of coalescent shadow bodies, arisen due to the Bora wind action, at about 60m from the shoreline. The average elevation is up to 2m. Landwards, the incipient forms are followed by five dune ridges, grown during relative stable beach phases and featuring progressive increasing dimensions, up to 4.5m high. A positive sedimentary budget has been computed for the present foredune area, 50-60m wide, nourished by deflation over the dry beach. The sediment feeds above all the incipient foredune, and only subordinately the present foredune, which is thus destined to become a secondary dune within a short time. From the sedimentological point of view, the beach is made of fine sand, which, for the grain-size characteristics does not represent a limitation to the aeolian transport. Anyway, the effectiveness of the selective process by the wind is such to nourish dune with sand considerably finer and better sorted than the beach one. On the whole, the Ca'Roman beach highlights a high potential for foredune development and conservation, due to the favourable natural morphodynamic condition. The knowledge of the aeolian and beach dynamic constraints may address the local managers to more correct actions toward beach-dune reconstruction proposal, which recently involved the neighbouring beaches and partially also the Ca'Roman site itself.

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Geomorphology and evolution of Ravenna's dune system (Italy)

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Abstract

During the last few decades coastal dunes, for centuries a distinctive feature of Ravenna's coastline, have been seriously affected by tourist development and human activities. Considering the importance of these structures as natural defences against beach erosion from sea storms, the main purpose of this work is to characterize the dunes and to reconstruct their recent evolution from both a botanical and a geo-environmental point of view. Another purpose is to evaluate the future natural evolution of dunes in this type of coast.

Keywords: Coastal dunes; Phyto-sociological surveys; Fugitive dust model.

Introduction

Dunes have a great role in the coastal dynamical equilibrium. They are the less expensive and more efficient type of protection against seawater ingressions, mostly in the Province of Ravenna where landward areas are generally below the average sea level. Researches on this particular area outlined that, among the human activities which mainly affect the dunes, the most dangerous are: excavation of sand from the riverbeds that reduces sand supply to the beaches; uncontrolled groundwater withdrawal, methane extraction and the construction of buildings along the seaside, all these last factors cause the enhancement of the natural subsidence rates (Comune di Ravenna, 1996).

Methods

In order to evaluate the recent evolution of this environmental heritage, aerial imageries of the studied area (the coastline from Porto Garibaldi to Cervia in the years 1954, 1972, 1988, 1994 and 2000) have been analysed. A GIS has also been created.

Another important aspect considered in this study is the characterization of the vegetation present today and its comparison with the one of the past. Several phyto-sociological surveys (Braun-Blanquet, 1964) have been carried out on some of the most representative dunes of the Province of Ravenna. These surveys have allowed us to calculate the species diversity, to evaluate the degree of naturalness of each dune and to outline the evolution of the vegetation, based on the data collected in the seventies

(Giacomini, 1974; Gerdol and Piccoli, 1984). Moreover, in order to establish dunes efficiency, to work out reliable future scenarios and to define the recovery chances of some dunes, the following features have been evaluated: crest height, steepness index, lateral continuity, conservation state, sedimentological characteristics.

In two research cases (Marina di Ravenna and Lido di Classe), a FDM (Fugitive Dust Model) simulation has been carried out to evaluate their hypothetical natural evolution (Hsü, 1974; Kroon and Hoekstra, 1990; Wingers, 1990). The FDM is a software, created by EPA (Environmental Protection Agency), which calculates the aeolian transport and dust deposition. The FDM model, readapted to the dune system, allowed us to outline dune evolutional trends and was a useful tool for a qualitative evaluation and for decision making in the management interventions.

Results and discussion

The decrease in dunes extension is remarkable: in the year 2000 the area occupied by dunes was one quarter of the total area covered in the year 1954. From the seventies until now, an increasing number of bathing establishments built on the dunes can be observed. This, in the majority of the areas, caused the complete disappearance of dune systems.

The observed vegetation communities are not clearly defined, because of the stress caused by tourism, bathing-huts, paths, game fields and bathing establishments. Such a stress had seriously compromised the naturalness of the typical succession, causing the disappearance of some species and the appearance of weeds. Another important result is that the highest diversity of species and the main stability due to the presence of the *Tortuleto-Scabiosetum* community were observed in the only dune that has been protected. The protection consists of a simple fence, which keeps tourists from approaching dunes. Thus, some protections, less invasive than the artificial introduction of stabilizing species, would surely be more effective and less hazardous.

Results from the FDM simulations show that the heaviest and most hazardous destructions occurred in the foredunes. In many cases dunes become thinner and lower and they are damaged by many wide gaps which, in the future, as following FDM simulations show, won't be able to brim and close naturally. Such damages will deeply affect the backdune areas, too: evident episodes of vegetation destruction caused by marine aerosol can occur.

Conclusions

Management of coastal endangered areas must therefore consider dunes, backshore and foreshore as three united elements of the same environment: dealing with only one of them would imply accepting consequences on the other two.

The dunes area of Ravenna became very touristic and the present huge economic interest seems not to allow any recovery of the original naturalness. Indeed, a good compromise between protection needs and beach use can be found. Measures must be planned on a long term and space scale, because many different factors such as coastal erosion, beaches use, vegetation naturalness, presence of buildings and dune position in relation to pinewood need to be evaluated.

Acknowledgement

It is with pleasure that we acknowledge the collaboration of Servin (Servizi Integrati Gestionali Ambientali) from Ravenna (Italy) and especially of Dr Giuseppe Patrizi for his helpful availability in placing the Fugitive Dust Model at our disposal and for having readapted the FDM to the beach-dune system conditions. We sincerely thank Prof. Carlo Ferrari who led the work for the characterization of the vegetation.

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Evaluation of the effects of recent nature development measures in the Yser Estuary on ground beetle and spider assemblages

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Abstract

Since 1990, populations of ground beetles and spiders are continuously monitored in the coastal dune and saltmarsh habitats of the Yser Estuary (Nieuwpoort), within the context of a long-term study on invertebrate diversity, population dynamics and ecological and genetic effects of habitat fragmentation. By now, we know in detail the faunal composition of practically all available habitats in the study area. This is an ideal framework to monitor the effects of the nature development activities that started in 2001 in the area. Results of five large sampling campaigns in 2001-2003 (more than 25.000 carabid beetles and spiders, 218 species) show a number of new ground beetle and spider species and assemblages, but warrant that many of these could be rapidly lost again.

Keywords: Long-term monitoring; Dunes; Saltmarsh; Ground beetles; Spiders.

Introduction and methods

As a part of this study, pitfall trap sampling is being performed without interruption for more than 14 years along a transect from seaside marram dunes to inland moss dunes and dune grassland. Faunal assemblages are compared with those from surrounding habitats and microhabitats in the same study area. The studied invertebrates belong to the most appropriate bio-indicators for saltmarshes and different coastal dune habitats. Amongst other characteristics, these animal groups show a high biodiversity and/or abundance and productivity, a lot of highly specialized and stenotopic species and a high variation in their dispersal power. They offer unmatched possibilities as model organisms for studies on differing spatial and temporal scales. Our long-term study is an ideal framework to monitor the effects of the nature development activities that started in 2001 in the area (*cf.* project 'MONAY'), in order to evaluate, understand, and possibly even predict changes in faunal assemblage structure and population dynamics. We started sampling newly created habitats immediately after nature development

management activities were finished. Our long-term sampling has been continued on a number of reference sites from the main habitats in the area ('old' dune habitats, 'old' saltmarsh). Besides, intensive short-term sampling is also performed on a large number of sites (Fig. 1) along transects in the entire nature development area, by simultaneous monitoring of target invertebrate species and abiotic as well as vegetation characteristics.

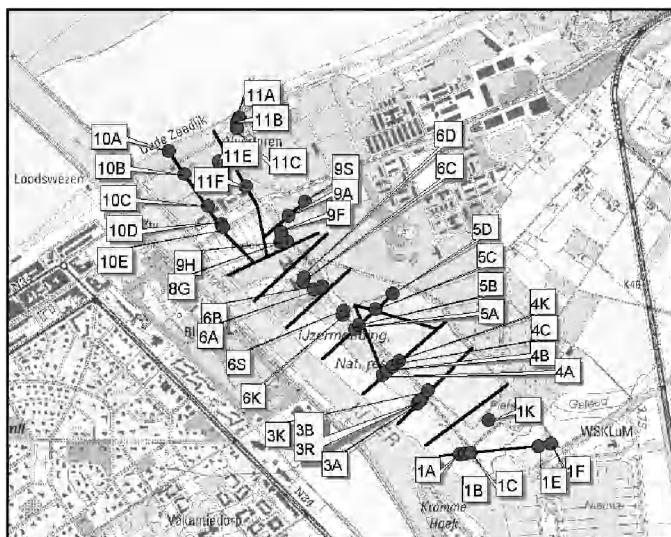


Fig. 1. Sampling sites of ground beetles and spiders in the Yser Estuary nature development area.

Results and conclusions

Results of five large sampling campaigns in 2001-2003 (more than 25.000 carabid beetles and spiders, 218 species) show a number of new beetle and spider species and assemblages for the study area, including intermediate assemblages between those from 'old' marram dune, dune grassland and transitions to saltmarsh habitat. Some completely new habitat types were created such as a brackish dune pond, dikes, and marshy areas associated with freshwater seeping at the base of newly constructed dikes. Assemblages of ground beetles and spiders have quickly colonized all of these habitats, although the speed of colonization is habitat-specific and differs between beetles and spiders. Among these arthropods, we observe not only ruderal species but also a number of species with high conservation interest. Our preliminary results however seem to indicate that such species could be lost again in short time, unless natural dynamic processes are kept ongoing. Such processes generate special assemblages typical for first stages of succession in saltmarshes and dune slacks. It is, however, still unclear whether the newly created saltmarsh habitats will evolve as hoped for, because of the observation that the newly deposited sediments in the saltmarsh are relatively coarse-grained (sand instead of silt). Further invertebrate monitoring is therefore imperative not only for a better understanding of the patterns and processes generated by the nature restoration measures, but also as a possible early warning system for the need of additional management measures in the future.

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Species richness in Sea-Buckthorn scrub

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Abstract

The expansion of Sea-Buckthorn in dunes reduces species richness as well as the cover of mosses and lichens. The decrease in species richness is likely to be due to the shading effect of the scrub. As many regionally rare plants are restricted to dune areas, the spreading of this densely growing scrub might be a serious threat to the phytodiversity of open semi-fixed dunes.

Keywords: *Hippophae rhamnoides*; Scrub encroachment; Relative irradiance; Species richness.

Introduction and methods

In many coastal dune areas of north-western Europe scrub such as Sea-Buckthorn (*Hippophae rhamnoides*) is currently spreading, because of changing land use during the last two centuries. Shrubs were originally planted for coastal protection and have since then increased in abundance often due to the decline in cattle and rabbit grazing (Fuller and Boorman, 1977). The main purpose of this study was to determine whether the expansion of Sea-Buckthorn and the shading-out effect affects species richness.

We investigated the vegetation of Sea-Buckthorn scrub at seven sites on the island of Schiermonnikoog (The Netherlands). At each site, three neighbouring plots (each 2m²) significantly differing in shrub cover (on average 88, 55 and 19%, One-way ANOVA $p<0.001$) were compared. Relative irradiance was determined by measuring the light values above and beneath the scrub and by calculating the ratio of the two values. The species composition of vascular plants and cryptogams was sampled in each plot and analysed by means of Detrended Correspondence Analysis (DCA) of cover weighted species using PC-ORD.

Results

The species composition in the three site types differed considerably (Fig. 1).

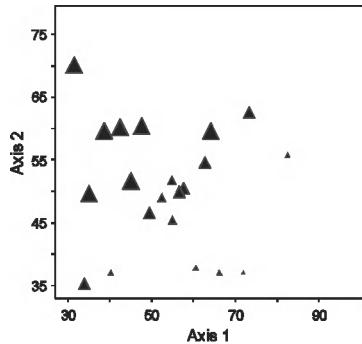


Fig. 1. Ordination of plots. The size of the plot symbol reflects the cover of shrubs.

At the upper left of the diagram plots with high shrub cover are found, at the lower right are situated those with low shrub cover.

Species richness decreased with increasing shrub cover, both with respect to total species number (Fig. 2) and with regard to the number of herbs and grasses as well as the number of mosses and lichens.

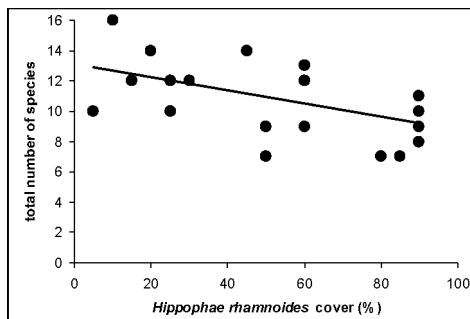


Fig. 2. Relationship between the shrub cover of *Hippophae rhamnoides* and total species number ($R^2_{adj} = 0.226$, $p = 0.017$).

Although the overall number of mosses and lichens was very low, their cover reached high values of up to 75% in the more open Sea-Buckthorn scrub. The cover of mosses and lichens decreased strongly with increasing shrub cover to values less than 20% (Fig. 3).

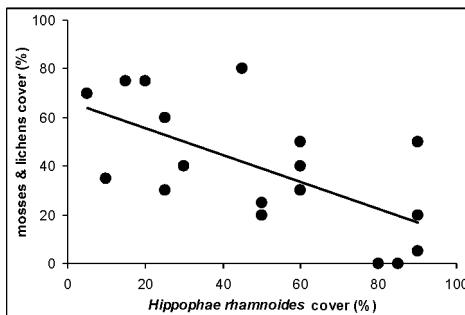


Fig. 3. Relationship between the shrub cover of *Hippophae rhamnoides* and the cover of mosses and lichens ($R^2_{adj}=0.421$, $p=0.001$).

In very open shrubland the relative irradiance beneath the scrub reached about the same level as above the scrub (Fig. 4). The light intensity decreased strongly when shrub cover increased to about 20%, then the decrease proceeded at a lower rate. In closed scrub the relative irradiance at ground level reached only about 10% of that above the scrub.

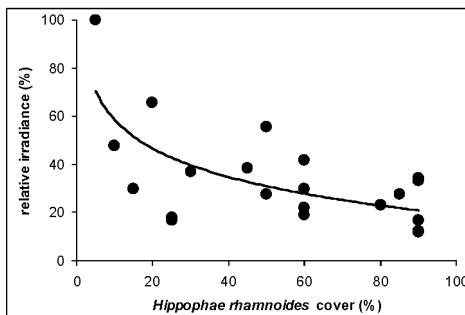


Fig. 4. Relationship between the shrub cover of *Hippophae rhamnoides* and the relative irradiance beneath the scrub ($R^2_{adj}=0.296$, $p=0.016$).

Discussion

The number of species decreased with increasing shrub cover, probably because of the strong decline in the relative irradiance beneath the scrub. In a similar study of Sea-Buckthorn scrub in Irish dunes the total number of species decreased more strongly by 50% (Binggeli *et al.*, 1992). In general, depending on growth form and foliage, the shading-out effect of scrub varies. The extent of the decrease in the number of species due to the shading-out effect depends on plot size; in smaller plots a marked decrease is already reached in the case of lower shrub cover (Rejmánek and Rosén, 1988). In dune

areas many regionally rare plants are found (Dunwiddie, 1997), hence the expansion of densely growing shrub species might be a serious threat to open semi-fixed dunes.

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Sandy coastline ecosystem management – Bridging sustainability and productivity of sandy beaches

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Abstract

Scientists, resource managers and medical experts today widely accept the idea that human society is dependent upon a healthy environment and that continued environmental degradation threatens the quality of life (Bickham *et al.*, 2000). Although direct links between ecological effects and human health have proven difficult to establish, the use of wildlife species as sentinels of environmental problems is the conceptual basis for this connection (Colborn, 1994). Furthermore, considering the principles of sustainable management of marine and coastal areas, defined in the Rio conference of 1992 (Chapter 17, Agenda XXI), the topic of sustainable management has acquired a fundamental role in the country policies all over the world, and must be faced at an international and multidisciplinary level. The intervention through management plans and the use of supporting tools in decision-making acquires particular importance for relatively fragile ecosystems such as sandy beaches.

Keywords: Sustainability and productivity of sandy beaches; Sandy shoreline ecosystem health and stability; Human impact; Integrated Coastal Zone Management; Integrated assessment.

Recommendations

Exposed sandy beaches are highly hydrodynamic. These ecosystems usually present low biodiversity and high specialization, due to the regime of permanent abiotic changes that governs their functioning. The tiny number of species, however, hide high biomass and production rates along all the trophic web, and the surf zone has been recognized as a nursery for many marine fish species (Brown and McLachlan, 1990). The biodiversity of, and the impact of tourism on, sandy beach biodiversity is a subject currently generating great scientific interest in Europe. It is the key topic of the international research programme “Sandy”, which involves scientists from 12 European countries and has recently been funded by the European Commission (e.g. MECO, MEDCORE, COSA, BaltCoast/IKZM-Oder). Part of this concern is expressed in initiatives like the SCOR Working Group 114 on permeable sediments (SCOR, 1998; <http://www.scor-wg114.de>). The Importance of Critical Transition Zones (including sandy beaches) was the focus of the SCOPE meeting (Levin *et al.*, 2001). To meet the challenge of progressing Integrated Coastal Zone Management (ICZM) and governance, baseline

interdisciplinary research is required (Emeis *et al.*, 2001). The importance of those ecosystems for the countries in different regions (*e.g.* Europe, South America, South Africa, Australia) has been pointed out in the workshop “Beaches: what future?” (Florence, 2001; Proceedings in Scapini *et al.*, 2003). This focused on adaptation of communities and populations along the world’s coasts and it highlighted the need of common protocols and frequent exchanges between the partners of the research network on beaches (Scapini, 2002). It set out to fill important gaps in our knowledge concerning sandy beach biodiversity in Europe, and to link beach biodiversity to tourist impacts, using both a descriptive and an experimental approach.

ESF Marine Board (2002) recommends integrated marine science to be needed to describe the polyfunctional properties, carrying capacities and limits of marine ecosystems. Integrated coastal zone and ocean governance policies and management are also needed to properly evaluate and sustainably extract the marine environment’s multitude of benefits for society creative fusion of marine science and environmental economics sets a new generic knowledge-based framework for delivering the practical policies, investment strategies and management actions needed for sustainable use of marine and coastal resources. The studies, proposed to be financed, should intend to confront a problem of fundamental importance in the environmental field of study, as the evaluation of the quality of the coastal environment, and its sustainable management is surpassing the local level to consider its general value. The beach ecosystem, in fact, has a strong relationship with the sea, which permits a communication between different beaches, over natural and political boundaries: the quality assessment has to be built under this global point of view, with a strong attention on the repercussions on local sustainable development. A number of levels and subject areas should be shown as related to each other in the ICZM projects.

Currently, some authors believe that studies – based on functional analysis of ecosystems – are better tools for scientific research and conservation purposes (Walker, 1992), considering functional diversity as a fundamental concept to be added to the traditional levels of biodiversity (genetic diversity, specific diversity, ecosystem diversity; Setälä *et al.*, 1998). This concept is particularly suitable to low biodiversity beaches, which are important as transition environments. The functional approach to the study of the ecosystem leads to an understanding of relationships between biotic and abiotic components, allowing the identification of matter fluxes and energetic relationships that govern the development and the functionality of the system. The same approach also permits one to follow the organisms’ adaptation and their role in fluxes control. Besides the functional analysis applied to the beach system represents an instrument for coastal management, providing useful information on ecosystem health to identify eligible interventions.

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Integral water management on the Wadden island Vlieland

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Abstract

As a result of the increasing knowledge of the causes of dehydration (the last 20 years) there had been a growing realisation that tackling only the groundwater recharge on the Wadden islands would not lead to the desired (partial) recovery of the hydrological system and the related nature value. It became clear that other activities and interests were exerting their influence on the hydrological system and, in turn, the groundwater level and quality, and the natural features that are dependent on them. It shows us that an integral approach of this problem has more effect than sectoral solutions. The two realised integral water management projects on Vlieland and Schiermonnikoog have shown this.

Keywords: Integral water management; Wadden islands; Restoration; Hydrological system.

Problem

Vlieland is one of the four Frisian islands. This island amidst the salty waters of the Wadden and the North Sea is a favourite holiday spot. Translated, the island's drinking-water requirement varies strongly in proportion to the number of tourists.

For the drinking water groundwater is used from the freshwater lens beneath the island. The yearly recharge is around $200,000\text{m}^3\text{yr}^{-1}$ and this demand is still growing.

Realised activities and results

The natural hydrological system on the Frisian Islands consists of an island with a freshwater lens underneath it that has been formed as a result of surplus precipitation. The freshwater lens is able to expand down to considerable depths under massive dunes. In addition to fresh rainwater infiltration to the subsoil, there is also shallow runoff via the dunes in the direction of the North Sea. Moreover, groundwater also flows through the soil and via the surface water out of the dunes in the direction of the Wadden Sea. Before the water reaches the Wadden Sea, it passes the inner edge of the dunes and the undiked salt marsh. The hydrology and related ecological features of the Frisian islands form a complex whole, within which all sorts of factors exert an influence.

This natural hydrological island system has been influenced in many ways in the course of centuries. The tidal salt marshes have been embanked and the water balance in the

resulting polders is highly regulated. The requisite number of changes in the dune areas themselves have been made. In some cases, localised areas of dunes have been drained for the cultivation of dune meadows. In order to fix the dunes, large areas of coniferous forests were planted on most of the islands around 1900. These areas have become dehydrated. Furthermore, the withdrawal of groundwater for drinking water supplies on the islands increased greatly after 1950 as a result of the growth in tourism. All these activities have had a detrimental effect on the natural hydrological island system. They are the logical result of a long-term social process that enabled the residents to survive, live and work on the islands.

As a result of the increasing ecohydrological knowledge of the causes of dehydration, there was a growing realisation that tackling only the groundwater recharge on the island would not lead to the desired (partial) recovery of the hydrological system. It also became clear that other activities and interests were exerting their influence on the hydrological system and, in turn, the groundwater level and quality, and the natural features that are dependent on them. To diminish the resultant dehydration, Vitens set up, with other parties, an integral water management project in 1994. Objective of this project was to restore the island's hydrological conditions as much as possible, on the precondition that an independent and sustainable waterproduction would still be possible on the island. The following solutions/results were found:

- reduce vaporisation in the coniferous forest by cultivating vegetation in the area;
- partial transfer of pumpingwells from the centre to the southern coastline of the island;
- partial transfer of pumping wells from the first to the second, deeper aquifer;
- nature-restoration project in the dune slack 'Kooisplek';
- supplementary hydrological and ecological monitoring in different dune slacks;
- the measured hydrological and ecological effects on Vlieland are positive.

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Evolution of sandy beaches in Estonia as indicator of increased storminess in the Baltic Sea region

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Abstract

Warmer winters, increased cyclonic activity and frequent occurrence of extremely strong storms in northern Europe seem to be closely related phenomena caused by climate change. Climatic changes in moderate and high latitudes have led to critical changes in the dynamics and development of coastal areas. In Estonia, the greatest destruction occurs on sandy beaches that are well exposed to waves and is associated with stormy periods when storm surge elevates sea level. Ice-free sea and unfrozen sediments enhance the activity of shore processes.

Keywords: Climate change; Shore processes; Sandy beaches; Baltic Sea.

Climate change and increased storminess

The Baltic Sea region has seen a statistically significant increase in mean air temperature from 0.5 to 0.9°C over the past century. Global climate warming is very well expressed also in Estonia. Statistically significant increase in monthly mean temperature is present only during the period from January to May with the maximum in March. The decrease in duration of snow cover in Estonia and ice cover in the Baltic Sea is also a clear consequence of the higher mean air temperature. Changes in atmospheric circulation over Estonia have taken place during the last decades. Warmer winters, increased cyclonic activity and frequent occurrence of extremely strong storms in northern Europe seem to be closely related phenomena caused by climate change.

Time series of annual frequency of storm days in the coastal stations indicate high temporal variations and a general increase in storminess. Results of the Mann-Kendall test show that the increasing trend in storminess is statistically significant on P<0.05 level. Change in annual frequency of storm days is significant in coastal stations of Estonia but changes in monthly values are of different magnitude. In general, increase in January and February is the most substantial.

Local sea level fluctuations caused by changes in the wind regime

SW winds prevail above the Baltic Sea with the increase in westerlies due to the climate change over the last half-century. In strongly indented and semi-enclosed coastal areas the conditions vary considerably between straight coasts and long tapering bays, leeward and windward sides of the sub-basins, etc. The local sea level differences may be up to 1m or even more at a distance of only about 100km. An increase in wind speed from specific directions, for instance 220° for the Pärnu Bay, elevates the sea level in that bay. The effect is very small in case of low wind speed values but very strong during storm events. The effect is more pronounced in semi-enclosed small sub-basins of the Baltic Sea, like the Gulf of Livonia and some others (Suursaar *et al.*, 2004).

Influence of increased storminess on shore processes

Warmer winters in moderate latitudes have led to critical changes in the dynamics and development of coastal areas. Extensive erosion and alteration of depositional coasts, e.g. sandy beaches, has been observed during the last decades in Estonia (Orviku *et al.*, 2003 *etc.*). The lack of evidence for sea level rise during this period suggests that beach erosion is largely due to the recent increased storminess in the eastern Baltic Sea. The greatest destruction potential in the coastal zone in Estonia occurs on depositional coasts that are well exposed to waves and is associated with stormy periods when storm surge elevates sea level. The results of comparison of maps from different times and the field measurement results in study sites clearly reveal an increased activity of both erosion and accumulation processes.

Dynamics of sandy beaches on Harilaid Peninsula

Changes in shoreline displacement and the shore processes characteristics have been studied throughout the 20th century on Harilaid Peninsula, NW Saaremaa Island. The north-westernmost point of the peninsula consisting of sandy beaches has migrated remarkably to the north-east during the last century. The main reason for the migration of the cape is intense erosion on the western coast and transport of sand along the western coast to the south, where it is re-deposited. Part of the eroded sediment is also deposited on the north-eastern and eastern coasts of Harilaid. Extrapolation from aerial photographs from 1957, 1981, 1995 and 1998 suggests the western coast has receded by over 30m or nearly 2m per year. The last three intense erosion events on NW coast of Harilaid have been recorded in winter 1999/2000, 2001/2002 and 2004/2005.

Measurements and calculations at Järve beach

A comparison of topographic surveys at Järve study site on the southern coast of Saaremaa made before and just after the stormy period in winter 1990 (eight days with storm, maximum wind speed 25m.s⁻¹, S, sea level +171cm) shows that the 4km-long scarp in sands had receded by 4-5m. Over 6,500m³ of sand was eroded from the scarp. This coastal destruction resulted from the cumulative effect of strong storms with high sea level and the absence of ice cover. During the next relatively passive period (without

severe storms) from 1990-1999, beaches in the west Estonian archipelago were more stable. A new vitalisation of shore processes has started since 1999.

Changes on the eastern shore of Ruhnu Island

Ruhnu Island in the middle of the Gulf of Livonia has experienced cyclic beach development. Sediment is typically transported along the eastern shore from north to south, which is deposited as an excellent sandy beach with foredunes and dunes. Strong southerly storms at the end of February 1990 (six days with storm with maximum wind speed 19m s⁻¹, S and SW, sea level +143cm) caused a reversal in sediment erosion, transport and accumulation processes. An extensive fresh scarp was eroded into the foredunes in the SE and the sand was transported along the shore to the north. A 1.5km long and 15-20m wide sandy beach was formed in the long-term area of erosion. During the next five years, the newly-formed beach was completely eroded away by northerly storms. The sand was transported southwards, and accumulated on a 10-15m wide active beach to form a series of young foredunes.

Adaptation and restoration options of sandy beaches in Estonia

A number of sandy beaches high in recreation value have strongly suffered from strong storms over the last half-century. Pirita beach in Tallinn, the capital city of Estonia, Pärnu and Valgeranna in the south-western part of the mainland, Järve beach on Saaremaa are just a few examples. In many cases natural processes without interruption of man can restore the destroyed beaches. In most cases preserving the beaches in good condition needs certain protection measures. Beach nourishment, an expensive technique used for instance in restoration of Narva-Jõesuu sandy beach in the end of the 1980s, has shown good results so far in Estonia.

Conclusions

The frequency and magnitude of storms has increased during the last decades. The most exceptional changes in shoreline position and contour of sandy beaches are attributable to a combination of strong storms, high sea level and ice-free sea. As a result, the balance between erosion and deposition is fragile and an initial shape of beaches may not be restored in natural way between the storms.

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Storm surges in the Oder Estuary in 2002-2003 – numerical study

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Abstract

The application of the 3-D operational hydrodynamic model, based on the POM model for the study and forecast of storm surges in 2002 and 2003 revealed its high usefulness. In case of high amplitude and significant water level fluctuations the model correctly approximated the changes of water level and reflected the hydrological situations properly. Potential users such as emergency command centres and services dealing with environmental and flood control as well as with the safety of navigation can take advantages from current 0-60-hour hydrological forecasts for the region of the Szczecin Lagoon and the Pomeranian Bay via a quick website access (<http://model.ocean.univ.gda.pl>).

Keywords: Storm surges; Numerical modelling; the Oder Estuary.

Introduction

The Oder River forms one of the major estuaries in the southern Baltic Sea. In its downstream reach, the Oder opens first into the Szczecin Lagoon. Then it drains into the Baltic Sea through three straits: the Swina, the Dziwna and the Peenestrom. That shallow, coastal water body is exposed among others to storm surges. Caused by deep low-pressure systems passing the Baltic Sea the storm surges are the result of wind activity and changes of atmospheric pressure on the sea surface.

The description of the model

In recent years numerical modelling has become an essential tool in the flood control of coastal areas (among others Funkquist, 2001; Kalas *et al.*, 2001). In our study a 3-D operational hydrodynamic model of the Baltic Sea, developed at the Institute of Oceanography, University of Gdańsk, was applied to the study and forecast of storm

surges in the Oder Estuary (Kowalewski, 1997). Theoretical and numerical solutions of the model were based on the coastal ocean circulation model known as POM (the Princeton Ocean Model), described in detail by Blumberg and Mellor (1987). The model was adapted to the Baltic conditions and for the 48-hour numerical meteorological forecast of ICM (Interdisciplinary Centre of Mathematical and Computational Modelling, Warsaw University). Because of wind-driven back-up in the Oder mouth, a simplified operational model of river discharge based on water budget in a stream channel was developed. Linking the Oder discharge model with the Baltic Sea model as one system made possible to simulate operationally water levels and currents as well as water temperature and salinity in the Oder Estuary (Kowalewska and Kowalewski, 2004). The adequate fit between the predicted and observed water level series from the gauging stations on the Szczecin Lagoon and the Pomeranian Bay encouraged to apply the model to studying and forecasting storm surges in 2002 and 2003.

Storm surges in the Oder Estuary

Fourteen storm surges were recorded in the Oder Estuary in 2002 and 2003. During five of them the typical wind-driven back-up in the Oder branches was observed. In those cases continuous increase of water level was observed, starting from the Pomeranian Bay and then within the whole estuary. Finally the continuous fall of water level was recorded. The negative phase of the wave caused by the changes of air pressure on the sea surface was clearly seen.

Six storm surges were observed during spring, melting season, while high water levels in the branches of the lower Oder were notified. In those cases the rise of water levels within the estuary caused by the passage of deep low-pressure system over the Baltic Sea was more intensive. Sometimes it resulted in flooding events like during storm surge from 19 to 27 February 2002 (Fig. 1). In Świnoujście, on 19 February, the water level decrease until 472cm was correctly approximated by the model. Then, sea level rise was observed till 635cm on 21 February as a result of low centre shifting over the Southern Baltic (overlapping of two effects: the strong north-easterly winds of 11°B and positive phase of baric wave). In Świnoujście, the maximum was predicted two hours before the real maximum in the forecast from 20 February and two hours after in the forecast from 21 February. The forecast of the rapid sea level fall to 415cm on 22 February, being the result of low shifting over Scandinavia (negative phase of baric wave), was accurate as far as the time and the minimum level are concerned. During that storm surge on the Szczecin Lagoon significantly weaker changes of water level were observed. In Trzebiez, the water level maximum of 596cm followed with 8-hour lag in comparison to the sea level maximum in Świnoujście. All the phases of the storm were properly approximated by the model as far as the time and the extreme levels are concerned.

Only two short-lived storm surges were recorded at the coasts of the Pomeranian Bay. They were the result of fast deep low shifting over the Baltic Sea like in the beginning of December 2003 (Fig. 2). Following the minimum water level of 459cm in Świnoujście on 5 December, correctly approximated by the model, the sudden rise of sea level began. It reached the maximum value of 594cm on 6 December. The forecast from 5 December overestimated the maximum and calculated it 6-hour earlier, however the forecast from 6 December underestimated it. The last one predicted the subsequent decrease of water level until the minimum on 7 December sooner as well. On the contrary, the forecast

from 7 December overestimated that fall of sea level. Because of the fast low passage on the Szczecin Lagoon significantly weaker fluctuations of water level were recorded, followed by a delay to sea level changes. It is because of too low flow capacity in the straits connecting the Szczecin Lagoon and the Pomeranian Bay. In Trzebież, the fluctuations of water level between 487cm on 5 December to 546cm on 7 December were properly predicted by the model.

Three storm surges were recorded caused mostly by the strong wind. In those surges both the increase and decrease phase of water level is slow and mild. The effect of the changes of air pressure is imperceptible. The raised water levels are observed within the whole estuary.

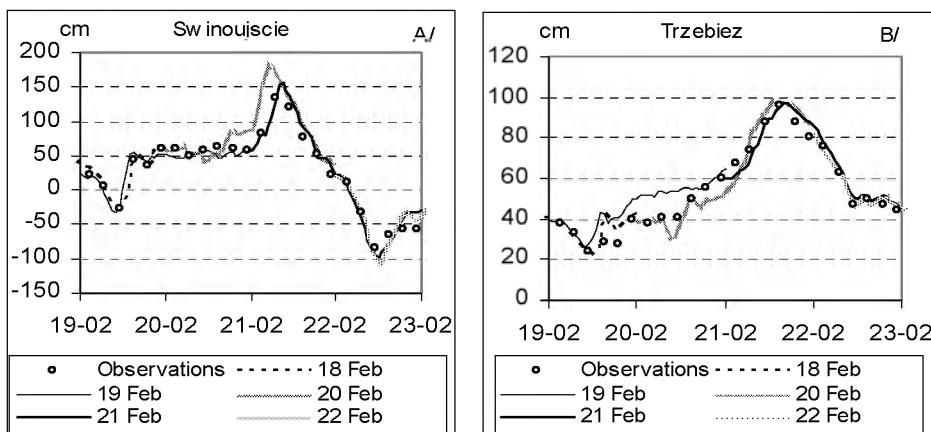


Fig. 1. Observed and predicted course of water level changes in Swinoujście (A) and Trzebiez (B) during the storm surge in February 2002. In legend: forecasts from 18 to 22 February.

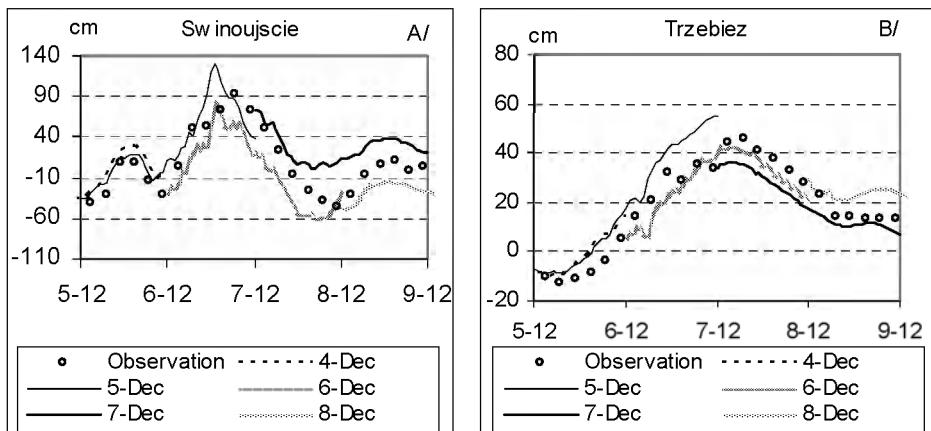


Fig. 2. Observed and predicted course of water level changes in Swinoujście (A) and Trzebiez (B) during the storm surge in December 2003. In legend: forecasts from 4 to 8 December.

Conclusions

The analysis revealed that the highest increases of water level were recorded in the cases of the movement of deep depression with a trajectory running close to the coasts of the Southern Baltic Sea (mainly the effect of air pressure) and strong northerly winds (damming up of waters close to the coasts). Overlapping of both factors caused the intensification and prolongation of the storm surge. In that case the reverse slope of water free surface was recorded. It resulted in the intrusion of brackish water from the Pomeranian Bay into the Szczecin Lagoon, reduced river outflow and rising of water levels within the whole estuary. Occasionally it resulted in flooding events like in February 2002.

Current 0-60-hour hydrological forecasts via a quick website access (<http://model.ocean.univ.gda.pl>) give potential users an opportunity to predict water level fluctuations, especially storm surges within the Szczecin Lagoon and the Pomeranian Bay. That information can be very important for emergency command centres and services dealing with environmental and flood control of coastal areas as well as with the safety of navigation and harbour operations. It may affect other areas of human life and activities, e.g. sport or recreation.

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Rise of groundwater level and vegetation development in the calcareous dunes near Haarlem, The Netherlands

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Abstract

Groundwater depletion in the dunes near Haarlem has led to a decline in size and quality of wet dune slack vegetation types. The 'Masterplan Regeneratie Duinvalleien Nationaal Park Zuid-Kennemerland' offers new chances for the restoration of wet dune slacks. After six years of vegetation monitoring the results offer interesting perspectives for the future.

Keywords: Regeneration; Wet dune slacks; Monitoring; Vegetation development.

Introduction

The coastal sand dunes near Haarlem comprise 3600 hectares and are part of the 'Nationaal Park Zuid-Kennemerland', managed by PWN (Water Supply Company of North-Holland), Staatsbosbeheer (State Forestry Service) and Vereniging Natuurmonumenten (Nature Conservancy).

During the past century the dunes have suffered from groundwater depletion as a result of several factors: drinking water production for the population in the region, reclamation and groundwater management of nearby polders, construction of a large canal through the dunes to the North Sea, and establishment of vegetation in formerly barren dunes. During the last decades nature managers more and more realized the deterioration of vegetations in dried-out dune slacks. The need for recovery became an important issue. In the same period new techniques of water extraction were developed. This offered possibilities for diminishing the extraction of dune water. Hydrological model-studies indicated that ending water extraction for drinking water would lead to an increase in the area of wet slacks from 35 to 300ha. It was realized that without accompanying management the rise of water levels would lead to an increase in vegetations with tall grasses and large herbs, and not to a restoration of characteristic dune slack vegetation types, because most dune slacks had formerly been used as agricultural fields. A plan, called the 'Masterplan Regeneratie Duinvalleien Zuid-Kennemerland' (Jaspers en Korstanje, 1999), was initiated to recover the characteristic ecosystems of dune lakes and wet dune slacks. In this plan several measures were

proposed such as low-density grazing with cattle and horses and yearly mowing. In some dune slacks vegetation structures such as grasslands, shrubs and woods were removed completely, including the nutrient-rich top soil layer, in other cutting sods was carried out up to the mineral sands. To attain a good judgment in the autonomous development of the dune slacks no management measures have been performed in some slacks.

New techniques of drinking water production from surface water have cleared the way for reducing the extraction of groundwater in the dunes from 14 up to 6,5 million cubic meters in 1998. In 2002 the extraction of groundwater was ended completely. As a result water levels have risen to about one meter and in some cases even more.

Research and results

In 1998 a research program was started to monitor vegetation developments in about 30 different dune slacks. The research was performed on the basis of fixed lines of permanent squares representing wet-dry gradients, or with so-called Tansley relevés. Each year one third of the plots were investigated. Preliminary analysis after 7 years of monitoring reveals various effects on the vegetation of dune slacks. In 2004 many dune slacks show development towards moist or even water vegetation types. In a few dune slacks the groundwater table didn't rise enough to enter the root zone, so no change in vegetation took place. At the time of writing, analysis is still under way (Kruijssen, in prep.). Therefore just some typical examples are presented here.

The dune slack 'Klein Olmen' showed a vegetation characteristic of dry calcareous grasslands belonging to *Taraxaco – Galietum* and *Festuco – Galietum*. Rising water levels just reached the root zone, causing the appearance and spread of some species confined to humid soils within these vegetation types. For the time being it appears that in this case there is no difference between dune slacks with or without a mowing régime. One of the first new settling species, *Agrostis stolonifera*, is a good example of this development.

When the water table rises well into the root zone of grasslands and shrubs, as in the dune slacks 'Langerak' and 'Kleine Zijp', these vegetations turn into 'roughs'. Plant species confined to nitrogen-rich soils establish themselves or increase in coverage, like *Urtica dioica*, *Eupatorium cannabinum*, *Lycopus europeus*, *Carex hirta*, *Galium aparine* and *Holcus lanatus*.. This is certainly the case when no accompanying management is being employed. A strong rise in water levels in *Hippophae*-shrub causes dying of *Hippophae rhamnoides*.

In dune slacks where measures like cutting sods and removal of topsoil have been employed we see the development of several moist vegetation types. In dune slack 'Houtglop', where the existing vegetation was removed as well as the top soil down to the mineral sands, the water level rose over two meters. During winter the dune slack is now inundated for about half its surface. One of the most valuable vegetation types of wet dune slacks, the *Junco baltici – Schoenetum nigricantis* is beginning to emerge, as shown by the establishment or increase of characteristic species like *Schoenus nigricans*, *Epipactis palustris*, *Parnassia palustris*, *Linum catharticum*, *Gentianella amarella* and

Bryum pseudotriquetrum. In dune slacks where comparable measures have been undertaken but which have become less wet than 'Houtglop' we see the development of another valuable but more pioneer vegetation type, the *Centaurio – Saginetum*, on the bare moist sands. Here pioneer species like *Centaurium littorale*, *Sagina nodosa*, *Gnaphalium luteo-album*, *Bryum warneum*, *B. algovicum* and *Didymodon tophaceus* are establishing. Dune slack 'Groot Olmen' is an example of this development.

Conclusions

Restoration of water levels in the 'Nationaal Park Zuid-Kennemerland' near Haarlem has lead to re-establishment or increase of several moist and wet vegetation types in the dune slacks. Without further management restoration of water levels leads to 'rough' vegetation types with tall grasses and herbs. Most dune slack vegetations are still in development.

Suggestions

Although water levels are stabilizing since 2001 many vegetations in the dune slacks are still 'on the move'. Continuation of the monitoring is therefore useful. In some cases adjustment of the management régime has been advised.

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Morphodynamics of the central Świna Gate Barrier foredunes (Polish coast) since 1995: a case study

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Abstract

The fieldwork was carried out on the Świna Gate Barrier shore (Polish Baltic coast). The investigations were started after a strong storm surge, that washed out foredunes on the Polish coast in November 1995. Since 1996, a new dune ridge has been observed to be expanding on the still developing beach. Although affected by storm surges and wave action, the new ridge has been persistent. The beach has become increasingly wider each year, more and more plants colonising the new dune ridge.

Keywords: Foredune morphodynamics; Aeolian processes; Świna Gate Barrier (Poland).

Introduction

The foredune is the first dune ridge behind the beach zone where sand continues to accumulate (*e.g.* Hesp, 1984; Carter *et al.*, 1990). During 1-2 years, the ridge may increase in height and grasses will stabilise it within the subsequent 5-8 years (Carter *et al.*, 1990). A developing coast and a progradating dune system of middle Świna Gate Sandbar is a rarely encountered phenomenon on the Baltic coast. The multi-year morphology changes on the investigated area show that particularly the middle part of spit on Wolin has tendencies for rapid dune development.

Study area and methods

The study area is located on the islands of Wolin and Usedom on the Pomeranian Bay coast (Fig. 1). In Poland, the spit extends for c. 16km from the morainic plateau at Międzyzdroje (Wolin Island) to the state border in Świnoujście (Usedom Island). At present, the entire barrier is covered by dune ridges formed during different accumulation stages. The ridges differ in morphology, lithology, and trending to reveal the consecutive phases of spit accretion and development. The youngest dunes, termed the “white dunes”, have been forming since the 17th century. The study area is affected primarily by westerly and southerly (S, SW, W) winds (as recorded over 1961-1995 in the town of Świnoujście), while the north-easterly winds are the heaviest. Prolonged wind action enhances material transport from beaches located west and east of the area

to its central part. The upper beach is built up mostly by medium and fine sand (35 and 60%, respectively). The material building the foredune ridge contains up to 85% of fine and very fine sand and not more than 15% of medium sand. In winter, the importance of medium sand in the foredune increases (to 30- 40%) in winter. Plant species typical sand accumulation on young dunes or dune fields include the psammophilous *Ammophila arenaria*, *Calamophila baltica* and *Elymus arenarius* and the halophilous *Honckenya peploides*. Other plants are characteristic of older fixed dunes.

The study involved measuring (i) dune relief changes, (ii) vegetation dynamics, (iii) human or animal influences, (iv) storm surges impact, and (v) wind impact. The measurements were taken several times during the year, particularly – and whenever possible – after every major manifestation of factors impacting the dunes. Relief changes were measured with geodesic devices from fixed plots (5x5m) along transects (1km apart, in various areas).

Other measurements provided

comprehensive information on the dynamics of the entire environment, e.g.: sand grain size, wind fields, vegetation dynamics or storm surges. The study is a part of the author's project focusing on the entire belt coastal dunes in Poland called ANDDY (Anthropogenic-Natural Dunes Dynamics; web pages: bramaswiny.szc.pl and polishdunes.szc.pl). The aim of the paper is to describe the development of the central part of the Świna Gate Barrier (Polish coastline kilometre 420-421; Fig. 1).

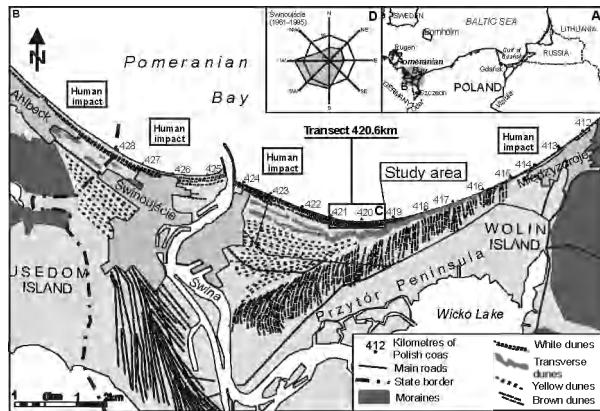


Fig. 1. Location of the Świna Gate Barrier (B) on the Southern Baltic (A); study area (C); wind rose (D).

Foredune morphodynamics

In 1995, the upper beach of the area between 420-421km, up to 30m from the foredune, featured numerous small, 0.1 to 0.5m high, aeolian forms and was vegetated by pioneer plants. Hillocks on the beach were separated from each other by deflation depressions, the blow-outs, with organic material accumulated on their bottoms. The mean width of the beach was about 60-90m. The seaward slope of the foredune, i.e. the dune ridge closest to the beach and not yet stabilised, was abraded. The foredune measured up to 4m in height. In late autumn 1995, a very strong storm (surging to 1.5m above ASL) destroyed the beach's dense hillocks and plant habitats. It also cut the foredune off and/or washed it away in many places. In late spring 1996, however, the upper beach was again covered by numerous small aeolian forms. Locally, the foredune still showed an abraded seaward slope, but storm gaps were in many places filled up by the accumulated sand. Rather low (up to 0.2m) sandy "tongues" were seen on the foredune top. As of 1997, the hillocks were growing in size (Fig. 2). In some places they

connected with the foredune slope and looked like long, grass-fixed tongues running across the ridge and the water line. The increasingly denser grasses entrapped progressively higher amounts of sand. The highest hillocks and grasses posed major obstacles to the aeolian transport. Consequently, sand accumulation on the foredune was clearly diminishing, whereby the ridge was slowly becoming stabilised (by other plants). As a result of aeolian accumulation, the abraded seaward slope of the dune became initially transformed into a gently-shaped form. Between the ridge and a new one that was growing a deflation depression – a blow-out – appeared. Between 1998 and 2000, the narrow depressions between the hillocks were filled up by the sand. The embryo dunes became linked into a single dune ridge, parallel to the old one. The landward slope of that ridge was steep, the seaward one being flat. The new foredune did not have any straight ridge. It was a single ridge consisting of joined-together tops of the embryo dunes. Ridges of the embryo dunes run transverse to the new foredune ridge. The ridge described reached up to 2m. In front of it accumulation process and plant succession started again. In autumn and winter 2001, a few heavy storms (water level to 1.5m above ASL) damaged the dunes, with several storm gaps appearing in the foredune ridge of the studied area. The gaps, wider than 20m, allowed sea water incursions to the low-lying ground behind the foredune. No storms affected the area in winter 2002. It was only the ice cover of the beach that stopped sand transport from the lower beach in the direction of the foredune direction. In spring 2002, the sand accumulation process started filling all the gaps and gates in the foredune. The next cold season proceeded without storms; the accumulation was very small (0.1-0.2m), even on fixed dunes. In spring 2003, the foredune was up to 3m high. The low-lying part behind it became stabilised. During the growing season, a slow colonisation by mosses and lichens was observed. The sand was transported only through the storm gates where an active surface was visible. In autumn 2003, the foredune ridge was damaged by a single storm surge (with water reaching 1.5m above the ASL) and the entire upper beach was levelled off. The dune hillocks (up to 0.6m high) were cut off and the deflation depressions were filled with sand; the beach, however, was still c 70-90m wide. The heavy wind during the storm in question produced aeolian accumulation on the surfaces behind the foredune, fixed previously by mosses. In early spring, the sand, blown over the foredune from places that had not been ice-covered, accumulated on it, producing an 0.4m thick layer; the sand accumulated also in the previously stabilised depression between the first two dunes. In spring, the foredune was 4m (ASL) high and completely covered by grasses. Until summer 2004, the upper beach was covered by numerous hillocks 0.3-0.7m high. They were covered by grasses growing at a density comparable to that observed in 1997.

Conclusions

The foredune in the central part of the barrier is not sufficiently stabilised by grasses and wide enough to withstand heavy storms. The foredune has been rising for the last 9 years. The former foredune had emerged in the area between 1986 and 1995; its formation took 9 years as well. Last autumn (2004), the foredune began to be colonised by plants that, as opposed to those that had been establishing themselves before, were not tolerant of sand fill-up.

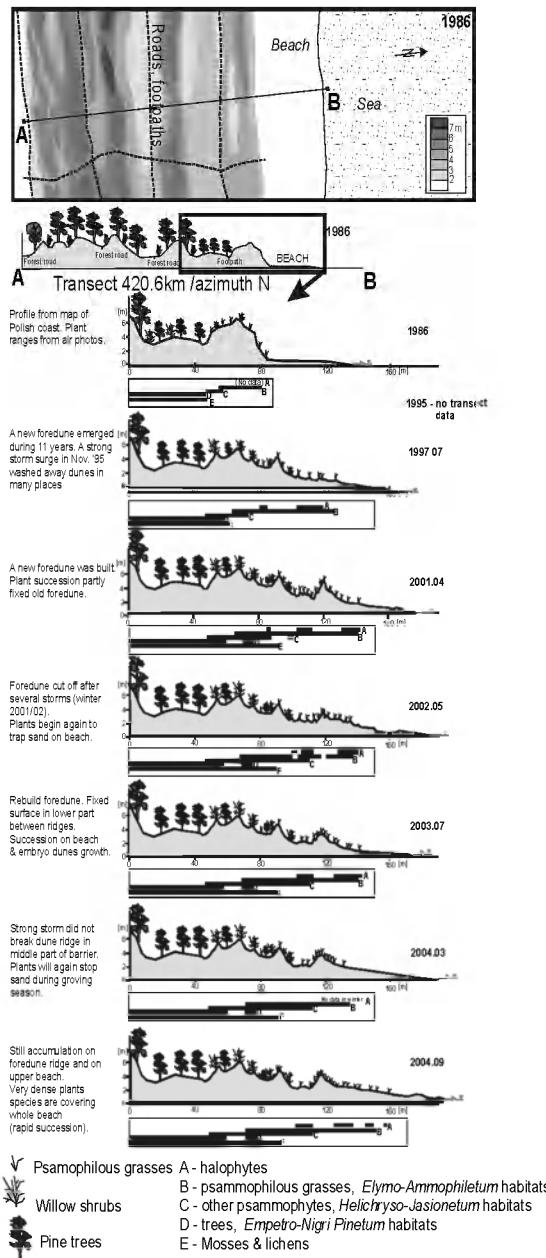


Fig. 2. Foredune morphodynamics with habitat changes in the central part of the Swina Gate Barrier: an example transect at km 420.6 off the Polish coast.

The new initial field of the foredune (third since 1986) was 30-40m wide, consisting of dune hillocks (shadow and embryo dunes) up to 1m high, densely vegetated by grasses. New dunes in the area do not develop at an identical rate; instead, the rate varies due to the wind and storm events. The winter season in the area may feature numerous storms one year (as in winters of 1995/6, 2001/2 or 2003/4) to be devoid of them next year. The same is true with respect to the wind regime. As a result of all the factors, new dunes emerge and will probably do so in the future. Storm surges are causing abrasion of the dunes but supply the beach with material. Low thickness of sand helps in aeolian transportation along barrier beaches. Absence of mass tourism leads to natural dune development in the middle part of the investigated barrier.

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Tourists ecological awareness – key to understanding human behaviour in coastal environment

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Abstract

As developing tourism endangers the environment today we should recognise people's rest preferences, knowledge and lifestyle to protect and properly use coastal natural values. This paper shows some conclusions from data collected on the basis of the questionnaire (22 questions and 200 respondents) carried out with tourists in the years 2002 and 2003 on Polish beaches. The main research question was on what tourists' ecological awareness depends? In many questions education, pollution and litters were the main problems pointed by asked tourists. But also it is clearly visible, that people do not want a lot of buildings and infrastructure close to the beach. For them bigger value is the natural landscape and environment in which they can really rest.

Keywords: Ecological awareness; Human behaviour; Coastal socio-economic problems.

Introduction

Settlement, tourism and economy development has a negative impact on coastal areas. Major impacts of tourism industry in coastal areas are (i) infrastructure with hotels, transport system and garbage, (ii) recreation with human activity, and (iii) coast protection against abrasion. If the coastal environment is damaged or destroyed, tourism will decrease. Too less attention for the environment is equal to a smaller number of tourists and a smaller income from tourism industry. People do not think about threats for coastal environment. Tourists and citizens of the coastal villages do not have knowledge about coastal processes and dangers caused by storm and human impact. It is seen in their behaviour: left litter on the beach, trampled dunes, more and more construction for tourism close to the beach. If we want to protect and keep natural environment we should strongly influence on tourism participants to change their knowledge and behaviour. Today when developing tourism endangers the environment we should recognise people's rest preferences, knowledge and lifestyle to protect and properly use coastal natural values. The critical issue for decision-makers in such matters would be the empirical question about the degree to which any proposed uses deprecate the resource. Since the basis of our principle is a respect for the values of others, the strategy that minimises user impact overall most respect those who argue for

preservation and least respect those advocating various consumptive uses (Harman *et al.*, 2004). A first step in promoting the improvement of the environmental situation is to make information and knowledge about it available (Ryden, 2003). The ecological awareness should be understood as defined level of knowledge about threats of life and health resulting from unsuitable relation of man to nature. Awareness consists of knowledge, opinions and imagination, also values and norms of the behaviour (Fig. 1).

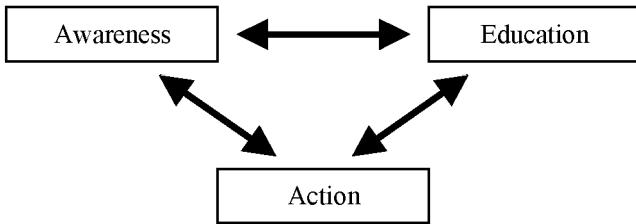


Fig. 1. Relation of awareness, knowledge and behaviour-action (Ryden, 2003).

Methods and the aim of the study

This paper shows data collected on the basis of the questionnaire (22 questions and 200 respondents) carried out with tourists. Used questions were about (i) knowledge about coastal environment and its dynamics, dangers, (ii) opinions on its theme, (iii) its value for tourists, (iv) behaviour presented by tourists in environment. The main research question was on what tourists' ecological awareness depend? These researches were done on beaches of Polish coastal villages in the summer 2002-03 (data in this paper is only from 2002 research with 100 respondents). The study is the sociological part of an own research project ANDDY (see in web: polishdunes.szc.pl).

Tourists awareness in the light of their opinion on the coast

To the question about what adds attraction to the seaside landscape and environment, most of all people answered that it is the contact with the sea, rest on beach and microclimate. Only few people answered (below 20%) that these are also: promenades, historic places and museums, recreational infrastructure, park with reservations and luxurious hotels (Fig. 2). Tourists, observing polluted beaches, dunes, sea and villages probably understand the threat for nature from human impact. To the question about kinds of preservation of seaside nature over 60% of the tourists pointed on: taxes and punishments for nature poisoning, paths to walk, not roads for cars, sewage treatments, selection of litter and education (Fig. 3). Among the proposed threats for seaside nature (Fig. 4) most persons pointed quantity of litters and waste material (79%), absence of sewage treatments (67%) and the increasing number of tourists (54%). For most respondents the presence of large numbers of tourists in little seaside villages is the threat for nature (81%). Infrastructure development close to the beach is a major problem of tourism development and for coastal protection. In a separate question about these investments only 10% of the tourists answered: 'yes - it should be built close to the beach' (restaurants, hotels), but 65% answered: 'no!'. To the question with a picture of a natural coast and a coast covered by infrastructure (town), 84% of people prefer a natural

landscape; only 22% prefer a coast with town buildings. Also 79% of the interviewed tourists prefer to rest in small villages, because of the calmness, silence and absence of tourists.

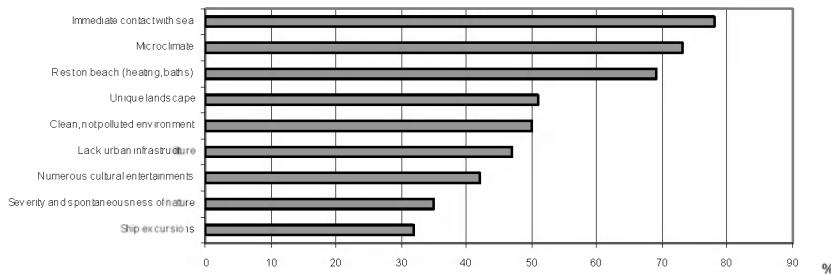


Fig. 2. Respondents opinion on the theme of what adds attraction to the seaside environment (over 30% of answers) (Labuz 2003ab).

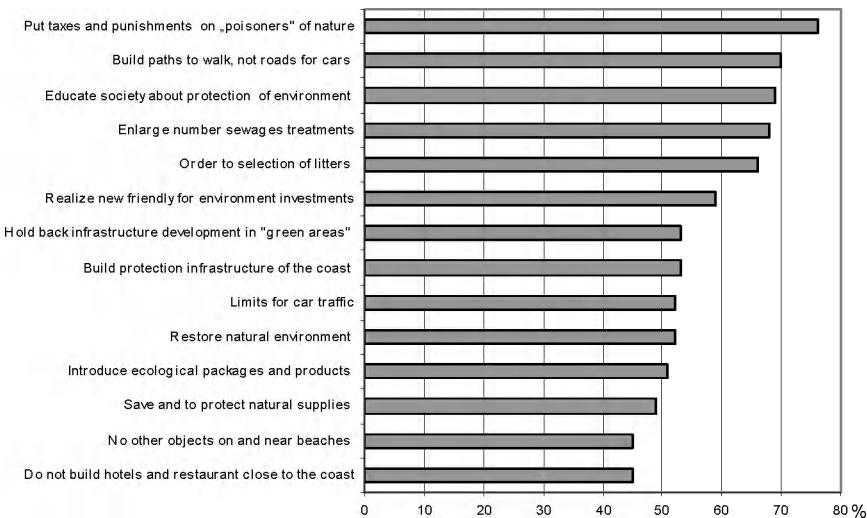


Fig. 3. Respondents opinion on what kind of action really protects the seaside environment (over 45% of answers) (Labuz, 2003ab).

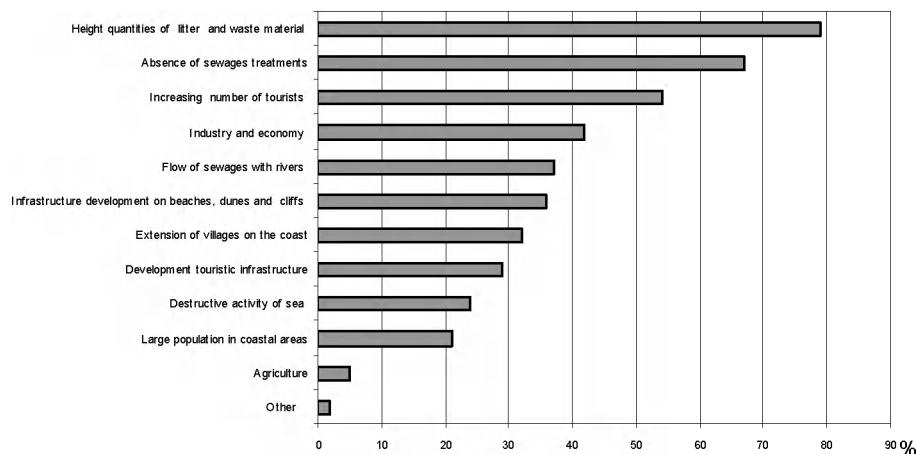


Fig. 4. Respondents opinion on the theme of threats for seaside nature (Labuz, 2003ab).

Conclusions

In many questions education, pollution and litters were the main problems pointed by asked tourists. But also it is clearly visible, that people do not want a lot of buildings and infrastructure close to the beach. For them the natural landscape and environment in which they can really rest is more important. Probably a better knowledge of the coastal environment may increase their friendly activity for the environment. Local communities and schools should take care of the education on the seaside environment. Various opinions not true knowledge and not accepted behaviours of tourists should be regulated. Their awareness and attitudes should be changed. In other cases the natural environment will be soon destroyed. And social costs of protection will rapidly increase.

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Characterization and preservation of silt-laden soils in the humid depressions of Hatainville's dune massif (Manche, France)

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Abstract

Hatainville's dunes have become a symbolic example on the western coast of Cotentin on how to preserve a remarkable natural heritage be it from the point of view of geomorphology, landscape or flora. The study of the silt-laden soils in the humid depressions of the dune massif appears to be essential in order to understand the process of floristic growth and the presence of hygrophile vegetable communities.

Keywords: Silt-laden soil; Humid depressions; Dune massif; Hatainville; Preservation.

Introduction

The dunes on the Cotentin western coast are a remarkable natural heritage whether from the point of view of geomorphology and landscape or at the biological level of fauna and flora (Provost, 1975; Livoiry and Stallegger, 2001). Since 1976, many dune sites in south Normandy have been purchased by the 'Conservatoire du Littoral' in order to preserve natural environments. Hatainville's dunes have become a symbolic example of the work done by the 'Conservatoire du Littoral' of south Normandy. A preservation plan is being elaborated, promoting experimental action in the site in order to preserve a living and diversified dune massif. Because of their extensive resources, the preservation of the humid depressions in Hatainville's dune massif is considered a priority aim in the general preservation project as defined in conformity with the document set up and signed in 2001 for Natura 2000 sites (Mouchel, 2001; Galloo, 2002). If that wealth is partly related to the topo-geomorphological conditions of the site, it is actually revealed through the nature and properties of the soils, resulting in ecological and floristic diversity. The study of the soils thus appears as essential to understand the process of floristic growth and the presence of rare or more common plants. That is why, for two years now, we have been focusing on the research of the relationship between soil and vegetation in the humid depressions, so as to give the administrations in charge of Hatainville's site food for thought in terms of management recommendations aiming at the preservation of the dune ecosystem.

Characterization of silt-laden soils

If the relationship between the texture of the soils with the sand basis is generally observed, the significant presence of silt in many pedological profiles is truly typical of soils in humid depressions (Le Gouée *et al.*, 2005). Those silt-laden soils thus appear as a particularly interesting natural heritage as they are closely linked with the presence of hygrophile vegetable communities among which, for example, *Apium repens*, a species mentioned in Annex II of the ‘Directive Habitat’. A close analysis both on the site and in laboratories has made it possible to describe the silt soils very accurately, to define the origine of these soils, to confirm the importance of their hydric properties for hygrophile communities, and to work out a precise map of the humid depressions characterized by that type of soil on the site.

The appearance of silt-laden soils is quite recent; indeed it occurred in the 50’s when the deflation process of the sands was stopped as the vegetables gradually stabilized the dune massif. The thinness of the pedological cover and the process of carbonatation are evidences of the juvenile character of the soils. The origin of the silt is both biogenic and detrital. As local phreatic waters are renewed over winter months, intra-dune depressions are recurrently filled up. The appearance of shallow pools gives life to aquatic ecosystems where diatoms and characeae can develop (Round, 1992). These decamicrometric weeds form a deposit in the depressions once the waters have completely levelled away. The repetition of this phenomenon accounts for such particles covering the sands. Besides, the examination of the silt soils under the microscope shows that the biogenic elements are caught in a bidetrital matrix made of quartz grains and gastropod fragmites that have been brought into the depressions by the wind. Eolian particles settle down depending on how sheltered the depressions are and how much of a trap the pools can be.

When subsoil waters level away, the hydric needs of hygrophile vegetable communities then become dependent on the quantity of useful available water, on how it can get depleted and renewed. Laboratory analysis first shows large quantities of useful available water, about 100mm. This results from an important organic fraction, with a significant capacity of water retention. Besides, the analysis of the curves of characteristic moistures reveals a very gradual depletion of useful available water during drying sequences. Hygrophile vegetables benefit from a hydric environment that is favourable to their development in spite of lusting drying conditions. Last, the renewal of useful available water is efficiently ensured by a very good surface absorptivity when rainfall is low and the presence of significant capillary rises when phreatic water is just below the topographic surface (Hillel, 1974).

The surveying of the humid depressions characterized by silt-soil shows they are generally situated half-way between the higher beach and, further inland, the paleocliff. The confrontation of GPS surveys with centimetric precision in x, y and z with the piezometric values show that the location of silt soils corresponds to the areas where the depressions are most likely to fill up with water as lastingly as possible.

Conclusion

Actions for the protection of diversity and ecological resources are associated with the tradition of extensive pasture which contributes to the preservation of Hatainville's dune massif. Yet, the watering places which the humid depressions can be are not numerous enough. The high density of cattle around the pools leads to an intensive trampling of the soil which seriously endangers its edaphic and ecological balance. The preservation of silt-laden soils as natural heritage thus goes together with the creation of artificial pools accessible to cattle.

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Conservation of dune systems: contributions from morphodynamics and vegetation ecology

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Abstract

Coastal areas are extremely dynamic and sensitive systems which undergo geomorphological changes that reflect the conservation status of both aeolian forms and plant communities. Recently, several studies have been performed in order to correlate aeolian forms (as the landscape supporting framework) and associated vegetation complexes. Evidence shows that a close relationship exists between dune vegetation and coastal dune types, supporting the idea that they can be used as the background for bioindication models of erosion and stability in the coastal zone. In this paper, we discuss results from recent studies and identify the main indicators of coastal processes and related dynamics. We stress that coastal planning and management require integrated studies, including the knowledge from several scientific approaches.

Keywords: Coastal stability; Geoforms; Plant communities; Sedimentary dataset.

Introduction

Coastal areas suffer shaping due to natural processes like sea level changes, coastal processes, climate, sedimentary budget and neotectonics, which result in changes like coastal advance or retreat (Granja *et al.*, 2000; Favennec, 2002; Soares de Carvalho *et al.*, 2002). In spite of the recognized importance of anthropic influence on inland beach migration, the so-called 'coastal/beach erosion' is now accepted to be mostly due to natural causes, the human influence being complementary and with limited impacts when compared with natural processes.

Cyclic natural geomorphological transformations in the coastline are being studied through the use of georeferenced aerial photographs complemented by the study of sedimentary sequences. Vegetation analysis also gives important information about the conservation/evolution status of littoral areas. In fact, the close relationship between geomorphology and plant communities along the dune system is being documented by several authors who stress the importance of integrated studies in order to achieve well-supported knowledge on coastal areas.

Coastal systems: vegetation vs. geoforms

The close relationship between coastal geoforms and vegetation is nowadays widely accepted and is being used as a diagnosis and evaluation tool of the conservation status of coastal systems. This method relies on the fidelity of sand dune vegetation types to specific biotopes within dune systems, and can be performed by using:

- 1) presence/absence of specific vegetation types (*e.g.* Granja *et al.*, 2000);
- 2) abundance of species and of character-species in each vegetation type; and/or
- 3) the occurrence of vegetation types in ‘secondary’ (=atypical) positions within the dune system (*e.g.* Loidi, 1994; Araújo *et al.*, 2002).

Embryonic dunes (foredune system) are closely associated to beach dynamics, so they can be considered efficient indicators of recent coastal evolution. It is possible to distinguish several scenarios concerning the contact between beach and dune system:

- 1) absence of embryonic dunes – these situations distinguish coastal areas under continuous erosion phenomena and can be recognized according to both geomorphological (contact between beach and dune system is performed by cliffs) and phytosociological (absence of *Euphorbio-Agropyretum junciformis* vegetation) features;
- 2) presence of stable embryonic dunes – in this case, due to a balanced sediment budget, the contact between the beach and embryonic dunes is gradual and smooth, and *Euphorbio-Agropyretum* communities are well represented; and
- 3) accretion *vs.* regression phases – frequent situations in which accretion phases alternate with regression ones.

Modifications in the foredune system (both geomorphological and ecological disturbances) induce changes in the entire dune system as higher accumulation of mobile sand in its internal face results in dramatical ecological changes in the plant communities of interior dunes:

- 1) an increase of vegetation types which are normally typical of embryonic (*Euphorbio-Agropyretum*) and foredunes (*Otancho-Ammophiletum australis*); and
- 2) a decrease of character species of both the *Iberidetum procumbentis* (typical perennial vegetation) and the annual communities of interior dunes (*Thero-Airion*), whereas character species of both the *Euphorbio-Agropyretum* and the annual pioneer vegetation of highly mobile foredune sands (*Linaron pedunculatae*) typically increase. Anthropic influences (*e.g.* stepping and driving on dunes) act as a complement of natural causes and may favour both the disruption of embryonic and foredunes, and the replacement of *Iberidetum procumbentis* by annual nitrophilous formations of class *Stellarietea mediae* (Araújo *et al.*, 2002).

Conclusions and conservation remarks

In conclusion, we stress that natural dynamics strongly influence aeolian forms present in dune systems, as well as their plant communities. This close relationship between dune types and plant communities should be widely used as a diagnostic tool for both conservation and planning purposes. The main advantages of such approach are:

- 1) the integration of geomorphological and biological data, allowing a more complete diagnosis of the coastal segment;
- 2) the performance of accurate evaluations of current preservation status and near future trends of dune system dynamics; and
- 3) the possibility of establishing reliable indicators to monitor the geomorphological changes, as well as changes in plant communities, generated by both natural and anthropic causes.

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New perspectives for fish in the Scheldt Estuary

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Abstract

The integration of a 600ha floodplain to the stream corridor of the tidal freshwater Scheldt Estuary will increase populations of eurytopic and rheophytic b species.

Keywords: Estuarine fish community; Controlled floodplain; Habitat restoration.

Introduction

After severe flooding in 1976, a flood prevention plan was developed to protect the tidal Scheldt catchment from new calamities. The plan comprised the construction of 512km dikes, 1133ha controlled floodplains and a storm surge barrier. The largest floodplain (578ha) is now under construction on the west bank of the river at Kruibeke, Bazel and Rupelmonde. The integration of the floodplain to the stream corridor is expected to significantly alter the structure and abundance of different fish populations in the river. Using different life history characteristics of estuarine fish species, we attempt to make a qualitative assessment of future changes to the species composition.

Reference condition

The fish community of Western European lowland rivers under tidal influence consists of about 20 rheophytic species, showing a particular preference for slow running, warmer water (Table I). Rheophytic A (RA) species use only the channel and the riparian zone. Examples include anadromous lampreys, salmonids, shads and sturgeon. RA cyprinids are mainly restricted to headwaters and are uncommon in lowland rivers. Apart from the river lamprey *Lampetra fluviatilis*, most species are absent in the tidal freshwater reach of River Scheldt due to population extinctions, migration barriers, spawning habitat reduction and overall pollution. Rheophytic B species (RB) include burbot, loaches and some cyprinid species. The species make essential use of backwaters along the river during their life history. Only *Leuciscus idus* is a typical member of a lowland river fish community but it occurs only sporadically in the Scheldt Estuary.

Rheophytic C species (RC) are confined to slow running brackish waters. These species are frequently caught in the river. Eurytopic species (E) do not have particular habitat demands. In dry periods, marine fishes may penetrate this zone while also typical limnophytic fish preferring lentic waters can be found. Both groups are not considered here.

Table I. Reference fish fauna for a tidal fresh water estuary with respective life cycle category and spawning habitat [for abbreviations, see text; relative abundance based on average daily fyke net catches in the Scheldt at Antwerp (4: >1 fish day⁻¹; 3: >1 fish week⁻¹; 2: >1 fish month⁻¹; 1: >1 fish year⁻¹; 0: not present); expected change in the population size after integration of the floodplain to the river corridor (+: increase; 0: no change)]

Species name	Abundance	Life cycle	Spawning habitat	Expectation
<i>Abramis brama</i>	3	E	plant or substrate	+
<i>Acipenser sturio</i>	0	RA	gravel	0
<i>Alosa alosa</i>	0	RA	gravel	0
<i>Alosa fallax</i>	0	RA	midwater	0
<i>Anguilla anguilla</i>	4	E	ocean	0
<i>Coregonus oxyrinchus</i>	0	RA	midwater	0
<i>Esox lucius</i>	0	E	plant	+
<i>Gasterosteus aculeatus</i>	4	E	nest	+
<i>Gymnocephalus cernuus</i>	2	E	gravel	+
<i>Lampetra fluviatilis</i>	1	RA	gravel	0
<i>Leuciscus idus</i>	1	RB	plant or substrate	+
<i>Liza ramada</i>	1	RC	ocean	0
<i>Osmerus eperlanus</i>	3	RC	sand	0
<i>Perca fluviatilis</i>	3	E	plant or substrate	+
<i>Petromyzon marinus</i>	0	RA	gravel	0
<i>Platichthys flesus</i>	4	RC	ocean	+
<i>Pungitius pungitius</i>	1	E	nest	0
<i>Rutilus rutilus</i>	3	E	plant or substrate	+
<i>Salmo salar</i>	0	RA	gravel	0
<i>Salmo trutta</i>	0	RA	gravel	0
<i>Silurus glanis</i>	0	E	soft bottom	0
<i>Stizostedion lucioperca</i>	2	E	nest	0

Future development of the fish community

We expect that the floodplain will autonomously develop into a fish nursery as long as permanent aquatic habitats are provided: small ponds and creeks are refugia to which juvenile fishes withdraw once the flood water is drained to the main river channel. The increased availability of spawning and nursery habitat is predicted to result in a notable increase of the total fish density in the oligohaline and freshwater parts of the estuary. The addition of inundated areas to the stream corridor particularly favours RB species such as ide (*Leuciscus idus*), which is now virtually absent in the Scheldt Estuary. Measures that support the recovery of the ide population may therefore be successful.

However, not all species are likely to increase in abundance. Anadromous fish such as *Lampetra fluviatilis* and salmonid species will not benefit from increased habitat diversity since their distribution is limited to the main river channel.

Hydrological conditions for the survival/remaning of a unique southern Baltic marsh as a habitat of endangered fauna and flora species

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Abstract

The coasts of the southern Baltic are characterized by diverse environmental conditions, caused by different genesis of physical and biochemical processes. In this special region where an interaction of salt-water with fresh water occurs, there are essential differences in local hydrological conditions. The southern Baltic is famous for separate, extensive branches of great rivers, direct mouths of rivers from postglacial lake areas, estuaries, coastal lakes (inner-dune, trough, deltaic) and numerous wetlands. Quoted types of objects differ from one another by area, depth and connection with the sea.

Keywords: Marsh; Coastline; Habitat; Human influence.

The uniqueness of the southern Baltic marshes

The current environmental condition of the Polish coast is a result of both a natural development and human activity, as well as of water circulation. For several years the Department of Hydrology of Gdańsk University conducts research in order to define the hydrological conditions, which must exist if these unique environments are to remain. One of the objects of our interest is a unique hydrological area on the Polish stretch of coast-marsh, located near the Reda river mouth and Puck Bay (Gdańsk Bay – southern Baltic).

The object of investigation

Salt-marshes are very attractive as regards environment, landscape and tourism. This is an area of landscape protection (Seaside Landscape Park), proposed for the system of Baltic Sea Protected Area (BSPA). This is also a mainstay of European rank.

In 1988, in order to preserve and take into account the avifauna breeding and flying (*Calidris alpina schinzii*, *Motacilla citreola*) as well as moisture salt meadow so-called

Juncetum gerardi (*Plantago maritime*, *Epipactis palustris*), Beka reserve has been established. Marsh is a low-situated zone in humid times swamped by the soil-water. From a hydrological point of view, the uniqueness of this marsh is a result of the fact that the marsh is situated on a coast with a half-closed sea, where tides do not exist. Fluctuations of water level induced by wind set-ups are the factors which cause cyclic swamp.

Natural conditions

All the hydrological conditions result in biotope environmental (halophile plants, flying fowl, periodic settled and breded flow) variability. They cause sea-water intrusions from Puck Bay. They create numerous, ephemeral pools. Simultaneously from the higher parts there is a confluence of fresh water. The hydraulic gradient is minimal. That is why the phreatic waters are low. The effects of this fact are the spatial and temporal differences in physical and chemical water composition. They decide about the remaining or extinction of unique habitats of endangered flora and fauna species in the southern Baltic.

Anthropogenic pressure

Very essential for the preservation of this area is human activity. The positive action is an annual mowing of reed during the spring time. This makes the reed weaker. A grazing of different species of animals also positively influences the salty plant. The animals that are grazing are: cows, sheep and horses. Also the number of animals changes. The best animals for grazing are the cows, whereas the worst are the sheep. That is because the sheep eat the plants growing a few millimeters from the ground.

The negative fact is that in this place there is no proper supervisor over the land improvement system. The result is the overgrowing of a number of channels, hence their reduced conveyance and hydrological rank. Simultaneously uncontrolled tourism, especially during birds breeding time is another negative form of human activity. Also illegal cottage building in the outline of the reserve, results in disturbance of water circulation.

Conclusion

To recapitulate, the hydrological processes and human influence very closely shape the biotope environment of the present marsh. The effect of this interaction between nature and human activity is the 'Beka reserve' which, should be propagated as a unique marsh on the southern coast of the Baltic.

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The GEMEL experience: an association as a link between estuarine environment, scientific research and stakeholders

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Abstract

This paper presents the French association (according to 1901 law) GEMEL, acronym for Groupe d'Etude des Milieux Estuariens et Littoraux that can be translate in Estuarine and Coastal Environments Research Group. Since its creation and through its organization and aims, the originality of the structure is explained. Some examples of GEMEL initiatives are given, showing its independent and special position in the network of the environmental lobby, from study and monitoring to management and e-learning.

Keywords: Association; Estuarine and coastal research; Environmental education.

Creation

In the early 1970s, French oceanographic research was mostly dedicated to open sea and deep sea research. There were little scientific activities dealing with the coast and tidal shores, generating a lag in organized data acquisition. At the same time, the teaching of oceanography, as an academic subject, was developing in selected universities. In 1981, in order to fill the gap, researchers at the start of their careers created GEMEL (Groupe d'Etude des Milieux Estuariens et Littoraux).

GEMEL was established as an association, according to French legislation, encouraging mutual support between members, in order to found and promote coastal and estuarine research. This coincided with a growing demand for studies on intertidal and subtidal coastal areas, as a result of coastal developments and the need for proper (integrated) management. One of the first multidisciplinary research teams on estuarine and coastal environments was built on both a scientific and social basis.

Organization and aims

After more than 20 years of activity on the western French coast (Picardie, Haute Normandie and Basse Normandie regions) GEMEL offers a high level of experience and maturity. The group has now found its niche as part of the civil society as a link between environmental scientists, stakeholders and citizens. The association is financed through members contributions, local and national governmental grants, and participation in research programs at local and European scale (*i.e.* COST 647 in the 1980s, MOREST in the 2000s) and involves non-profit making financial management.

The aims of the organisation are researching (including consultancy), acquiring structured data sets, proposing practical training, providing information and finally widely communicating about estuaries to a large public through a range of supports (international symposium organisation, teaching, exhibitions, world wide web,...). At the international level, links with global organisations such as EMECS (Environmental Management of Enclosed Coastal Seas) provide GEMEL with a mission well beyond France and Europe.

Originality of the association

The associative structure offers a high flexibility which facilitates the setting up of projects and efficient communication: between each member on the one hand (through communication and so enhancement of the expertise together with institutes such as IFREMER, French Water Agency, universities...) and politicians and managers on the other hand. The originality and strength of the association reside in its ability to deal both with fundamental research and practical applications.

GEMEL is dedicated to methodological and inter calibration approaches and to ecological surveys. It further provides objective expertise and carries out monitoring in a long term perspective (long data series of selected parameters, mainly in the Somme, Seine and Veys). Such data is valuable in the context of an increasing pollution risk. It also provides knowledge of community dynamics and biodiversity in the context of the global change, helping to distinguish between "natural" and anthropogenic influences. The understanding of trends is necessary to supporting the rational and integrated management of sensitive areas such as estuaries.

Conclusion

To conclude, it seems that such organization can be particularly interesting in a context of environmental education emergence and of debate on the future of French and European research and university.

The humid zones of the dunes in northern France: areas of exception with multiple issues at stake

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Abstract

Wet dune slacks are depressions in dune systems which are flooded during winter and most of spring. In these humid depressions, pioneer vegetation has a great conservation value. But, artificial forest composed of non native species can change the hydrological systems with serious consequences for the ecosystems of wet dunes. Management conservation is very important for the preservation of the pioneer communities characterised by a high species diversity.

Keywords: Dune; Wet slack; Vegetation; Afforestation; Management.

Introduction

The north-west coast of France is mainly covered with dunes of variable extent whose value as part of the national heritage is nowadays fully recognized. To people visiting them, these dunes offer a variety of landscapes including humid zones well-loved by those familiar with them and of the greatest interest to naturalists (Petit-Berghem, 2002). They can be considered as exceptional areas in that they provide privileged sites for endangered plant and animal species. The survival of these species depends on management practices respecting the quality of the environment.

The policy of conservation

The policy of conservation of the peaty depressions has gradually developed in France over the last 10 years. It began in the Nord-Pas-de-Calais region, then spread to upper and lower Normandy. As in the Netherlands, innovative practices such as reactivating the dynamics of the dune have encouraged the reappearance of groups of plants typical of humid zones (Jungerius *et al.*, 1995). The vegetation in wet dune slack is determined by a poor nutrient supply of the soil. The reactivation of blowouts in coastal dunes can be a measure against the effects of acidification and eutrophication (Van Boxel *et al.*, 1997). Today the exchange of experiments and knowledge contributes further towards precisely-targeted and effective intervention. The technicians' know-how is instrumental in the setting-up of different protocols of intervention and monitoring, and also in

acquiring a better understanding of the response mechanisms of the peat environments to the experiments and management modes applied to them.

Conflicts for management

If this policy of conservation is approved by actors in the protection of the coast, it is not always understood by those who have a different conception of how to enhance the value of these areas. Conflicts arise or continue due to conceptions and representations of the multiple issues at stake which diverge in their aims. For an understanding of the reality of these issues, a historical framework is necessary to follow the evolution of Man's relation to Nature and the changing ways of thinking over the centuries and during the past few decades. Old maps and written accounts throw light on the occupation of space and on the way it has developed. Not only does a historical perspective show changes in the uses land has been put to, it also reveals the ambivalence of Man and coastal societies where the all-important question of how to enhance the value of these exceptional areas is concerned. Finally, the humid zones must be placed in a wider geographical context, that of the dune system affected by its own dynamics, and also in the broader context of the coastal and inland areas, where the systems of logic and functioning must be envisaged and confronted with those of the humid zones. Telling examples of present issues will be taken from the north of France (Nord-Pas-de-Calais, Picardy, lower Normandy regions) and will be compared with foreign sites (Great Britain, the Netherlands) where similar problems are posed (Owen *et al.*, 2004).



*Fig. 1. Dune woodland (Dune of Marquenterre in the Picardy region, France).
Author: Y. Petit-Berghem (photograph taken in May 2004)*

Conclusion

On the north-west coast of France, the main lines of vegetation are correlated with groundwater depth, microtopography, soil profile build-up and substrate acidification. Afforestation has deeply modified the coastal dunes. Lowering of the water levels and stabilisation of the dunes can lead to the slacks becoming dry and progressively invaded by woody plants such as *Salix repens* or *Hippophae rhamnoïdes* and eventually scrub and woodland. Sufficient water levels must be maintained in the dune slacks to keep the pioneer communities. Today a management policy of conservation is being implemented and, thanks to regulation and the use of technical means adapted to the situation, it has become possible to preserve or restore biodiversity in the species or the landscapes.

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The geomorphological impact of the January 2005 hurricane strength storm on the Atlantic coastline of the Outer Hebrides

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Abstract

In January 2005 the Atlantic Coast of the Outer Hebrides was struck by winds in excess of 100 knots. Hurricane force winds set-up exceptionally high destructive waves. Elevated sea levels caused extensive flooding. In addition to property damage there was also loss of life by drowning. Storms and erosion are frequent in the Outer Hebrides but the severity of this event called into question the level of awareness of coastline vulnerability in specific localities. In addition, the debate on possible rise in sea level and increased storminess re-emerged not only in a theoretical context but also with a sense of application to real life problems.

The coastlines affected were all low-lying machair landforms with extensive sand and occasional shingle beaches. Machair is a type of calcareous sand dune system of great antiquity (in excess of 6 to 8000 years old). It is especially important for archaeological and conversational sites. For more than forty years geomorphological and archaeological research has demonstrated systematic erosion and reworking of the machair coastline, albeit with pronounced local differences. As a result of this research the hurricane impact of 2005 can be seen as an extreme event within a long-standing pattern. Nevertheless the strength of this event underlines the power of the Atlantic storm environment and possible impacts on both economic and cultural assets which are likely to need enhanced protection.

Developing a European Coastal Dune Management Network

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Abstract

An informal network of European sand dune conservation managers and researchers has existed since a conference in Leiden, the Netherlands in 1987. At the European Symposium 'Coastal Dunes of the Atlantic Biogeographical Region' held in Southport, England, during 1998, the sand dune community met again and reaffirmed its presence. This event identified the benefits of sharing experience of conservation practice through a European network of common interest in coastal dune management. To this purpose and with the support of the EUCC-The Coastal Union, a first step was taken to develop a European Coastal Dune Management Network at the Littoral 2004 conference, Aberdeen, Scotland during September 2004. The developing network aims to promote sustainable use and share experience of conservation practice in coastal dune management amongst a distinctive and yet diverse community. The Dunes and Estuaries 2005 conference provides an opportunity to develop the Network as a platform that will benefit European coastal dune management.

Keywords: European Sand Dune Network; Conservation practice; Sustainable use.

Introduction

In 1987 academics and managers of sand dune coasts from throughout Europe came together in Leiden, the Netherlands, for the first time to discuss future directions for conservation management (Meulen van der *et al.*, 1989). This meeting set the seeds for a network of coastal dune management practitioners and academics.

Following 1987 the coastal dune community continued to share their understanding and practice using an informal network and taking opportunities to meet at coastal conferences and events held throughout Europe. However in 1998, reflecting the 1987 event, researchers and managers from the dune community met again at the European Symposium 'Coastal Dunes of the Atlantic Biogeographical Region' held in Southport, north west England (Houston *et al.*, 2001). Arising from this symposium was a clear call for a coastal sand dune network to be developed further with the purpose of sharing conservation practice on a more active and focused basis.

With the support of the EUCC-The Coastal Union, a first step was taken to develop a European Coastal Dune Management Network at the Littoral 2004 conference, Aberdeen, Scotland during September 2004. At this meeting a field excursion to the Sands of Forvie NNR was used to launch the European Sand Dune Management Network. It was quite appropriate that the network was launched in the field by a group of managers and researchers standing on a high mobile dune while sharing their understandings of dune management.



Fig. 1. Launch of the European Sand Dune Network at Sands of Forvie NNR, Scotland.

The Coastal Dune Community

As coastal dune managers and researchers operate in the context of coastal zone management they are members of many communities, but their experience is based firmly in the distinctive environment of coastal sand dunes. The coastal dune community is diverse and yet distinct. Participation in the European Coastal Dune Network is taking a 'bottom-up' approach aiming to involve the major stakeholders. These include, amongst others, conservation and recreation managers, researchers, engineers and representatives of the golf sector, water companies and the military.

Purpose of the Network

The overarching purpose of the Network is to promote the conservation and sustainable use of the European coastal dune resource. With the support of the EUCC-The Coastal Union the developing Network aims to do this through sharing experience of European conservation practice in coastal dune management. The purpose of this is to increase the capability of those charged with the responsibility for coastal dune management and to improve their practices by ensuring that they are informed by current understandings and sound research. Linkages between sectors in this diverse community will be promoted. Readily observed and tangible benefits will be identified for participants. These may include practitioner led workshops and field meetings and a Network website hosting a discussion forum, best practice reports, summary research findings and a contact list.

Conclusions

The European Sand Dune Management Network continues to grow. The Dunes and Estuaries 2005 conference provides an opportunity for the dune community to consider its priorities, promote dialogue and build relationships that will further develop the Network as a platform that will benefit European coastal dune management.

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Managed realignment in northern Europe – a comparative study of England and Germany

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Abstract

The coastal management measure ‘managed realignment’ (to create intertidal habitat) has aroused increasing interest over the past decade. This doctoral research project has so far concentrated on a comparative study of England’s and Germany’s approaches to managed realignment, to determine similarities and differences, and make predictions on its future use. Qualitative interviews were undertaken with key experts; supported by an extensive literature review and communication with coastal practitioners. All interviewees perceived managed realignment as a positive development, although the likelihood of its increased future use was judged differently. Some 36 schemes exist. Motivation for English, and to a certain extent on Baltic Sea schemes, seems more driven by long-term, multi-causal factors than on Germany’s North Sea coast, where managed realignment has to date only been motivated by habitat mitigation needs. However, there are signs that on this coast, conservation could be an important driver for its increased use in the 21st century. Thus managed realignment is now firmly on the agenda in both countries, reflecting a radical departure from the recent past. However, take-up is likely to differ notably both between and within these countries.

Keywords: Coastal defence; Managed retreat; Coastal management; Sea-level rise; Intertidal habitat.

Managed realignment in England and Germany

Managed realignment (MR) ‘involves setting back the line of actively maintained defences to a new line inland of the original [preferably to rising ground] and promoting the creation of intertidal habitat between the old and new defences’ (Burd, 1995) (European synonyms incl.: ‘dike-realignment’, ‘de-polderisation’). Possible MR steps include the construction of a new sea wall and breaching/removal of the old sea wall [the use of pipes/slue gates to control tidal flow (termed ‘Regulated Tidal Exchange (RTE)) was disregarded]. Intertidal habitats fulfil important, often under-valued functions. MR can thus fulfil various purposes: improve flood defence/coastal protection, reduce flood defence/coastal protection costs, create additional accommodation space for natural change, (re)create valuable wetland habitat for conservation purposes, (re)create habitats

to mitigate for harmful development to designated sites, influence the hydrodynamics of an estuary or coast, and improve water quality (e.g. CIRIA, 2004).

A comparative study of England and Germany was undertaken as the first phase of a research project which aims to make an informed prediction of the future application of MR of coastal defences in the countries of the southern North Sea (incl. the Netherlands and Denmark). Qualitative interviews were undertaken with key experts; supported by an extensive literature review and communication with coastal practitioners.

It was found that some 36 MR schemes exist in the two countries [excluding some 18 RTEs totalling about 2.250ha] - these are concentrated mostly on the coasts of eastern England, and the German federal states of Lower-Saxony (LS) and Mecklenburg-Western-Pomerania (MWP) (almost 2.000ha in Germany and some 400ha in England) [some 30 references, incl.: Halcrow Group *et al.*, 2002; Bury *et al.*, 2003]. In England and on Germany's Baltic Sea coast, MR is often seen as the cheaper and sustainable coastal defence option – thus the objectives and priorities of conservation and coastal defence bodies frequently coincide and create a situation conducive to MR. In MWP in particular, various factors led to an extensive uptake of MR, such as the offering of attractive management/compensation options to landowners and consistently asking for contributions to defence costs from landowners. In England, the implications of MR in terms of loss of other habitats (e.g. coastal grazing marsh) remain a concern (Lee, 2001). On Germany's North Sea coast, MR would be more costly than maintaining the status quo, at least over the next few decades. Thus, MR appears unnecessary until economic and/or environmental conditions change considerably. Major MR potential exists within the summer polders in LS, however, this would mostly increase coastal defence costs and only serve conservation purposes. Furthermore, public opposition to such schemes would be fierce, as the North Sea population, which has fought a long and bitter fight against flooding/erosion, views returning land to the sea as a serious failure. As a result, the immediate future for MR on this coast, beyond compensation measures, looks limited. In order to gradually move the coastal population away from this 'protect at all costs' attitude, Schleswig Holstein and LS could possibly learn from the English experience by introducing a few genuine trial schemes whilst closely interacting with local communities and landowners – a strategy which has shown some success in England (see Myatt *et al.*, 2003). Initially, RTE rather than MR may be the favoured approach as the control this affords seems to have made the existing schemes possible.

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Managed realignment a comparative study of England and Germany

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Rabbits (*Oryctolagus cuniculus* L.) in coastal dune grasslands

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Abstract

We describe a field experiment for examining the impact of wild rabbits (*Oryctolagus cuniculus* L.) on the vegetation in two Flemish coastal dune grasslands. When numerous, rabbits had a major impact on the vegetation. This impact can be considered positive in the case of the studied grasslands, as evidenced by a decreasing abundance by dominant grass species and a declining species richness. The decrease of the number of rabbits, due to VHS, may hence negatively affect dune grassland species richness. Introducing large herbivores can be part of the solution for preserving the dune grasslands, and this introduction may even have positive effects on rabbit populations through feeding facilitation.

Keywords: Rabbit; Herbivory; Coastal dune grassland; Grazing management.

Introduction

After the last glacial, the wild rabbit (*Oryctolagus cuniculus* L.) has been restricted to Spain and southern France. After its reintroduction in western Europe during the Middle Ages (Tack *et al.*, 1993), the rabbit became very abundant in coastal sand dunes in Belgium, and is since then the most important "natural" herbivore in this area (Rappé *et al.*, 1996). The impressive impact of this herbivore on the vulnerable coastal dune vegetation has been reported several times (e.g. Zeevalking and Fresco, 1977; Wallage-Drees, 1988; Olff and Boersma, 1998). Here, we will describe the results of a field experiment that was constructed to assess the influence of the wild rabbit and large herbivores on vegetation characteristics in two Belgian coastal dune areas.

Field study on the impact of rabbits on vegetation

The study was carried out in two coastal dune grasslands in Belgium (in the IJzermonding in Nieuwpoort and in the Doornpanne in Oostduinkerke). To counteract the increasing dominance of grasses and shrubs in this type of grasslands, large herbivores were introduced in both nature reserves (sheep in the IJzermonding, Shetland

Ponies in the Doornpanne). An experimental approach was used to assess the impact of these large herbivores, of the wild rabbits, and of the interaction between rabbits and large herbivores, using exclosures with three treatments (five exclosures in the IJzermonding and three in the Doornpanne). In one treatment all kinds of herbivores can graze. In the other two treatments large herbivores only and large herbivores and rabbits are excluded respectively. After two years, we examined several characteristics of the vegetation (such as species richness, the presence of particular plant species, the vegetation height and the dominance of grasses). Rabbit pellets in the plots were counted every four weeks, because they can be used as a measure for the abundance of the rabbits in the vegetation.

After two years of monitoring, we were able to conclude that, when the rabbits are abundantly present, grazing by rabbits is a very important factor determining vegetation structure and species composition in these grasslands:

- In the IJzermonding, the grassland was regularly visited by rabbits. Treatments from which they were excluded resulted in a dense and high vegetation, with dominance of only a few grass species, a lot of dead organic material and less annual plant species. This treatment was clearly negative for some species e.g. *Sedum acre*, *Arenaria serpyllifolia*, *Phleum arenarium*. In plots that could be visited by rabbits, they proved to be as effective as the large herbivores in reducing dominant plant species. Furthermore, the digging of the rabbits, created some uncovered soil, resulting in safe sites for germination and seedling establishment for plant species that have no opportunities in a high and dense vegetation.
- In the Doornpanne, the plots were hardly visited by rabbits. The vegetation had grown high and dense in the plots, except for these plots were the ponies were able to graze. Nevertheless, large herbivores were not able to compensate for the lack of digging by rabbits, so there was hardly any uncovered soil in the plots.

Conclusions and consequences for dune management

Based on the results of this experiment, we conclude that the impact of rabbits can be impressive when they are numerous: rabbits play an important role in the ecosystem of a dune grassland. If dune management aims at a mosaic of nutrient-rich and nutrient-poor patches of vegetation (shifting mosaics), rabbits can contribute in this process. Although the rabbit is a non-native species in our region, it has become an important part of the system, and the maintenance of the rabbit population is necessary for the preservation of the high species richness of dune grasslands. The recent decrease in the number of rabbits (Janssen, 2004), especially due to VHS (Viral Haemorrhagic Syndrome), should not be ignored in this context. If the number of rabbits in our dune areas keeps declining, introducing large herbivores will be even more important than before. Furthermore, it is possible that large grazers have a positive influence on the rabbit population through feeding facilitation (Arsenault and Owen-Smith, 2002; Drees, 1989; Williams *et al.*, 1974).

In the nearby future, the Terrestrial Ecology Unit of Ghent University will continue investigating the impact of rabbits on vegetation and on the existence of facilitation.

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The choice between keeping out chronic pollution versus acute mortality due to emersion: the case of the Tricolor oil pollution prevention in the Zwin nature reserve (Belgium)

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Abstract

As a result of the impending Tricolor oil pollution in the Southern Bight of the North Sea the Zwin nature reserve was blocked from the North Sea by use of a sandbarrier. This method of protection has an important consequence for tidal flat ecosystems: the absence of the tide. The effects on the ecological very important bottom-life of the tidal flats could not be estimated beforehand. All species that were present before the damming up were still present afterwards. During the emersion period *Talitrus saltator* and *Orchestia gammarellus* were found in high densities while these species were absent before and after the emersion. Strikingly was the strong decline in abundance of all species which were present in high densities in a sampling station and the abundance of *Aphelochaeta marioni* and *Pygospio elegans* declining in all sampling stations during the period of emersion.

Keywords: Tidal flat macrobenthos; Tricolor oil pollution; Zwin nature reserve; Emersion.

Introduction

On 14 December 2002, the car carrier Tricolor collided with the containership Kariba in the English Channel and sank in French waters nearby the Belgian border. Five weeks later, on 22 January 2003, approximately 170 tons of fuel leaked from the wreck of the Tricolor during salvage operations. Due to the meteorological conditions, with strong onshore winds, the oil washed ashore on Belgian, French and Dutch beaches and threatened some coastal nature reserves, among which the saltmarshes of the Zwin nature reserve. To keep out the oil from the Zwin nature reserve both entrance channels were blocked by use of a sandbarrier.

Catching up a dam prevents the tidal regime within the area. It is generally accepted that biotic and abiotic aspects of saltmarsh ecosystems are strongly determined by the frequency and duration of emersion by the tidal waters. Closure of intertidal areas with the ambient sea may therefore result in minor to irreversible effects on organisms and ecosystems. This method of protection therefore led to a lot of discussion: the choice

between keeping out chronic pollution *versus* acute mortality due to emersion. The damming up was taken as the ideal opportunity to study the effects of a medium-term emersion on macrobenthic species of a northwestern European intertidal habitat in winter, with a view of making better estimations in the future whenever this measure of protection could be needed.

Materials and methods

To study the effects of a medium-term emersion on macrobenthic species, samples (macrobenthos and physical variables) were collected starting just before, during and frequently after (to study recovery) the damming up. Sampling stations were localized at specific places in order to encompass a maximal diversity of benthic habitats and species.

Results and discussion

This study shows a high resistance of all macrobenthic species to a medium-term emersion during winter. Two ecological patterns could be distinguished during the emersion: 1) immigration into the intertidal zone of *Talitrus saltator* and *Orchestia gammarellus*, and 2) decreasing densities of polychaete species which were very abundant before the construction of the sandbarrier. However both patterns were not significant. *Pygospio elegans* and *Aphelochaeta marioni* declining in all sampling stations where these species were present. Both species are known to be very sensitive for periods of emersion, even during winter (Fortuyn *et al.*, 1989).

The high resistance of the tidal flat macrobenthos to the emersion is presumptively associated with the season of emersion: the winter. During winter, intertidal macrobenthic organisms need only a few food and oxygen.

The high abundance of *T. saltator* and *O. gammarellus* during the emersion and their low abundance afterwards can be explained by the natural distribution of these species. Both species are found most frequently nearby the high-water mark at the supralittoral, semi-terrestrial habitats (Jones and Wigham, 1993). Immigration into the intertidal zone of both species from these habitats during emersion seems likely.

Because no strong effects were detected as a consequence of the medium-term emersion, we can properly not consider any recovery. For that reason, density changes after the removal of the sandbarrier are believed to be due to natural temporal variation.

Conclusion

In view of the high survival of the macrobenthos to a medium-term emersion and the fact that oil pollution in the nature reserve was inhibited, the choice to protect the reserve from the impending oil pollution by use of a sandbarrier may be positively evaluated.

Acknowledgements

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Oosthoekduinen: a satisfactory agreement between nature development and recreation - a nature restoration project by the Flemish government

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The nature development project 'Oosthoekduinen' includes the Oosthoekduinen s.s., the Calmeynbos and the Krakeelduinen. The area is situated at De Panne and covers 190ha. This area is legally protected in several ways: protected landscape, 'green area' on the zoning plans drawn up under the 'Law of the organization of town and country planning', Special Protection Areas in application of Bird directive (79/409/EEC) and Habitat Directive (92/43/EEC), and partly under the Decree for protection of the dunes (BS 31/8/1993).

This protection status contrasts with the continuous growing recreational pressure on the area. To accommodate those apparently opposing interests, the Nature Division of the Ministry of the Flemish Community commissioned the VLM to develop and execute a nature restoration project in this area.

The project aims at the restoration and development of:

- open dune habitats of dune grassland and moss dune ('grey dunes');
- dune shrub communities;
- dune pond and pools;
- moist to wet polder grassland and low productive natural grassland;
- introduction of ecological forest management;
- zoning of recreation.

Degradation of the grey dunes, a priority habitat protected by the Habitat Directive is caused by a lack of nature management and too much treading by recreation. A grazing area was established to maintain the dune grassland vegetation.

The Krakeelduinen form a mosaic of dune shrubs, dune grassland and moss dunes. To maintain the dune shrub vegetation invasive plant species such as Ontario poplar (*Populus candicans*), Grey poplar (*Populus canescens*) and Sycamore (*Acer pseudoplatanus*) were removed. The cutting down of the planted poplar lanes was the first step towards the restoration of the parabolic dune landscape.

The Calmeynbos is originally a diverse afforestation from around 1900. Nowadays about 60% of the initially planted taxa is still present. Their regeneration however, is difficult except for the Sycamore. The purpose of the project is to introduce ecological forest management. Therefore coniferous plantations are replaced by deciduous trees, forest structure is improved, regeneration of indigenous tree species like Common ash (*Fraxinus excelsior*) and Elm (*Ulmus spec.*) is facilitated by clearing more competitive species and the proportion of dead wood is increased.

In the former military zone, all military infrastructure such as store houses, concrete platforms, watch-towers are removed except for one blockhouse which will be restored as a hibernation shelter for bats.

Before the start of the project, the dune-polder transition zone was in intensive agricultural use. This zone was acquired by the Nature Division of the Ministry of the Flemish Community and has now the statute of Flemish Nature Reserve “Duinzoom”. The restoration of the dune-polder zone was established by locally removing the nutrient rich surface horizon, increasing microrelief on former arable land, reprofiling the banks of the watercourse “Langgeleed” and other ditches, enlarging existing pools and digging new ones. Part of the area is managed by mowing, the other part by permanent grazing.

To channel the recreational activities, agreements were made with neighbours and users (e.g. the scouting, mountain bike and horse riding clubs). Therefore trails were established for walkers, mountain bikers and horse riders. In conflicting situations where walkers, mountain bikers and horse riders interfered too much the paths were separated or rerouted altogether.

The effectiveness of these measures will be monitored during 10 years. Lessons that will be learned from this monitoring will be of value in future management projects.

Assessing coastal dune rehabilitation using very high resolution digital elevation models: an example from Leffrinckoucke, northern France

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Abstract

A part of the dune restoration zone in Leffrinckoucke (northern France) was monitored using high resolution DEMs from 1999 to 2001. Maps comparison shows regular dune growth in the fence-equipped area. Volume computation and statistical analysis confirm the accretional trend detected from map analysis and enable a quantitative assessment of the efficiency of the fences and brushwood barriers.

Keywords: Dunes rehabilitation; Topographic survey; Digital Elevation Models; Volume computation; Statistical analysis; Leffrinckoucke, France.

Study area

Until the early 1990s, much of the coast between Dunkirk and the Belgian border (Fig. 1) suffered severe erosion involving dune blowouts and breaches and bluffs cut into the dunes.

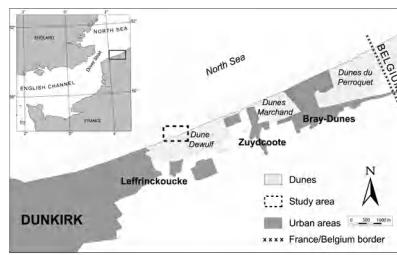


Fig. 1. Location of study area.

This coast is presently in a state of stability. Since 1997, dune restoration has been undertaken by the "Conseil Général du Nord" (Departmental authorities) and the "Conservatoire du Littoral". This restoration scheme has focused on a large blowout in Leffrinckoucke, and has involved the use of longshore oriented sand fences, cross-shore

oriented brushwood barriers and the planting of *Ammophila arenaria*. The monitored sector reported in this study is a part of the rehabilitation zone, and comprises the upper beach, and the dune front and crest.

Methodology

From September 1999 to October 2001, very high resolution topographic surveys were carried out every 2 months and half on average over a 25x30m sector using an electronic total station (Leica TC600), Vanhée (2002). An average of 708 data points were collected each time (*i.e.* ≈ 1 point per m^2). This dataset was used to create nine Digital Elevation Models (Fig. 2) from which nine comparison maps were computed (Andrews *et al.*, 2002; Rebêlo *et al.*, 2002). Eight maps were generated following subtraction of one DEM from the next one and represent topographic changes between two surveys (Fig. 3).

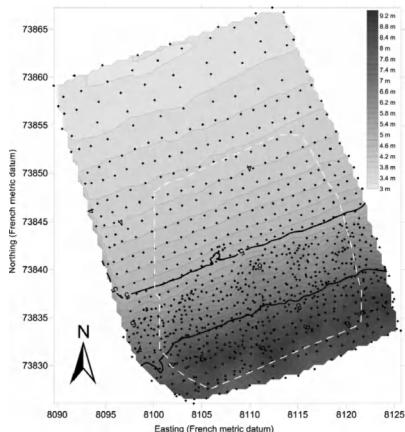


Fig. 2. Example of DEM (elevations are relative to French datum, bold lines represent the 5 and 7.5m contours, dots indicate measurement points, white dashed line indicates comparison zone).

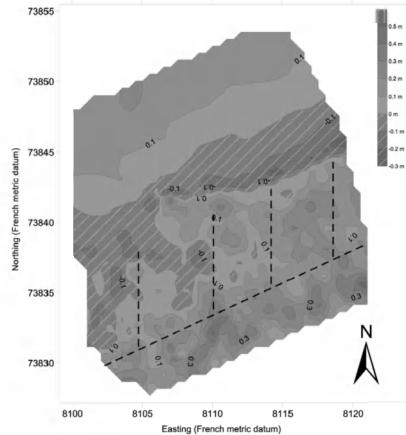


Fig. 3. Example of a comparison of two DEMs (April and October 2001). Dashed lines represent sand fences and brushwood barriers. Positive values express accretion, negative values erosion.

The last map was produced by comparing the first and the last DEMs and hence represents the total topographic changes for the complete survey period. These maps show regular dune growth in the fence-equipped area (dune front and crest). The DEMs were divided into three sub-zones (upper beach, dune front and crest) for computing volume changes, using the 5 and 7.5m contours (relative to French elevation datum) as limits (Vanhée *et al.*, 2001).

Results

Calculations of global and partial volumes were carried out and then statistically synthesized (Fig. 4 and Table I). Means and Standard Deviations were used to calculate

variation coefficients (St.Dev. divided by Mean), which can be interpreted as a measurement of evolution regularity (low value = regular, highest value = irregular). Slopes are the b parameter of a linear equation ($y = bx + a$), indicating value of daily evolution (in m^3). R (Bravais-Pearson correlation coefficient) expresses the trend intensity (varying between -1 = strong negative relation and 1 = strong positive relation).

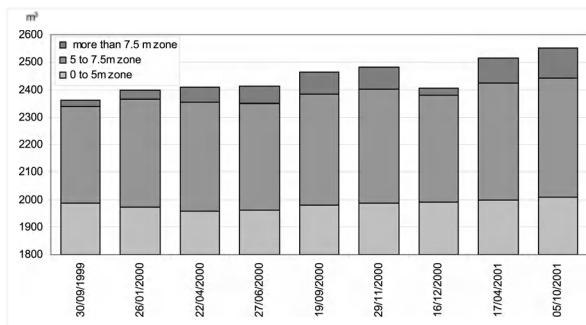


Fig. 4. Volumes of the three sectors at each date of measurement.

Table I. Main statistical parameters used in data analysis (calculated using raw volume data)

	Mean (m^3)	St Dev (m^3)	Variation coef.	Slope (b)	R
0 to 5 m	1982.61	16.71	0.01	0.05	0.69
5 to 7.5 m	399.44	23.21	0.06	0.09	0.88
more than 7.5 m	62.70	30.57	0.49	0.11	0.80
Total	2444.75	61.65	0.03	0.25	0.91

Fig. 4 shows that the lower zone (upper beach from 0 to 5m) of the DEM suffered little erosion at the beginning of the study and then experienced very mild accretion. This sector shows the most regular evolution (Table I: variation coef. = 0.01), but also the slowest ($b = 0.05$ $r = 0.69$) of the three sectors.

The dune front (5 to 7.5m) and crest (more than 7.5m) accreted less regularly but more rapidly than the upper beach (variation coef.= 0.06 and 0.49, $b = 0.09$ and 0.11). It is important to note that the 0.49 variation coefficient for the dune crest is due to erosion between November and December 2000. These results not only confirm the accretional trend detected from map analysis, but enable a quantitative assessment of the efficiency of the fences and brushwood barriers.

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The role of EU regional policy on the ethical responsibility for the development of recreation and tourism and conservation of European coastal habitats

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Abstract

Due to impending changes coming from the integration into the EU Regional Environmental Policy, the restoration and conservation of European coastal habitats and their relation to the development of the recreation and tourism business are likely to become a major area of research in the future. In accordance with the priorities of the EU Regional Policy and the Environmental Action Programme, sustainable management practices will have to be implemented in managing the coastline of the EU. The results indicate that integrating the coastal zone management process of EU into the larger EU Regional Policy Programmes must therefore be connected so that recreation and tourism, environmental restoration and development in European coastal habitats can be balanced sustainably.

Keywords: Ethical responsibility; Situational ethic algorithm; EU Regional Environmental Policy; Model integrated socioeconomic responsibility.

Introduction

In order to integrate socioeconomic responsibility into the management of coastal areas within the European economic integration, it is necessary to formulate their integrated responsibility conception. As empirical and practical evidence suggests, the bulk of ideas in modelling integrated socioeconomic responsibility into the coastal management strategies and development perspectives came up after the accession of the new EU members.

It is necessary to analyze problems and potential solutions in balancing habitat restoration, recreation and tourism development in the European coastal habitats. Additionally, there is a need to examine propositions of socioeconomic responsibility. Thirdly, environmental issues in the European Regional Policy must be projected. Lastly, there is a need to prepare a model of study to solve these problems in the future.

Methods, measures, results and discussion

Some different methods and frameworks, which may be useful to study and solve these problems, are: 1. Looking at the overall objectives of the EU Environmental Systems for Integrated Coastal Zone Management and sustainable development, which were provided to the Commission of the Communities (1992, 1993, 1994), and the European Commission (2000) in a package of documents detailing environmental issues in the European Regional Policy; 2. Studying a particular region, using three different conceptual frames provided by Ryden (2002): a) Regional development as a political process focuses on regional institution building, where a long common history of political interaction exists. A situation has finally evolved where we find much cooperation in many different fields, from regional politics and economy to culture, education and environment protection to mention but a few; b) Regional development as economic process focuses on recreation and tourism development as a process – or even progress – focusing on trade, human society, and ethical responsibility; c) Regional development as a so-called spatial process also includes recreational development, which may be seen as a spatial process focusing on resource use. The communication infrastructure, combined with the laying of roads, railroads, ferry lines, also involves the use of natural resources and the environmental impact of this resource use. The concept of developing sustainable recreation and tourism opportunities combines political, socio-economic, ethical and environmental aspects; 3. Analyzing the ethical responsibility of development according to ‘situational ethic algorithm’ proposed by Hoffman and Moore (1990), in which the basic tenet underlying situational ethics is that circumstances alter cases. According to the principles of the European Regional Policy and the EU Environmental Action Programme, which has demonstrated the need for integrating conservation of coastal habitats with sustainable development, managing coastal recreation, and the demands of the tourist industry can be negotiated by applying the EU Environmental management systems, and Situation ethic algorithm, developed by ourselves.

Conclusion

Complex and significant ethical decisions are made based on the situation at a particular moment in time. The input factors for the ‘situational ethics algorithm’ include: goals, methods, motives, and consequences. As the consequences of a decision become more complex and unpredictable, situational ethics become a necessity in the recreation and tourism industry if European coastal areas are to be conserved and appropriately managed in the future.

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TideSed: intertidal sediment characterization using HyMap imagery

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Abstract

The Scheldt Estuary is internationally known for its nature and as an important commercial shipping route. Obtaining accurate data on the basic biological, chemical and physical processes in intertidal sediments is expensive and difficult: the accessibility to the site is limited, and estuaries are characterized by a wide spatial heterogeneity. Remote sensing methods can produce detailed information on intertidal sediments in a cost-effective manner. Hyperspectral HyMap imagery is combined with intensive ground truthing to quantify the most important biological and physical parameters. To achieve these goals a consortium consisting of five research institutes with complementary skills in remote sensing, marine (and coastal zone) ecology and sediment mechanics, joined forces in the TIDESED project.

Keywords: Scheldt Estuary; Intertidal sediment; Remote sensing.

Introduction

With one of the largest wading bird populations in western Europe, and several rare habitat types such as tidal marshes, the Scheldt Estuary is internationally known for its nature. On the other hand, the estuary is also a site of heavy industry. Decision making by coastal zone managers can be improved if better knowledge of ecological processes is available. Many of the most important biogeochemical processes occur on the large

areas of loose sediments which are exposed at low tide. For example, the distribution and binding of heavy metals is controlled by the fraction of fine sediment. Photosynthesis by benthic microalgae fuels primary production, supporting many grazing animals and birds. Accumulations of algal cells in a surface biofilm cause the sediment to become more stable. However, grazing and bioturbation by macrofauna enhances the erosion rate.

Methodology

Hyperspectral HyMap imagery of the Molenplaat in the Westerscheldt is combined with intensive ground truth measurements of materials of interest (MOIs). The sediment samples are analyzed on grain size distribution, water content, pigments, and biological composition (macrofauna and microphytobenthos). The location of each sediment sample is determined by differential GPS measurements. For each material of interest, hyperspectral features from HyMap will be matched to ground measurements at the relevant pixel in order to produce predictive algorithms. In addition, value-added products with relevance for coastal zone management will also be produced. For example, benthic primary production will be calculated at each pixel from knowledge of benthic chlorophyll and light availability and sediment stability will be assessed from the biophysical properties of sediment, elevation and hydrodynamics.

First results

The HyMap image and field measurements were obtained on 8 June 2004 (Fig. 1). The field measurements are being interpreted. Supervised and unsupervised classifications are being performed to produce maps of the MOIs. Preliminary results show that intertidal sediments can be classified using HyMAP imagery.

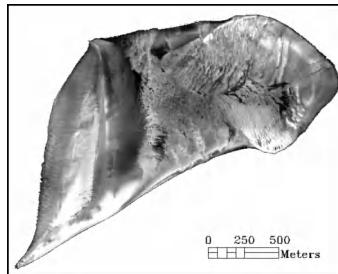


Fig. 1. Black and white representation of the HyMap image of the Molenplaat.

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LAI determination in dune vegetation: a comparison of different techniques

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Abstract

Research was conducted in the nature reserve De Westhoek (De Panne, Belgium) in order to determine leaf-area-index (LAI) in different dune vegetation types by both direct (destructively) and indirect optical measurements. The destructive LAI determination was conducted in herbaceous and shrub vegetation types. It was found that the LAI of herbaceous vegetation ranges between 0.87 and 4.60 and the LAI of shrub vegetation between 2.25 and 3.58. Ground-based optical determination of LAI was only conducted in the shrub vegetation, by means of the SunScan (Delta-T Devices Ltd, Cambridge, UK). This indirect LAI method systematically overestimated direct LAI. Another applied optical method is the hemispherical photography (Nikon Coolpix 5000 camera). Airborne remote sensing data are used to establish a relationship between direct LAI and some vegetation indices. Based on the above established relationship a map of the horizontal LAI distribution in the nature reserve De Westhoek will be produced.

Keywords: Dune vegetation; Destructive sampling; SunScan; Hemispherical photography;
Airborne remote sensing.

Introduction

To be able to scale up transpiration at the leaf level to species- and stand-level, leaf-area-index (LAI) is used as a scaling factor. Leaf-area-index is defined as the single sided surface of leaves per square metre of soil ($m^2 \cdot m^{-2}$). Former research (Sevenant *et al.*, 2003) showed a low LAI for dune vegetation and a large overestimation of the LAI measured by optical methods compared to those measured by destructive sampling.

The main objectives of this paper are (i) to directly determine the leaf-area-index (LAI) in different vegetation types destructively, (ii) and indirectly by different non-destructive optical methods (including airborne remote sensing), (iii) to compare the applied

methods to estimate LAI, and (iv) to produce a map of the horizontal LAI distribution in the research area.

Material and methods

Research was conducted in the nature reserve De Westhoek (De Panne, Belgium) during the 2004 growing season. The destructive LAI determination was conducted in ten plots representing herbaceous vegetation and in three types of shrub vegetation (*Salix repens* L., *Hippophae rhamnoides* L. and *Ligustrum vulgare* L.). The leaf area of the destructively sampled plots was measured using a planimeter (Li-3000, Li-Cor, Nebraska, USA). The ground-based optical determination was only conducted in the shrub vegetation, by means of the SunScan (Delta-T Devices Ltd., Cambridge, UK) and hemispherical photography (Nikon Coolpix 5000 camera). The software used to analyze the hemispherical photographs is CAN_EYE (INRA-Avignon, France). Airborne remote sensing data are used to establish a relationship between direct LAI and some vegetation indices such as the Normalized Difference Vegetation Index (NDVI). Both a false colour digital orthophoto and hyperspectral (32 bands) data are used.

Results

It was found that the LAI of herbaceous vegetation is low and ranges between 0.87 and 4.60, with a mean LAI value of 2.11 ± 0.34 . The destructive LAI of shrub vegetation ranges between 2.25 and 3.58, with a mean LAI value of 3.03 ± 0.19 . The indirect LAI determination (SunScan), with a mean value of 5.67 ± 0.50 , systematically overestimated the direct LAI. The first results of the analysis of hemispherical photographs also indicate a systematic overestimation. Probably, the most important reason for this overestimation is that besides the leaf area, also woody area is measured, so the plant-area-index (PAI) instead of the LAI is measured. Preliminary results indicate that the woody area can contribute up to 64% in the PAI. First results of the analysis of the remote sensing data revealed a (quasi) log linear relationship between direct LAI and NDVI derived from false colour orthophotos ($R^2 = 0.77$).

Conclusions

The LAI of both herbaceous and shrub dune vegetation is rather low. The indirect LAI determination overestimated the direct LAI determination. Probably, the reason for this overestimation is that the plant-area-index (PAI) instead of the LAI is measured.

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Monitoring dune dynamics in 'De Kerf' (NL) 1997-2003

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Abstract

In the Netherlands 'De Kerf' was initiated as a pilot project for dynamic coastal management. Within this pilot project five years of monitoring and evaluation was applied. The monitoring of the geomorphological development and of the vegetation and flora was sufficient for recording significant changes in ecotopes. The monitoring of macrofungi and Carabidae confirmed these results. The monitoring of reptiles and birds gave only qualitative information.

Keywords: Monitoring; Evaluation; Coastal dunes; Restoration; Management.

Introduction

'De Kerf' is located in 'de Schoorlse Duinen' in the northern part of the mainland coast of Holland and is managed by Staatsbosbeheer. It was here that in 1997 a notch was created in the foredune. Vegetation and topsoil were removed from the dune slack behind and active management was stopped. These measures were part of a pilot project within a bigger program for dynamic coastal management from the Dutch government. The general objective of the programme was a more natural coastal defence and the return of landscape forming processes, which characterize dune ecosystems. Marine influence, active sand transport and deflation of dune slacks till groundwater level, lead to gradients in the landscape and to a larger diversity of ecotopes. This pilot project became well known as 'De Kerf'. Part of the pilot was a monitoring programme and an evaluation after five years of the processes and development of the abiotic and biotic-environment of 'De Kerf' (Staatsbosbeheer, 1997).

Monitoring

The geomorphological development was monitored. Parts of the dune slack are stabilised by vegetation after five years. However, because of the notch in the foredunes, sand was blown from the beach and transported inland, resulting in the deposition and the development of small dunes. The supply of fresh beach sand and occasional flooding, in combination with a high recreation pressure, prevented stabilisation. Another effect of

fresh beach sand was the input of carbonates in a more acid ecosystem, resulting in a greater biodiversity (Arens, 2003).

The development of vegetation and flora have a direct relation with the degree of dynamics in the area. During the first years the inundations had a substantial effect on the vegetation development in the sod cutted southern part of the duneslack. Because the frequency and scope of inundations have decreased during the last years, the influence of the suppletion of sand increased. Monitoring of the vegetation and flora recorded great changes. Diversity in communities and species has increased. Red list flora species have grown from 8 up to 15 species in 2003. These changes point at an increase of marine and aeolic influence in the area and indicate gradient-richness (dry-wet, saltwater-freshwater, acid-basiphilous) (ten Haaf and Kat, 2003).

In the monitoring program the Mycoflora is described as a quick responder on changes in the degree of coverage and vegetation development (Staatsbosbeheer, 1997). The results of the monitoring confirmed this. A problem with the monitoring of macrofungi is their great variety in fructification each year. To obtain a representative scope of the Mycoflora three continuous years of monitoring are required (Groenendaal, 2003).

Though a lot of research has been done on Carabidae, the use of this specific group of Coleoptera for monitoring is not very common. The indications of ecological changes in the population (species and numbers) of Carabidae in 'De Kerf' match with the results of monitoring geomorphological development and changes of vegetation, flora and macrofungi (Vertegaal *et al.*, 2003).

Although the monitoring programme proposed an annual breeding bird inventory, actual monitoring only took place in 2002. Because of the very small populations and size of the monitoring area, the statistics are not very discriminating. It's hard to tell whether changes are caused by the habitat development on the site or by chance. Monitoring of birds on this scale isn't reliable, and therefore not useful for evaluation (Wondergem, 2003a).

According to the monitoring program Sand lizard (*Lacerta agilis*) should also have been monitored. Unfortunately no standardized monitoring was done until 2002. In 2002 the species was recorded within 'De Kerf', but not on the open sod cutted dune slack. Within the Carabidae-monitoring Sand lizard was also caught, mostly in the borders of the dune slack. The population of Sand lizard was probably not negatively influenced by the initiation of dynamics in 'De Kerf' (Wondergem, 2003b).

Conclusions

Monitoring of 'De Kerf' resulted in a lot of information and knowledge of restoration of dynamics in the dune. The measures were a novelty within the Dutch tradition of coastal defence and some aspects of the monitoring were a novelty too.

Development and changes of 'De Kerf' were well recorded by monitoring the geomorphological development and confirmed by the monitoring of vegetation and flora. The monitoring of macrofungi and Carabidae also confirmed these conclusions,

though methods were not standardized. Breeding birds and Sand lizard (*Lacerta agilis*) showed some qualitative information though methodological problems occurred. Essential information is collected by monitoring geomorphological development and vegetation and flora. For a successful monitoring programme two premises are relevant: a detailed description of the site (abiotic and biotic) before measures are taken and the use of reference sites during the monitoring period to discriminate site-specific factors from local, regional and national trends (Vertegaal *et al.*, 2003).

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