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# Ecology, Management and Monitoring of Dune Grassland in Flanders, Belgium

Sam Provoost[1], Carole Ampe[2], Dries Bonte[3], Eric Cosyns[4] & Maurice Hoffmann[1,4]

[1]*Institute of Nature Conservation, Kliniekstraat 25, B-1070 Brussels, sam.provoost@instnat.be*

[2]*Ghent University, Laboratory of Soil Science, Krijgslaan 281, B-9000 Gent, carole.ampe@rug.ac.be*

[3]*Ghent University, Laboratory of Animal Ecology, K.L. Ledeganckstraat 35, B-9000 Ghent, dries.bonte@rug.ac.be*

[4]*Ghent University, Laboratory of Botany, Krijgslaan 281, B-9000 Ghent, eric.cosyns@rug.ac.be*

Abstract

Being a priority habitat type of the EU Habitat Directive, conservation and management of grey dunes demands special attention. Therefore, basic ecological insight is important. Grey dune succession is initiated by fixation and driven by the complex of soil formation (humus accumulation) and vegetation development. Leaching and mobilisation of $CaCO_3$ complicate the picture and are important in nutrient dynamics. But at present, rough grass- and scrub encroachment greatly overrule these fine scaled soil processes and cause substantial loss of regional biodiversity. Belgium has a shared international responsability in grey dune conservation due to its limited range of its characteristic vegetation, flora and fauna. As biomass removal seems essential in grassland preservation, grazing is an important management tool. Evaluation of management measures focusses on biodiversity measurement, which is done on the levels of landscape, community and species.

## 1. INTRODUCTION

Grey dune, known as "Fixed coastal dunes with herbaceous vegetation" in the CORINE biotope classification, is considered priority in the annex I of the EU Habitat Directive. This status implies that grey dunes deserve special conservation attention. Plenty of reasons to focus on the ecology of these dune grasslands and to discuss the contribution of ecological research to conservation strategy, management and monitoring. This paper summarizes the experience in Belgian coastal dunes, based on several research projects. To a large extent this research is funded by the Nature division of the Ministry of the Flemish Community, with contributions of LIFE.

## 2. WHAT IS GREY DUNE?

Coastal 'grey dune' is most readily defined using plant communities. Vegetation includes moss dominated dunes as well as dune grassland (with a distinct organic soil layer) belonging to the Cladonio-Koelerietalia.

Ecologically it is merely the dry component of the "stressed dune landscape", where ecological dynamics are situated in the field of tension between top down regulating stress factors and bottom up (xerosere) organisation.

The main differentiating processes are related to dune fixation, soil formation and vegetation development. Each process is in close interaction with spatial patterns and is characterised by certain spatio-temporal dimensions.

### 2.1 Processes

#### *2.1.1 Dune fixation and erosion*

Dune fixation implies a decrease in aeolian activity and stabilisation by vegetation (Jungerius 1990). Rhizome forming plants like *Ammophila arenaria* and *Festuca juncifolia*, which keep up with a slight sand accumulation, play an important part and can be an important nitrogen source in early stages of grey dune development (decaying material from tussocks of *Ammophila arenaria* for example).

In Europe, mobility of dunes are generally affected by coastal defence works (stabilisation) and human activities leading to erosion. Centuries of agricultural use of dunes have probably caused large part of secondary sand drift and as these activities ceased somewhere during the 20th century, dune landscapes got fixed and vegetated. Other elements, such as the military activities during WW1, have been quite devastating in a much shorter time span. More recently, intensive recreation causes soil and vegetation degradation, often resulting in local dune mobilisation.

#### *2.1.2 Humus accumulation and decomposition*

The initial dune substrate is not very hospitable for plant growth. Parent material of Belgian dune soils consists of well drained sand (mean median grain size between 175 and 250 µm) with low nutrient content. Drought stress is caused by climatological, geomorphological and soil factors.

Grey dune surface in Belgium, exposed to the sun can heat up to more than 60°C and soils can dry down to 20 cm deep (Aggenbach & Jalink 1999). Especially in moss dunes, the additional effect of water repellence, caused by soil organic matter, is an underestimated factor of drought. This drought stress regime can strongly retard vegetation succession and soil development.

But except for these extremely harsh conditions, even in the early moss dune stages some biomass production can take place. This is the key element in soil development. Humus colloids, produced by decomposition of organic matter, increases moisture retention and nutrient availability. Accumulation of humus is reflected in species composition and species' competitive abilities; plant species as *Sagina nodosa* or *Linum catharticum* for example, can grow in dunes beyond reach of groundwater, only if soils are rich in humus. Soil and vegetation processes being highly interwoven, early stages of dune grassland development represents a classic example of internal succession according to the resource-ratio model (Tilman 1985). Much of this story takes place in the rhizosphere and is driven by competition for water and nutrients. According to Slings (1994), grass roots are the main source of organic matter in grey dune soils. Veer & Kooijman (1997) found that root and moss biomass each are twice as large as above ground vascular plant biomass, so probably mosses play an important role as well.

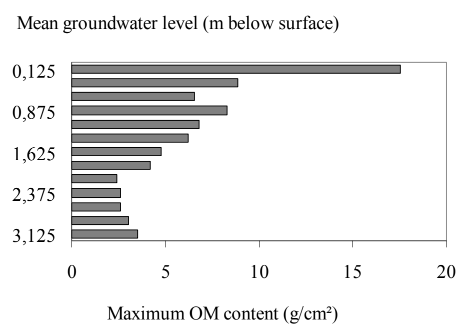


Figure 1: Maximum soil organic matter content (loss on ignition) in relation to groundwater level (n=168, several dune grasslands in the western part of the Belgian coast).

Soil humidity is a main determining factor in biomass production and soil development. The effect of the groundwater level on soil organic matter in dune grasslands is clearly illustrated in figure 1. Taking into account annual groundwater fluctuations of 0,5 to 1 m and a maximum capillary effect of 1 m, groundwater exceeding a depth of about 2 m under the soil surface is no longer accessible for most grassland plants.

In these dry zones, maximum soil organic matter content seems to stabilise at about 3 g per cm². In moist dune grassland, the groundwater table is at most 2 m deep and soils never get wet. In these situations, organic matter contents of up to 10 % are observed. These figures are comparable to the situation in dunes on Goeree, The Netherlands (Annema & Jansen 1998). Wet soils are permanently influenced by groundwater and show a spectacular increase in biomass production and maximum soil organic matter content.

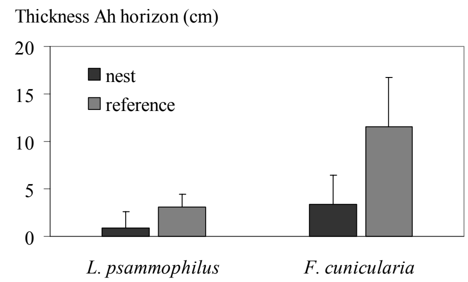


Figure 2: Effects of the presence of nests of the ants Lasius psammophilus and Formica cunicularia on the thickness of the organic soil layer.

Humus accumulation is counteracted by several processes. In young moss dunes, physical humus erosion can be substantial, but in stable grassland, main losses of soil organic matter are caused by biochemical decomposition. The ions formed by mineralisation processes are susceptible to leaching, caused by the precipitation surplus, which also reduces the amount of soluable minerals, such as $CaCO_3$. Bioturbation enforces decomposition and mineralisation. According to Bonte et al. (subm), ants affect the thickness of the organic soil layer and its penetration resistance (figure 2). These animals and also snails, for instance, are abundant in organic soil layers. Decomposition rates show an optimum-type response in relation to soil moisture. Within the humidity range of dune grassland however, the magnitude of biomass production exceeds the differences in mineralisation rate. The net effect, as far as grey dunes are concerned, is an increase in biomass production with soil moisture. This causes the pattern in soil organic matter contents shown in figure 1.

### 2.1.3 Soil decalcification and nutrient dynamics

Stabilised dune soils decalcify due to continuous chalk leaching. At time of deposition, the sand is slightly calcareous (up to 8 % $CaCO_3$) due to shell fragments (Depuydt 1972, figure 3).

$CaCO_3$ is the main buffering substance and pH remains neutral to alkaline (6,5 up to 8) as long as chalk concentrations exceed about 1% (figure 3). But below this point soil acidity shows an abrupt and steep decline, which means the gradual character of decalcification is not reflected in soil pH. The calcium threshold of 1 % exceeds the value of 0,3 % found in Dutch dunes (Rozema *et al*. 1985, Aggenbach & Jalink 1999), probably due to differences in methodology.

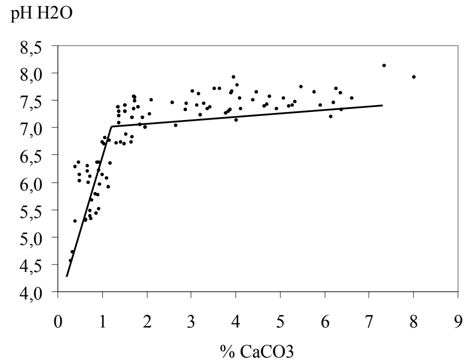


Figure 3: Relationship between $CaCO_3$ content and pH ($H_2O$) in 100 soil samples of "De Westhoek" dune reserve, De Panne. $CaCO_3$ content based on calcium concentration, which was measured using ICP after extraction with aqua regia.

Acidity is an important parameter, affecting many soil processes. Decomposition and mineralisation of organic matter is slowed down in acid soils (pH < 4,5 to 5), resulting in an increasing humus content (Aggenbach & Jalink 1999). During soil development, humic acids are released which enforce leaching of $CaCO_3$ . This means humus production and decalcification are involved in a positive feedback loop. Soil samples from Belgian grey dunes however, do not reveal this effect (figure 4) because the investigated sites are hardly decalcified (compared to Rozema et al. 1985 or Annema & Jansen 1998).

Decarbonatation of grey dune soils is slowed down by mobilisation of calcareous sand. Bioturbation is probably an essential element. Ants (*Formica cunicularia*) certainly increase the superficial lime content (Bonte et al. subm). Weeda (1992) also considers 'sand spray', a slight sand accretion, as an important and characteristic natural cause of recalcification. According to this author, this process prevents soil acidification and enhances decomposition and mineralisation of organic material in Taraxaco-Galietum dune grasslands.

On the other hand sand accumulation increases the thickness of the top soil layer, which probably explains the appearance of thick Ah-horizons (>10 cm) with neutral pH in figure 4.

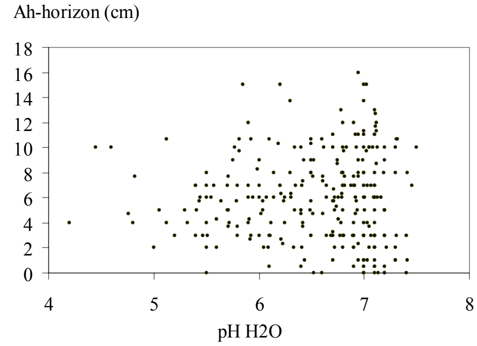


Figure 4: Thickness of Ah horizon in relation to ph-$H_2O$ (n=287, several dunes grasslands in the western part of the Belgian coast).

Nitrogen and phosphorous are key elements and partly co-limiting in nutrient dynamics of grey dunes (Kooijman *et al.* 1998). Nitrogen is mainly supplied by decomposition of plant residues. The total nitrogen content is highly correlated with soil organic matter and generally increases during succession. Mineralisation in plant-available nitrogen shows a different response and is rather correlated with standing crop biomass and plant litter content. Phosphorous availability is pH dependent and shows an optimum at pH 5. At higher pH, phosphorous is largely fixed in calcium phosphate, limiting biomass production (Kooijman 2001).

### *2.1.4 Vegetation development*

In natural dune systems, fine-scaled soil processes as mentioned above, physical destruction by blowing sand and invertebrate herbivory might be sufficient to preserve grey dune vegetation and its characteristic species, at least within an ephemeral pattern. But at present, substantial removal of plant biomass seems essential for sustainable dune grassland development. Coastal dune vegetation in Belgium and many other European countries evolve in one direction towards coarse grassland with *Calamagrostis epigejos*, *Avenula pubescens* or *Arrhenatherum elatius*, scrub with *Hippophae rhamnoides*, *Ligustrum vulgare* or *Salix repens* and woodland (van Til et al 2002, Provoost & Van Landuyt 2001). Grass encroachment is probably stimulated by atmospheric deposition but once established, grass dominated vegetation is highly self-maintaining due to an increased nitrogen mineralisation (Kooijman et al. 1998, Veer & Kooijman 1997).

Scrub expansion is mainly caused by drastic changes in land use. Up to the middle of the 20th century, livestock grazing was common in Belgian dunes and shrubs and trees were harvested for fuel. These activities kept the grey dune area far above the natural portion within the coastal ecosystem.

Grazing and mowing can maintain vegetation structure but do not stop succession (De Raeve 1989). Another pathway is chosen with new elements, such as trampling and dung deposition, playing an important part in soil development. The natural processes described above can lead to moder humus, whereas in situations with livestock grazing a mullmoder humus is formed (Slings 1994, Aggenbach & Jalink 1999).

## 2.2 Spatial patterns

### *2.2.1 Regional and landscape level*

Biogeographical patterns are related to climate, soil and history. Atlantic grey dunes are subject to a major gradient in temperature from southwest up to northeast and a substantial variety in precipitation (Dahl 1998). Coastal dunes of Belgium and the adjacent areas take an intermediate position with a mean temperature of the coldest month of 2°C and an annual precipitation of about 750 mm. Considering the importance of drought stress in grey dunes, climate is determinative for grey dune development and different vegetation types can be distinguished according to the geographical position (Weeda & Schaminee 1990). Invertebrate communities from North-Atlantic grey dunes respond to these climatological differences as well and are clearly reflected in the declining presence of Mediterranean species with higher latitudes.

Species pools are also affected by the geographical position. North of Belgium, sand deposits and dunes along the rivers Rhine and Meuse act as an ecological corridor between the coast and inland habitats for species such as *Euphorbia cyparassias* and *Eryngium campestre* (Doing 1993). But Belgian dunes are more clearly influenced from the south, by the chalk-grasslands in northern France. Most probably, they enriched the dune flora with species like *Asperula cynanchica*, *Helianthemum nummularium* and *Thesium humifusum*. Salisbury (1952) describes the same phenomenon of 'species supply' of British dunes from downs. Differentiation in invertebrate communities is detected in function of the surrounding landscape: if woodland, heathland or chalk grassland is present in the proximity, typical species from these habitats also colonise grey dunes, probably within a source-sink context.

On a landscape level, distribution of grey dunes is limited to dry or moderately moist zones within fixed dunes.

As most of the dune ridges along the Flemish coast were still mobile some decades ago, only young moss dunes are found in these zones. Fixed dune grassland with a distinct soil profile is limited to intermediate elevations within large dune slacks or to relief-poor inner dunes.

Stress factors form another element in grey dune distribution. The "sand spray" effect for example, will only take place in the vicinity of mobile dunes. Herbivory pressure can be linked to rabbit density and present-day or historical livestock grazing. In Dutch dunes, an effect of agricultural activities related to sea villages is reflected in vegetation and species composition (Slings 1994) but this is not observed along the Belgian coast.

Finally, fragmentation of grey dunes due to scrub stands decreases the number of typical invertebrate species within each isolated patch (Bonte et al. in press) because of smaller surfaces and metapopulation dynamics, where colonisation and extinction depend on connectivity.

### *2.2.2 Local level*

Grey dune landscapes are usually characterised by an explicit microrelief, causing a small scaled variability in microclimate and edaphic factors. These elements primarily determine species composition and performance. Superimposed, plant population dynamics, vegetation architecture and biotic interactions contribute to the development of complex vegetation patterns. As many biological processes such as seed dispersal or herbivory are highly stochastic, prediction of species occurrence becomes precarious (see e.g. Lichter 2000 for a dune example).

Data for several dune grassland species from the Belgian coast show no relation of species distribution with soil pH, which suits the absence of pattern in the relation of pH with soil organic matter content mentioned above. But concluding that pH is not a conditional factor for plant growth would be premature because of the limited pH range of the samples (figure 4). Moreover, plant rooting depth is an important feature which was not taken into account here. Mosses for example are sensitive to superficial changes in chalk content that have no impact on deeper rooting perennials.

Several plant species show a significant response to thickness of the Ah-horizon, i.e. the volume of soil organic matter (figure 5) but not to the organic matter concentration (these parameters are not correlated). Since the Ah-horizon is the result of the soil ontogenesis, figure 6 suggests that species assemblages change in function of development time, which underlines the importance of the complex processes of plant growth, biotic interactions and soil formation. Terrestrial springtails respond positively to this soil characteristic as well.

Spiders, which are their predators, aggregate in a similar pattern, not because of numerical responses but indirectly by co-evolution for similar microhabitats.

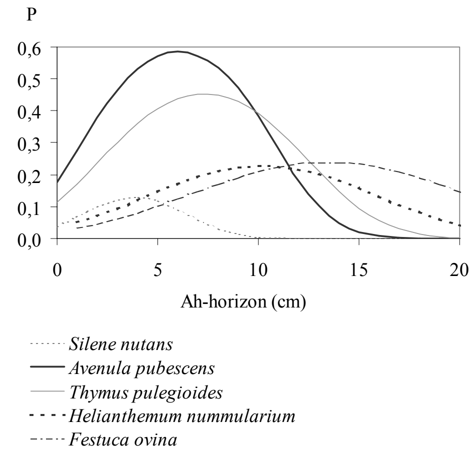


Figure 5: Logistic regression of occurrence of some characteristic grassland species to thickness of the humous Ah-horizon (after Waumans 2001, $\chi^2$-tests $p<0{,}001$, except for quadratic terms of *Helianthemum nummularium*, $p<0{,}01$ and *Festuca ovina*, $p<0{,}05$).

Insect & spider communities largely depend on vegetation structure and assemblage stability is strongly influenced by the landscape patterns. Small patches are subject to significant edge effects, resulting in a high number of atypical species and a high spatial community instability (Bonte et al. 2002). Communities in large patches are more stable due to higher internal microhabitat variation and the possibility of attaining viable population sizes. Biotic interaction also explain certain patterns in species composition: a number of invertebrates are bound to typical host plants (monophagous beetles, bugs and butterflies), while other invertebrates are bound to typical invertebrate hosts. Ants are peculiar in this respect since they host very rare myrmecophilous spiders, bugs, woodlice and probably a lot more invertebrate taxa.

In the other direction, invertebrates can also influence the presence of plant species. Ants again are of major importance since their nests create suitable germination conditions for several plant species (e.g. *Thymus pulegioides*). Additionally, they transport seeds to these nests.

### 2.3 Classification of grey dune vegetation

Syntaxonomic vegetation research contributed substantially to the present knowledge of dune grasslands (Weeda et al. 1996, Rodwell 2000).

Most of the Belgian grey dunes are categorised within the Cladonio-Koelerietalia, an order of calcicole dune vegetation within the Koelerio-Corynephoretea. Two alliances are distinguished; the Tortulo-Koelerion, including pioneer grasslands and moss dunes and the Polygalo-Koelerion containing closed grasslands on soils with a distinct organic layer. The variety reflected at the association level is much more ambiguous and depends largely on local circumstances; each segment of the European coast is after all characterised by a unique combination of climate, geomorphology, soil (e.g. reflected in $CaCO_3$ content) and history.

Dutch calcareous dune grasslands for example are divided into Taraxaco-Galietum, a more natural type and Anthyllido-Silenetum, a vegetation type associated with the above mentioned old sea villages (Weeda et al. 1996). Although general species composition is largely the same in both areas, these Dutch syntaxa are not encountered in the analysis of ca. 1000 relevés from Flemish coastal dunes (Waumans 2001). Classification reveals several distinct types, but these can not be related unambiguously to environmental parameters. These findings indicate that Flemish dune grasslands belong to only one association, the Anthyllido-Thesietum, described by Heineman (in Lebrun 1949).

Syntaxonomical vegetation classification, with an emphasis on species composition, is quite abstract and often field situations are hard to fit into the scheme because they are degraded, in a subdeveloped stage or hold an intermediate position between ‘pure’ associations. The presence of one species, for example *Rosa pimpinellifolia*, will hardly affect the position in a vegetation classification but might be of major importance for an invertebrate’s habitat.

A local typology for management planning or evaluation or other ecological applications can be more useful if physiognomic properties and species dominance is emphasized. Also, the use of fuzzy classification techniques, with gradual transitions between distinct types, might be promising.

## 3. NATURE CONSERVATION AND MANAGEMENT

### *3.1* Why preserve grey dunes*?*

In conservation policy, (loss off) biodiversity is generally used as a framework for nature (e)valuation (Reid & Miller 1989). In the ecosystem vision on coastal dunes of the Flemish government, this is translated as “conservation or development of the characteristic habitat diversity by as natural as possible means” (Provoost & Hoffmann 1996).

In an international context, the importance of grey dunes is reflected in the designation as priority habitat in the EU Habitat Directive, mainly because of the limited range. The Cladonio-Koeleretalia are considered a northern Atlantic order (Weeda & Schaminée 1990). Most of the characteristic grey dune plant species appearing in Belgium however, are not threatened, at least not in a European context. Not one is included in the Bern Convention list. A number of species, such as *Erodium lebelii* (=*E. glutinosum*), and probably some infraspecific "*maritima*" variants of *Ononis repens*, *Koeleria albescens* and others, are limited to Atlantic grey dunes (Doing 1993, Roisin 1969). This underlines the habitat specificity and the international responsibility for conservation. *Asparagus prostratus* Dumort. is probably the best 'flagship' species for Flanders, since it is limited to Atlantic grey dunes and it is very rare within the region. Recent research has confirmed its species status, discerning it from garden asparagus *A. officinalis* (Kay et al. 2001).

Within the Flemish region, grey dunes are also important for conservation of Red list species, including regionally rare chalk grassland flora (*Thesium humifusum*, *Cirsium acaule*, …) or species characteristic for dry to moist nutrient poor grasslands.

From an invertebrate fauna perspective, grey dunes are the most endangered dune habitat, certainly within a Flemish context. Most characteristic dune invertebrates however, are found in more dynamic habitats like mobile dunes and young dune slacks.

### 3.2 Threats and management

Along the western part of the Belgian coast, the grey dune area decreased from 730 to 350 ha since the fifties, mainly due to urbanisation and scrub encroachment. In addition, grey dunes are subject to internal degradation due to the grass encroachment mentioned above. Until now, this evolution was not accompanied by a drastic decline in the global number of grey dune species. However, there is an apparent qualitative shift toward a less specific flora, amongst others because of garden escapes of exotic species (Provoost & Van Landuyt 2001).

This decline of at least regional biodiversity urges managers to take active nature management measures. Removal of scrub and woodland, mowing and grazing, have proven to be appropriate tools in dune grassland restoration. Well documented examples of management schemes are available for the Dutch dunes (e.g. Annema & Jansen 1998) and the LIFE initiative at the Sefton coast in the UK (Houston et al. 2001). In Belgian dunes, around 15 ha of scrub has been removed and currently nearly 350 ha are grazed (Herrier & Killemaes 1998). Mowing is only very locally used for grey dune management.

### 3.3 Preliminary evaluation of grazing

Expectations of grazing as a management tool are often ample. Herbivores should maintain the open areas after mechanical shrub removal and prevent scrub encroachment. They are expected to preserve biodiversity and to transform species poor vegetation into species rich grasslands.

But vegetation reaction on grazing is rather slow (years to decades) and in order to evaluate on short term, feeding ecology of introduced ungulates (Konik and Shetland pony, donkey and Scottish Highland cattle) is studied in several dune areas along the Belgian coast. Diet, habitat use and behaviour are directly registered through all seasons and day periods. The first results show that all domestic herbivores are mainly grass eaters (70 to 80% of their diet is composed of grasses and sedges) and prefer grassland to feed (Hoffmann et al. 2001, Cosyns et al. 2001).

Diet composition is affected by seasonality: during winter and early spring especially cattle and donkey consume a significant amount of browse (*Ligustrum vulgare* or *Salix repens*). Nonetheless browsing intensity is not sufficient to push back or to prevent scrub encroachment (van Breukelen et al. 2002). *Hippophae rhamnoides,* the most prominent scrub species, is hardly eaten by the herbivores. But the animals do seem to anticipate with spontaneous vegetation development. Roughage, dominated by *Calamagrostis epigejos*, which succeeds in patches of decayed scrub, is successfully tackled and the impact of grazing on these and other species poor grasslands can be significant. In most cases biomass of the dominant grass species collapses and after 3-4 years several stress tolerant dune grassland species occur.

However, grazing does not simply undergo scrub dynamics but it also affects shrub seed germination and development via soil and vegetation structure. Probably vegetation dynamics under grazing management fits in a shifting mosaic pattern of climax vegetation as described by Olff et al. (1999) for grazed woodlands.

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Recruitment of favourable plant species seems to be promoted not only by grazing activity itself but also by trampling, scratching or dust bathing (creating favourable germination micro sites) and defecation, the latter having the potential to bring in significant amounts of viable seeds of several plant species including some of conservation interest. Invertebrates react even faster on changes in the vegetation and landscape structure.

Soil nutrients are redistributed through excretion. Most long-term observations show a decrease in C/N ratio. Simultaneously a large number of dung fauna appears in the soil system, increasing bioturbation and enlarging the available soil volume for rooting.

## 4. MONITORING

### 4.1 What kind of monitoring?

Also in Belgium, dune management surpassed the experimental, small-scaled stage. One of the future challenges will be to elaborate sustainable and efficient management programmes, efficiency being measured mainly in terms of biodiversity gain related to cost. This will require more detailed measurements in monitoring and continuous feedback to management planning (figure 6).

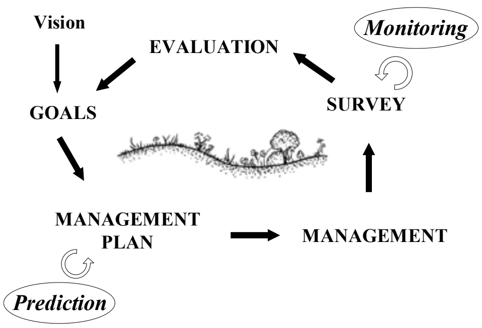


Figure 6: Cyclic process of planning, management and monitoring in nature conservation.

In a strict sense, monitoring implies repeated survey and an assessment to what degree the results deviate from a predetermined norm (Goldsmith 1991). In practice however, a lot of ‘monitoring’ does not meet this definition. The surveillance of the environmental context (climate, geomorphology and hydrology) is meant as a multi-purpose frame of reference which must enable us to estimate the relative importance of general (natural) and local, management driven change.

Firstly, direct information can be gathered on many taxonomic groups using various sampling techniques. However, there is a strong trade-off between detail and geographical range. If the inventory effort seems too high, indirect biodiversity measurement using habitat models is more appropriate. This requires the selection of a set of habitat parameters of a certain species or species group, which are easily mapped on a large surface. And of course, before all, the species' habitat characteristics must be thoroughly understood.

### 4.2 Landscape level

Detailed information about topography, preferably in combination with hydrology, is important for dune research. In a GIS environment, abiotic habitat characteristics, such as surface slope and exposition, can easily be derived from a digital elevation model.

Vegetation structure is a basic biotic layer to be added. Vegetation mapping using remotely sensed images is a very powerful tool for planning and evaluation of management in spatially heterogeneous environments as in coastal dunes.

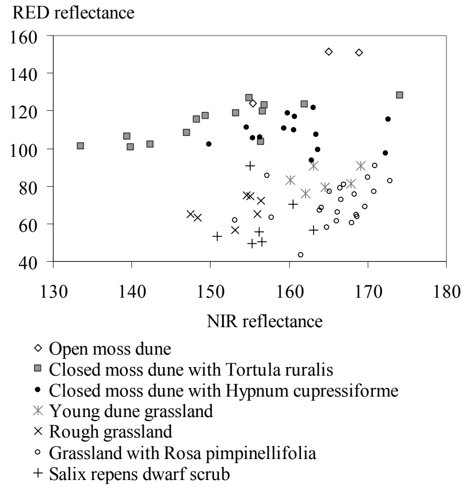


Figure 7: Spectral signatures of several grey dune vegetation types in red and near infrared bands, based on scanned false colour orthophotos.

Most remote sensing techniques are based on detection of reflected solar radiation. Interaction with earth surface features alters the characteristics of the electromagnetic waves, leaving behind a “spectral signature” (Lillesand & Kiefer 2000). Sand, for example, reflects most radiation, while green plants absorb red light (wavelength 0,6 - 0,7 µm) for photosynthesis and reflect near-infrared (NIR; 0,7 – 2 µm) due to plant tissue structure. This property allows us to estimate the amount of vegetation biomass using detected reflectance differences in red and NIR bands. It is the basic idea of vegetation indices. Many ecological applications in remote sensing are based on multispectral images, consisting of several information bands. False colour photos for instance, with near infrared, red and green bands are very useful for vegetation mapping. Hyperspectral imagery, consisting of up to hundreds of narrow bands, offers very promising possibilities for vegetation monitoring but research is still in a early stage.

Detailed nature management evaluation requires high spatial resolutions. At present, satellite sensors offer a 4 m resolution multispectral. Very high resolution images (in order of magnitude of dm) can only be achieved with digitised aerial photographs or airborne scanners.

For management evaluation in some Belgian coastal dunes, digital false colour orthophotos are used with a spatial resolution of 15 cm. The spectral discernibility of several grey dune vegetation types, based on these images, is illustrated in figure 7. Using this information, highly detailed vegetation structure maps can be produced (Droesen 1998) which can be used in habitat models or for evaluation of for instance effects of grazing on grass encroachment. In digital grid files, a fuzzy information system can be used, in which affinities for several vegetation types can be assigned to each pixel.

### 4.3 Community level

Evaluation of species composition requires a detailed survey for which a variety of sampling techniques is at our disposal. Plant communities can be mapped in classical vegetation maps, but these only contain general features. Plot measurements are considered on two levels. Typically, plots with a surface of at most several m² are used for vegetation research. They can cover homogeneous patches and are necessary to reveal detailed information on vegetation patterns and processes (Bakker *et al.* 1996). A stratified random set of some 100 permanent quadrates of 3x3 m² for example, is used for monitoring the effects of different management regimes in Flemish coastal dunes (Bonte *et al.* 1998).

However, for management evaluation on site level, using these small pq's would imply a very large number of samples to be representative for the whole area. Larger plots, up to several hundreds of m² (20x20, 50x50) could be more appropriate. An approximately equal time investment will provide information on a much larger number of species, although subtle changes in abundance will no longer be detectable. The results will enable a broader quantitative evaluation, which has the extra advantage of being less susceptible to annual fluctuations caused by weather conditions. Plots will be spatially heterogeneous but this should not be considered a disadvantage, since we aim at conclusions at a higher resolution level than the plant community. Changes can be measured using scores for several habitat types, based on species specificity and abundance. Standardised pitfall trapping is an effective method for monitoring changes in faunal (invertebrate) composition.

### 4.4 Species level

Due to sampling, the collected data will usually not include a statistically sufficient number of replicas for rare species. But precisely these peculiarities and Red list species are of great interest to the conservationist.

Especially for perennial vascular plants, detailed and site-covering inventories of a selection of 'target species' should therefore be considered. If possible, individuals are mapped, otherwise the abundance is estimated within a patch. The occurrence of mobile animals, annual plants and fungi is ephemeral and requires repeated extensive inventories. Using this method, largely excludes mistakes due to erroneous statistical analysis because the entire population is considered. An example of integral plant inventories in grey dunes is given by Annema & Jansen (1998) for the dunes of Goeree, The Netherlands. A program is set up for the Flemish coast, based on experience in the western region "Westkust" (ca. 2000 ha). Plant species included in this inventory are characteristic for grey dunes (*Viola curtisii* or *Asparagus prostratus*), chalk grasslands (*Helianthemum nummularium, Silene nutans* or *Thesium humifusum*) or other grassland types (*Rhinantus minor, Thymus pulegioides* or *Briza media*).

A detailed mapping of animal populations at present is done on the individual (territorial) level for birds (*Oenanthe oenanthe, Saxiola torquata* or *Galliruda cristata)* or on the level of the patch occupancy for typical and easily observable invertebrates such as *Hipparchia semele*, *Oedipoda caerulesces*, wolfspiders and the Sphecid *Bembix rostrata.* Especially a follow-up of colonisation and extinction dynamics can reveal interesting data for species conservation management.

## 5. CONCLUSIONS

A highly entwined complex of vegetation and soil development is the driving force in grey dune succession. In natural situations fine scaled sand, $CaCO_3$ and nutrient dynamics are probably sufficient to maintain low grey dune vegetation.

At present, grey dunes spontaneously evolve towards scrub and vegetation dominated by coarse grasses. Biomass removal, e.g. by grazing is essential for preservation of dune grassland but significantly alters the natural system's characteristics.

The investigated characteristic dune grassland plant species show no relation with soil pH or organic matter concentration. A significant response is found for plants and Collembola to the thickness of the organic Ah soil horizon, emphasizing the importance of biological development processes, rather than the mere underlying abiotic pattern.

Atlantic grey dune conservation is of international importance due to the limited range of the characteristic flora and vegetation. Syntaxonomical classification is a valuable tool in conservation but shows some major limitations for vegetation mapping.

Incorporation of vegetation structure and physiognomy is important. Fuzzy classification techniques are promising, also in respect to vegetation maps derived from remotely sensed images.

Biodiversity monitoring requires surveys on different scale levels. A combination of detailed vegetation structure maps and inventory of a selection of characteristic and indicative species is a powerful tool for management evaluation. Distinguishing management effects from other changing parameters (natural as well as anthropogenic) remains a difficult but essential task in evaluation.

Grazing management has, at least on short notice, a strong impact on vegetation structure, composition and dynamics and indirectly on faunal elements as well. Its effects on the natural grey dune determinants, such as soil development, remain obscure and should be followed in detail.

REFERENCES

Aggenbach, C.J.S. & Jalink, M.H. 1999. *Indicatoren voor verdroging, verzuring en eutrofiëring in droge duinen*. Staatsbosbeheer, Driebergen, 210 p. ISSN 0926-4558-1995-4.

Annema, M. & Janssens, A.E.M. 1998. 'Het herstel van het vroongrondgebied Midden- en Oostduinen op Goeree'. *Stratiotes,* 17, pp. 20-60.

Bakker, J., Olff, H., Willems, J. & Zobel, M. 1996. 'Why do we need permanent plots of long-term vegetation dynamics?' *J. Veg. Science,* 7, pp. 147-156.

Bonte, D., Ampe, C., Hoffmann, M., Langohr, R., Provoost, S. & Herrier, J.-L. 1998. 'Monitoring research in the Flemish dunes: from a descriptive to an integrated approach'. Proceedings European seminar on coastal dunes, management, protection and research. Skagen, Denmark, pp. 39-79.

Bonte, D., Maelfait, J.-P. & Baert, L. 2002 (in press). 'Spider assemblage structure and stability in a heterogeneous coastal dune system (Belgium)'. *J. Arachnol.*

Bonte, D., Dekoninck, W., Provoost, S., Cosyns, E. & Hoffmann, M. (subm). 'Microgeographical distribution of ants (Hymenoptera: Formicidae) in a dune grassland and their relation to the soil structure and mesophytic plant species'. *Neth. J. Zool.*

Cosyns, E., Degezelle, T., Demeulenaere, E. & Hoffmann, M. 2001. 'Feeding ecology of Konik horses and donkeys in Belgian coastal dunes and its implications for nature management'. *Belg. J. Zoology*, 131 (Supplement 2), pp. 111-118.

Dahl, E. 1998. *The phytogeography of northern Europe (British isles, Fennoscandia and adjacent areas)*. Cambridge University, 297 p. ISBN 0-521-38358-7.

Depuydt, F. 1972. *De Belgische strand en duinformaties in het kader van de geomorfologie der zuidoostelijke Noordzeekust*. Verhandeling van de Koninklijke Academie voor Wetenschappen, Letteren en Schone Kunsten van België, XXXIV, nr. 122, Brussel, 214p.

De Raeve F. 1989. 'Sand dune vegetation and management dynamics'. In van der Meulen, F., Jungerius P.D. & Visser J.H. (eds.). *Perspectives in coastal dune management*. SPB Academic Publishing, Den Haag, pp. 99-109. ISBN 90-5103-025-8.

Doing, H. 1993. 'Het Sileno-Tortuletum (ass. nov.), een karakteristieke associatie van het zeedorpenlandschap'. *Stratiotes,* 6, pp. 40-52.

Droesen, W. 1998. *Spatial modelling and monitoring of natural landscapes with cases in the Amsterdam Waterwork Dunes*. Ponsen & Looijen, Wageningen, 161 p. ISBN 90-5808-054-4.

Goldsmith, B. (ed.) 1991. *Monitoring for conservation and ecology*. Chapman and Hall, London, 275 p. ISBN 0-412-35590-6.

Herrier, J.-L. & Killemaes, I. 1998. 'Acquisition and protection of the coastal dunes of Flanders'. *Coastline,* 4, pp. 10-15.

Hoffmann, M., Cosyns, E., Deconinck, M., Lamoot, I. & Zwaenepoel, A. 2001. 'Donkey diet in a Flemish coastal dune area in the first year after introduction'. In: Houston, J.A., Edmondson, S.E. & Rooney, P.J. (eds.). *Coastal dune management, shared experience of European conservation practice*. Liverpool University Press, pp. 95-107. ISBN 0-85323-854-5

Houston, J.A., Edmondson, S.E. & Rooney, P.J. (eds.). *Coastal dune management, shared experience of European conservation practice*. Proceedings EUCC symposium, Southport, September 1998. Liverpool University Press, 458 p. ISBN 0-85323-854-5

Jungerius, P.D. 1990. 'The characteristics of dune soils'. In: Bakker, T.M.W., Jungerius, P.D. & Klijn, J.A. (eds.). *Dunes of the European coasts*. *Catena Supplement,* 18, pp. 155-162. ISBN 3-923381-23-9

Kay, Q.O.N., Davies, E.W. & Rich, T.C.G. 2001. 'Taxonomy of the western European endemic *Asparagus prostratus* (*A. officinalis* subsp. *prostratus*) (Asparagaceae)'. *Botanical Journal of the Linnean Society,* 137, pp. 127-137.

Kooijman, A.M. 2001. 'Sleutelrol voor N of P? Consequenties van nutriëntenbeschikbaarheid voor regeneratieperspectieven van duinvalleien'. *Landschap, 3, pp. 199-210.*

Kooijman, A.M., Dopheide, J.C.R., Sevink,J., Takken, I. & Verstraten, J.M. 1998. 'Nutrient limitations and their implications on the effects of atmospheric deposition in coastal dunes; lime-poor and lime-rich sites in the Netherlands'. *J. Ecol.,* 86, pp. 511-526.

Lebrun, J., Noirfalise, P., Heinemann, P. & Vanden berghen, C. 1949. 'Les associations végétales de Belgique'. *Bull. Soc. Roy. Bot. Belg*., 82, pp. 105-207.

Lichter, J. 2000. 'Colonisation constraints during primary succession on coastal Lake Michigan sand dunes'. *J.Ecol,*. 88, pp. 825-839.

Lillesand, T.M. & Kiefer, R.W. 2000. *Remote sensing and image interpretation*. 4th edition. John Wiley & Sons, New York, 724 p. ISBN 0-471-25515-7.

Olff, H., Vera, F., Bokdam, J., Gleichman, J., De Maeyer, K. & Smit, R. 1999. 'Shifting mosaics in grazed woodlands driven by the alternation of plant facilitation and competition'. *Plant Biology,* 1, pp. 127-137.

Provoost, S. & Hoffmann, M. (eds.) 1996. *Ecosysteemvisie voor de Vlaamse kust*. 2 volumes. Ghent University, Institute of Nature Conservation & Ministry of the Flemish Community, Nature division. Brussels, 375 + 130 p.

Provoost, S. & Van Landuyt, W. 2001. 'The flora of the Flemish coastal dunes (Belgium) in a changing landscape'. In: Houston, J.A., Edmondson, S.E. & Rooney, P.J. (eds.). *Coastal dune management, shared experience of European conservation practice.* Liverpool University Press, pp. 393-401. ISBN 0-85323-854-5

Reid, W.V. & Miller, K.R. 1989. *Keeping options alive: the scientific basis for conserving biodiversity*. World Resources Institute, Washington DC, 128 p. ISBN 0-915825-41-4.

Rodwell, J.S. 2000. *British plant communities: maritime communities and vegetation of open habitats*. Cambridge University, 512 p. ISBN 0-521-64476-3.

Roisin, P. 1969. *Le domaine phytogeographique atlantique d'Europe*. Presses agronomiques Duculot, Gembloux, 262 p.

Rozema, J.P., Laan, P., Broeckman, R., Ernst, W.H.O. & Appelo, C.A.J. 1985. 'On the lime transition and decalcification in the coastal dunes of the province of North Holland and the island of Schiermonnikoog'. *Acta Bot. Neerl*. 34, pp. 393-424.

Salisbury, E. 1952. *Downs & dunes: their plant life and its environment*. Bell & sons, London, 328 p.

Slings, Q.L. 1994. 'De kalkgraslanden van de duinen'. *De Levende Natuur,* 95 (4), pp. 120-130.

Tilman, D. 1985. 'The Resource-ratio hypothesis of plant succession'. *American Naturalist,* 125, pp. 827-852.

Van Breukelen, L., Cosyns, E. & van Wieren, S. 2002. 'Wat weten we van terugdringen van duinstruwelen door herbivore zoogdieren?' *De Levende Natuur,* 3, pp. 101-105.

Van Til, M. Ketner, P. & Provoost, S. 2002. 'Duinstruwelen in opmars'. *De Levende Natuur* , 3, pp. 74-77.

Veer, M.A.C. 1997. 'Nitrogen availability in relation to vegetation changes resulting from grass encroachment in Dutch dry dunes'. *Journal of Coastal Conservation,* 3, pp. 41-48.

Veer, M.A.C. & Kooijman, A.M. 1997. 'Effects of grass-encroachment on vegetation and soil in Dutch dry dune grasslands'. *Plant & Soil,* 192, pp. 119-128.

Waumans, F. 2001. *Vegetatie-ecologie van droge duingraslanden aan de Westkust*. Unpublished. Ghent University, Gent, 133 p.

Weeda, E.J. 1992. *Zandviooltje (Viola rupestris) in de duinen van Noord-Kennermerland: hoe een dwerg uit de steppetoendra standhoudt temidden van zand, zeewind en konijnen*. Wetenschappelijke mededelingen 206, Koninklijke Nederlandse Natuurhistorische Vereniging, Utrecht, 88 p.

Weeda, E.J., Doing, H. & Schaminée, J.H.J. 1996. 'Koelerio-Corynephoretea'. In: Schaminée, J.H.J., Weeda, E.J. & Westhoff, V. (red.). *De vegetatie van Nederland 3. Graslanden – Zomen – Droge heiden*. Leiden, Opulus Press, pp. 61-144. ISBN 90-5011-058-4.

Weeda, E.J. & Schaminee, J.H.J. 1990. 'Nomenclatorische en systematische notities met betrekking tot de Koelerio-Corynephoretea'. *Stratiotes,* 13, pp. 77-97.