Chapter 7: An ecosystem approach towards Belgian coastal policy

In this chapter, a general discussion, conclusions and future challenges are given. Beach research results are translated towards beach nourishment recommendations and policy guidelines for an ecosystem-based, integrated sandy beach management. Furthermore, beach fact sheets, criteria for a good ecological beach, a plea for a multi-disciplinary, integrated beach spatial plan and some future beach research suggestions have been made.

Abstract

The Belgian coastal zone hosts a complex of space-use and resource-use activities with a myriad of pressures impairing environmental conditions both on the coastline and on coastal waters. Specifically at the beach, predictions on sea level rise, intensified storms, accelerated erosion and flood risk for the North Sea have led to the drafting of the Belgian Integrated Coastal Safety Plan. The preferred coastal defence measure is beach nourishment as it safeguards the natural dynamics of the coast and has little impact on the beach ecology and tourism compared to other options. However, together with the multitude of human beach functions such as tourism and economic development, beach nourishment potentially threatens the natural characteristics of the beach ecosystem.

As management of the coastal zone is clearly a multi-faceted and complex endeavour, where the interests of several stakeholders need to be combined, coastal management desperately needs ecological dimensions. Hence, solid and meaningful biological and ecological information is needed. Clear and user-friendly management tools are essential to guide integrative and ecosystem-based strategies to sustainably manage ongoing space-use activities at the Belgian coast. From 1997 to 2011, relevant research data was gathered in 16 intertidal and 10 shallow subtidal coastal locations, over 8 years in 3 different seasons to (1) give an overview of the natural spatial and temporal variation in the Belgian coastal zone and (2) define the realized niches of the dominant intertidal and shallow subtidal macrobenthos. The *in situ* impact effects of an ecological nourishment were tested according to a Before After Control Impact (BACI) design (2008 – 2012) straddling the nourishment event (2009). The sediment preferences of the dominant Belgian intertidal beach macrofauna were experimentally tested both in single-species and combined-species conditions.

All these research results and data were used to (1) formulate research based guidelines for Belgian policy, especially regarding ecological beach nourishment, (2) develop an ecological model to predict the ecosystem response of beach nourishment scenarios at different trophic levels, (3) establish a scientifically sound and spatially based biological valuation of the Belgian coastal zone, using the marine biological valuation method (Derous et al. 2007a) and (4) produce beach records, encompassing all relevant data gathered on the 16 intertidal and 10 shallow subtidal studied coastal locations. These management tools will assist local decision makers and allow for the integration of 'nature' at an early stage of coastal policy implementation. Some future perspectives for Belgian coastal research are provided as well.

Keywords: beach nourishment, ecosystem based management, coastal policy, guidelines, tools, monitoring

1. Introduction

The Belgian coastal region is an extremely valuable social, ecological and economic environment, consisting mostly of sandy beaches with sea walls in front of the cities and dunes in between. The main long-term threats are linked on the one hand with the social and economic use of the land on or immediately behind the dunes and on the other with natural impacts like erosion and climate change. Storms and associated erosion present the most substantial universal hazard to beach ecosystems (McLachlan et al. 2013). Sea level rise due to climate change can cause flooding, accelerated coastal erosion and the loss of flat and low-lying coastal regions (Brown & McLachlan 2002), like the Belgian coastal region. Furthermore, it increases the likelihood, frequency and intensity of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands. Projections by the Intergovernmental Panel on Climate Change (IPCC) for the end of the 21st century suggest a sea level rise between 18 – 59 cm above the average 1980 – 2000 level, with indications it might be even higher. This would cause waves to increase by 2 m at our coasts (Doody et al. 2004).

The threat of coastal flood risk might be not acute but the set-up of a precautionary principle driven design is vital from an ecological point of view. Within the Belgian legal system, coastal safety is already regarded as the most important priority in the decision making process for the Belgian coast, being a prime reason of public health concern. The recently approved Integrated Coastal Safety Plan (10 June 2011) contains a series of measures and alternatives to be taken between now and 2050, guarding against the dangers of a superstorm and preventing present and future flooding (Mertens et al. 2008). For the next years, Belgian beaches will thus face a multitude of coastal defence activities, including large-scale long-term beach nourishment projects.

Meanwhile, international and European legislation is trying to counteract the deterioration of the coastal environment in terms of biodiversity and ecosystem functioning. The coastal conservation and protection is laid down in the EU Water Framework Directive, the EU Bird and Habitat Directive, and in international treaties and recommendations. The Belgian sandy coast is indeed much more than just a biological desert providing a natural defence against the sea. Therefore, management of beaches should involve more caution than is often the case. Even though a significant proportion of the beach inhabiting organisms is adapted to the naturally high environmental stress of tides, waves and winds, this adaptation has its limitations (Speybroeck 2007). The Belgian coastal zone is also an important nursery area for juvenile fish and birds and falls under the habitat type 1140 (Mudflats and sandflats not covered by seawater at low tide; cf. NATURA 2000) of the European Habitat Directive (Annex II). Thus far, six intertidal beach zones have been proposed for the Natura 2000 framework. However, no restrictions on activities have been formulated yet and possible protection of these zones has not been incorporated in the Provincial Spatial Implementation Plans (PSIPs). There are some agreements, based on European legislation (precautionary principle in Convention on Biological Diversity), that stipulate that the loss or degradation of intertidal habitat due to impact activities like beach nourishment should be discussed and accordingly compensated. Depending on the impact effects, two compensation options are available: (1) when the nourishment activity is strongly impacting the area, leading to severe loss of valuable habitat, it can be compensated by creating ecological valuable habitat on another location or (2) by considering an ecological alternative nourishment, where the majority of the nourishment characteristics (sediment used, slope of the nourishment, timing, techniques) are ecologically adjusted. Therefore, guidelines for ecological adjustment of beach nourishment, leading to a minimization of the impact on the beach ecosystem are needed. However, a suitable assessment for every beach nourishment remains needed, in accordance with European legislation (CBD, Convention on Biological Diversity, 1992; Precautionary principle; Directive on Enviornmental Impact Assessment (Commission 2011)).

Flood risk management and coastal defence can deliver benefits for both people and nature. According to the 2002 EU Recommendation on Integrated Coastal Zone Management, the 2008 Marine Strategy Framework Directive and the recent proposal for a Directive establishing a framework for maritime spatial planning and integrated coastal management (Commission 2013b), the management of the coast has to be based on a comprehensive and integrated ecosystem approach (Janssen & Mulder 2005). This environmental management approach recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species or ecosystem services in isolation. It aims at maintaining an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need (McLeod 2005). Ecosystem based spatial planning is then the tool for its implementation by bridging the gap between science and practice and filling the current need of both governments and non-governmental organizations for more practical management tools (Douvere 2008). In essence, it is an integrated planning framework that informs the spatial distribution of activities in the area of interest in order to support current and future uses of its ecosystems and maintain the delivery of valuable ecosystem goods and services for future generations in a way that meets ecological, economic and social objectives (Foley et al. 2010). Since natural coastlines do not respect political borders, these coastal spatial plan initiatives should further develop into cross-border and regional plans to fully implement a sustainable coastal ecosystem based management.

Belgium was among the first countries to implement an operational, multiple-use marine spatial plan, covering its territorial sea and exclusive economic zone (Maes et al. 2005b). It aims at achieving both economic and ecological objectives, including the development of offshore wind farms, the delimitation of marine protected areas, a policy plan for sustainable sand and gravel extraction, the mapping of marine habitats, protection of wrecks valuable for biodiversity, and the management of land-based activities affecting the marine environment. Unfortunately, the Belgian beaches, from dunes to the mean low water level (MLW), are not (yet) incorporated in this plan because of the Belgian legal intricacies (figure 1). The federal government has jurisdiction over the entire Belgian part of the North Sea, including the Exclusive Economic Zone (EEZ, more than 12 nautical miles) and the Territorial Sea (between MLW and 12 nautical miles). Within this regard, the shallow subtidal coastal zone (between MLW and 1 nautical mile) falls under federal jurisdiction. The Flemish regional authority governs the inland territory, including inland waters and estuaries, and the coastal waters above the MLW, including the intertidal coastal zone. Environmental and coastal defence policy competences are thus shared between the federal and regional levels (Herrier et al. 2005). The Coordination Centre for Integrated Coastal Zone Management encourages and promotes sustainable and integrated coastal management by allowing a platform to discuss cross-sectorial themes between the federal, Flemish and provincial policy levels (Cliquet 2001).

Figure 1: Coastal legal system in Belgium (1NM: 1 nautical mile; MLW: mean low water level; MHW: mean high water level; WFD: Water Framework Directive, MSFD: Marine Strategy Framework Directive; ICZM: Integrated Coastal Zone Management) (Laporta 2012)

The current study highlights the recent Belgian beach research and proposes four coastal management tools: (1) a scientifically sound and spatially-based biological valuation map of the Belgian coastal zone, using the marine biological valuation method (Derous et al. 2007a), (2) an ecological model that can predict the ecosystem response of beach nourishment scenarios at different trophic levels, (3) research based guidelines for Belgian policy, especially regarding ecological beach nourishment and (4) beach fact sheets, encompassing all relevant data gathered on the 16 intertidal and 10 shallow subtidal studied coastal locations.

2. Beach research

In order to protect the coastal environment, one has to know what to protect (Janssen & Mulder 2005). Good knowledge of the Belgian beach ecosystem in both the intertidal and shallow subtidal zone provides us with a baseline condition. This is the condition of the natural resources and ecosystem services that would have existed if no impacts had occurred, estimated on the basis of historical data, reference data or control data. To this end, data gathered between 1997 and 2011 in 15 intertidal and 9 shallow subtidal coastal locations over 8 years in 3 different seasons was analysed (chapter 2). The partitioning of macrobenthic community structure within the Belgian beach ecosystem showed a large within beach variability, linked to elevation on the beach and median grain size of the sediment, in both the intertidal and shallow subtidal zone. Several spatial and temporal trends in abiotic factors (overall median grain size between 150 and 300 µm) and in macrobenthic species richness (intertidal: 0 – 19 species; shallow subtidal: 0 – 28 species), abundance (intertidal: 0 – 3989 individuals.m^{-2}; shallow subtidal: 0 – 1949 individuals.m^{-2}) and biomass (intertidal: 0 – 7 g AFDW.m^{-2}; shallow subtidal: 0 – 246 g AFDW.m^{-2}) were measured. The mean macrobenthic abundance in the intertidal and shallow subtidal zone fluctuates between 0 and 350 individuals.m^{-2} over the years. Between these minimum and maximum values the natural variation on Belgian beaches runs its course. Furthermore, the observed niches and interpolated occurrence of the dominant macrobenthic species of the Belgian beaches were defined as the area where these species really live during low tide, characterized by elevation on the beach and median grain size of the sediment (figure 2).

To document environmental impacts and assess the effectiveness of management actions, the natural noise in the system should be taken into account in order for any impact signal to be determined. All these findings assess the natural variability on the Belgian beaches and increase the strength, efficiency and accuracy of monitoring strategies to detect possible impact effects on the Belgian beaches.

Adaptive ecosystem based coastal management is the best mind-set for ecological intervention. We cannot control or manage populations or ecosystems, rather we control the level of human interaction with an intervention in natural systems. Optimizing the technical aspects of future nourishment projects is as such indispensable to maintain an ecologically healthy beach ecosystem. From March until September 2009, a nourishment was performed on the Belgian beach of Lombardsijde under optimal ecological conditions, e.g. phased nourishment project with nourished sand closely matching the original sediment and only moderate beach profile changes. The timing was suboptimal although the nourishment was originally planned during the more preferable winter season. In chapter 3, the *in situ* impact effects of this 'ecological' nourishment were tested according to a Before After Control Impact (BACI) design (2008-2012) straddling the nourishment event (2009) in Lombardsijde. As a temporal control, before-impact baseline data is necessary while selection of an area that will remain unimpacted serves as a spatial control (Grober 1992; Smith et al. 1993; Underwood 1994; Schlacher et al. 2012). A wider, higher and flatter intertidal beach with coarser sediment (from 216 ± 3.6 µm in 2008 to 280 ± 8.9 µm in spring 2010) was created and no return to the pre-nourishment abiotic conditions was visible three years after nourishment. The sediment grain size distribution had changed as well, showing slow recovery in the three post-nourishment years. The analysis of the macrobenthos community structure showed that nourishment under ecological optimal conditions does not yield any significant effects on both the intertidal and shallow subtidal beach ecosystem 6 months after the nourishment. Within this time frame, the macrobenthos community had recovered from the impact of the ecological nourishment. Ecological nourishment thus proves to be the least ecologically damaging way of combating erosion, compared to all other coastal engineering activities.

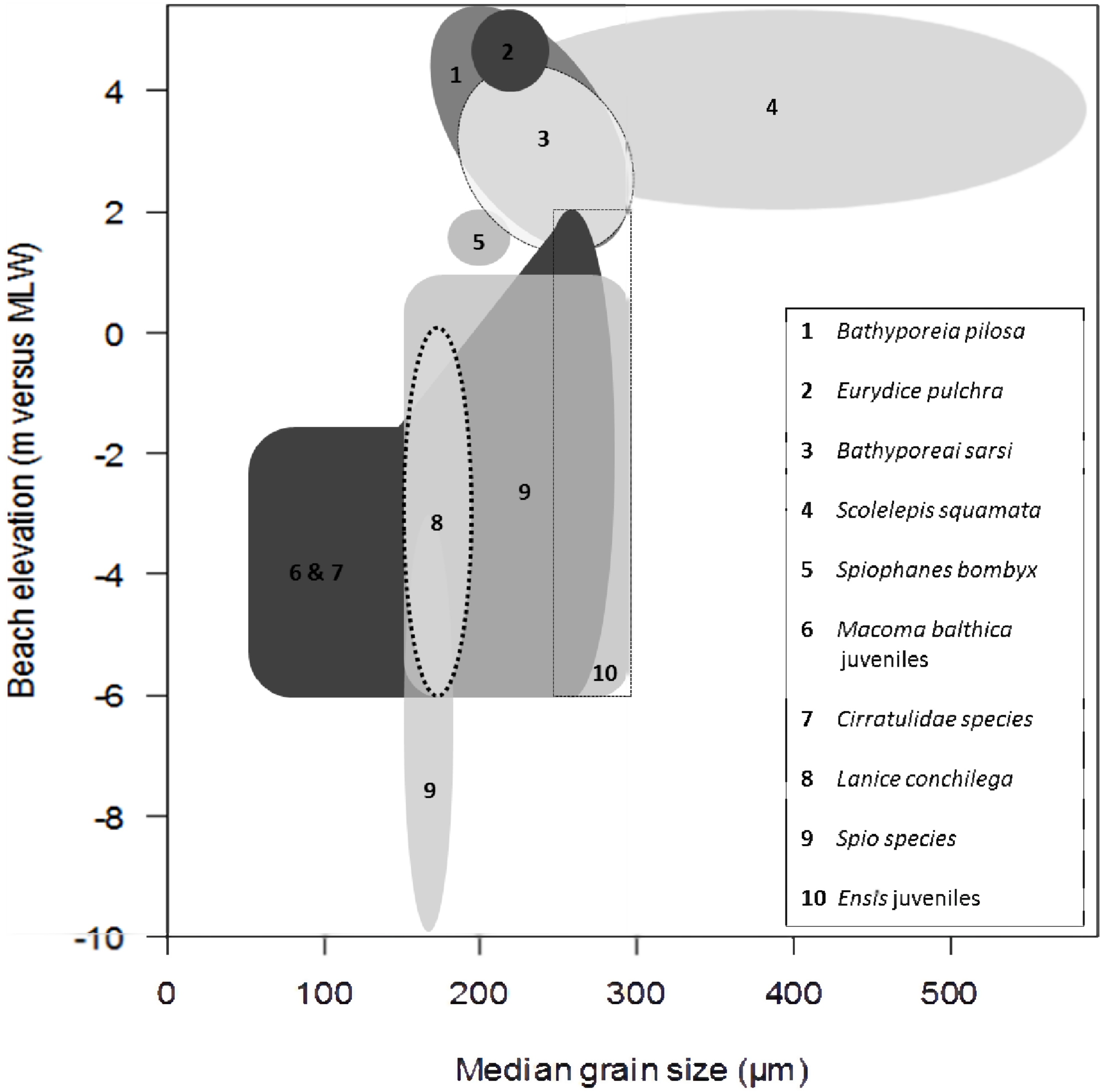

Figure 2: Observed niche and interpolated occurrence of the dominant Belgian macrobenthic species along an 'average' Belgian beach transect

The sediment preferences of the dominant Belgian intertidal beach macrofauna were experimentally tested both in single-species and combined-species conditions in chapter 4. Results of the experiments indicated that *Bathyporeia pilosa* and *Eurydice pulchra* prefer the finest sediment (< 250 µm), while *Bahyporeia sarsi* (250 – 355 µm) had a broader preference and also occurred in medium-coarse sediments. Interspecific competition between the sympatrically occurring amphipods was found to change the sediment selection of the amphipod *Bathyporeia pilosa* towards the coarser sediments where *Bathyporeia sarsi* occurred in lower frequencies. The polychaete *Scolelepis squamata* had the broadest preference (355 – 500 µm) and even showed a high occurrence in coarse sediments that are not naturally occurring on the Belgian sandy beaches. These preferences imply that beach nourishment with coarse sediment will have a major effect on *Bathyporeia pilosa* while effects of coarse sediments on *Scolelepis squamata* will be minor.

3. Research based guidelines for Belgian coastal policy

3.1 Monitoring guidelines

Good research starts with the collection of baseline environmental data to identify as much unknown variables as possible. Studies should be done at the appropriate spatial and temporal scales depending on the questions to be answered and they should be standardized to assure similar methodology throughout the long term dataset. Research surveys must be designed to take into account the fact that benthic fauna is extremely patchy in distribution and abundance (Eleftheriou & McIntyre 2008). The sampling method has to quantify, minimize and/or explain all scales of variability in the benthos and provide a solid base for ecological comparisons across, along and between shores or from year to year (Hayward 1994).

These few guidelines would allow for a good follow-up of beach conditions. On each beach, a sequence of samples (0.1026 m^2 sampling size with a depth of 0.15 m) arranged at uniform time intervals along the across-shore gradient has to be taken, both in the intertidal (15 samples with quadrat frame) and shallow subtidal zone (15 samples with Van Veen grab), preferably during two seasons, being spring and autumn. Physical characteristics of a beach act on beach macrobenthos at a single place and on a single time (Hacking 2007), making physical data at the time of sampling essential to predict beach macrobenthic communities. A sample of sand, sieved and analysed, gives an immediate and quite precise insight into the ecology of the habitat at the sampling location. The abiotic factors measured, especially beach height and median grain size, should provide a good overview of the physical characteristics of the Belgian beaches.

Traditionally, sandy beach ecologists have sampled along transects, e.g. shore-normal lines of samples from MHW to MLW. Due to the spatial autocorrelation among individual transect samples, they cannot be treated as replicates from one another. Data obtained from an individual transect should be pooled, thereby integrating the across-shore variability and providing a point estimate without confidence intervals. However, other disciplines often use stratified random sampling designs to quantify sources of variability in community descriptors along environmental axes. This technique allows for random sampling site selection within strata, horizontal layers of material harbouring a similar community, rather than by investigators, hereby ensuring that they are representative, unbiased and can be extrapolated to show the ecological condition of the entire stratum. Each set of macrobenthos samples collected within a stratum, is considered to consist of replicate samples of that stratum and should provide a representative view on the macrobenthos of the stratum. In theory, the samples within the intertidal or shallow subtidal zone could be regarded as replicates of one another. In reality, there is a macrobenthos zonation gradient present on the Belgian beaches, leading to smaller groups of 'replicates' according to the different beach height zones. The stratified random sampling approach is, however, often considered impractical on beaches because across-shore strata are difficult to define a priori (Schlacher, Schoeman et al. 2008). According to figure 2, two big strata can be detected in both the intertidal (between 2 and 6 m above MLW and between 0 and 2 m MLW) and shallow subtidal zone (between 0 and -6 m above MLW and below -6 m above MLW).

The number of samples taken in a given area is always a compromise between having sufficient replication at any site to allow statistical testing and having a wide enough coverage of sites in time and space to answer questions about the temporal and spatial patterns in the benthos (Gray & Elliott 2009). Capturing spatial and temporal variability on sandy beaches also requires true replication of sampling stations over appropriate scales. No single sample size is appropriate for all quantitative ecological studies but several authors (McLachlan 1983; Schlacher, Schoeman et al. 2008; Schoeman, Nel et al. 2008) postulated an aggregate area between 0.25 and 5 m² for accurate sampling to avoid underestimation of species richness. Using the quadrat frame and Van Veen grab (surface area, 0.1026 m²), three replicates would suffice to reach the bear minimum. Replication of samples was however not feasible due to time constraints on work effort. Schlacher et al. (2008) suggest taking samples to a minimum depth of 0.25 m to capture the largest possible fraction of resident organisms. The samples in this study were taken to a maximum depth of 0.15 m.

Researching a greater number of transects and replicating samples in the intertidal and shallow subtidal zone, at different seasons, seems to be unnecessary to characterize the macrobenthos zonational patterns but could provide statistical power to detect these patterns (Elliott, Degraer et al. 1997). Moreover, conventional parametric approaches will probably be confounded by the autocorrelation in the abiotic and biotic variables, violating the assumptions of parametric analysis, making non-parametric analyses the preferred statistical option.

To research ecological impact of beach nourishment, it is advised to monitor at least two unimpacted beaches parallel to the impacted beach to provide for a reference framework. Sampling on all beaches should begin at least a year prior to nourishment during spring and autumn. Sampling should be restarted as soon as the nourishment activities are finished. A more intensive sampling scheme during the first year (1 week, 1 month, 3 months and 6 months) could monitor the short term development of the nourished beach while long term effects should be researched up to 3 years after nourishment.

3.2 Nourishment guidelines

In many instances, it is still assumed that the only reason for ensuring apparently pristine beaches is to attract tourists and holiday-makers. Technical aspects were therefore dominant in taking management decisions for coastal defence. Easily available sand with coarse grain size and a rather steep, more stable beach slope were the standards of any beach nourishment project. It has been shown (chapter 2) that Belgian beaches do harbor a healthy beach ecosystem, when given the chance. The research conducted in chapters 2, 3 and 4 provide us with sufficient findings to formulate guidelines for ecological adjustment of beach nourishment, based on the initial set of guidelines recommended by Speybroeck et al. (2006).

Nourishment sediment characteristics

Every effort should be made to ensure that the nourished sediment is similar to that occurring naturally, in hydraulic properties and characteristics, including grain size (McLachlan 1996; Hamm et al. 2002), clay/silt portion and shell content (Peterson & Manning 2001), to minimize environmental impacts (Greene 2002). Nourished sediment should be non-contaminated (Essink 1999). As Belgian beaches have an average sediment grain size range of 150 – 300 µm and all dominant macrobenthos do show a preference to these sediments (chapter4), it is advised to use fine to medium sand for beach nourishment (< 300 µm). The total amount of nourished sediment should be kept as small as possible (Speybroeck et al. 2006a).

Beach profile

In order to protect the biota, beach profiles should be changed as little as possible (Short & Wright 1983; Defeo & McLachlan 2005; McLachlan & Dorvlo 2005). Severe profile change will impact the ecosystem and determine the efficiency and the lifetime of the nourishment. Certain profiles can favor or reduce specific species and their habitats. These effects will only be temporarily as the profile will ultimately evolve towards the pre-nourishment conditions. A very steep slope however will enhance the risk of a complete community shift on the intertidal beach.

Belgian beaches are characterized by gentle slopes and fine sediment and harbor a specific beach ecosystem (Speybroeck et al. 2008a) while beaches with steep slopes and coarse sediment are inhabited by a less species-rich macrobenthic community (McLachlan & Dorvlo 2005). When the morphodynamic features of a beach are changed to such a degree that they resemble the features of a reflective beach, e.g. steep slope and coarse sediment, a shift to the less species-rich alternative community is very likely.

Nourishment location

As the Belgian sandy beaches can be considered as one ecosystem, disturbances on a local beach can be counterbalanced by the complete system. However, the different harbor inlets also divide the Belgian beach ecosystem into separate parts. Although the across-shore zonation is stronger than the along-shore differences (chapter 2), it seems wise to maintain a precautionary approach regarding the resilience of the entire Belgian beach ecosystem.

Due to the high technical effort characterizing beach nourishment, only a limited amount of the beach area (1 – 2 km) is impacted at once. These nourishment dimensions enable species to escape to adjacent areas and species from source populations on other beaches to recolonize the nourished beach. Hence, alternation of impacted and non-impacted beaches and phased nourishment (nourishing only parts of a beach at one time thereby expanding the nourishment area slowly) is essential for the maintenance of a healthy and well-balanced beach ecosystem.

Both foreshore and backshore nourishment are no real alternatives for beach nourishment. The impact effects of foreshore nourishment are not yet known and the shallow subtidal beach zone is a noted refuge, nursery and feeding area for epibenthos and hyperbenthos (Beyst et al. 2001b).
Moreover, foreshore nourishment becomes only effective after three to five years, providing no effective defence against short-terms coastal defence threats, for instance predicted storm or flooding events. Backshore nourishment involves sand deposition at the dune foot. Unfortunately, this sand is easily removed by waves and winds, creating a steep beach slope (Harte et al. 2002).

Nourishment timing and recovery period

When scheduling beach nourishment operations, it is important to avoid the breeding and recruitment season of all beach inhabitants, e.g. infauna, macro-crustaceans, marine fish and birds, since their occupancy of the intertidal beach and their recovery rates are then at their highest (Speybroeck et al. 2006a). The most opportune time of year for carrying out such work is during the winter months, as the reproductive cycle of most species begins in March and can extend beyond October. That way, the freshly nourished beach can quickly be recolonized by the recruits and seeds when reproduction starts in spring. As the winter period is also the less touristic season, it is considered the best period for nourishment both from a touristic and ecological point of view.

Several short nourishment projects in time (minimum one week in between) and space (leaving beach strips unnourished) are preferred over broad-scale, long lasting ones, especially in areas where short term morphological changes are unpredictable (Hillen & Roelse 1995)

If no further nourishment projects or other pressures are impacting the beach, the system should evolve towards the pre-nourishment conditions although it remains impossible to predict the timeframe of that evolution. Not only the specific characteristics and timing of the nourishment are determining factors, but also the specific features of the beach ecosystem. Recovery will only take place if the nourished beach possesses the right characteristics for planktonic dispersing larval stages and passively migrating adults to settle upon. However, some species can recolonize faster than others. Especially marine animals with pelagic larvae are swift colonizers, while crustaceans with brood care are slow colonizers. The post-nourishment monitoring data (chapter 3) suggest that at least in some cases nourishment under ecological optimal conditions can show no significant effects in the macrobenthos community structure 6 months after the nourishment (2010S). Within this short-term time frame, the macrobenthos community recovers from the impact of the ecological nourishment, showing no dispersal or recruitment limitations.

Nourishment technique

On Belgian beaches, most of the nourishment projects supply sand on the upper zone of the beach through pipes while bulldozers further divide the sediment over the entire beach. Schlacher et al. (2012) showed that this approach can have large ecological impacts that vary with elevation on the beach. The discovered patterns even suggest that burial, crushing and sediment compaction by the bulldozers were the most probable causative factors for these observed ecological impacts. The finishing work done by bulldozers is not always necessary as the action of the waves and tides restores the natural appearance of the beach in a relatively short period of time (Adriaanse & Coosen 1991). The most benign strategy is slow nourishment by sheeting a spray of sand and water (rainbow spraying). This allows beach organisms to keep up with the sediment overburdens as they are applied (Grober 1992; Schlacher et al. 2012).

4. Management tools for Belgian coastal policy

(Speybroeck et al. 2006a) indicated that an ecosystem vision on nourishment effects is generally missing. Hence, extensive scientific information on the complete beach ecosystem and clear and easy to use management and decision support tools are provided.

Predictive model for the effects of beach nourishment

The nourishment simulation model for the Belgian beach ecosystem, developed in chapter 5, integrates species envelope-based projections for the dominant macrobenthos species and mechanistic foodweb modules for higher trophic levels, e.g. epibenthos and birds. It enables the user to compare the effects of nourishment with varying technical features. According to the model, the sediment grain size is the most important factor determining beach-level diversity and production, with strong deterioration of the beach ecosystem after nourishment with too coarse sediment (e.g. >> than 300 µm). Therefore the gradient in sediment grain sizes that is advised for nourishment of fine-grained beaches is defined as 200

– 300 µm with the critical median sediment grain size set at 300 µm. Although the effect of nourishment slope was less strong compared to the sediment, nourishment slope did also affect species zonation patterns. For a uniform sediment grain size, high-shore nourishment was found to positively influence the abundances of high-shore species such as *Bathyporeia pilosa*. Patterns for higher trophic levels do not follow these decreasing patterns in macrobenthos abundance and biomass. Both the slope of the nourishment project as well as the sediment can be varied in the model, enabling the user to determine the combination with the lowest impact on the ecosystem. This first predicting model for nourishment effects can as such be a valuable tool in the selection process for compensation options.

Baseline maps depicting the ecological value of our beaches

In chapter 6, a scientifically sound and spatially based biological valuation of the Belgian coastal zone is given, using the marine biological valuation method (Derous et al. 2007a). Spatial coverage and overall data availability were satisfactory and allowed for significant trends and patterns to be observed. Although the Belgian coast is entirely composed by sandy beaches, there is indeed biological diversity among distinct subzones. A strong mosaic pattern of biological value along the coastline and a clear lack of (benthic) data at the eastern part of the Belgian coast was detected. Around 70 % of the shallow part of the subzones scored rather *high* biological values, compared with the intertidal part and *high/very high* biological values were consistently found in intertidal zones located immediately to the east of the harbours Nieuwpoort, Oostende and Zeebrugge. A detailed analysis of protected areas and areas under coastal flood risk indicated that the use of Biological Valuation Maps (BVMs) is very promising in order to differentiate between several impact values. BVMs provided a strong visual support to the proposal for the extension of some already existing nature reserves and to the need for more data to allow for significant conclusions regarding the biological value of other reserves. The designation of marine reserves adjacent to protected beaches is of the uttermost importance to achieve a successful and ecologically justified implementation of beach reserves (Herrier 2002). BVMs will allow for the integration of 'natural/ecological values' at an early stage of policy implementation, spatial planning and nature conservation.

Beach fact sheets of all studied Belgian beaches, combining all research information

The beach fact sheets in Appendices – Chapter 7 – Beach Fact sheets provide all information gathered during this PhD research (chapter 2 – 6) on the 16 intertidal and 10 shallow subtidal studied coastal locations. In a clear and easy to work with format, each beach record gives an overview of its location, legal circumstances (Provincial Spatial Implementation Plan and nature conservation status), possible coastal defence activities, biological value and current scientific knowledge.

5. Conclusions

5.1 Beach Spatial Planning = science + policy

The Belgian coastal zone should be evaluated against all beach functions, including coastal environmental protection, coastal defence and tourism to obtain an integrated beach spatial plan. In some coastal areas a conflict is present between locations sensible to coastal flood and locations displaying *high/very high* biological value, e.g. Middelkerke, Oostende-East and Knokke-Heist (chapter 6). If coastal defence activities are to be performed in these areas, appropriate (mitigation) measures should be drafted.

Beside the delineation of Habitat 2000 areas, European legislation also forces the member states to define a good ecological status for these areas and to formulate conservation objectives. As a high human impact has been influencing the beach ecosystems in the past, it is difficult to determine the best possible quality of a Belgian beach. The current most valuable beaches are not necessarily the best possible beaches as we do not know their (possibly better) condition in the past. On the other hand, beaches that now show a lower intrinsic value could have the potential for valuable nature development. Hence, the definition of a good ecological beach (a healthy beach of habitat type 1140) has to be formulated in a human impacted time and space, making it a very hard exercise. Nevertheless, such a definition is essential for formulating conservation objectives. The criteria for a good ecological beach have to indicate what ecosystem components and processes in ecosystem functioning need to be available on a healthy beach and what state they have to be in. Figure 3 gives a preliminary overview of criteria based on my own research. Future research can elaborate and specify these criteria.

There is still a pressing need for better communication and cooperation between scientific institutions involved. Currently, the Research Institute for Nature and Forest (INBO) is responsible for suitable assessments and beach protection but not all necessary information is available to this institution. Therefore, a good communication and regular deliberation between Belgian beach ecology experts and INBO is essential for the best possible assessments and conservation objectives. Regarding coastal defence activities, all research conducted during this PhD research amounted to updated guidelines for ecological adjustment of beach nourishment as summarized in figure 4. Furthermore, relevant marine scientific institutes should be more visible in determining important guidelines for spatial planning. Although uncertainty is inherent to the scientific process, research institutions should dare to make statements and predictions, necessary for an integrated spatial beach planning.

A multi-disciplinary, integrated beach spatial plan, combined with the marine spatial plan of the shallow subtidal Belgian zone should be the ideal scenario for the Belgian coast. Integrated consultation and deliberation with all stakeholders, institutes and authorities involved will become an important issue in the future. However, this will always be a tremendous task as local authorities will not be keen on ceding power to higher authorities. Nevertheless, narrowing local authority power and making decisions on higher jurisdiction levels will be the only solution for establishing a long-term, integrated and sustainable beach and coastal spatial plan for the entire Belgian coast.

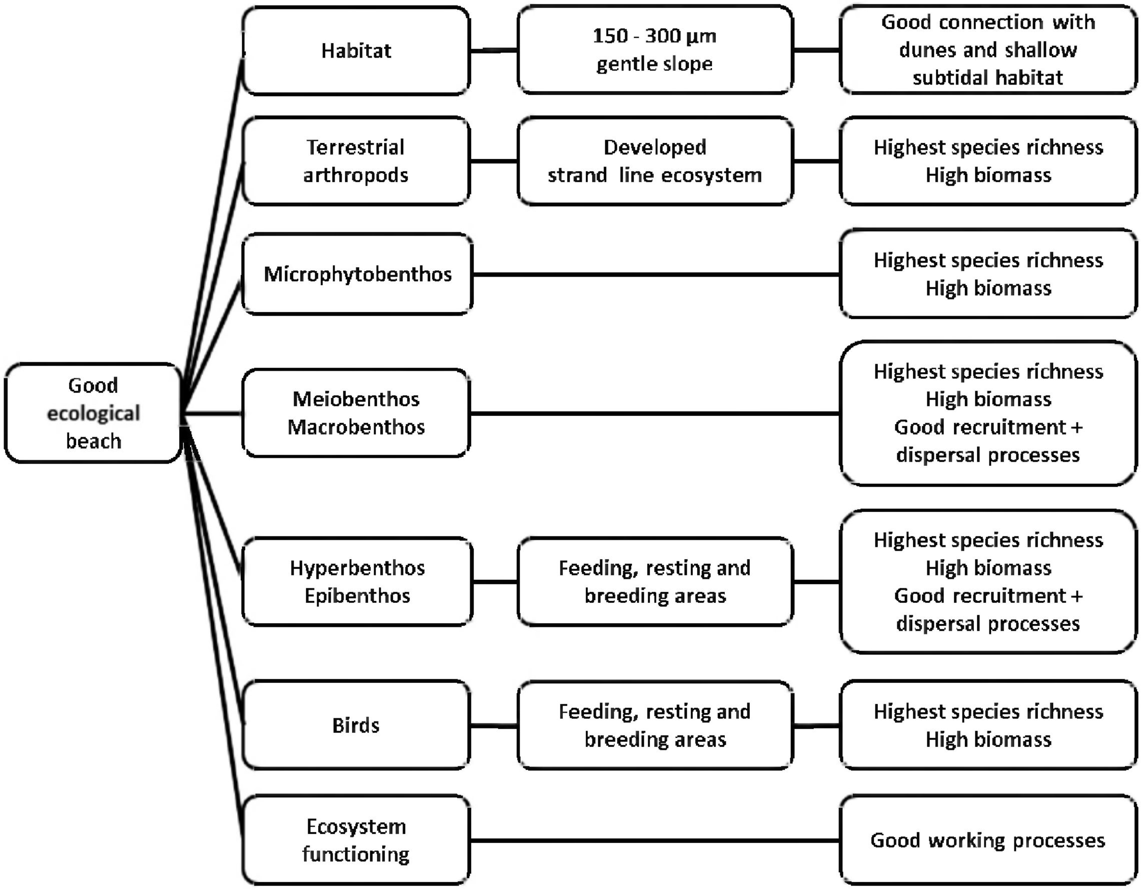

Figure 3: Criteria for a good ecological beach

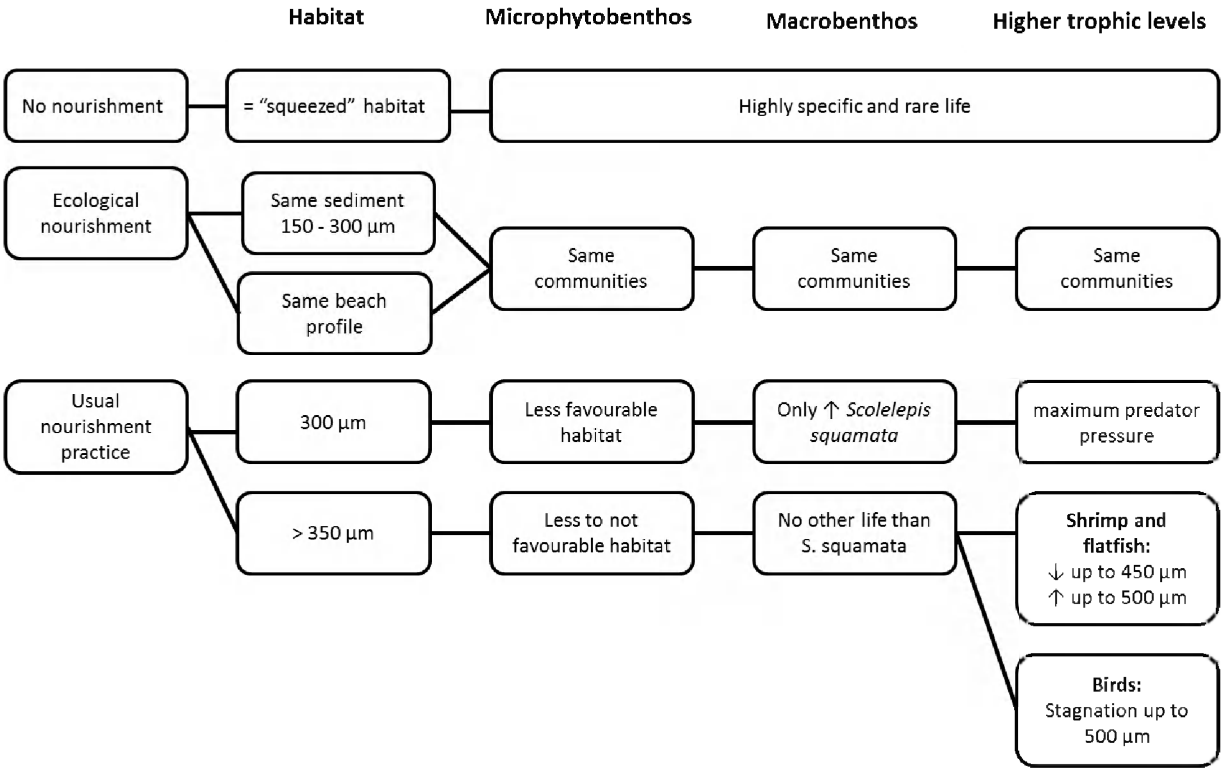

Figure 4: Guidelines for coastal defence, in particular ecological nourishment

Sacrificing bits of nature (urbanised beaches) in order to protect the Belgian beach ecosystem (benthic protected areas)

As highly touristic, (semi-)urban, top priority coastal defence beaches with a high percentage of development along the coast are heavily threatened by coastal erosion and sea level rise and need the most protection, beach nourishment will be applied repeatedly on these beaches. Furthermore, to enlarge the 'lifetime' of the nourishment, both steep slopes and coarse sediments will be used, leading to negative impacts on the ecosystem of these beaches. However, these beach ecosystems are already strongly impacted and consequently impoverished by beach cleaning, trampling, pollution and presence of coarse material due to previous (local) nourishment projects. Moreover, these impacts suppress any possible development of healthy beach ecosystems. Therefore one could suggest to 'sacrifice' touristic and top priority coastal defence beaches in the light of nature protection in order to focus on the protection of ecologically more valuable beaches (determined in chapter 6). That way, both the intrinsic value of the beach ecosystem could be protected and human use of the beach can be kept on the biologically less valuable beaches.

When beach nourishment is executed under ecological optimal conditions, following the guidelines for coastal defence, compensation measures are minimal. The loss of touristic, top priority coastal defence and/or ecologically low valuable beaches should not be considered at the same level as the loss of ecologically valuable beaches, urging for compensation measures to be more attuned to the economic reality of the beach. Communication between institutions that monitor the impact of beach nourishment and institutions that have a more advising role is such crucial to formulate valuable guidelines for compensation or ecological nourishment in the suitable assessments of announced nourishment projects. Furthermore, a good knowledge on the response of the beach ecosystem following nourishment is essential (chapter 3 and 5) and a suitable environmental impact assessment for every beach nourishment remains needed, in accordance with European legislation (CBD, Convention on Biological Diversity, 1992; Precautionary principle(Commission 2011)).

A good connection between biologically valuable beaches and connections with both protected dune areas and protected (shallow) subtidal areas ascertains the protection of an overall valuable beach ecosystem. Concerning beach conservation, one of the first tasks will be to evaluate and designate the area of the proposed habitat type 1140. In the evaluation process, the connectivity with (shallow) subtidal protected areas and dune reserves is essential. As this condition is generally fulfilled for the proposed areas, the location of these areas is well-considered but the ecological value should still be evaluated with the recently available BVM of the Belgian beaches (chapter 6). This evaluation shows that the most important flaws of the proposed Habitat 2000 areas are the absence of protected areas in the central part of the Belgian coastal zone and the non-incorporation of ecological valuable beach areas located immediately to the east of the three prominent Belgian harbours. The major wind-driven and tidal currents and waves at the Belgian coast have a southwest-northwest direction (van der Molen & van Dijck 2000; Speybroeck et al. 2008a). The east side of these prominent hard structures (also referred to as lee-side) is a sheltered area where hydrodynamics are less intense and sand deposition occurs, creating a wealth in soft-bottom habitats and proper environmental conditions for benthic colonization. Furthermore, connectivity of protected beach zones should be well considered. Therefore, the central part of the Belgian coastal zone should be better covered with protected beaches, in connection with the protected dunes in this area.

Combination of coastal defence techniques

In some conditions, the best approach for coastal defence is a combination of management measures. The construction of groins may be beneficial in some situations, not only to protect the physical (nourished) beach, but also to provide refuge for certain shorebirds and other threatened species. However, these hard structures introduce a new, not naturally occurring habitat and ecosystem into and onto the Belgian beaches (Engledow et al. 2001). Such constructions need careful planning and execution and a thorough knowledge of sand transport and budgets in the area is mandatory. Moreover, beach nourishment, foreshore nourishment, the construction of technically highly enhanced dykes that do not disturb the view, dune creation, reshaping, brushwood hedges and the construction of groins can all be combined to obtain a sound beach safety plan that includes a minimum of costs and work while minimally impacting the beach ecosystem.

Beach nourishment can encourage further development along unstable shorelines which can further reduce future alternative management options, such as shoreline retreat (Greene 2002). The project 'Vlaamse Baaien' aims at developing a Masterplan for the Flemish Coastal Zone by 2050, regarding five basic concepts : safety, naturalness, attractiveness, sustainability and development. One of the proposed projects involves the creation of barrier islands in front of the Belgian coast. These islands can have different functions, including coastal protection, green energy support ('Socket at Sea' principle, a place to store energy at sea), maritime safety support and development of durable energy. However, functions on these islands will only move the actual coastline further seawards since these islands will then suffer the impact of erosion and climate change instead of the Belgian beaches. Consequently, coastal defence will be necessary on these islands. Research on barrier islands showed profound impacts of beach nourishment. A steeper beach profile is created when sand is stacked on the beach during the nourishment process and this condition can lead to greater wave energy on the beach and greater beachside erosion (Kaufman & Pilkey 1983). It can also preclude wave overwash, leading to further erosion on the soundside. Under normal conditions, barrier islands move slowly landward with rising sea level (Pilkey & Clayton 1989; Pilkey 1998). Some scientists have predicted that efforts to keep these dynamic areas in a fixed location through for instance beach nourishment, will ultimately result in their demise.

Beach Ecosystem vision

The Belgian beach ecosystem has been thoroughly described by Speybroeck (2008). The necessity for a good ecosystem approach and a solid ecosystem interpretation led to the development of a nourishment model (chapter 5). It was the first attempt to link different trophic levels to one another in a food web framework. Based on the baseline information on Belgian beaches (chapter 2), the impact effects of both an ecological nourishment (chapter 3) and the effect of coarser median grain size on the intertidal macrobenthos (chapter 4), a better beach ecosystem vision was incorporated in the model in chapter 5 and as a result, the nourishment impact on the distribution and zonation of microphytobenthos, macrobenthos, fish and birds was modeled. The presence of a lot of birds or a high macrobenthos biomass on the beach can be a deceiving indicator for the beach ecosystem health. Indeed, the model shows that after nourishment with coarse sediment (> 300 µm), both total macrobenthos biomass as well as bird abundances increase. However, this is the result of the decrease in biodiversity and the increase of the abundance of one opportunistic macrobenthos species, *Scolelepis squamata*, resulting in the attraction of trophically linked bird species. The quality of the beach ecosystem and the importance of the biodiversity in the functioning of the beach ecosystem is as such not visible by only assessing for instance the biomass flow through trophic levels. Nutrient sediment cycles (nitrogen, carbon…) also play a significant role through primary production, microbial cycles and so on. Hence, the observation and evaluation of a too limited selection of ecosystem variables will hamper a good ecosystem approach. The combination of at least biodiversity and biomass provides for a better assessment of the beach ecosystem quality.

The intertidal Belgian beaches represent the largest nursery area for both marine fish as well as birds along the Belgian coast (Beyst et al. 1999a; Vanermen et al. 2009). Hence, degradation of the intertidal beach will heavily impact these higher trophic levels (Stienen & Van Waeyenberge 2004; Stienen et al. 2005). Nourishment impact on biologically valuable beaches with rich feeding grounds for birds and fish (chapter 6) will have an important effect on the populations of higher trophic species of the whole area. It is however impossible at the moment to exactly quantify the minimum impact area of valuable beaches that will have a meaningful effect on the higher trophic levels of the ecosystem.

The combination of one major beach nourishment project, followed by a foreshore nourishment for maintenance, will probably be a bad option for juvenile epibenthos and hyperbenthos feeding on the beach. The major beach nourishment will render the intertidal nursery area (temporarily) unavailable while the foreshore nourishment will impact the alternative nursery area, the shallow subtidal. Moreover, the shallow subtidal cannot be used as a refuge for marine intertidal species during the beach nourishment so this combination can have a negative local effect on these benthic communities. The preliminary results of the Ameland reports contest this statement but more research is needed. The combination of beach and foreshore nourishment needs careful consideration and should be evaluated on a site-specific basis.

5.2 Future beach research

If we continue monitoring the Belgian beaches in a standardized way, we will succeed in building a long term dataset at meta-analysis scale. For the understanding of large-scale patterns, intensive long-term sampling in a few areas would be meaningless, and a large number of snapshot samples covering a wide range of conditions is more appropriate (McLachlan & Dorvlo 2005). Regarding future monitoring, we suggest surveying every beach of interest in both the intertidal and shallow subtidal zone, preferably replicated in an appropriate manner. Seasonal variation can be monitored in spring and autumn although yearly monitoring in autumn will suffice as well. Prior to future research, pilot studies could be performed to determine the relative efficiency, accuracy and precision of: (1) combinations of sample size, depth of sampling and sieve mesh size, and of (2) macrobenthos sampling stratification in order to assess feasibility of a stratified random sampling design and hence a possible reduction in the required number of samples. It might also be interesting to gain insight in the hydrodynamic and turbidity conditions of the sandy beach ecosystem.

For examining most environmental impacts and many other ecological hypotheses, the temporal scales of change are not known and can seldom be predicted. *In situ* monitoring in the field also goes hand in hand with environmental heterogeneity, unpredictable biotic and abiotic environmental fluctuations and sampling variances, making the detection of impact effects difficult and arduous. In spite of all this, monitoring still remains the best way forward as other techniques have their constraints as well, e.g. experiments representing an artificial environment or models with possible incomplete algorithms predicting unrealistic patterns and trends. Ideally, research in the field should be combined with experimental research to study the tolerance and preference of species for certain beach dependent factors, like beach slope, turbidity and silt fraction, and to study migration and recruitment patterns.

Much research remains to be done on ecological relationships between macrobenthos and other trophic beach levels (meiobenthos, hyperbenthos, epibenthos, microphytobenthos and birds). Gaining a comprehensive understanding of how these communities fit into the larger beach ecosystem and food web will be necessary to fully assess the impact of anthropogenic activities. Cumulative ecological effects of beach nourishment in both space and time remain hardly unknown (Greene 2002; Speybroeck et al. 2006a) and research on foreshore nourishment as a prime and cumulative defence technique is of the utmost importance in the near future. All this information could lead to a better understanding of the sandy beach ecosystem and its resilience to withstand impacts, not in the least the impact of nourishment.