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How may beach nourishment affect the sandy beach ecosystem? The case of Belgian beaches

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Abstract

Though often regarded as biological deserts, sandy beaches provide a unique habitat for several species. Research was conducted by a consortium of experts with as a first objective to provide an integrated overview of the Belgian beach ecosystem and all its major components. A second objective comprised a review of available literature on the ecological impact of beach nourishment. To meet the first objective, an integrated overview of the Belgian sandy beach ecosystem based on spatial and temporal variation of fauna and flora of 11 sandy beaches is provided. The presented results corroborate the overlooked ecological significance of sandy beaches as a habitat. Besides sedimentology and hydrodynamics, five ecosystem components were taken into account: microphytobenthos, vascular plants, terrestrial arthropods, zoobenthos and avifauna. Nourishment of beaches is a large scale anthropogenic influence on sandy beach ecosystem. Sandy beaches are regarded as systems with a strong resilience towards such impacts. Nevertheless serious (short term) ecological effects can be expected. A review of prior studies indicates that the impact of nourishment is rather case-specific and that it is difficult to draw general conclusions. Short term impact is mostly large due to total mortality of benthic life. It seems very likely that potential recovery from the impact of nourishment will be limited to two essential, species specific pathways: (1) survival by resident organisms and (2) re-colonisation by immigrating individuals, the latter depending on both the dispersal capacities and habitat demands of the organisms. Further research is needed to explore possibilities for reducing detrimental ecological effects. Specific studies are needed towards the survival options, the dispersal capacities and habitat demands of the species present. These should allow for management guidelines to be drawn in terms of preferable nourishment sediment characteristics, timing and practice of the deposition of the sand.

Keywords: Sandy beaches; Belgium; Beach nourishment; Beach ecosystem.

Introduction

Sandy beaches are often regarded as biological deserts, mainly in contrast with rocky shores. Yet, while they do not exhibit the same level of biodiversity as their hard substrate counterparts, sandy beaches possess a clear functional role. Besides providing a habitat for a number of beach-specific organisms, sandy beach ecosystems play an important role in providing food and serving as breeding grounds, resting area and nursery for several plants and animals. This is illustrated by *e.g.* the importance of macrobenthic intertidal fauna as a food source for wading birds (Smit and Wolff, 1981; Glutz von Blotzheim *et al.*, 1984; Hulscher, 1996; Cramp, 1998) and intertidal juvenile flatfish (Lasiak, 1983; McLachlan, 1983; Nicolaisen and Kanneworff, 1983; Gibson and Robb, 1996; Beyst *et al.*, 1999; Van der Veer *et al.*, 2001). In a first part of this paper, we will demonstrate that sandy beaches are valuable ecosystems, using 11 Belgian sandy beaches as an example. Instead of investigating a single ecosystem component, we aim at providing an integrated ecosystem perspective. Therefore, five important beach ecosystem components have been taken into account: microphytobenthos (benthic micro-algae), vascular plants, terrestrial arthropods, marine zoobenthos and avifauna.

Many beach users (managers and recreational beach users) consider sandy beaches as “unbreakable”. As long as the beach sand stays in place, it is often assumed the beach is in good health and – if taken into consideration – so is the beach ecosystem. The numerous anthropogenic influences on sandy beaches, like beach cleaning, beach nourishment, beach fisheries, spraying against wrack associated bugs etc., do however pose possible threats on the ecology of sandy beaches. Within this paper our attention goes specifically to beach nourishment.

Beach nourishment is defined as ‘the process of mechanically or hydraulically placing sand directly on an eroding shore to restore or form, and subsequently maintain, an adequate protective or desired recreational beach’ (Greene, 2002) or as ‘deliberately placing an amount of sand on an eroding beach or creating a beach where no beach or only a narrow beach was present before’ (National Research Council, 1995). It is a rather recent phenomenon (*e.g.* National Research Council, 1995; Hamm *et al.*, 2002; Hanson *et al.*, 2002; Basco, 1999) and the overall awareness and attention towards problems of coastal erosion in general and towards beach nourishment and physical and biological monitoring in particular has grown during the last decades. As an alternative for “hard” coastal protection both positive and negative aspects of beach nourishment are mentioned. The higher chance of erosion as a consequence of “hard” coastal protection, often at other (nearby) locations than where the actual nourishment took place (through long shore transport of the sediment) is mitigated if nourishment is applied (Peterson *et al.*, 2000a). Beach nourishment gives rise to smaller changes in the dynamics of both sediment and water, thus a natural equilibrium is reached sooner, more easily and stays in effect for a longer time (Peterson *et al.*, 2000a). Negative aspects are the higher costs as a consequence of the need of replenishment every few years and the lower applicability on beaches with high wave energy (Esteves and Finkl, 1998). Some cost efficiency options are discussed by Raudkivi and Dette (2002).

Nourishment is widely considered as a better alternative for coastal protection than the construction of hard structures to mitigate detrimental erosive effects (*e.g.* Dankers *et al.*, 1983; Adriaanse and Coosen, 1991; Charlier *et al.*, 1998; Basco, 1999; Brown and McLachlan, 2002; Finkl, 2002; Greene, 2002; Hanson *et al.*, 2002; Hamm *et al.*, 2002). Even though beach nourishment is considered as the more ecology friendly option, this form of beach restoration too brings about sizable changes in the sandy beach ecosystem. Due to the highly dynamic nature of the beach environment, the benthic organisms inhabiting the littoral zone of sandy beaches are limited to those species with a high tolerance towards several forms of environmental stress. Therefore, according to many authors, nourishment should cause only minor damage to the ecosystem (*e.g.* USACE, 2002b; Löffler and Coosen, 1995; Miller *et al.*, 2002). This high tolerance is however not unlimited (Moffet *et al.*, 1998; Jaramillo *et al.*, 1996). On short terms, a large part of the beach inhabiting flora and fauna is destroyed by covering the resident sediment with a thick layer of nourishment sand. Changes in the beach habitat after nourishment like altered beach profile and sedimentology will influence the rate of recovery of the ecosystem's natural equilibrium. An impact of such magnitude can be expected to impact the entire beach ecosystem. Nevertheless, most research has been carried out on the intertidal benthic macrofauna (*e.g.* Rakocinski *et al.*, 1996; Peterson *et al.*, 2000a) and other ecosystem components remain mostly out of consideration. Most studies are short term investigations of the benthic macrofauna, little is known on the long term effects or the effects of repeated replenishment at the same site (cumulative impact). The biological focus of this paper is to provide an ecosystem perspective. Whereas the majority of past research focused on macrobenthic infauna, we feel a functional ecosystem approach has a much higher scientific value. Therefore here too, the same five beach ecosystem components have been taken into account: microphytobenthos (benthic micro-algae), vascular plants, terrestrial arthropods, marine zoobenthos and avifauna.

In the specific case of beach nourishment, no environmental impact studies are available from Belgian beaches. Yet, some lessons can already be drawn from available literature. In a second part of this paper, we will briefly review what is known on the ecological effects of beach nourishment from the available literature. Combined with the knowledge obtained from the first part, this will allow scientific assessment of future nourishment effects on the Belgian beach ecosystem.

Aims

The aims of this research are twofold and can be summarized as (1) demonstrating the biological value of sandy beaches through an integrated ecosystem approach using 11 Belgian beaches as an example and (2) reviewing what is known from available literature on the ecological effects of beach nourishment to provide a baseline for future research.

Material and methods

The results presented here are the final output of two different research projects, financed by different branches of the Flemish government. Within the framework of the BEST project (financed by AMINAL-Nature – file number AN.GKB/2002/nr.2) an inventory of the five aforementioned ecosystem components was made for 11 selected beaches along the Belgian coastline. Samples and observations where gathered from all 11 beaches, for most components both spatial and temporal (seasonal). A theoretical study on beach nourishment (financed by the Flemish Coastal Waterways Division – file number 202.165) compiled from literature all available knowledge on (1) the Belgian beach ecosystem and (2) the ecological impact of beach nourishment (on a global scale). Additional funding was provided by Ghent University (GOA2005).

Sandy beaches do have ecological importance: a case study from Belgian beaches

Briefly presenting the results of the BEST project, some details of the Belgian beach ecosystem will be discussed next, dividing the beach into three conventional zones.

Supralittoral zone

Terrestrial arthropods, vascular plants and birds are the most important ecosystem components present on the supralittoral zone, considered here from strandline to the foot of the dunes.

Many (semi-)terrestrial arthropods living on the strandline and on the dry part of the beach play a crucial role in the natural decomposition of stranded seaweeds (mainly kelps and brown algae), while others feed on those decomposers. Especially the strandline harbors a diverse community, as demonstrated by a total number of 236 species encountered in the samples of the BEST project.
Within the BEST project research, 27 species of vascular plants were found on the 11 investigated beaches. Most of these species form the first steps in the fixation of beach sand and the formation of coastal dunes. Four species comprised 94% of the mapped plant populations, while all remaining species are classified as “very rare” to “extremely rare”.

Birds use the dry part of the beach to rest (mainly at high tide) or the nest. Nesting of birds is at the moment however non-existent on Belgian beaches.

Littoral zone

The intertidal part of the beach is inhabited by microphytobenthos and benthic infauna (macro- and meiobenthos) but it is also important for foraging birds and tidal migrating hyper- en epibenthic animals.

Sediment related differences between different beaches were among others apparent from the BEST results on microphytobenthos. This component is largely dominated by Bacillariophyta (diatoms).

The BEST results on macrobenthos are concordant with prior research (Degraer *et al.*, 2003), showing an increasing number of species from high water level towards low water level and with the flat, ultra-dissipative beaches reaching highest values for both number of species and densities. Conclusions for meio-, epi- and hyperbenthos are less apparent but it is clear that all these components have a specific use of beaches, albeit regarding specific communities (meiobenthos, Gheskiere *et al.,* 2004) or the use of beaches as a nursery (epibenthos and to a lesser extent also hyperbenthos - Beyst *et al.,* 2001ab).

Feeding largely on intertidal macrobenthos, a number of birds (e.g. Sanderling *Calidris alba*) use sandy beaches for foraging while others feed on stranded dead animals or just use the beach to rest (gulls). BEST results showed the littoral zone being much more used by birds than the supralittoral zone, with more than 90% of the observed birds (mainly gulls) being present in the intertidal zone.

Infralittoral zone

The nearshore infralittoral zone can be equally affected by beach nourishment (especially with foreshore nourishment).

Benthic organisms occupying more stable nearshore habitats are said to be more vulnerable towards changes in their environment than animals living in the littoral zone (Thompson, 1973). Prior research demonstrated the importance of this zone for *e.g.* macrobenthos, with a number of diverse communities being encountered (Degraer *et al.,* 2002) and their role as food for seabirds like *Melanitta nigra* feeding on bivalves like different *Spisula* species (*e.g.* Durinck *et al.,* 1993; Leopold, 1995).

The information gathered within the BEST project on the flora and fauna of these 11 beaches provides a tentative, yet valuable overview of the Belgian beach ecosystem and this case substantiates the often overlooked ecological importance of sandy beaches.

Beach nourishment affects the sandy beach ecosystem: a review

The ecological effects of nourishment can be classified into three main groups (Fig. 1): (1) effects related directly to aspects of the nourishment project – the construction, (2) effects related to quality characteristics of the nourishment sediment and (3) effects related to quantity characteristics of the nourishment sediment. Furthermore, the size of the effects can be classified by (1) place, time and size of the nourishment project and (2) the chosen nourishment technique and strategy. As they can regulate at the level of several aspects, these are not included in Fig. 1.

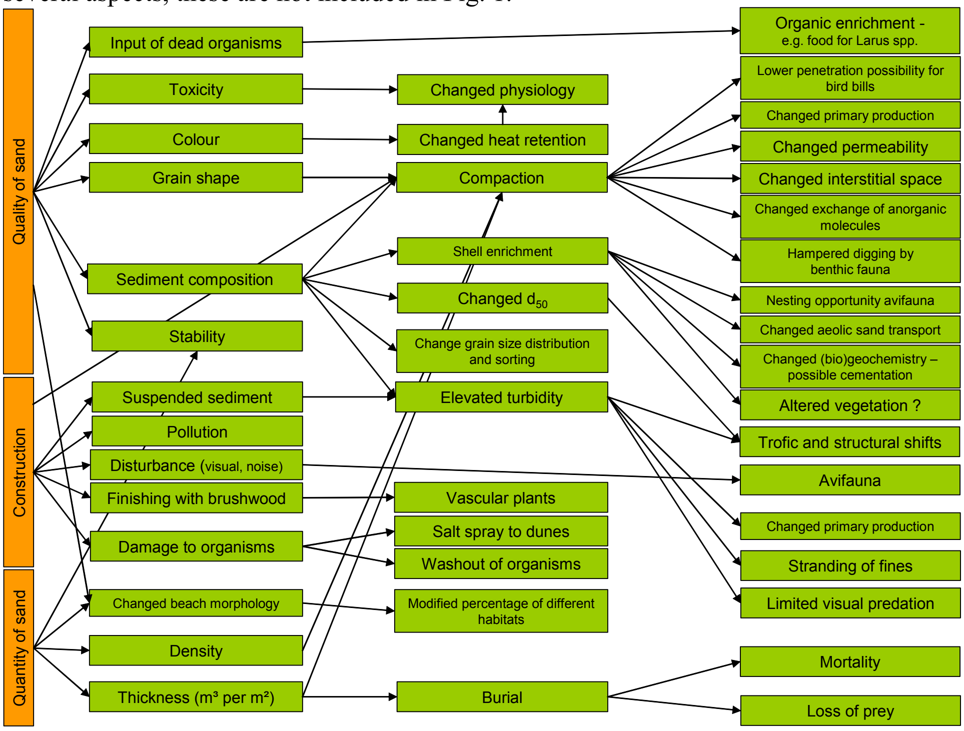

Fig. 1. Integrated network of the ecological effects of beach nourishment. The scheme is a tentative summary resulting from the compiled literature data and consultation of all authors, each of them expert in a specific ecosystem component.

From all effect pathways demonstrated in Fig. 1, some selected aspects (stressing options for impact reduction) are discussed below.

- From the available literature it can be deduced that sediment characteristics play a very important role in the impact of beach nourishment on the ecosystem sediment composition and beach morphology. Beetles of the genus *Bledius* do not live in sand too rich in shells due to their digging behaviour (Den Hollander and Van Etten, 1974) and a slower recovery of a *Donax* (intertidal clam) population after nourishment with sediment containing a high percentage of shell fragments, has been noted (Peterson *et al.,* 2000a). A high level of fines in the fill sediment can result in slow recovery of macrobenthic organisms (Saloman and Naughton, 1984; Gorzelany and Nelson, 1987; Rakocinski *et al.*, 1996), because of *e.g.* limited juvenile survival (*Donax, Scolelepis squamata* ~ Reilly and Bellis, 1983). McLachlan (1996) studied a beach on which grain size was artificially increased while tidal range, wave energy and turbidity remained constant. The beach's morphodynamic state evolved from dissipative to intermediate. The changes in grain size and slope could both separately be correlated with a decreasing species richness and macrobenthic abundance. Eventually, the local

Donax species disappeared. Yet, some scientists question the importance of grain size distribution of the nourishment sand for ecological recovery and state that the grain size distribution will be restored very fast by physical conditions like currents and storms (J. Cleveringa, pers. comm. in: Harte *et al.*, 2002). A gradual shift towards a morphological equilibrium (depending on the current hydrodynamic conditions) can indeed be expected but it is crucial to understand that an ecological recovery can only be expected after this equilibrium is established. Thus, to limit the ecological impact, it is sensible to choose nourishment sands with a comparable sediment composition to that of the original sediment. If the sediment composition (grain size distribution and organic matter content) of the nourished sand matches the original sediment, the benthic fauna is least impacted and will recover fastest (Parr *et al.*, 1978; Nelson, 1993; Löffler and Coosen, 1995). Apart from these ecological arguments some geologists are also in favour of retaining the original grain size to avoid a sharp transition from dissipative to reflective beaches (Anfuso *et al.*, 2001).

- Compaction of the sediment after nourishment may be three or four times higher than on the original beach and increases sometimes (Ryder, 1991). Effects of compaction are manifested through changes in the interstitial space, the capillarity, the water retention, the permeability and the exchange of gasses and nutrients (USACE, 1989). Apart from the penetration of bills of wading birds also vertical locomotion of the infauna is inhibited when grain size and composition of the fill sediment differ too much from the original beach sediment and compaction is enhanced (Maurer *et al.*, 1978). This can be solved by ploughing or 'tilling' the beach (Dean, 2002) but it is mainly a short-term problem, as wave action will soften the beach, especially during storms.
- While the impact of sediment colour is largely unknown it seems precautionary to apply again the same colour as the original sediment. Toxic substances should also be absent from the fill sediment (USACE, 1989; Adriaanse and Coosen, 1991; USACE, 2002a).
- When aiming at a minimal ecological impact, nourishment should be completed within a single winter, starting after October and ending around March (USACE, 1989). This timing is optimal for nesting birds (MMS, 1999), while summer is better to avoid an impact on resting and foraging birds. A swift recovery of the macrobenthic fauna has been observed when timing was chosen accurately (Saloman and Naughton, 1984). If nourishment activities continue until May, recovery can be postponed until the next recruitment, macrobenthic animals can become smaller sized and average biomass may drop gradually (Peterson *et al.*, 2000a). Yet, as a number of organisms spend the winter months in the shallow infralittoral zone, it is possible that the reduced impact due to accurate timing becomes undone with foreshore nourishment (Grober, 1992).
- In general it is stated that a number of smaller projects (< 800m) should be preferred over a single large nourishment project (Adriaanse and Coosen, 1991; Löffler and Coosen, 1995; Peterson *et al.*, 2000b). The small distance between nourished and unnourished beach strips allows swift re-colonisation, depending on species-specific dispersal capacities. This may very well be the case for infauna but may be only to a lower degree true for birds.
- No clear choice can be made among the three currently used nourishment strategies (classic, profile nourishment, foreshore nourishment and backshore nourishment). It seems advisable to decide on this point in view of the local natural value of each ecosystem component on the nourishment site.

- For all further aspects, the reader is referred to Speybroeck *et al.* (submitted).

Options for future research

The biological processes, relevant for assessing nourishment effects, comprise (1) the process of disturbance and survival during nourishment (in short terms) and (2) the process of re-colonisation after nourishment (in medium to long terms) (van Dalfsen and Essink, 2001). Disturbance and survival are mainly determined by species specific tolerances, while re-colonisation is determined by (1) species specific dispersal and migration capacities and (2) species specific habitat demands and tolerances, including physical and biological elements. If the necessary scientific attention is paid to these processes for some key species within the beach ecosystem, it will allow beach managers to execute an ecosystem directed evaluation of scheduled nourishment.

Conclusions

Though sandy beaches are often regarded as biological deserts *e.g.* in contrast with rocky shores, they form a habitat for a number of specific species of vascular plants, terrestrial arthropods, microphytobenthos, zoöbenthos and birds. These components display a number of biological interactions (*e.g.* through grazing and predation), stressing the need for an integrated ecosystem approach. The obtained results from 11 Belgian sandy beaches support this.

In an ecological comparison, beach nourishment turns out to be the least damaging option for coastal protection. In a few cases beach nourishment is even applied to offer protection to threatened or protected species like turtles or nesting birds (Ryder, 1991).
From the presented review it may be concluded that on short and medium term negative ecological effects of beach nourishment dominate. After restoration of the physical equilibrium, the degree of recovery of the beach ecosystem largely depends on the physical characteristics of the equilibrium, shaping the habitat.
An overall ecosystem approach of nourishment effects is always lacking: each study is limited to a certain ecosystem component, omitting to draw an overall image. As the effects of nourishment may differ largely depending on the considered ecosystem component, it is today impossible to obtain an objective general image of the ecosystem effects.

The referred studies in this overview all picture the ecological effects (on mostly just one ecosystem component) of a specific nourishment project (*i.e.* monitoring). Thus, it remains hard to estimate the effects of future nourishment projects. These studies describe the effects rather than investigating the biological processes which are causing these effects and thus are relevant for assessing the ecological effects of beach nourishment. Only by approaching these processes, effects of future projects can be anticipated scientifically and thus ecological adjustments in nourishment practice can be suggested.

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