Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

The protection of sandy shores – Can we afford to ignore the contribution of seagrass?

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A R T I C L E I N F O

Keywords:
Shore nourishment
Soft coastal protection
Seagrass
Ecosystem services
Sediment stabilisation
Beach profile

A B S T R A C T

Shore nourishment is considered an effective soft coastal protection measure for sandy shorelines. However, sand demand and costs are high, especially as nourishment has to be repeated regularly due to ongoing erosion. Seagrass meadows are able to trap and stabilise sediment by reducing bed shear stress. Moreover, they reduce flow velocity and wave energy in regions beyond their boundaries. Especially small species may not provide these ecosystem services sufficiently to protect shorelines from erosion, but they may stabilise beach profiles enough to increase nourishment intervals. This review discusses the potential benefits of integrating ecosystem services provided by seagrass meadows, both existing and newly planted, in nourishment plans, and also addresses potential limitations such as unsuitable hydrodynamic conditions and seasonality. Finally, it highlights knowledge gaps that should be addressed by interdisciplinary research to improve nourishment plans and use seagrass ecosystem services to their full potential.

1. Introduction

Beach or shore nourishment is a standard method of shoreline protection (Hamm et al., 2002) which conforms with the shift towards soft engineering solutions and ecosystem-based approaches (Temmerman et al., 2013). It is considered more environmentally friendly and a on the long term a more effective form of coastline preservation than so called ‘hard’ engineering methods such as seawalls or breakwaters (Hanson et al., 2002), especially as annual costs are in the same order of magnitude (van Rijn, 2011). Moreover, Dean and Houston (2016) showed that beach nourishment is an effective strategy for protecting sandy shorelines against sea level rise. Nourishment works on the principle of replacing sand lost due to erosion and allowing the system to rework the added sediment factoring in losses through further erosion (Hamm et al., 2002). Thus, nourishment is not a one-off solution, but has to be repeated in regular intervals.

It is estimated that European countries use 28M m^3 of sand per year to nourish coastlines (Hamm et al., 2002). In the USA a comparable amount is spent on federal projects with involvement of the US Army Corps of Engineers in the USA (Hamm et al., 2002). Annual fill volumes range from $< 6\ m^3/m$ of nourished coastline in Italy to $> 40\ m^3/m$ in Spain. However, these volumes are not applied annually but rather periodically. This leads to average volumes per fill between $104 \times 10^3\ m^3$ (France) and $733 \times 10^3\ m^3$ (The Netherlands) (Hanson et al., 2002). The cost of sand is just under 5€/m^3 for the Mediterranean (Martino and Amos, 2015); this highlights the fact that each nourishment project is a multimillion Euro exercise. The Netherlands, for instance, spend about 10–15M € per year to nourish the coastline between Hoek van Holland and Den Helder alone (van Rijn, 2011).

Even though shore nourishment has a long standing tradition – the first nourishments were carried out in the 1950s (Hanson et al., 2002) – the cost for this work has rarely been evaluated economically. In Germany, for instance, nourishment projects for coastal protection do not require economic justification or optimisation, and projects that are undertaken for recreational purposes are usually not accounted for either financially or from a protection point of view (Hanson et al., 2002). Only recently have management tools been developed to assess the economic feasibility of such projects, optimising sand volume and nourishment timing (Martino and Amos, 2015 and references therein).

One potential reason for these optimisation efforts is that sand availability is becoming an increasing issue. Nourishment sand is usually dredged offshore and borrow sites are often sought close to the fill site to keep transport costs low (Hamm et al., 2002). However, constraints on the grain size and sorting of the borrowed sand limit the number of suitable borrow sites (Capobianco et al., 2002) and many of the suitable sites have already been exhausted. Other potential sites are or may become protected for nature conservation, leading to further reductions in sand availability and thus increasing costs for transport from more distant borrow sites (Weisner and Schernewski, 2013).

Sand requirements could be reduced by stabilising it at the fill site. While it is impossible to eliminate erosion completely, it may be reduced leading to longer intervals between nourishments. Such an

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http://dx.doi.org/10.1016/j.marpolbul.2017.08.012
Received 24 February 2017; Received in revised form 24 May 2017; Accepted 5 August 2017

approach has long been applied to dune nourishment where brushwood fences but, more importantly, vegetation has been used to stabilise the sand sustainably to great effect (Hanley et al., 2014). Grass species such as *Ammophila* sp. trap wind-blown sand with their shoots, stabilise the sand with their extensive root and rhizome systems and can grow under constant sand burial (Maun, 2009). The same stabilising functions, albeit under water, have been demonstrated for many seagrass species (Ward et al., 1984) through studies dating back to the late 1950s (e.g. Ginsburg and Lowenstam, 1958).

It is therefore not surprising that reviews promote the value of seagrasses based on their ecosystem services including sediment stabilisation and accretion (Barbier et al., 2011; Koch et al., 2009; Mtwana Nordlund et al., 2016). Yet, it is still difficult to quantify these services to either incorporate them in coastal protection schemes directly or evaluate their potential to support existing coastal protection measures. Ondiviela et al. (2014) for instance provide a detailed review of coastal protection services for European seagrasses. However, they only focus on the direct protection service caused by wave and flow attenuation. Moreover, their review is mainly a qualitative description of the involved processes, limitations and methods to determine wave attenuation by seagrass.

Indirect protection services offered by seagrass have been assessed through the effect vegetation has on bed shear stress and critical shear stress (Le Hir et al., 2007): In addition to describing the underlying processes, the authors compiled quantitative results from the reviewed literature. However, they were unable to draw general conclusions that could feed into estimations of erosion rates. Inconsistent use of terminology in the literature together with lack of detailed descriptions of bed shear stress computations make it difficult to compare studies (Le Hir et al., 2007). As a consequence, these authors called for common protocols with respect to erosion rate and suggested that it should be given as a function of bed shear stress or of the ratio between bed shear stress and erosion threshold. Within this paper, I will follow this recommendation to explore if the sediment stabilising service of seagrass can help to reduce erosion which may then reduce nourishment costs by extending nourishment intervals. Additionally, potential benefits and limitations of integrating ecosystem services provided by seagrass meadows in nourishment plans will be discussed. In this context, both the effect of existing seagrass meadows as well as implications for additional seagrass planting will be addressed. Based on the review of existing literature from both disciplines (nourishment and seagrass ecosystem services), knowledge gaps will then be highlighted that should be addressed by interdisciplinary research to improve nourishment plans and use seagrass ecosystem services to their full potential.

The focus will be on small seagrass species (e.g. *Halophila*, *Zostera*) which are considered less effective with respect to regulatory ecosystem services (Mtwana Nordlund et al., 2016) and are hence often neglected during the discussion about the role of seagrass in coastal protection. Emphasis will be placed on processes at or near the bed to complement a recent review that comprehensively linked seagrass presence, suspended sediment concentration and light availability focussing on processes within the water column (Adams et al., 2016). Finally, studies solely working on muddy sediment have been excluded from the review. Since erosion of sand differs from that of clay and silt (Cerco et al., 2013), estimates of critical shear stress in the presence of small seagrass species on muddy beds (e.g. Amos et al., 2004; Thompson et al., 2004) cannot be used to estimate the potential of seagrass to stabilise the sand at nourished sites.

2. Shore nourishment

Shore nourishment is the deliberate (mechanically or hydraulically) placement of sand on a shore to produce or restore a beach with adequate protective or recreational function (CERC, 1984). The location of such placement can vary from the first dune row to the shoreface which is why the more general term shore nourishment is preferred over beach nourishment (Hamm et al., 2002). Multiple reasons for shore nourishment exist, e.g. coastal stability, coastal protection, beach width. While it is considered to have less adverse environmental effects than 'hard' engineering solutions (Hamm et al., 2002) it is still controversial with respect to its impacts on flora and fauna (Nordstrom, 2005; Speybroeck et al., 2006).

Nourishment is designed to combat erosion which, in this context, is defined as the permanent loss of sediment from a spatially defined system (van Rijn, 2011). Beach erosion can be described as a combination of suspension by waves along the cross-shore profile and advection by longshore currents (Dreier and Fröhle, 2015). Consequently, both the cross- and longshore dimensions need to be considered in nourishment design (Capobianco et al., 2002). In addition to the spatial dimension (i.e. shape and extent of the nourishment area), a nourishment plan has a temporal dimension (i.e. nourishment intervals) whereby spatial planning affects the frequency of re-nourishment, and in order to minimise costs, both dimensions have to be considered (Raudkivi and Dette, 2002).

Given the cost of a nourishment exercise, it would be expected that long nourishment intervals would be desirable to reduce the financial requirements of a longer-term nourishment plan. However, a theoretical model showed that the required annual sand volume increases rapidly with increasing nourishment intervals (Dette et al., 1994). Initial erosion may lead to a shore geometry promoting further erosion or even rip currents that transport material out of the system offshore, as observed in Egmond (the Netherlands) (Hamm et al., 2002). To avoid high erosional losses and hence decrease the demand for nourishment material, short nourishment intervals with small volumes have been advocated (National Research Council, 1995; Raudkivi and Dette, 2002). To further increase nourishment intervals, the lifetime of the nourishment needs to be increased for instance by considering the location for placement of the nourishment material (Fig. 1). van Rijn (2011) compared shoreface and beach nourishment under North Sea wave conditions both numerically and from field observations along the Dutch coast. He found that the benefits of shoreface nourishment last 5 years before renourishment is necessary, while beach nourishment has to be repeated every 2 years. It should be noted, however, that these nourishment types serve different purposes: Shoreface nourishment is used to naturally feed the nearshore zone on the long term in coastal regions with wide and high dune belts. Beach nourishment, on the other hand, is applied in regions of critical coastal stability with narrow and low dunes, to compensate local erosion or to create recreational beaches (van Rijn, 2011).

Modelling results suggest that the lifetime of beach nourishment can be enhanced by the use of coarser material: Nourishment sand of 0.3 mm had a 50% longer lifetime than material of 0.2 mm (van Rijn, 2011). Hence, nourishment is often conducted with material coarser than the native sand thus enhancing stability (Nordstrom et al., 2007), producing more dry beach area per unit volume of nourished sand, and a more reflective beach type (Benedet et al., 2004). Use of finer

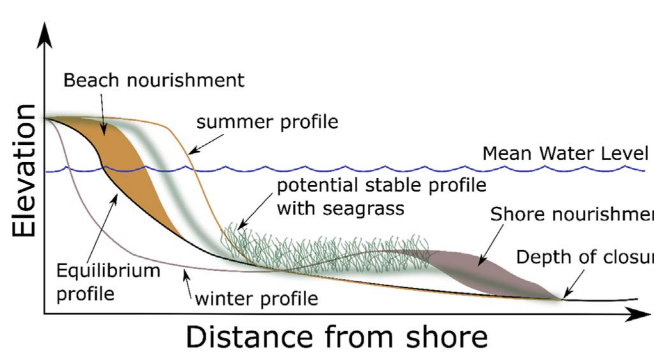

Fig. 1. Conceptual diagram of typical beach profiles and nourishment locations as well as the potential influence of seagrass on the overall profile shape.