Ocean & Coastal Management xxx (2016) 1–9

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Factors influencing the initial establishment of salt marsh vegetation on engineered sea wall terraces in south east England

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ARTICLE INFO

Article history:
Received 23 February 2016
Received in revised form
31 October 2016
Accepted 6 November 2016
Available online xxx

Keywords:
Salt marsh
Salt marsh plant colonisation
Sea walls
Coastal management
Sea defence
Gabion terraces

ABSTRACT

Sea walls provide vital flood protection for lowland coastal property. We investigated the integrity of a cost-effective method of repairing sea defences, which has potential to create habitat for coastal and salt marsh flora. Experimental stone-gabion and clay-filled terraces were installed as a soft engineered approach to repair damaged sea walls in estuarine embayments in south east England. Changes in the surface heights of sediment and vascular plant colonisation were monitored over a 22 month period. Seven of the 12 terraces were colonised, by 12 species of plant, reaching a maximum of 85% cover. The main drivers of plant colonisation were sediment stability, elevation, exposure and sediment shear strength. Terraces with least change in the surface height of sediments were favourable for plant colonisation. Ordination (Canonical Correspondence Analysis) showed 72% variation in plant distribution explained by elevation (37%), exposure (30%), terrace length and sediment shear strength (5%). Elevation was the most influential variable; recruitment increased as terrace height approached the height of existing marsh ($r^2 = 0.43$). This cost-effective approach has the potential to provide protection to sea walls and create additional habitat for wildlife. Key considerations for the improvement of terrace design and construction are discussed.

1. Introduction

Salt marshes are important coastal habitats (Ford et al., 2013), supporting a range of terrestrial and marine species (acting as nursery grounds for various fish species, Green et al., 2009) and feeding, roosting and nesting sites for various species of shorebirds (Norris, 2000). Salt marshes play a valuable role in attenuating the energy of waves which can otherwise undermine the integrity of sea wall embankments built as flood protection structures (Möller and Spencer, 2002; Möller et al., 2014). Wave attenuation is a complex process affected by the reflection of wave energy on marsh edges (cliff face), wave shoaling and vegetation (Möller and Spencer, 2002; Möller, 2006), and can be as high as 60% even during storm surge conditions (Möller et al., 2014).

In the U.K. there is concern over the loss of salt marsh habitat, with two thirds of salt marsh loss having occurred in the lowland regions of south east England (Dixon et al., 1998; Paramor and Hughes, 2004) at a rate of 40 ha yr^{-1} (Thomson et al., 2011). Coastal squeeze on salt marshes (i.e. the reduction in available habitat space caused by the combined effects of rising sea levels, isostatic land mass adjustments and static sea defences) accelerates the rate of salt marsh loss at the very locations where their presence may be most beneficial (Burd, 1992; Thomson et al., 2011). In eastern England, relative sea level is currently predicted to rise over the next century at an average rate of 5 mm yr^{-1} for a high emissions climate scenario (Thomson et al., 2011). The North Sea coastline of south eastern England is highly modified with flood defence seawalls, many of which were repaired and enhanced after the major storm surge and flooding in 1953. The 1953 flood was the most extreme natural disaster to befall Britain in the 20th century (Baxter, 2005) causing the loss of over 300 lives. In response extensive coastal defences were created, which included the raising of approximately 2,100 km of earthen sea wall embankment around the coasts of England and Wales (Gardiner et al., 2015). These conventional defences will eventually need to be replaced because they are approaching the end of their design life and are challenged by rising maintenance costs (Temmerman et al., 2013).

In addition to the protection of people and property, coastal defence strategies must take into consideration the preservation of

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http://dx.doi.org/10.1016/j.ocecoaman.2016.11.010

nature and conform to regulations such as the Conservation (Natural Habitats) Regulations 1994 (Lee, 2001). A desirable solution would be a cost-effective ecosystem-based flood defence strategy that addresses regulatory requirements, while reducing the capital investment required to build and repair conventional hard engineering (Temmerman et al., 2013). The expense of repairing sea wall defences can be significantly reduced if there is salt marsh present, compared to a site with no marsh at all; a 6 m wide fringe of salt marsh can reduce costs by 70% (Adnitt et al., 2007).

Scouring of sediments at the toe of sea defences undermines the structural integrity of sea walls and is a prevalent, serious, and costly problem in the U.K. (Bradbury et al., 2012). One strategy which has been shown to be effective in reducing wave energy involves artificially creating narrow fringes of salt marsh in front of existing sea wall structures (French and Reed, 2001). Salt marsh fringes can be created through the installation of gabions (cages of wire mesh filled with stone) to protect the toe of existing sea walls. Positioned to form a solid margin which is then backfilled with clay or sediment to form a terrace (i.e. a flat strip of raised ground on the seaward face of the sea wall), such terraces have the potential to enhance the local environment by creating new space which can be colonised by salt marsh vegetation. If successfully colonised, vegetated terraces could contribute to the dissipation of wave energy and further protect the sea wall. Gabion terraces have similar initial installation costs; £660 m^{-1} for the present study compared to approximately £635 m^{-1} (D. Gauntlett, pers. comm.) for the concrete blockwork and toe-board protection usually constructed for 'hard' engineered sea wall repairs. Through natural accretion and vegetation growth, the structural integrity of gabion terraces often increases over time, and they can withstand relatively high velocity flows (Miller and Rella, 2009).

By applying knowledge gained from disciplines such as restoration ecology and conservation biology during the design and installation of sediment-filled terraces, it should be possible to increase the potential of these structures to contribute to biodiversity. The zonation and vegetative recruitment of salt marshes is affected by a variety of inter-correlated environmental variables (Davy et al., 2011). Successful recruitment of vegetation is more likely when sites are adjacent to areas of existing and well-developed salt marsh (Wolters et al., 2008; Mossman et al., 2012a), with colonisation by salt marsh plants slow or absent if the availability of plant propagules is limited (Wolters et al., 2005; Dausse et al., 2008). Herbivory, particularly on seeds and seedlings by *Nereis diversicolor*, can also slow the process of colonisation (Paramor and Hughes, 2004), and storm events can result in substantial sediment erosion, which reduces the rate of colonisation by vulnerable seedlings (Boorman, 2003). Height within the tidal frame is a significant variable affecting sedimentation (Marion et al., 2009) and salt marsh vascular plant zonation (Crooks et al., 2002; Davy et al., 2011; Mossman et al., 2012a, 2012b). Elevation affects the duration and frequency of tidal inundation which can alter the community composition of salt marsh plants (Dawe et al., 2000). In addition to water logging of sediments, elevation can influence sediment redox potential, which can in turn determine the composition of vegetation (Crooks et al., 2002; Davy et al., 2011; Mossman et al., 2012a). Sediment water content and un-drained sediment shear strength also affect the capacity for salt marsh to resist erosion (Crooks et al., 2002).

In 2012, the U.K. Environment Agency (EA) (Eastern Region, Essex, Norfolk and Suffolk) piloted a scheme to trial the gabion and clay-infill approach. Soft engineered terraces of this kind have previously only been employed in tidal riverine settings (e.g. Greenwich Penninsula, London EA, 2015); this approach is therefore a novel intervention for sea wall repair on more open coastlines. As part of the ongoing programme of repairing erosion-damaged sea defences, 12 gabion-built terraces were installed at three locations in the Blackwater and Colne estuaries of Essex, S. E. England. The success of the trial would be assessed on the ability of the terraces to protect the "toe" of sea wall blockwork revetment over time, and by the recruitment of salt marsh vegetation onto the new surfaces, in areas where the marsh had been lost to erosion.

In this study, we investigated the rate of vascular plant colonisation and changes in the height and surface topography of clay infill. The aim was to determine the relationships between plant colonisation, terrace durability and controlling factors such as terrace area, height in tidal frame, location and exposure. This study covered a 22 month period which included a storm surge in December 2013, which created the highest water levels since the floods of 1953 (Spencer et al., 2015b). In the longer term, plant colonisation of the terraces could be considered successful if community composition were to converge with those found in existing marshes. However, recognising the considerable timescales (decades) required for stable communities of natural salt marsh vegetation to establish (Mossman et al., 2012b), in this study it was the appearance of pioneer (e.g. *Salicornia* sp.) and early perennial (e.g. *Atriplex portulacoides*) species which were of particular interest. The outcomes of this research could inform further trials of this approach to sea wall repair, and determine whether gabion terraces can provide a cost-effective solution to sea wall maintenance with the additional benefit of providing biodiversity gains for salt marsh communities.

2. Material and materials

2.1. Terrace installation

Twelve soft engineered terraces were installed by the EA at three sites within estuarine embayments along the Essex coastline. Langenhoe and Wellhouse (Mersea Island) both had five terraces, Tollesbury had two (Fig. 1, Table 1). Construction work commenced in January 2012 and the terraces were completed sequentially from June 2012, with the final terraces at the Wellhouse site being finished in August 2012 (Table 1). Individual gabion baskets filled with approximately 2 m^3 of stone were placed in front of the toe-boards at the base of the sea wall. The terraces were created by backfilling clay into the space between the gabion baskets and the sea wall (Fig. 2). The clay for the terraces at Langenhoe and Wellhouse was imported. At Tollesbury the clay was locally sourced by digging linear lagoons, this method involved extracting clay from the grazing marsh and had the benefit of creating additional aquatic habitat. The 12 individual terraces varied in size (from 4 m to 42 m in length and 1.5 m–3.0 m in width) due to variation in the extent to which sections of blockwork and toe needed repair (Table 1). This provided an opportunity for the trial to include size (length) as a factor affecting terrace stability and recruitment.

The Wellhouse site contained three 4 m long terraces (W2, W4 and W5) and two 6 m in length (W1 and W3). The top of the gabions were between 6.24 m (W2) to 6.41 m (W1) above Chart Datum (CD). Five terraces were constructed at Langenhoe, ranging from 5 m (L4) to 42 m (L2) in length. The terraces at Langenhoe were relatively low in the tidal prism, between 5.2 and 5.8 m above CD (Table 1). The Tollesbury site consisted of two terraces; T1 which at 52 m in length and 156.3 m^2 in area was the largest terrace in the study. The Tollesbury terraces also contained the gabion placed at the highest level above CD (T2. 6.85 m) (Table 1). The north-west facing sites at Wellhouse were subject to the lowest wave exposure and wind fetch ($F = 0.05$), Langenhoe was slightly less sheltered ($F = 0.13$), with the most exposed terraces present at Tollesbury (Table 1; $F = 2$). In comparison, the open coast salt marsh at Colne Point which had approximately 270° exposure to the open