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Hidden biodiversity in cryptic habitats provided by porous coastal defence structures

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ABSTRACT

In response to flood risk from rising and stormier seas, increasing amounts of natural coastline worldwide are being replaced by a proliferation of coastal defence structures. While the primary role of defence structures is protecting the coastline, consideration should be given to the biological coastal communities they support. Artificial structures are currently seen as poor habitats for marine organisms. They are constructed in harsh coastal environments, lack structural complexity, and are subjected to episodic disturbance from maintenance, reducing their suitability as habitats for coastal species. Recent work has focused on mitigating the impacts of coastal defence structures, through secondary routes such as enhancing biodiversity by encouraging colonisation of marine biota. Research thus far has focused on enhancements to improve structural complexity on the external surfaces of coastal defences. Many structures are porous with internal compartments. To date no work has been undertaken on the habitat provided by the internal surfaces of the blocks used in building structures.

We investigated the role of porous coastal defence structures in habitat provision. Taking advantage of a groyne reduction from 45 m to 20 m length, we surveyed the internal environment of the structure. We also considered the impacts of maintenance activity on coastal assemblages. Our work shows that the internal environment of artificial structures provides functional habitat space supporting higher species richness and diversity than external surfaces. The more benign environment of internal surfaces protects from desiccation stress and is probably less scoured by mobile sediments, and as such is of unrealised importance to coastal assemblages. External surfaces are also subject to high levels of disturbance from maintenance activities, further limiting the potential ecological contribution this area of the artificial habitat might otherwise develop. These findings reveal the multifunctional role of porous coastal defence structures, acting as engineering protection and habitats for coastal assemblages.

1. Introduction

Coastal areas provide essential economic resources and satisfy a variety of societal needs. Coastal ecosystems account for a substantial proportion of global ecosystem services (Costanza et al., 1999; Martínez et al., 2007), including coastal protection (Bulleri et al., 2005; Chapman and Underwood, 2011; Dugan et al., 2011; Garcia et al., 2004). Faced with the effects of accelerated climate change, coastal regions are susceptible to flooding and loss of land, requiring adaptational actions (Airoldi et al., 2005; Burcharth et al., 2007; Nicholls and Mimura, 1998; Philippart et al., 2011). The development of coastal defence structures (CDS) is fundamental in protecting land, property, infrastructure and other economic and environmental resources. Thus, in many areas worldwide, coastlines are becoming dominated by artificial structures (Airoldi et al., 2005; Bulleri and Airoldi, 2005; Firth et al., 2014; Firth et al., 2013a; Liquete et al., 2013; MAFF, 2000; Moschella et al., 2005) causing significant changes to shores through loss, replacement or fragmentation of natural habitats. This places intense pressure on coastal resources and the environment, and affects the structure and functioning of related marine ecosystems (Airoldi and Beck, 2007;

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Airoldi et al., 2005; Bulleri and Chapman, 2004; Connell and Glasby, 1999).

Infrastructure placed in any natural environment will inevitably become colonised by primary settlers such as epibenthic marine organisms and biofoulers (Evans, 2016). Artificial structures can be viewed as surrogate habitats for natural shores (Burt et al., 2011; Connell and Glasby, 1999; Moschella et al., 2005). With the aid of additional structural modifications to ameliorate habitat heterogeneity, increased colonisation and enhanced biodiversity of marine species on artificial substrates can be encouraged (Evans et al., 2016; Firth et al., 2013a, b, c). Currently, CDS are seen as poor substitutes for natural rocky shores because they support lower species diversity (Bulleri and Airoldi, 2005; Bulleri et al., 2005; Chapman and Blockley, 2009; Moschella et al., 2005). Coastal defence structures are typically built in high-energy environments with stronger wave action than most natural rocky shores (Burt et al., 2011; Evans et al., 2016; Jonsson et al., 2006), providing harsh habitat conditions for common rocky shore organisms, and opportunities for invasive non-native species through new hard substrata (Airoldi and Bulleri, 2011; Firth et al., 2013a). These conditions are made worse by scouring from sand, gravel and cobbles (Bulleri and Chapman, 2010; Moschella et al., 2005). Coastal defence structures are also less topographically complex than natural rocky shores, reducing habitat and microhabitat provision (Hawkins, 2012; Martins et al., 2010). Their extent is often smaller than natural shores (Moschella et al., 2005), inevitably leading to a restricted species pool and altered biological interactions amongst species (Bulleri and Chapman, 2010; Bulleri, 2005; Bulleri et al., 2005; Coombes et al., 2015; Jackson et al., 2008).

In conjunction with factors considered above, there is constant pressure on the structural integrity of CDS due to erosion, scouring, overtopping and undermining (Airoldi and Bulleri, 2011; Firth et al., 2013a; Kamphuis, 2010). Over time this can affect the stability and function of the structure, requiring maintenance (Airoldi, 2003; Dayton, 1971; Moschella et al., 2005; Sousa, 1979). Maintenance, however, can result in severe ecological disturbance. It can remove large areas of the habitat and causes disruption to settled communities by the abstraction and replacement of part or all of the structures (Tsinker, 2004; Airoldi and Bulleri, 2011). Such works can dislodge, crush or expose colonising species, potentially reduce biodiversity and open up space to opportunistic species (Dayton, 1971; Hutchinson and Williams, 2003; Sousa, 1979). Large costs are also incurred in the upkeep of the structures (Roebeling et al., 2011).

Porous rock defence structures are widely used in coastal engineering (Crossman et al., 2003). They serve a practical role in the protection of coastlines by reducing wave transmission, reflecting incident waves from the shores, and dissipating wave energy (Burcharth et al., 2015; Dalrymple et al., 1991; Garcia et al., 2004; Losada et al., 1995). Wave dampening is an important function that many other impermeable defence structures do not provide sufficiently (Garcia et al., 2004). The porous structure allows some of the wave energy to pass through whilst creating flow resistance and some reflection from the structure, resulting in turbulence through the porous medium and dissipation of wave energy (Garcia et al., 2004; Jung et al., 2012; Silva et al., 2000). Consequently, essential protection to the shoreline is provided whilst still allowing the natural process of water run-up on the coast. This imitates many natural shoreline barriers, such as coral reefs, mangroves and rocky shores, which can provide natural protection against waves and storm surges (Fernando et al., 2008; Hu et al., 2014; Lowe, 2005a, 2005b; Monismith, 2007).

Porous defence structures are also seen to be more environmentally friendly than solid CDS because they have a smaller physical footprint creating less disturbance to benthic soft sediment organisms (Koraim and Rageh, 2013), and can be more aesthetically pleasing (Garcia et al., 2004). Considerable recent work has focused on improving secondary functions of CDS, particularly enhancing their colonisation by marine biota. Research into artificial enhancements such as boring holes to create rock pools and drilled grooves to increase heterogeneity have been extensively researched (Borsje et al., 2011; Chapman and Blockley, 2009; Coombes et al., 2015; Evans et al., 2016; Firth et al., 2012, 2014, 2013, 2013b; Moschella et al., 2005; Naylor et al., 2011). Other studies have investigated the use of different materials to encourage settlement on the surface of these structures (Coombes et al., 2011a, 2011b, 2013; Green et al., 2012). Whilst this work has been a successful and an integral step towards working with nature by creating “green” infrastructure, the focus has been solely on the external surfaces of CDS. To date no work has been undertaken on the habitat provided by the internal surfaces of the rock units used in building porous CDS because of logistic constraints. Thus, this study presents the first opportunity to document the internal section of a porous rock armour structure. This is potentially a habitat providing some refuge from the harsh physical conditions of the intertidal zone in general (e.g. desiccation and wave action) and defence structures in particular (e.g. scouring).

The use of porous structures in coastal engineering can be viewed as providing a multifunctional role, protecting vulnerable coastlines and supporting intertidal communities. Our paper compares the community composition, abundance and biodiversity of species of internal versus external surfaces, taking advantage of the reduction of a groyne from 45 m to 20 m extent at Highcliffe on the South coast of the UK as part of reconfiguring an existing coastal defence scheme. More formally we tested the following hypothesis: internal habitats on the porous defence structure will support greater species richness and diversity than external habitats, in particular higher numbers of invertebrate species. In addition, we evaluate the extent of anthropogenic disturbance caused by the removal process, to indicate potential levels of general coastal defence maintenance disturbance and consider their possible impacts on coastal species.

2. Methodology

2.1. Study location

The study took place at Highcliffe in Christchurch Bay on the south coast of England, UK (Fig. 2.1), Christchurch Bay has a steadily eroding coastline of Barton clay beds and cliffs. It experiences a low amplitude double high tide, which is characteristic of the Solent area, meaning it encounters a further four tidal oscillations in addition to the standard semidiurnal UK tides. In spring tides the area experiences fluctuations in mean water levels of approximately 1 m (Nicholls, 1988; Tyhurst, 1986). There is also a complex tidal current system that circulates within the bay and a south-westerly wave pattern causing high-energy beaches to the west and local sediment drift and erosion. The area receives some protection from the Isle of Wight situated to the east and Durlston Head to the West (Tyhurst, 1986). The Highcliffe coastal defence scheme reverted from timber to rock groynes in 1992, and currently comprises eleven rubble mound groynes, consisting of short and long structures (30–45 m) and a bastion, made from Portland Oolitic limestone (Harlow, 2013; Tyhurst, 1986) (Fig. 2.2). The groynes are designed with 1 in 2 side slopes, 1 in 2.5 roundhead slopes and a 4 m crest width (Harlow, 2013). These are situated amongst a mixture of shingle and sand beaches (CBC, 2008), and the structures are estimated to sit approximately 1 m into the substrate. Christchurch Borough Council (CBC) deemed the groyne system at Highcliffe to be over engineered with a number of the groynes not being fully utilised within the coastal defence system. Therefore it was decided that the best approach was to remove and recycle the rock units. Owing to the direct attack from the sea, this area regularly undergoes routine maintenance work that consists of the replacement of rock units, removal/replacement of sand, or in some circumstances the partial reconstruction of a structure (CBC, 2008). The management of this area is essential to retain the current