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Getting into the groove: Opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures

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ABSTRACT

Concrete flood defences, erosion control structures, port and harbour facilities, and renewable energy infrastructure are increasingly being built in the world's coastal regions. There is, however, strong evidence to suggest that these structures are poor surrogates for natural rocky shores, often supporting assemblages with lower species abundance and diversity. Ecological engineering opportunities to enhance structures for biodiversity conservation (and other management goals) are therefore being sought, but the majority of work so far has concentrated on structural design features at the centimetre–meter scale.

We deployed concrete tiles with four easily-reproducible fine-scale (millimetre) textures (control, smoothed, grooved and exposed aggregate) in the intertidal zone to test opportunities for facilitating colonisation by a dominant ecosystem engineer (barnacles) relative to natural rock. Concrete texture had a significant effect on colonisation; smoothed tiles supported significantly fewer numbers of barnacles, and those with intermediate roughness (grooved concrete) significantly greater numbers, after one settlement season.

The successful recruitment of early colonists is a critical stage in the development of more complex and diverse macrobenthic assemblages, especially those that provide physical habitat structure for other species. Our observations show that this can be facilitated relatively simply for barnacles on marine concrete by manipulating surface heterogeneity at a millimetre scale. Alongside other larger-scale manipulation (e.g. creating holes and pools), including fine-scale habitat heterogeneity in engineering designs can support international efforts to maximise the ecological value of marine urban infrastructure.

1. Introduction

Rapid population growth in most of the world's coastal regions means that more and more 'hard' structures such as sea walls and breakwaters are being built to manage the risks of sea level rise and increased storminess (Firth et al., 2013a; Pethick, 2001) and to support socio-economic growth (Airoldi and Beck, 2007). Structures built from rock and, in particular, concrete are also increasingly being deployed in the near-shore and subtidal zones as part of marine renewable energy schemes (Witt et al., 2012). While all of these structures provide novel habitats for marine life (Bulleri, 2006) there is strong evidence to suggest that the conditions they provide and the assemblages they support differ to natural rocky shores. Coastal structures, for example, typically support fewer species with lower abundances, and consequently altered competitive interactions among and between species (e.g. Bulleri, 2005; Bulleri and Chapman, 2010; Bulleri et al., 2005; Jackson et al., 2008). As such, the transformation of coastal habitats via urbanisation is a conservation issue of global concern, particularly in the face of concurrent major drivers of change including pollution and climate change (Hawkins, 2012; Hawkins et al., 2008; Thompson et al., 2002).

This creates a substantial management problem, given that the economic and social justification for building hard structures is clear but is in conflict with broader public interest and policy requirements to conserve biodiversity at a national and

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international level (Naylor et al., 2012). In Europe, for example, the Water Framework Directive (WFD) requires that careful environmental appraisal is undertaken for all heavily modified water bodies (including ports, harbours and defended coastlines, whether existing or new build) to identify measures for maximising ecological potential (Bolton et al., 2009). As an approach to engineering that explicitly considers ecological criteria in design, 'ecological engineering' (sometimes called 'reconciliation ecology') has significant potential to address these conflicts of interests (Bergen et al., 2001; Lundholm and Richardson, 2010).

In the coastal zone, a growing amount of experimental work is being undertaken globally to test manipulation of engineering designs for ecological gain (see Chapman and Underwood, 2011; Firth et al., 2013b, 2014; Naylor et al., 2011 for some recent discussions). The potential economic benefits of facilitating the growth of commercially exploitable species (e.g. Martins et al., 2010) and organisms that may afford some level of protection to engineering materials from marine weathering agents (e.g. Coombes et al., 2013) have also been highlighted. Much of this work is founded upon the known importance of physical habitat complexity for rocky shore species, and robust experimental evidence demonstrating the influence of various engineering design features on ecology, such as tidal position (e.g. Moschella et al., 2005) and the presence of water-retaining features (e.g. Browne and Chapman, 2014; Firth et al., 2013c).

Following pioneering work on the design and deployment of subtidal artificial reefs (see Baine, 2001 for a review), to date most ecological enhancement trials in the intertidal zone have focused on increasing physical habitat complexity at the centimetre–meter scale. This can be achieved either post-construction (e.g. drilling holes in otherwise flat walls) or by retrofitting and (more rarely) designing-in habitat 'units' during the build to provide refuge during low tide (e.g. artificial rock pools) (Browne and Chapman, 2011; Chapman and Blockley, 2009; Firth et al., 2014; Martins et al., 2010; Moschella et al., 2005). In comparison, very little has been done to test enhancement opportunities at finer scales (millimetres) simply by roughening the materials that structures are built from. This is surprising given substantial experimental evidence of the importance of fine-scale texture for the development of marine biofilms, the settlement of invertebrate larvae and spores, recruitment of juveniles, and the nature of community interactions on rocky substrata (e.g. Chabot and Bourget, 1988; Decho, 2000; Hutchinson et al., 2006; Menge, 2000; Walters and Wethey, 1996). On artificial structures, existing fine-scale topographic features have been shown to significantly influence the abundance of dominant organisms (e.g. Moschella et al., 2005), but attempts to manipulate texture at this scale remain noticeably absent.

On natural rocky shores, fine-scale habitat heterogeneity (millimetres and less) is created by weathering, involving the wetting and drying of rocks, salt crystallisation, chemical breakdown, and biological weathering and erosion (Coombes, 2014). Whilst the rate that these processes create roughness is largely dependent on rock type, one critical factor that artificial structures generally lack in comparison to natural shores is time. Engineering materials are subject to the same weathering processes as in situ rock (e.g. Coombes et al., 2011) but they are inevitably 'newer', less weathered, and less physically complex (at multiple spatial scales) than the rocks comprising rocky shores. Consequently, artificial structures are comparatively lacking in fine-scale complexity unless pre-weathered rock can be used or artificial texturing is applied. The potential ecological significance of weathering processes in altering substratum properties such as hygro-thermal behaviour is also recognised (Coombes and Naylor, 2012). For example, weathering morphologies on limestone—which develop relatively quickly in the intertidal zone—can support rich species assemblages (Coombes, 2014), as demonstrated on older historic structures (see Firth et al., 2013c; Moschella et al., 2005 in reference to Plymouth Breakwater).

Concrete, which can be cast in situ or used as precast units (Allen, 1998; CIRIA, 2010), typically lacks fine-scale topographic complexity when produced using standard moulding techniques (Fig. 1). Furthermore, a disproportionately small amount of experimental work has been done on the responses of intertidal species using, specifically, marine-grade concrete (e.g. Anderson and Underwood, 1994; McGuinness, 1989) and even less on concrete manipulation at a sub-centimetre scale (e.g. Borsje et al., 2011; Perkol-Finkel and Sella, 2014). This is a significant knowledge gap given that concrete is perhaps of greatest applied relevance in a context of coastal urbanisation, habitat homogenisation, and biodiversity conservation (Hawkins, 2012). Certain concrete chemistries may also limit (via exclusion and/or delay) the development of epilithic communities, via pH effects and metal leaching for example (Terlizzi and Faimali, 2010; Wilding and Sayer, 2002). More broadly, the potential to generate novel ecosystem service flows using ecological engineering techniques in urban environments, including biodiversity maintenance, is underexplored in the marine realm (Gaston et al., 2013).

To address this gap we tested the hypothesis that the settlement and recruitment of a dominant early colonist (barnacles) on marine-grade concrete would vary between treatments with different fine-scale (millimetre) surface textures. We focus on barnacles as they have been described as 'ecosystem engineers' in

Fig. 1. Concrete coastal structures with typically vertical, relatively smooth surfaces often have limited ecological value.