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Creation of microhabitats (tidepools) in ripraps with climax communities as a way to mitigate negative effects of artificial substrate on marine biodiversity

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A B S T R A C T

Urbanisation and the construction of commercial structures on coasts cause a significant impact on natural marine habitats. The concept of ̈Ecological Engineering ̈, recently applied to marine biology, integrates ecology, economy and society's needs into the design of artificial marine structures. Recently, some ecological designs, such as the addition of pools, pits, and crevices, have been proposed in order to reduce habitat modification, diminish colonization by invasive species, and spread and maintain ecosystem functioning and biodiversity indexes that are more similar to those of the natural environment. Within the features that may increase artificial habitats' diversity, tidepools are unique habitats that reduce stress in the intertidal, favouring breeding and feeding, as well as providing shelter and a greater degree of moisture to a certain group of species, which may present an advantage for them. Nevertheless, the ecological benefits that arise from the inclusion of these features on fully mature artificial structures are still poorly known. In the present study, tidepools were created on artificial substrate with an affordable method (jackhammer) in the locality of Ceuta (Strait of Gibraltar). The pools were carved on dolomitic riprap at two different intertidal levels, high and low shore (+0.75 m and +0.25 m higher than the lowest tide, respectively) with an average area of 195.2 cm^2 and 353.01 cm^3 of volume. These coastal defence structures were built more than eight years ago, thus the biota has substantially completed its colonization period and is set in terms of species composition. To test humidity effects on benthic assemblages around tidepools, the adjacent halo around the pool, with a width of 5 cm, was equally traced. Pool assemblages were compared to adjacent artificial and natural substrate and also to nearby natural pools. One year later, the results in species richness and diversity were significantly higher in the tidepools than the other two studied treatments (5 cm and control), artificial pools exceeded control species richness by 39.21% and control diversity by 30.70%. Focusing on the tidepool halo (5 cm) effect in the artificial substrate, the results show that the biological assemblages were different than tidepool and emerged rock, indicating that the newly created habitat extends its influence beyond the limits of the tidepools. Tidepools increased the number of species on ripraps and contributed to reduced fragmentation of some vagile species' populations, as they favoured settlement of species that previously seemed excluded from artificial substrate such as *Pisania striata, Fisurella* sp., *Phorcus turbinatus* and *Lepidochitona* sp. In the case of *Siphonaria pectinata,* it increased its presence in the tidepools and most of its egg masses were observed inside the pools. Finally, it should be mentioned that the pools have extended the upper vertical limits of infra-littoral level species such as *Paracentrotus* sp., mostly young individuals, and *Aiptasia* sp. These results may help to modify existing artificial shores to reduce their ecological impact.

1. Introduction

Coastal habitats are being lost and modified, influenced by marine urban sprawl and climate change (Airoldi and Beck, 2007; Bulleri and Chapman, 2010). Artificial shorelines are getting longer and bigger to protect harbours and coastal cities from rising sea-levels, severe coastal storms and flooding (Asif and Muneer, 2007). In addition, there are growing demands for coastal urban development, aquaculture facilities,

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and offshore energy infrastructures (Asif and Muneer, 2007).

There is growing consensus that the biota in artificial systems is different from nearby natural systems (Glasby, 1999; Glasby and Connell, 1999; Chapman and Bulleri, 2003; Bulleri and Chapman, 2004; Moschella et al., 2005; Firth et al., 2013; Aguilera et al., 2014). The impacts that occur during the different engineering stages (construction, operation, and decommissioning) are mainly related to the physical disturbances these produce (noise, turbidity, shock, vibration and hydrodynamism) and can negatively affect marine communities (Gill, 2005; Dafforn et al., 2015). The presence of artificial structures has local (such as sediment grain size and organic content, alterations in water flow velocity and stagnation, water quality and detritus) and regional (such as habitat fragmentation of native species populations and facilitation of non-native species establishment and dispersion) impacts on marine biodiversity with relevant consequences on a national, and even international, scale (Bulleri and Chapman, 2010; Airoldi et al., 2005; Govaert and Lauwaert, 2009; Dugan et al., 2011; Maes et al., 2015).

Designs that minimise changes between natural and artificial environments and designs that mimic natural habitats could help to support the maintenance of native biota and, as a consequence, hinder the settlement of non-native species (Dafforn et al., 2015). The increases in invertebrate abundance and species richness have been associated with more complex artificial structures (Walters and Wethey, 1996; Coombes, 2011; Loke et al., 2014; Loke et al., 2015; Loke and Todd, 2016). Similarly, different synthetic materials can influence the development of species assemblages (Grozea and Walke, 2009). Usually, the homogeneity in the design and the use of materials are the driving force behind the establishment of a suite of generalist fouling species that dominate artificial structures in harbours and coastal areas (Dafforn et al., 2015). Consequently, the physical design of artificial structures can have major effects at multiple trophic levels and across seascapes (Dafforn et al., 2015; Burgos-Rubio et al., 2015).

Only recently, have the ecological consequences of such structures been reviewed (Bulleri and Chapman, 2010) and mitigation strategies attempted (Dafforn et al., 2015; Chapman and Blockley, 2009; Chapman and Underwood, 2011; Browne and Chapman, 2011; Browne and Chapman, 2014; Firth et al., 2016). The “Ecological Engineering” concept, recently applied to marine biology, integrates ecological, economic and social needs into the design of man-made ecosystems. Essentially, it represents the incorporation of ecological goals and principles into the design of marine artificial structures (Bergen et al., 2001; Schulze et al., 1996; Firth et al., 2014).

Marine artificial structures, particularly seawalls and cubic concrete blocks, have recently begun to be designed to support higher biodiversity, including new microhabitats in the intertidal, such as cavities, lips to form pools, and pits or crevices (Chapman and Blockley, 2009; Browne and Chapman, 2011; Firth et al., 2014). It is known that, in natural rocky shores, intertidal pools provide important nursery grounds (Orton, 1929; Norris, 1963; Lewis and Bowman, 1975; Thompson, 1980; Bennett, 1987; Delany et al., 1998; Firth et al., 2014), feeding habitats (Wai and Williams, 2006; Noël et al., 2009) and refuges (Schonbeck and Norton, 1978; Underwood and Jernakoff, 1984; Moran, 1985; Fairweather, 1988) for a wide range of organisms. Biological assemblages in pools differ greatly to those on emergent rocks and can extend the upper vertical limits of many organisms susceptible to desiccation; although while some species tend to aggregate in pools, other species avoid them (Johnson and Skutch, 1928; Goss-Custard et al., 1979; Metaxas and Scheibling, 1993; Araujo et al., 2006; Firth and Crowe, 2008; Firth and Crowe, 2010; Firth et al., 2013).

Water-retaining features (such as rock tidepools) are particularly important in artificial habitats (Moschella et al., 2005; Chapman and Blockley, 2009; Firth et al., 2013). However, experimental data is still scarce and, to our knowledge, there are only two previous studies dealing with the creation of artificial rock pools in existing coastal defence structures (Underwood and Skilleter, 1996; Evans et al., 2016). The present study delves into the ecological benefits of tidepool construction in an existing coastal defence structure and also the effect on the humidity halo that occurs around tidepools. In contrast to both of the studies mentioned above, this study was carried out on selected riprap structures that were constructed more than eight years ago, so it can be stated that the colonization period of the structures was substantially completed and the assemblages, in terms of species composition, remain constant (Coombes, 2011; Dong et al., 2016; DELOAS project). The study was conducted in Ceuta, a town on the south coast of the Strait of Gibraltar. This area is a relevant biogeographic zone showing a highly urbanized coast and with great influence on maritime trade routes.

Therefore, the aims of the present study were: i) to test whether the creation of intertidal tidepools on dolomitic riprap coastal defence structures with climax communities increases the local biodiversity ii) to analyse the effect on the tidepool adjacent perimeter halo, iii) to test, as other studies have shown elsewhere in the world, if the Ceuta artificial structures have a poorer community than natural surrounding areas in the intertidal environment, iv) to explore which species were directly benefited by the newly created microhabitat, and v) to describe the biological assemblages of this type of microhabitats within the natural environment.

2. Materials and methods

2.1. Study locations

The Strait of Gibraltar is a biogeographical zone in which marine flora and fauna from the Mediterranean and Atlantic overlap. It is a very important geographic-geological region, bordering the Mediterranean, Lusitanian and Mauritanian biogeographic provinces. The convergence of these three different provinces confers great singularity, since the Strait constitutes a transitional border that allows the coexistence of organisms from the three regions. In addition, many endemic species contribute to the biological interest of the area (Castelló and Carballo, 2001; Guerra-García et al., 2010), which has been declared a Biosphere Reserve (CITA). It is also an area where many commercial routes converge and where important harbours are present (Algeciras, Gibraltar and Tangier Med); it is one of the areas with the most vessel traffic worldwide, which makes it an area with high risk of disturbances, impacts and environmental disasters (Piniella and Walliser, 2013; Rivera-Ingraham et al., 2013).

In this study, three dolomitic limestone ripraps were selected in Ceuta (Northern Africa, Strait of Gibraltar) along with three additional locations in nearby natural rocky shores (less than 650 m apart). The dock of Levante (A) in the port of Ceuta was finished in 1935 (Junta Obra del Puerto de Ceuta, 1942), the breakwater in the Chorrillo (B) beach was built in 1988 and the La Ribera beach (C) in 2006 (Angel Izar de la Fuente, Coast General Directorate, pers. comm.) (Fig. 1). These coastal defence structures were selected because they were built more than 8 years ago, so it is confirmed that their biota has substantially completed its colonization period and is set in terms of species composition, according to (Coombes, 2011) (Coombes, 2011); DELOS project, D46 (DELOAS project) and Dong, 2016 (Dong et al., 2016). Hence, it can be stated that these structures have reached their climax community.

2.2. Experimental design and sampling

On each selected riprap structure, five pools at the low midlittoral level (+0.25 m from lowest tide) and five at the high midlittoral level (+0.75 m from lowest tide) were created using a jackhammer (brand: DeWalt D25902K). Additionally, the same number of pools were selected in the nearby natural areas at the same tidal levels. The pools in the artificial substrate had a similar size to those located in the natural environment (average dimensions: 17.63 × 13.65 cm; 195.2 cm^2;