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Small artificial habitats to enhance the nursery function for juvenile fish in a large commercial port of the Mediterranean

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ABSTRACT

The concentration of human activities along the shoreline induces high levels of pressure, notably seascape urbanization caused by the proliferation of coastal and marine infrastructures such as ports, harbors, marinas and coastal defense structures. Because they are localized in sheltered and shallow coastal areas, these infrastructures inevitably lead to the loss of natural essential habitats once used as nursery ground by juvenile fish. Some studies have reported the presence of high juvenile densities on breakwaters and jetties suggesting those infrastructures could support the nursery function. However, ports seem unlikely to be used by juveniles due to their vertical and featureless docks. Here we explored the feasibility of using small artificial habitats to enhance the ecological value of ports. We set up a total of 108 artificial habitats in three different locations of the large commercial port of Marseille in the north-western Mediterranean. We then surveyed juvenile fish on the artificial habitats and control docks on 7 different occasions between June and September 2014. Average species richness and densities were higher on the artificial habitats but displayed high spatial and taxa-specific variations. Hence, small artificial habitats are promising ecological engineering tools to enhance the nursery function inside ports and thus reduce the ecological footprint of those infrastructures.

1. Introduction

Coastal areas represent less than 15% of the planet's land surface but they concentrate more than 60% of the human populations (EEA, 1999), and this proportion is expected to reach 75% by 2025 (Airoldi and Beck, 2007; Creel, 2003; EEA, 2006; Gray, 1997). The land–sea interface undergoes high levels of human activities (fishing, transportation, industry and recreation) leading to increased pressure through resource overexploitation, pollution, and habitat modification (Airoldi and Beck, 2007; Crain et al., 2009; Dugan et al., 2011). Habitat conversion, fragmentation and loss are considered one of the greatest threats to marine biodiversity and ecosystems (Airoldi and Beck, 2007; Coll et al., 2010; Dafforn et al., 2015; Gray, 1997; Halpern et al., 2008; Lotze et al., 2006; Seaman, 2007). The situation is particularly severe for coastal environments as a consequence of the growing number of man-made structures (ports, marinas, seawalls, breakwaters, groines, etc.) triggered by urbanization, commerce, industry, tourism and the need to protect the coast from erosion and flooding (Bulleri and Chapman, 2010; Gerland et al., 2014; Halpern et al., 2008; Scyphers et al., 2015). Some of the main characteristics of human-made coastal infrastructures are that it destroys, transforms or homogenizes the natural seascape mosaic: the intrinsic patchiness of the heterogeneous subtidal environment is replaced by homogeneous and less complex artificial habitats. It has been proven that the reduction of complexity (absolute abundance of individual structural components) and heterogeneity (relative abundance of different structural components) in terrestrial or marine environments leads to reduced abundances and survival of organisms (August, 1983; Brokovich et al., 2006; Fisher et al., 2007).

One of the essential functions offered by coastal habitats is their nursery role for marine organisms: during their life cycle, the het-

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erogeneity and complexity offered by the coastal seascape mosaic provide a wide range of habitat providing food and shelter suitable and essential for the juvenile stage of many different species (Beck et al., 2001). In the case of fishes for example, habitat homogenization and simplification may alter their "habitat quality" (sensu Dahlgren and Eggleston (2000)) and therefore ultimately impair their ecological function (Cheminée et al., 2016; Connell and Jones, 1991; Piko and Szedlmayer, 2007). If modifications of the native habitats and the functions they support are unavoidable (Airoldi and Beck, 2007; Airoldi et al., 2005; Martin et al., 2005) the creation of alternative habitats might support new ecological functions.

In this study we focused on the fish nursery function, which is of particular importance for population maintenance. Among man-made structures, it has already been shown that breakwaters host high densities of juvenile fish (Dufour et al., 2009; Pastor et al., 2013; Pizzolon et al., 2008; Ruitton et al., 2000) and adult fish species richness and abundances inside marinas seemed to be close to those found on natural rocky habitats (Clynick, 2008). Therefore, port and marina jetties might provide suitable nursery ground for juvenile fish (Dufour et al., 2009). However, ports are mainly characterized by vertical, featureless structures, such as docks and pontoons that seem unlikely to provide suitable habitat for juveniles.

The need to reduce the impact of man-made infrastructures and even to enhance their ecological value is becoming urgent since coastal hardening is predicted to increase in order to counter the foreseen global sea level rise and increasing frequency of large storms (Bray and Hooke, 1997; Michener et al., 1997; Thompson et al., 2002) and because of the high demand in marine transportation (e.g.: extension on Panama canal) and offshore energy.

However, combining ecological principles to urban infrastructure is a rather new concept (Bergen et al., 2001; Mitsch, 1996), especially in marine environments. Although ecological engineering has become a common practice in terrestrial and freshwater environments, it has just started to emerge over the last few years in marine environments (Browne and Chapman, 2011; Chapman and Blockley, 2009; Perkol-Finkel et al., 2006, 2008; Sella and Perkol-Finkel, 2015). Still, this kind of approach is rarely applied in the development of ports (Bouchoucha et al., 2016; Hellyer et al., 2011; Paalvast et al., 2012).

In a recent study, Bouchoucha et al. (2016) explored the potential role of marinas as habitat for juvenile seabreams (*Diplodus* spp.) and the used off small artificial units to increase habitat complexity. The habitats in large commercial ports are even more heavily transformed than in marinas, with much deeper waters, wide openings onto the sea and higher levels of human activities. Consequently, in the present study, we tested if a similar ecological engineering approach of marinas was implementable in a large commercial port and what benefit it could have on the assemblage of juvenile fish. We hypothesized that increasing habitat complexity would enhance the diversity (Browne and Chapman, 2011, 2014) and density of juvenile fish by furnishing shelter against predators (Bulleri and Chapman, 2010), thereby boosting the port's nursery value (sensus Beck et al. (2001), a habitat with greater contribution to adult population through higher juvenile densities, better growth and survival rates, and facilitated migration toward adult habitat). Furthermore we explored if the response to habitat complexification would be consistent through space or depend on the localization of the artificial units within the port.

Table 1
Characteristics of the three sampling zones according to Bourgogne and Blin (2015).

Area	A	B	C
Depth (m)	3.5	12.5	8.5
Distance to the sea (m)	2400	2374	1820
Relative opening	Open	Open	Close
Presence of fenders	No	Yes	Yes
Bottom type	Mud	Mud	Mud
Rock proximity	No	No	Yes
Exposition to current	High	High	Low
Presence of macro-waste	High	Low	Low
Presence of hydrocarbons	Medium	Low	Low
Freshwater discharge	High	Low	Low
Terrestrial activity level	Low	Low	Low
Maritime activity level	Low	High	Low
Metallic trace elements levels	Very high	Medium	Medium
Rare earths levels	Very high	Low	High
Organic contaminants levels	High	Medium	Medium
Bacteriological contamination levels	High	Medium	Low

2. Material and methods

2.1. Study area

The "Grand Port Maritime de Marseille" (GPMM) is the busiest port in France and the 2nd in the Mediterranean (behind Algeciras, Spain) (AAPA, 2014), with 78 million tons of goods and over 2 million travellers passing through in 2014. It covers 10,000 ha between the cities of Fos and Marseille, in southern France, and is composed of two main basins: the western harbors located in Fos and the eastern harbors in Marseille. The study was led in the interconnected eastern harbors that are protected from the dominating wind generated waves by a 7 km breakwater (Digue du large) (Fig. 1a and e) constructed more than a hundred years ago. All the harbors undergo high levels of activity due to the navigation of container and cruise ships, but minimal fishing and diving pressure, as the site is a restricted area with limited access. The experimental model was conducted on three different docks, referred to as areas A, B and C (Fig. 1b–d). Each area exhibited different characteristics as described in Table 1.

2.2. Artificial experimental units and set up

Our study included two treatments in each area: normal docks (as controls) and equipped docks with increased complexity. In order to increase habitat complexity, we used Artificial Experimental Units (AEU) provided by the Ecocean® company (dock Biohut®) composed of a pair of stainless steel alloy cages (50 cm × 80 cm × 25 cm) (as used in Bouchoucha et al., 2016). The inner cage has a 2.5 cm mesh and is filled with a biogenic component (oyster shells) to promote colonization by benthic fauna and flora, as well as to increase the structure complexity. The outer cage has a 5 cm mesh and is left empty; the use of a larger mesh enables juveniles fish to go in and out without any inconvenience and offers a predator free zone (Fig. 2). AEU were attached to the initial substratum of the docks between the surface and −1 m by drilling superficial small holes permitting the fixation of the trellis to which the units are then attached.

A total of 108 AEU were installed in the port of Marseille over three days (14–16 May 2014). They were spread over 30 m of dock in each of the three different areas. An additional 30 m long stretch of unequipped dock was randomly selected as a control treatment in each area. Depending of physical constraints (presence of tires and wooden logs used as dock defense) docks were equipped with between 30 and 35 AEU spaced approximately 40 cm apart (always keeping to the 30 m of equipped dock).

2.3. Sampling procedure

Juvenile fish assemblages were monitored during seven separate surveys by an Underwater Visual Census (UVC) between June and September 2014 (June 23, July 8 and 31, August 7 and 20,