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Spatial distribution of juvenile fish along an artificialized seascape, insights from common coastal species in the Northwestern Mediterranean Sea

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ABSTRACT

Along the littoral, a growing number of anthropogenic structures have caused substantial habitat destruction. Despite their detrimental impact, these constructions could play a role in the functioning of coastal ecosystems. The objective of this work was to assess the distribution of juvenile coastal fish along a seascape composed of various natural and artificial habitats in order to determine the potential role of coastal infrastructures as juvenile habitat. We surveyed juvenile populations on various infrastructures and natural sites along a 100 km shoreline of the French Mediterranean coast. Juvenile densities varied according to the level of artificialization of the sites. Densities were the highest on coastal defense structures, intermediate in natural sites and lowest in harbors. Focusing inside harbors revealed highly variable densities depending on the type of habitat, with densities on ripraps or jetties that were equivalent to those of natural sites. Our results underline the importance of anthropogenic structures as potential juvenile habitats, which is too often not considered in management plans.

1. Introduction

Due to an ever growing global population and a general migration to the coast, coastal areas already concentrate more than 60% of the human population while they represent less than 15% of the planet's land surface (EEA, 1999) and this proportion is expected to reach 75% by 2025 (Airoldi and Beck, 2007; Creel, 2003). As a result, the land-sea interface is subject to an unprecedented variety and magnitude of anthropogenic pressures making them particularly vulnerable. This translates into a multitude of consequences such as resource overexploitation, pollution, invasive species and habitat modifications (Crain et al., 2009; Dugan et al., 2011). The latter is known to be one of the greatest threats to marine biodiversity and ecosystems (Coll et al., 2010; Dafforn et al., 2015; Halpern et al., 2008) and is exacerbated by the flourishing number of coastal anthropogenic structures (e.g. harbors, marinas, coastal defense structures such as seawalls, breakwaters, groins, 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; Scyphers et al., 2015). The main consequence of coastal hardening is that it destroys, transforms or homogenizes the natural seascape mosaic, replacing the original patchiness of heterogeneous subtidal environments by homogenous and often less complex artificial habitats. It has been shown that the reduction of complexity and heterogeneity of seascapes leads to lower abundances and the increased mortality 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. The coastal seascape mosaic offers a wide variety of habitats, which provides suitable food and shelter essential for the juvenile stages of many different species (Beck et al., 2001).

Most coastal fish have a complex life cycle composed of two phases, a pelagic and a benthic (Armsworth, 2002; Jones, 1988; Mora and Sale, 2002; Öhman et al., 1998). The former is also known as the dispersive phase in which eggs are released into the water column and then hatch to produce larvae that disperse in open waters. After a period of about one month, during a transition called settlement, the larvae may reach the shore (Di Franco et al., 2013) and become a post-larva that will establish in its new benthic juvenile habitat. Newly settled juveniles will then grow in their juvenile habitat for approximately six months (variable upon taxa) until they reach a size permitting them to avoid

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most predation (around 8 cm), at which point they actively leave this habitat to recruit into the adult population (Vigliola and Harmelin-Vivien, 2001). The juvenile stage is critical as mortality is great (Houde and Hoyt, 1987; Macpherson et al., 1997; Planes et al., 1999; Vigliola et al., 1998) and the number of individuals that will eventually contribute to the renewal of adult populations is highly dependent of the quality of juvenile habitat. According to Beck et al. (2001), nurseries are habitats that contribute a greater than average number of individuals to the adult population on a per-unit-area basis in comparison to other juvenile habitats. The “nursery value” of a given habitat, which is a relative value, results from a combination of four parameters: (1) the initial density of juveniles, (2) their survival rate, (3) their growth rate and (4) their ability to migrate from the juvenile habitat and recruit into adult habitats. As it is logistically difficult to assess parameters (2), (3) and (4), the number of juveniles present in a given habitat at a given time between settlement and recruitment has often been used as a proxy of its nursery value (Cheminée et al., 2017a; Cuadros et al., 2017a; Macpherson and Zika, 1999; Pastor et al., 2013) and permits comparison between sites. Besides, the concept of “effective juvenile habitats” (Dahlgren et al., 2006) brings complementary information. Those habitats are habitats whose densities of juveniles are small, but have a high overall contribution to adult population due to the large surface they might represent in the seascape, which might be the case of coastal anthropogenic structures.

Because the alteration of nursery habitats can have direct adverse effects on juvenile survival and the subsequent maintenance of adult populations, it is of prime importance to identify and localize them in order to focus conservation efforts. Some recent studies have focused on these goals (Cheminée et al., 2013, 2014; Cuadros et al., 2017b) but anthropogenic structures were only slightly taken into consideration. However, structures such as breakwaters have been shown to host high juvenile densities of certain coastal fish (Dufour et al., 2009; Pastor et al., 2013; Pizzolon et al., 2008; Ruitton et al., 2000). Therefore, their potential role as juvenile habitat should not be neglected especially in the context of their growing ubiquity in the coastal seascape.

The main objective of this study was to assess the spatial distribution of juvenile coastal fish in a seascape composed of natural habitats and various anthropogenic structures. This was undergone by working on a relatively large spatial scale (around 100 km of coastline) permitting the inclusion of different artificialized and natural sites. We focused on Mediterranean coastal species settling in shallow heterogeneous rocky habitats. We first compared different levels of artificialization using a snap-shot of juvenile densities found in natural habitats *versus* those present on Coastal Defense Structures (CDS) and inside harbors (i.e. the two most widespread coastal anthropogenic structures in the area). Furthermore, as very little is known about these urban ecosystems despite their universality, we then concentrated inside harbors where we assessed the effect of habitat type on juvenile densities.

2. Material and methods

2.1. Study area and sampling strategy

The study was conducted on the southernmost French Mediterranean coast in the Gulf of Lion (NW Mediterranean). The sampled area stretches from Leucate to Cerbère (at the border between France and Spain) for approximately 100 km. This coast can be divided in two different types of regions, a sandy coast (SC) to the north, and a rocky coast (RC) to the south (Fig. 1-a). The entire study area is included in the Gulf of Lion Natural Marine Park (GLNMP) and encompasses the Cerbère-Banyuls Natural Marine Reserve (CBNMR). Within this area harbors are scattered along the entire studied shoreline and represent around 20 km of shoreline, which is approximately the same amount of linear coast as the RC. Juvenile habitats were identified and measured by the use of aerial images as in Cheminée et al. (2017a, 2017b): identification criteria of juvenile habitats consisted of shallow, protected from strong swell, gently sloping habitats with a heterogeneous substrate consisting of small blocks and rocks. Among the 83 sites identified as potential nurseries, 29 natural sites (Fig. 1-b) and 10 CDS (Fig. 1-c) were randomly chosen for sampling. Additionally, seven harbors (Fig. 1-d) were added to this sampling array, out of the nine present in the study area, for a total of 46 sampled sites. Within each harbor, random samples were performed among the different types of habitat: outer jetty, inner jetty, natural (which can consist of a hard or soft bottom depending on the region), dock (concrete walls) and riprap (see Fig. 1-e to h for description). Each harbor contained between four and five habitat types. Minimums of three replicates were performed for each habitat type in each harbor.

2.2. Studied species

This study focused on species that use the above described heterogeneous rocky and sandy habitats as a nursery ground (Harmelin-Vivien et al., 1995). For the first part of our study, comparing natural, CDS and harbor sites, we considered the following eight species for our surveys as a previous study showed they were present in the study area (Cheminée et al., 2017a) and are strongly affiliated to the studied habitat (Cheminée et al., 2011; Garcia-Rubies and Macpherson, 1995; Harmelin-Vivien et al., 1995; Vigliola, 1998): white seabream (*Diplodus sargus sargus* (Linnaeus, 1758)), sharpsnout seabream (*Diplodus puntazzo* (Walbaum, 1792)), yellowmouth barracuda (*Sphyraena viridensis* (Cuvier, 1829)), ornate wrasse (*Thalassoma pavo* (Linnaeus, 1758)), dusky grouper (*Epinephelus marginatus* (Lowe, 1834)), zebra seabream (*Diplodus cervinus* (Lowe, 1838)), red porgy (*Pagrus pagrus* (Linnaeus, 1758)) and common dentex (*Dentex dentex* (Linnaeus, 1758)). In the second part of our study, we focused within harbors and as very little is known about juvenile assemblages in those infrastructures, we decided to extend our selection for those sites. We considered all observed species with the exception of those forming large mobile schools (eg. *Sarpa salpa*, *Pagellus* spp.) and those of the labrid family (only *T. pavo* is included as it is part of the original sampling list of species) as the youngest individuals are hard to observe and might require a different sampling procedure. The sampled species for each part of the study are recorded in Table 1.

2.3. Sampling procedure

Sampling was performed according to the widely used Underwater Visual Census (UVC) protocols (Harmelin-Vivien et al., 1985). Trained and inter-calibrated divers snorkeled along the coast at a slow and steady pace and identified, counted, and estimated the size of juvenile individuals from any of the target species along a 1 m wide belt transect parallel to the coast. Transects were defined on a waterproof map depicting the coastline so divers knew were to begin and stop their transects. Observations were recorded on the same map, which also provided examples of different juvenile sizes (in increments of 5 mm) to aid in size estimations. We used 5 mm size classes to estimate Total Length (TL). Which is consistent with a previous study that estimated the precision of such underwater size estimation to be of ± 3.5 mm (Macpherson, 1998). For most rocky reef fishes in the Mediterranean, size at settlement is around 10 mm TL (Cheminée et al., 2013; Crec'hriou et al., 2015; Garcia-Rubies and Macpherson, 1995). The smallest specimens of the taxa studied were considered newly settled individuals. Our visual censuses took into account only the young of the year (YoY or y0 individuals), which might be newly settled individuals (for species settling during spring and summer) or individuals having settled a few months prior (for species settling during fall and winter) (maximum sizes retained for each species are available in supplementary material 1).

Sampling was performed during the last two weeks of July 2015 and 2016 which corresponds to one or two months after the known settlement or post-settlement periods of many Mediterranean species