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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,

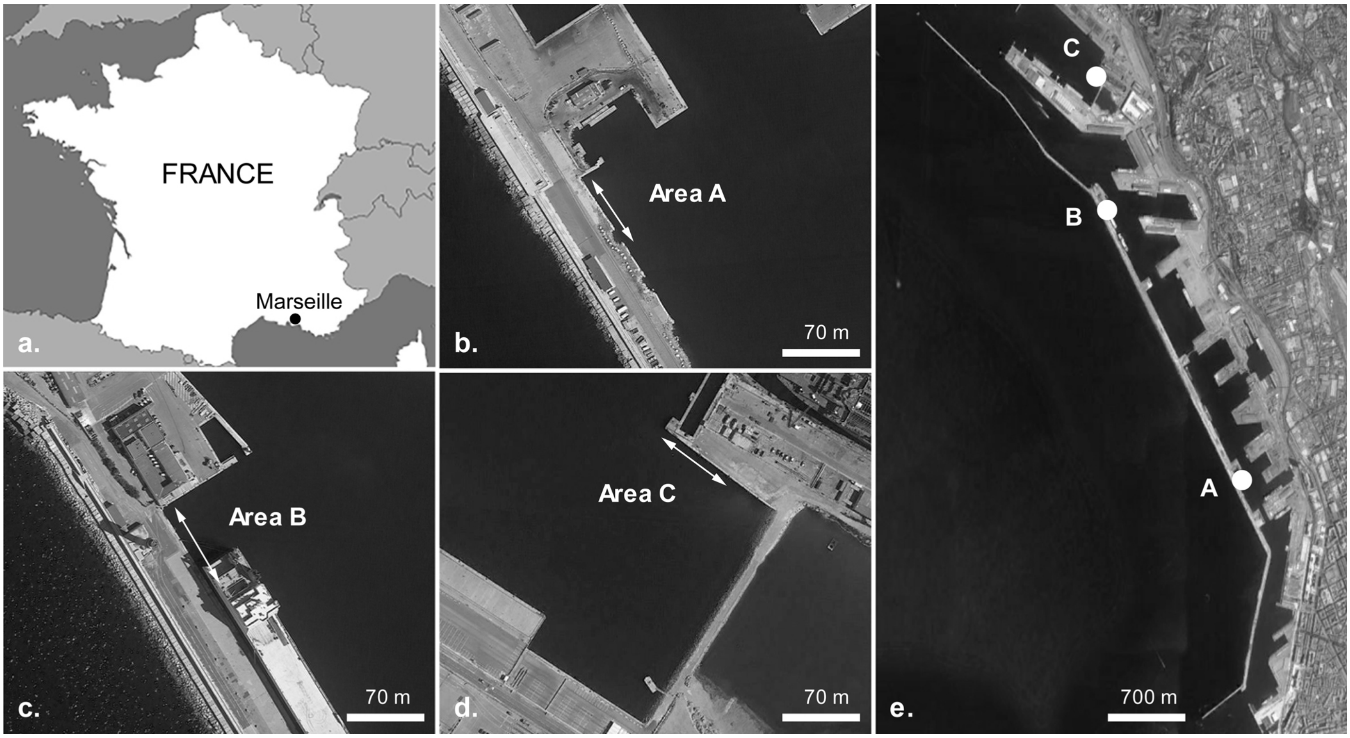

Fig. 1. Study area. (a) Marseille's location in southeast France (Gulf of Lion), detail of the three sampling zones: (b) Area A, (c) Area B, (d) Area C and (e) relative position of each area inside the eastern harbors of Marseille's ports.

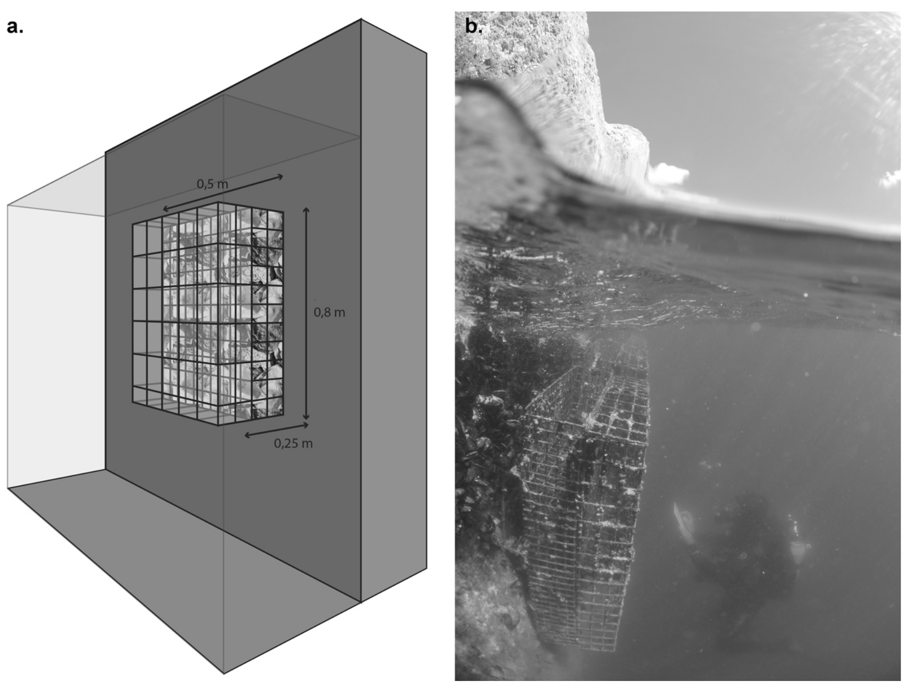

Fig. 2. (a) Composition of the AEU (Dock Biohut®) with the two stainless steel alloy cages, the inner grid with a 2.5 cm mesh and filled with oyster shells, the outer one with a 5 cm mesh and empty. (b) Installed AEU being monitored by scientific diver.

September 2 and 16). The UVC was realized among three replicate transects (10 m × 1 m belt transects) in each treatment (AEU and control dock) and each area (A, B and C). As juvenile fish have a relatively low swimming speed, a preference for shallow waters and a tendency to hide in small cavities, all transects were performed between the surface and 1 m depth while swimming slowly to enable maximal searching efficiency (Fig. 2b). Juvenile fish were identified, counted and sized to the nearest 5 mm size class. When underwater identification was not possible, pictures and videos were taken and analyzed back at the laboratory to aid identification. The same diver performed all of the samplings to minimize observer bias.

2.4. Data analysis

Statistical analyses were performed using the PRIMER 6 software with the PERMANOVA add-on (Clarke and Gorley, 2006; Clarke et al., 2014) and the R software (R version 3.0.3 – Rstudio Version 0.99.486). Uni- or multi-variate analyses of variance by permutations (PERMANOVAs) were performed to analyze the patterns of the following response variables: the univariate juvenile species richness, global juvenile density and taxa-specific density of species and the multivariate juvenile assemblage composition. As this method handles complex multiple factor designs, considers interactions of factors and does not require normal distribution of errors (Anderson, 2001), it was particularly suitable for our data. Response variables were modeled according to the following model with 3 factors: factor "treatment" has two levels (AEU, docks) and is fixed; factor "area" has 3 levels (A, B, C) and is random; factor "survey" has 7 levels (survey 1–7) and is fixed. Analyses were based on Bray–Curtis dissimilarity matrixes generated on square-root transformed data. *p*-Values were calculated by 999 random permutations of residuals under a reduced model and Type III sum of square (Anderson, 2001). The Monte-Carlo test was used when less than 200 permutations were generated. Post hoc pairwise tests were performed when relevant.

Furthermore, trends in multivariate data (juvenile fish assemblages) were graphically represented using the Principal Component Analysis (PCoA) on a Bray–Curtis dissimilarity matrix. This ordination method is well adapted to our data as it is applicable on a non-Euclidian distance matrix. It also presents the advantage of representing the data without distorting distances as it is based on eigenanalysis (Gower, 1966; Legendre and Legendre, 2012). SIMPER analyses were also conducted in order to determine which species would be responsible for differences between groups of samples.

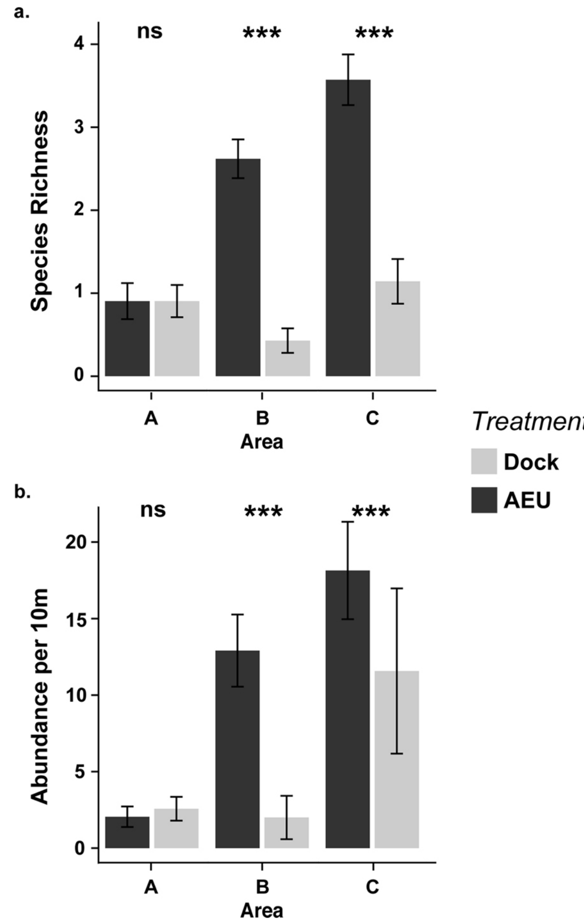

Fig. 3. (a) Mean (±SE) species richness by treatment and area. (b) Total mean density (±SE) (all species pooled) by treatment and area expressed in number of individuals per 10 m. Significant *p*-value: *<0.05; **<0.01; ***<0.001, ns = non significant.

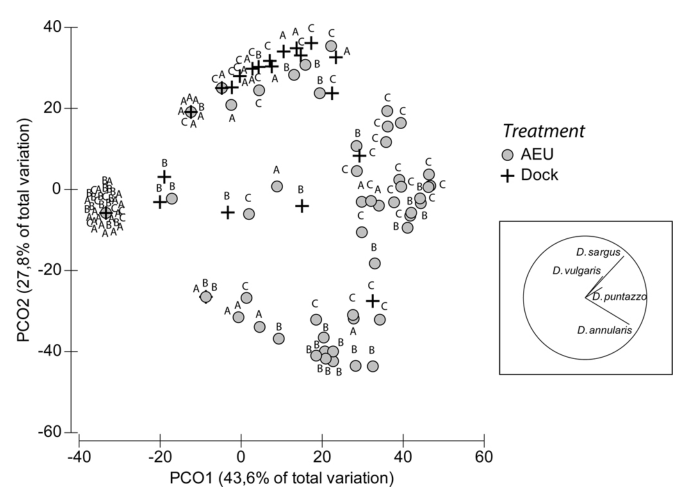

Fig. 4. PCoA plot for fish assemblages on AEU (gray circles) and control docks (black cross) for area A, B and C (labels). The dominant species correlated to similarity between the samples (Pearson coefficient > 0.2) are shown as vectors beside the plot.

3. Results

3.1. Species richness and total density

Overall, more than 16 species were observed (Table 2) with a maximum of 6 species per transect and survey. Sparids were the most represented fish families with 6 different species among which *Diplodus annularis* was the most abundant. For mean species richness, the interaction term between treatment and areas was significant (PERMANOVA, $F = 17.38$, $p = 0.001$). For two of the three areas (B and C), species richness was higher on AEU than on docks (2.62 ± 1.07 and 3.57 ± 1.40 species on AEU, 0.43 ± 0.68 and 1.14 ± 1.24 on docks respectively, pair-wise test, $p = 0.001$) (Fig. 3A). Total juvenile density trends were similar to those of species richness: a significant interaction between treatment and areas was detected (PERMAVONA, $F = 14.65$, $p = 0.001$). The mean total densities of juveniles were higher on AEU than on docks for two of the three areas (12.90 ± 2.36 and 18.14 ± 3.18 individuals/10 m on AEU and 2.57 ± 0.78 and 11.57 ± 5.40 individuals/10 m on control docks for area B and C respectively, pair-wise tests, $p = 0.001$) (Fig. 3B).

3.2. Assemblages and taxa-specific densities

Similar trends were observed for assemblage composition (relative abundance of species). Assemblages differed significantly according to combinations of the interaction survey × area × treatment (PERMANOVA, $F = 1.36$, $p = 0.047$). The effect of the treatment (AEU vs docks) varied according to the spatial position (area) or survey (Fig. 4). Those variations are also displayed on the PCoA plot, with most of the dock samples concentrated at the very left of the *x*-axis for areas A and B or at the top of the *y*-axis for samples from area C. AEU samples segregate according to both axes being dispatched on the left diagonal of the plot with samples from area C being mainly on top and samples from area A and B being more dispersed. According to the vectors, *D. sargus* and *D. annularis* are the main contributors to the differentiation between treatments and areas.

Table 2
Fish species found on the AEU and control dock for the three areas with all surveys pooled.

Family	Species	Common name	Area A		Area B		Area C	
			AEU	Control	AEU	Control	AEU	Control
Atherinopsidae	*Atherina* sp.	Sand smelt				+	+	
Blenniidae	Blenniidae	Blennies	+		+		+	
Gobiidea	Gobiidea	Gobies	+	+	+		+	
Labridae	*Ctenolabrus rupestris*	Goldsinny wrasse					+	
	Symphodus roissali	Five-spotted wrasse			+		+	
	Symphodus sp.	Wrasses			+		+	
Mugilidae	Mugilidae	Grey mullets						
Mullidae	*Mullus* spp.	Red mullets					+	
Sparidae	*Diplodus annularis*	Annular seabream	+		+	+	+	+
	Diplodus cervinus	Zebra seabream						
	Diplodus puntazzo	Sharpnout seabream	+	+	+		+	
	Diplodus sargus	White seabream	+	+	+	+	+	+
	Diplodus vulgaris	Common two-banded seabream		+		+	+	+
	Oblada melanura	Saddled seabream						+
	Sarpa salpa	Salema porgy		+	+	+	+	+
Tripterygiidae	*Trypterigion* sp.	Threefin blenny			+		+	

Table 3
SIMPER analysis showing the contribution of the different fish species to dissimilarity between (A) treatments and (B) areas. Av.Abund: average abundance (in number of individuals by 10 m), Av.Diss: average distance, Diss/SD: dissimilarity/standard deviation Contrib%: contribution percentage, Cum.%: cumulative contribution percentage. Cut for low contributions was fixed at 90% cumulated contribution.

(A) SIMPER table of results habitat groups

Av.Diss = 87.25	Group Biohut	Group Dock				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
D. annularis	1.18	0.09	28.01	1.12	32.10	32.10
D. sargus	0.74	0.60	25.21	0.90	28.90	61.00
Symphodius sp.	0.39	0.00	10.01	0.51	11.47	72.47
S. salpa	0.18	0.18	6.54	0.40	7.50	79.97
D. vulgaris	0.10	0.15	3.94	0.47	4.51	84.49
Gobies	0.15	0.00	3.16	0.41	3.62	88.11
Blennies	0.13	0.00	2.34	0.37	2.68	90.79

(B) SIMPER table of results zone groups

Av.Diss = 79.35	Group 160	Group 123				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
D. sargus	1.12	0.34	31.15	0.92	39.26	39.26
D. annularis	0.91	0.75	13.00	0.71	16.39	55.65
S. salpa	0.30	0.20	7.81	0.44	9.84	65.50
Symphodius sp.	0.02	0.57	7.68	0.68	9.68	75.18
D. vulgaris	0.26	0.04	7.16	0.49	9.02	84.20
Atherina sp.	0.15	0.08	3.63	0.26	4.57	88.77
Gobies	0.17	0.02	2.39	0.49	3.01	91.78

Av.Diss = 77.34	Group 160	Group 108				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
D. sargus	1.12	0.55	34.50	1.07	44.60	44.60
D. annularis	0.91	0.26	16.14	0.75	20.87	65.47
D. vulgaris	0.26	0.07	6.61	0.60	8.55	74.03
S. salpa	0.30	0.04	4.93	0.36	6.38	80.41
Gobies	0.17	0.04	4.00	0.44	5.17	85.58
Blennies	0.16	0.02	2.76	0.49	3.57	89.15
Symphodius sp.	0.13	0.00	2.38	0.40	3.08	92.23

Av.Diss = 79.35	Group 123	Group 108				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
D. sargus	0.34	0.55	33.01	0.95	37.71	37.71
D. annularis	0.75	0.26	18.49	0.81	21.13	58.83
Symphodius sp.	0.57	0.00	14.56	0.68	16.63	75.46
S. salpa	0.20	0.04	8.07	0.41	9.22	84.68
D. vulgaris	0.04	0.07	4.79	0.32	5.47	90.15

This result is corroborated by the SIMPER analysis, which revealed high levels of dissimilarity between treatments and areas, in both cases mainly due to *D. annularis* and *D. sargus* (Table 3). *Symphodus* sp. also contributes to the dissimilarity between treatments and between area A and B, while *S. salpa* and *D. vulgaris* are

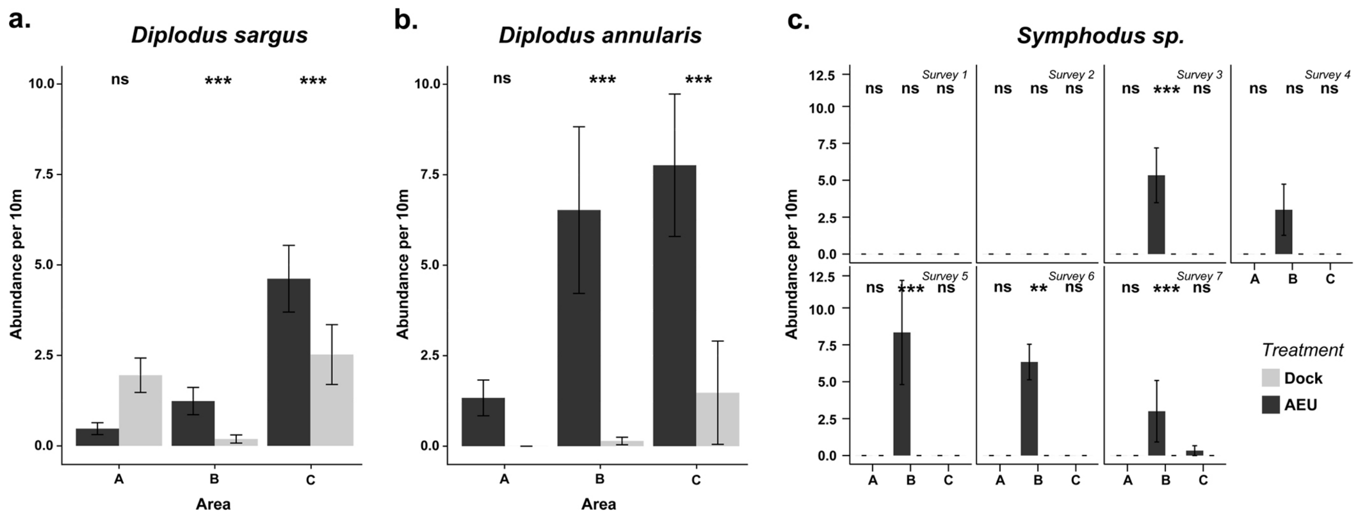

Fig. 5. Mean (±SE) taxa-specific densities according to significant interaction factor. (a) *Diplodus sargus* by area and treatment, (b) *Diplodus annularis* also by area and treatment and *Symphodus* sp. for all seven survey by area and treatment. Significant *p*-value: *<0.05; **<0.01; ***<0.001, ns = non significant.

the third contributors to dissimilarity between areas C and B, and C and A respectively (Table 3).

As *D. annularis*, *D. sargus* and *Symphodus* sp. are the main contributors to dissimilarity between treatments and areas (Table 3), they represent good indicators to assess the effect of the different factors on assemblage variability. Analysis of the variations in taxa-specific density of those species showed contrasting patterns according to species (Fig. 5). For instance, for *D. sargus* the interaction of the factors treatment and area was significant (PERMAVONA, $F = 7.25$, $p = 0.002$) with higher densities on AEU for area B (1.24 ± 0.38 individuals/10 m against 0.19 ± 0.11 on docks, pair-wise test = 0.007), no difference for area C and higher densities on docks for area A (1.95 ± 0.48 against 0.48 ± 0.16 for AEU, pair-wise test = 0.002) (Fig. 5A). *D. annularis* showed the strongest answer to treatment. Similar to *D. sargus*, a significant interaction between treatment and area was detected (PERMANOVA, $F = 4.73$, $p = 0.009$) but with significantly higher densities on AEU for the three areas (1.34 ± 0.49, 6.52 ± 2.30 and 7.76 ± 1.97 individuals/10 m against 0, 0.14 ± 0.10 and 1.48 ± 1.43 for areas A, B and C respectively) (Fig. 5B). Densities of *Symphodus* sp. were significantly different according to the interaction factor survey × area × treatment (PERMANOVA, $F = 5.14$, $p = 0.001$) with individuals present exclusively on the AEU as of the third survey on area B and only on the last one for area C (Fig. 5C).

In addition to their response to treatment, total taxa-specific densities (all areas and all treatments pooled) showed taxa-specific variation throughout the surveys. Densities of *D. sargus* and *Symphodus* sp. were relatively constant throughout the whole sampling period while *D. annularis* exhibited densities which reached a peak on the second survey and then decreased until the end of sampling (Fig. 6).

4. Discussion

This study proved the feasibility of implementing the small artificial units approach to a large commercial port and its role as a tool to improve the nursery value of such infrastructures. By complexifying habitat structure, these infrastructures can support greater juvenile fish densities and higher species richness, with however large spatial variations.

4.1. Ports as juvenile fish habitats

The presence of juvenile fish has already been recorded on breakwaters, jetties (Clynick, 2006, 2008; Pastor et al., 2013; Ruitton et al., 2000) and more recently inside marinas (Bouchoucha et al., 2016; Clynick, 2006, 2008; Dufour et al., 2009), but this is the first study to focus on the potential use of a large commercial port by fish during early life stages. Although the characteristics of such infrastructures cause us to think of them as poor candidates for successful settlement, our results suggest that at least some locations may host juveniles, particularly on the artificial habitats that we tested. The species observed during this study are typical to shallow water habitats known as nurseries, such as rocky bottoms, but also, and more surprisingly, *Posidonia oceanica* meadows and *Cystoseira.* Most *Diplodus* spp. are known to recruit in very shallow rocky bottoms (<2 m) with gentle slopes with the exception of *Diplodus annularis* whose settlement preferentially occurs in *Posidonia oceanica* meadows between 5 and 8 m depth (Harmelin-Vivien et al., 1995). As for *Symphodus* sp., they usually settle in macro algae forests, from 2 to 4 m depth (Cheminée et al., 2013; García-Rubies and Macpherson, 1995). The settlement of the *D. annularis* and *Symphodus* sp. on the port's hard structures suggests a higher than expected plasticity in juvenile habitat requirements, a result also found by Bouchoucha et al. (2016) who observed juvenile *D. annularis* in different Mediterranean marinas. One of their hypotheses was that as pelagic larvae often settle on the first suitable habitat encountered (Shapiro, 1987), the presence of juveniles in the port could result from lacking nearby suitable habitat, however, in our case, *Posidonia oceanica* meadows are present right at the entrance of the port. Therefore, an active selection of anthropogenic structure by the post-larvae cannot be excluded. High productivity and relatively low wave action could represent favorable conditions for post-larvae settlement (Clynick, 2006; Romer, 1990), which might explain juvenile presence in the port. Additionally, strong light intensity generated by the city may attract the larvae during the night (Longcore and Rich, 2004; Munday et al., 1998) resulting in a greater number of them reaching the shore in urbanized areas and especially inside ports.

Densities display high spatial variations. Such variations were also observed by Bouchoucha et al. (2016) between marinas, with the hypothesis being that differences in location and physico-chemical conditions explain the success or failure of *Diplodus* settlement. In the case of the Marseille port, the same hypothesis

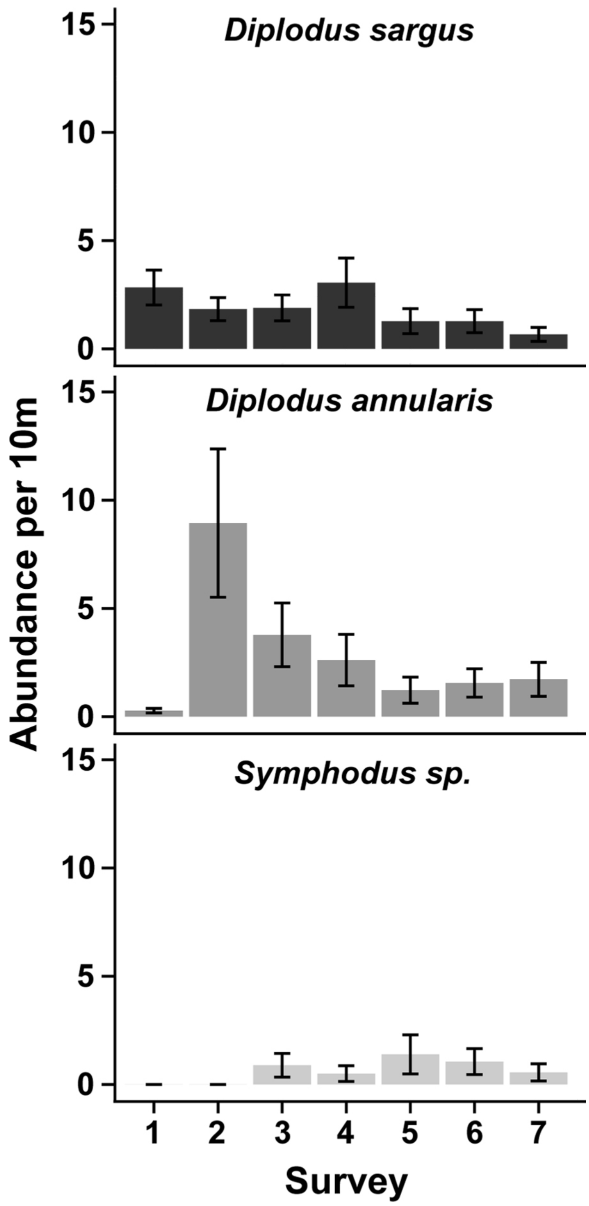

Fig. 6. Mean (±SE) taxa-specific densities per survey (from June to September) for all treatments and areas pooled, (a) *Diplodus sargus*, (b) *Diplodus annularis*, and *Symphodus* sp.

might be put forward to explain the observed disparity. The port is so large that each harbor composing it may have its own level and nature of anthropic pressures leading to particular structural and physico-chemical characteristics. Some locations submitted to frequent large ship traffic (e.g. area B) might undergo higher wave and courant exposure, which could influence the arrival of the juveniles as well as their survival. Low densities (such as for area A) may be due to other factors such as pollution or higher salinity variations, as this area is exposed to high freshwater discharge and exhibits the highest concentrations of all contaminants (Table 1). Chemical pollution is known to have adverse effects on fish physiology and may affect juvenile growth and survival (Kerambrun et al., 2012; Marchand et al., 2003). Contamination levels in ports and their impact on juvenile fitness should be investigated in order to determine the real potential of urban ecosystems as nursery grounds for fish. The depth of the port (between 6 and 8 m for the studied areas) would have been expected to be a limiting factor for successful settlement, preventing the presence of most juveniles in such environments. However, juveniles were observed in the 3 sampling areas despite the depth.

Sampling was done during the summer months which is a time period covering the settlement of most coastal fish species (Crec'hriou et al., 2015; Ventura et al., 2014). Indeed, the arrival peak of *D. annularis* was clearly observed in this study (survey 2), followed by a decrease in densities, which might be due to mortality (caused by predation and/or competition for food and space) but also by their potential displacement to adjacent habitats (Macpherson, 1998; Ventura et al., 2014; Vigliola and Harmelin-Vivien, 2001). *D. sargus* were also well represented in the port but no peak was observed suggesting that settlement had occurred before the beginning of sampling. This hypothesis is corroborated by the observation of numerous small juveniles at the end of May on adjacent habitats (authors personal observations). Other species that settle in summer were observed such as *Symphodus* sp., *Mullus* sp. or *O. melanura* but in low densities suggesting poor larvae supply or inadequate habitat for those juveniles. Species settling during fall or winter, such as the highly commercially valued gilt-head sea bream *Sparus aurata* or the sea bass *Dicentrarchus labrax*, might also use ports as juvenile habitat. Extending the sampling period to study the use of such infrastructure as potential nurseries for those species could be of good interest.

4.2. Nursery value enhancement by the use of small artificial units

Our results showed that increasing habitat structural complexity by the use of small artificial units proved efficient in augmenting juvenile fish abundance, which could minimize the detrimental effect of the infrastructure on the nursery function. Indeed, greater species richness and juvenile densities were observed on the AEU compared to bare dock. This study is comparable to Bouchoucha et al. (2016) results obtained in five marinas using this kind of rehabilitation approach. Even if our results support the working hypothesis according to which habitat complexification would enhance the port's nursery value, some points need to be qualified. High spatial variation in the juvenile response to habitat complexification is one of them. In fact, in certain locations the addition of artificial habitats seemed to have no effect (e.g. Area A), while in others they supported greater abundances (e.g. Areas B and C). This spatial variations might be linked to the one mentioned above for settlement. Comprehending the factors that may lead to successful settlement (larvae supply and juvenile survival) in urbanized ecosystems should be a priority in future studies in order to target rehabilitation efforts on the most appropriate sites. Undoubtedly, determining which parts of each port would benefit most from being equipped by AUE would help to increase the cost-efficiency of rehabilitation programs.

Additionally, we need a better understanding of the processes behind the higher abundances recorded on the AEU. This result could be explained by two hypotheses. AEU are designed to provide higher complexity habitats with appropriate cavity sizes, which could increase juvenile survival by providing more places for refuge and thereby limit predator induced mortality (Ammann, 2004; Bulleri and Chapman, 2010; Hixon, 1991; Vigliola et al., 1998). Nonetheless, the concentration of juveniles on the AEU could also be an explanation since hard complex structures are known to attract fish in a pelagic environment (Ammann, 2004). Similar to artificial reefs studies, determining the contribution of each process, production through reduced mortality on one hand and concentration through thigmotaxis on the other, is challenging but essential to evaluate the efficiency of these structures in their role as nurseries and in long-term fish population maintenance (Grossman et al., 1997). These questions could partly be answered through the study of growth rates on different habitats (AEU, dock, riprap, natural rocky habitats, etc.) by following size class evolution through time (Bouchoucha et al., 2016) or using otoliths.

The observed patterns were different for the three most abundant species found in the port suggesting taxa-specific variations in the responses to habitat complexification through the use of small artificial units. *D. annularis* showed the strongest positive answer to the presence of AEU with higher abundances in all areas. However, the individuals observed were young settlers, and following them over a longer period of time would have been interesting in order to know if this tendency remains until recruitment into the adult population. As mentioned above, the observation of this species on hard structures was surprising and raises new questions concerning its behavioral plasticity. The inconsistent response of *D. sargus* makes it hard to conclude on the efficiency of the method for this species. However, the absence of temporal variation in its abundance might imply that post-larvae settlement occurred outside the sampling window and that we missed the abundance peak usually observed during the settlement phase which occurs in June for this species (Crec'hriou et al., 2015). Also, younger (and so smaller) individuals are known to be strongly associated with their preferential sheltered habitat but they extend their territory as they grow bigger as they are less vulnerable to predation (Houde and Hoyt, 1987; Macpherson, 1998; Vigliola et al., 1998). This could explain the lack of a clear pattern in *D. sargus* habitat use, which might have been more distinct for earlier stages. Indeed, inside marinas, the youngest juveniles of this species have been found to have a stronger association to AEU than older life stages (Bouchoucha et al., 2016). *Symphodus* sp. were presents almost exclusively on area B's AEU, but more data is needed to be able to make accurate conclusions on the effect of the rehabilitation procedure on this taxon. The youngest individuals of this genus are hard to observe, even in natural habitats. An adaptation of the sampling procedure might be required for their study.

Usually, the goals of a restoration project are defined in regards to a reference, an ecosystem or a set of various attributes from different ecosystems, which would serve as target when planning and evaluating a restoration or rehabilitation program (Balaguer et al., 2014; SER, 2002). In this rehabilitation project, the objective was above all to give a nursery function to the port by complexifying habitat structure through the use of small artificial habitats. In order to test the effect of the artificial habitats on juvenile fish, we only compared our complex docks to the degraded state represented by bare featureless vertical docks. It was the original and novel aspect of this approach that was targeted, and this study represents the first step toward more integrated rehabilitation projects of port infrastructures. Forthcoming projects concerning nursery function rehabilitation should incorporate the study of nearby natural nursery grounds in order to evaluate the relative value of rehabilitated habitat and the efficiency of the tools and methods used.

5. Conclusion

Even though our study is lacking comparison with natural habitats and was conducted over a short period of time, our results demonstrate the clear role of the AEU to support juvenile fish through habitat complexification. Further studies would be useful to quantify the ecological gain provided by these infrastructures, and to gain a better understanding of the functioning of urbanized ecosystems in order to managed and restore them in the best possible way.

This kind of rehabilitation program is now possible thanks to the efforts by port managers to increase water quality by limiting all sorts of pollution (i.e. reject from boat fairing areas, gray and black water discharges, etc.). They also help to determine the presence and diversity of marine organisms within ports and marinas and are increasingly committed to the preservation of marine life. This is particularly true in the case of fish for which the improvement of survival and growth rates by means of good water conditions is seen as a way to sustain local fisheries. Recently, the French National Water Agency has integrated these kinds of actions into the French program proposal to the Marine Strategy Framework Directive, which should promote ecological restoration programs in coastal areas and particularly in ports, harbors and marinas.

Although eco-conception should be favored when building new structures or undertaking maintenance, the small artificial habitat approach can be used as a good complementary tool for existing hard coastal structures. Their potential should not be underestimated. Indeed, their easy installation and non-permanent character are more easily accepted by port managers and users and therefore might help to create good environmental dynamics or even to initiate bigger restoration projects.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2017.03.022.

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