Biological Conservation 219 (2018) 89–95

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Short communication

Promoting restoration of fish communities using artificial habitats in coastal marinas

Mohamed Selfati[a,b,c], Najib El Ouamari[b], Philippe Lenfant[c], Amélie Fontcuberta[d], Gilles Lecaillon[d], Abdelhakim Mesfioui[b], Pierre Boissery[e], Hocein Bazairi[a,*]

[a] Mohammed V University in Rabat, Faculty of Sciences, 4 Avenue Ibn Battouta, B.P. 1014 RP, 10000 Rabat, Morocco
[b] Institut National de Recherche Halieutique, 13, Bd Zerktouni, BP 493, Nador, Morocco
[c] CEFREM, UMR5110 CNRS/UPVD, Université de Perpignan, France
[d] ECOCEAN, 1342 avenue de Toulouse, 34070 Montpellier, France
[e] Agence de l'Eau, 62 Immeuble le Noaille, La canebière, 13002 Marseille, France

ARTICLE INFO

Keywords:
Marina
Biohut
Ecological restoration
Grouper
Marchica lagoon
Mediterranean

ABSTRACT

Rapid urbanization has become an area of crucial concern in conservation, owing to urban infrastructure impacts on natural ecosystems. Urban infrastructures are often poor surrogates for natural habitats, and a diversity of eco-engineering approaches has been trialed to enhance their ecological value.

Marinas are among the most common human-made infrastructures found on the shoreline, and cause substantial habitat destruction within the sheltered coastal areas previously used as nursery grounds by many fish species. The present study aimed at testing the suitability of installing artificial habitats (Biohut®) in marinas to reinforce the nursery function of the Marchica coastal lagoon, which historically hosts many species of juvenile groupers, including the endangered dusky grouper *Epinephelus marginatus*.

Our hypothesis – that artificial habitats, by increasing habitat complexity, enhance the ecological value of a marina – was strongly supported by our results. The Biohuts hosted a high relative density of juvenile dusky and comb groupers in comparison with natural habitats. They can, therefore, be considered as a reservoir for juvenile groupers, including the endangered dusky grouper, and are suitable to reinforce the nursery function of this coastal lagoon.

Subsequently, Biohuts can act as a ready-made nursery area to support the creation of small marine reserves that can reinforce the grouper population re-colonization along the coast of North Africa, which is considered to be the region from which the individuals populating the north western Mediterranean originated, and thus provide for long-term recovery of the endangered dusky grouper.

1. Introduction

Coastal regions are home to a large and growing proportion of the world's population. Over 70% of the world's largest cities are located within 100 km of the coast (Duarte et al. 2008). Of the many human activities presently contributing to habitat loss and species extinctions, urbanization is generally considered to have one of the greatest impacts across local to regional scales (Lotze et al. 2006; Grimm et al. 2008). Along urbanized coastlines, marine infrastructure is increasingly being constructed for a range of purposes, including coastal protection (e.g. seawalls, breakwaters, groynes), boating or recreational activities (e.g. marinas, piers, pontoons), supply of energy or resources (e.g. oil, gas platforms) and enhancement of fisheries yield (e.g. artificial reefs) (Strain et al. 2018). As a result, marine infrastructure impacts significantly on natural ecosystems in a variety of ways, including habitat loss and fragmentation, modification of ecological connectivity, ecosystem functioning and services, and the physico-chemical environment (Fischer and Lindenmayer 2007; McKinney 2008; LaPoint et al. 2015; Bishop et al. 2017).

Ecological restoration aims to return a system to a functional approximation of its pre-degraded state. One intent is "to establish a functional ecosystem of a designated type that contains sufficient biodiversity to continue its maturation by natural processes and to evolve over longer time spans in response to changing environmental conditions" (Clewell et al. 2000). Among many approaches, eco-engineering – the inclusion of ecological principles in the design of infrastructure to enhance its ecological value (Bergen et al. 2001) – can benefit terrestrial and marine environments alike (Chapman and Underwood 2011;

* Corresponding author.
E-mail address: bazairi@fsr.ac.ma (H. Bazairi).

https://doi.org/10.1016/j.biocon.2018.01.013
Received 15 February 2017; Received in revised form 3 January 2018; Accepted 12 January 2018

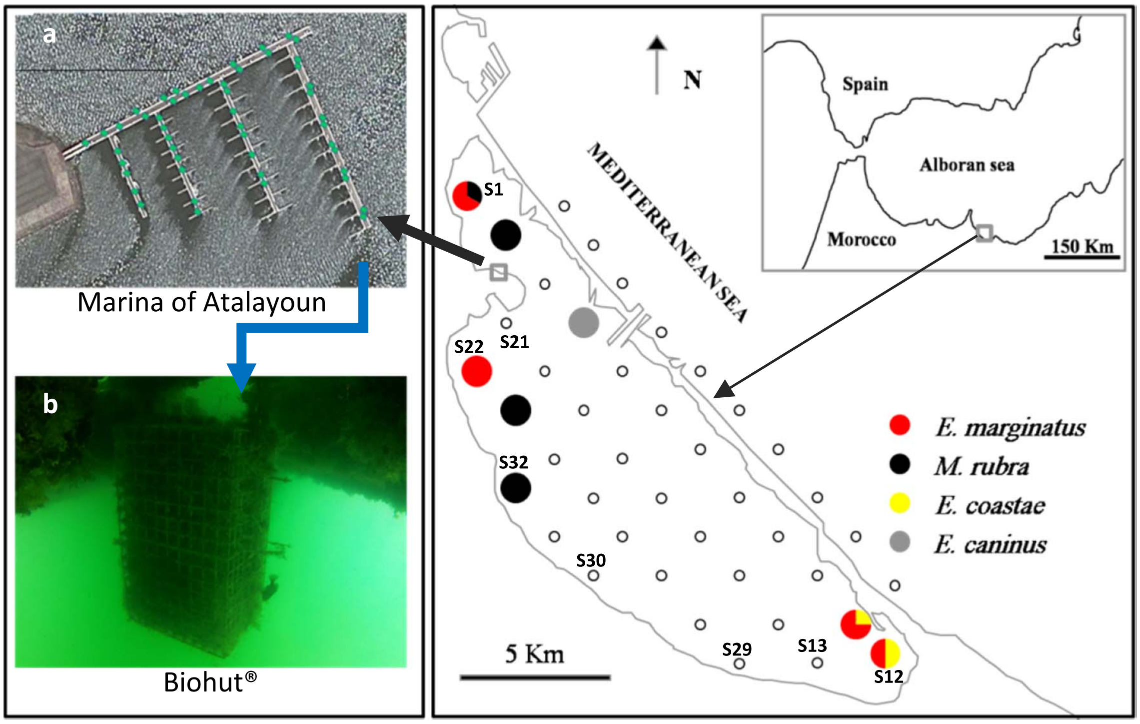

Fig. 1. Map showing the network of experimental fishing stations and the Biohuts installations. (a) Marina of Atalayoun; underwater visual counting area. (b) Pontoon on a Biohut cage fixed under a floating pontoon.

Francis and Lorimer 2011). In this context, as artificial structures are often poor surrogates for natural habitats, a diversity of eco-engineering approaches has been trialed to enhance their biodiversity, with varying success (Strain et al. 2018).

Marinas are among the most common human-made marine infrastructures, and can cause substantial habitat destruction within sheltered coastal areas previously used as nursery grounds by many fish species (Bouchoucha et al. 2016). Therefore, the need to reduce the impact of these infrastructures and even to enhance their ecological value is becoming urgent as their number is predicted to increase worldwide. Recently, the deployment of artificial microhabitats (Biohuts) (Fig. 1a) in marinas and ports (Bouchoucha et al. 2016; Mercader et al. 2017) as an ecological restoration action aiming at restoring the nursery function through habitat complexification, revealed that such artificial habitats enhance the diversity and density of juvenile fish by providing shelter from predators, thereby boosting the marina's and/or port's nursery value.

Nearshore ecosystems, such as coastal lagoons, are areas of high productivity (Duarte and Chiscano 1999) that support a range of natural services and functions highly valued by society (Gönenç and Wolflin 2005), including their role as nurseries. The present study aimed at testing, for the first time, the suitability of installing artificial habitats in marinas to reinforce the nursery function of a coastal lagoon. The study site is the Marchica Lagoon, which is unique in the Mediterranean for historically hosting many species of groupers, including the endangered dusky grouper (Lozano Cabo 1953; Aloncle 1961; Pérez-Ruzafa et al. 2007). The choice of the Marchica lagoon is supported by the fact that (1) it's the only lagoon on the Mediterranean coast of Morocco and (2) artificial habitats (Biohuts) were recently installed into a Marina built inside the lagoon. We hypothesized that increasing habitat complexity in the marina would enhance the diversity (Browne and Chapman 2011, 2014) and population density of juvenile groupers by providing shelter from predators (Bulleri and Chapman 2010), thereby boosting the lagoon's nursery value (Beck et al. 2001) and promoting its role in conservation of endangered groupers.

2. Materials and methods

2.1. Study site

The Marchica lagoon, also called the lagoon of Nador, is the second largest (115 km^2, 25 km long and 7.5 km wide) lagoon in northern Africa and the only coastal lagoon on the Mediterranean coast of Morocco (Fig. 1). The lagoon has a maximum depth of approximately 8 m and is separated from the Mediterranean Sea by a 25 km long sandbar. This sandbar is crossed by one artificial opening (300 m wide and 6 m deep) that ensures the renewal of water.

In addition to its ecological (Site of Biological and Ecological Interest since 1996; Ramsar Site since 2005) and socio-economic value (mainly artisanal fisheries), the lagoon is under pressure from a complex mixture of human-mediated stressors (increasing urbanization through multiple tourism projects around the lagoon, pollution by local uncontrolled fecal water effluents, urban discharges, sewage from a water treatment station, and slaughterhouse residues, etc.) (Ruiz et al. 2006).

2.2. Key features of groupers

Groupers (Pisces: Serranidae, subfamily Epinephelinae) are important top level predators both in temperate and tropical waters, where they play an important role in maintaining the ecological balance of marine ecosystems (Goeden 1982; Parrish 1987). Eleven species are known in the Mediterranean and belong mainly to the *Epinephelus* and *Mycteropera* genera. Most groupers are protogynous hermaphrodites. Individuals typically begin their reproductive life as females but change to males with age. Sex reversal seems to occur when individuals are 9–16 years old and about 60–90 cm long (total length) (Bruslé and Bruslé 1975, 1976; Chauvet 1988; Bruslé 1995). Large individuals are exclusively male and can measure up to 120 cm long and weigh up to

40 kg. Smaller individuals are females and their initial sexual maturity is reached when they are 5 years old and 40 to 50 cm long (Chauvet 1988). Current knowledge suggests groupers are secretive fish, inhabiting preferentially shelter-rich sites with littoral rocky bottoms (Smith 1961; Heemstra and Randall 1993). Juveniles are more frequently associated with nearshore habitats while adults and larger juveniles prefer deeper waters (Thompson and Munro 1978; Derbal and Kara 1995; Francour and Ganteaume 1999; Harmelin and Harmelin-Vivien 1999; Harmelin and Robert 2001).

Groupers from the Mediterranean are not fully documented. The dusky grouper (*Epinephelus marginatus*) is one of the most important flagship species of Mediterranean rocky coastal habitats. It is the target of many artisanal and sport fishing activities as well as recreational scuba or free diving. The highest densities of the dusky grouper occur on the north and north western coasts of Africa, from Tunisia to Senegal (Chauvet 1987). Reputed to be sedentary and territorial, *E. marginatus* favors rocky coastal bottoms that offer plenty of shelter (Harmelin and Robert 1992). The dusky grouper was considered to be fairly common in the Mediterranean, but because of spear-fishing, uncontrolled diving, poaching, overfishing and to a lesser extent pollution, it has become scarce on the north western coasts of the Mediterranean. Other still unidentified factors may also contribute to the decline in numbers. In addition, until recent years, the dusky grouper appeared to breed only south of a line running from Barcelona to Naples, in particular along the coast of North Africa, which is considered to be the region from which the individuals populating the north western Mediterranean originated (Chauvet and Francour 1990).

Due to the benefits resulting from environmental protection, in some marine protected areas, grouper populations became abundant and well structured (Chauvet et al. 1991; Harmelin et al. 1995; Zabala et al. 1997; Reñones et al. 1999; Chiappone et al. 2000). However, the MPA network was considered insufficient to maintain connectivity at the Mediterranean scale by the larval dispersal mechanism (Andrello et al. 2013), particularly in the North African Mediterranean, the preferential distribution area for dusky grouper (Chauvet 1987), where MPAs are less numerous. Such a south–north recruitment of dusky grouper has been previously suggested (Bodilis et al. 2003).

2.3. Data collection

Within the framework of a management project in the lagoon, 50 micro-artificial habitats, provided by the Ecocean® company (Pontoon Biohuts), were installed in the Atalayoun Marina in June 2014 (Figs. 1 and 2). To evaluate the efficacy of these artificial habitats, data on grouper species were collected based on experimental fishing and an underwater visual census of artificial habitats (Biohuts) installed in the Atalayoun Marina (Fig. 1).

Experimental fishing was conducted during June 2015, and the sampling design of this survey was based on a total of 32 fishing stations inside the lagoon and 10 stations in the adjacent marine waters (Fig. 1). The fishing gear was a purse seine (110 m in total length, 11 m in height and 6 mm as mesh size) targeting juveniles and adults of both pelagic and demersal/benthic species. The sampling effort was similar at all stations (UE = 2385 m^2), and the data collected can be considered as quantitative. All the individuals sampled were measured for total length (mm) and biomass (g of Fresh weight). The abundance was expressed as the number of individuals collected per fishing station.

The Biohuts are composed of 3 interconnected cages of stainless steel measuring 50 × 80 × 34 cm: the central cage has a 2.5 cm mesh and is filled with bivalve shells to promote colonization by benthic fauna and flora, as well as to increase the structure complexity. The two lateral cages, which surround the central one, have a 5 cm mesh and are left empty; the use of a larger mesh allows juvenile fish to enter and exit easily and offers a predator-free zone (Fig. 2). The Biohuts were suspended under floating pontoons between the surface of the water and 1 m depth by polyurethane ropes to provide a total vertical surface of ca. 4 m^2. They were all surveyed during June 2015, adopting a standardized visual counting protocol that is applied in 23 Mediterranean harbors in the framework of a monitoring network of fish recruitment, RESPIRE (www.medtrix.fr). This protocol is particularly appropriate in restricted areas with homogeneous habitats (Bohnsack and Bannerot 1986; Clynick 2008; La Mesa et al. 2011) and consists of an underwater visual census based on stationary point count. During the operation, which took 3 min per Biohut, the groupers were discriminated according to the morphological and size criteria given in FishBase (Froese and Pauly 2014) and counted, along with other species that interact with Biohuts. When in situ identification was difficult, pictures and videos of individuals were taken and interpreted onshore, with the assistance of expert underwater visual census divers.

3. Results

Overall, the experimental fishing survey in the natural habitats inside the Marchica lagoon reported the presence of four grouper species (Figs. 3 and 4). These are the dusky grouper (*Epinephelus marginatus* (Lowe, 1834)), the goldblotch grouper (*E. costae* (Steindachner, 1878)), the dogtooth grouper (*E. caninus* (Valenciennes, 1843)) and the mottled grouper (*Mycteroperca rubra* (Bloch, 1793)). However, no grouper species was captured in the adjacent marine waters surveyed outside the lagoon.

Sixteen individuals of the four species of groupers were captured inside the lagoon; seven dusky groupers, having an average size (AS) of 138.71 ± 5.87 mm and an average weight (AW) of 50.78 ± 3.66 g, five comb groupers, having an AS = 188.2 ± 8.03 mm and AW = 96.67 ± 17.71 g, three goldblotch groupers, with AS = 174.33 ± 8.57 mm and AW = 86.69 ± 11.04 g, and one dogtooth grouper having an estimated total length lower than 200 mm (specimen not measured and not photographed). All the groupers were juveniles, not mature individuals.

Of the 32 stations sampled inside the lagoon, groupers were present in 8 of them; two sandy-mud vegetated stations (dominance of *Caulerpa prolifera* and *Cymodocea nodosa*) both in the extreme NW (S1, S2), and in the extreme SE (S11, S12), the unvegetated sandy station nearest the pass (S4), and the three vegetated (dominance of *C. prolifera*) sandy-mud to muddy near-inland stations (S22, S23, S32) located in front of Nador city (Fig. 1).

In the Atalayoun Marina, which represents less than 0.1% of the lagoon's total area, 62 juvenile groupers were counted during June 5th, 2015, in/on the artificial microhabitats (Biohuts). These were 34 comb groupers (*M. rubra* (Bloch, 1793)) and 28 dusky groupers (*E. marginatus* (Lowe, 1834)) (Fig. 4). Their sizes were comparable to those of species caught in the natural habitats.

The groupers cohabit in Biohuts with at least five other species: three Sparidae (*Diplodus Sargus sargus*, *Diplodus cervinus cervinus* and *Sarpa salpa*), the European seabass (*Dicentrarchus labrax*) and the Mugillidae spp. The mean abundance was about 3 ± 2/4 m^2 with a net dominance of Mugillidae species. Our data, based on a unique sampling survey, do not allow exploring deeply interspecific competition for these habitats between groupers and the other species using the Biohuts.

4. Discussion

The artificial habitats (Biohuts) installed in the marina hosted a high relative density of juvenile dusky and comb groupers in comparison with natural habitats (Fig. 4). Our hypothesis – that Biohuts, by increasing habitat complexity, enhance the ecological value of a marina – was strongly supported by our results. Biohuts can, therefore, be considered as a reservoir for groupers, including the endangered dusky grouper, and are suitable for reinforcing the nursery function of this coastal lagoon. In addition, they can act as a ready-made nursery area to support the creation of small marine reserves that can provide for the

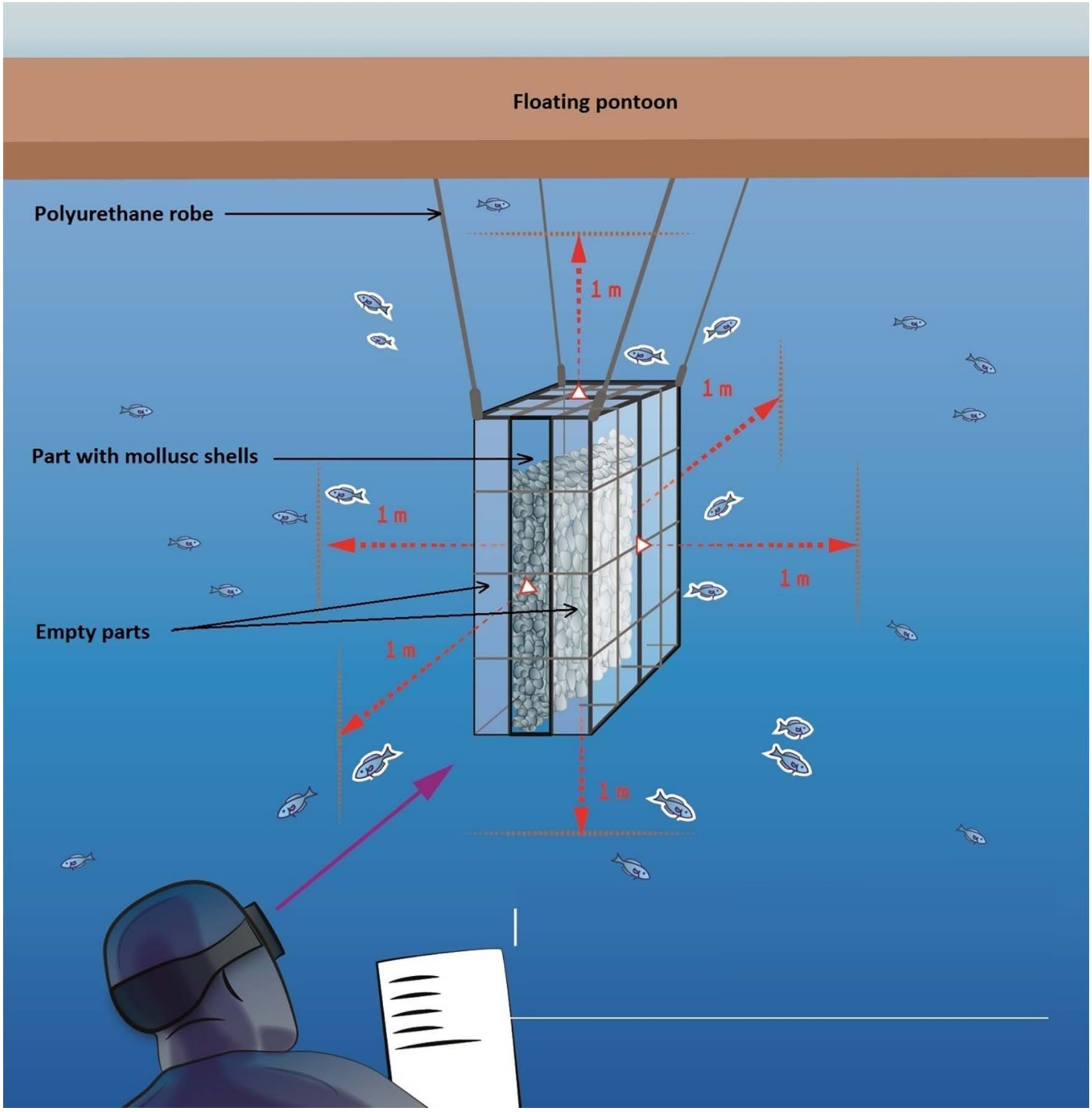

Fig. 2. Biohut and illustration of the underwater visual counting protocol.

long-term recovery of some endangered species (Afonso et al. 2011).

Until now, Biohuts were deployed only in open-sea ports and marinas (Bouchoucha et al. 2016; Mercader et al. 2016, 2017) as an ecological restoration action aiming at restoring the nursery function and thereby boosting the marina and port's nursery value. Artificial habitats in marine ecosystems are employed on a limited basis to restore degraded natural habitats and fisheries, and more extensively for a broader variety of purposes including biological conservation and enhancement as well as social and economic development (Seaman 2007).

Despite the survey efforts and methods for natural (32 purse seines, ~76,000 m^2) and artificial habitats (visual census, 50 × 4m^2) being vastly different, Biohuts seemed to show higher grouper density. Although the abundance of groupers could partially result from the marina's attractive effect (Coleman and Connell 2001; Moreau et al. 2008), adding additional structures as mitigation for the loss of coastal habitats could provide a significant source of hard habitats available to fishes, especially for species with demanding habitat requirements such as groupers (La Mesa et al. 2002). The availability of shelter is an important factor determining microhabitat suitability for juvenile groupers (La Mesa et al. 2002). In our case, the shelter opportunities provided by Biohuts are better than those offered by the mainly vegetated soft natural habitats. This is in accordance with La Mesa et al. (2006) suggesting that shelter opportunities provided by small cavities and crevices should be better than those offered by a dense algal coverage. In this context, the habitat choice of tropical groupers seems to be more strictly related to the need for shelter than for food (Parrish 1987). Moreover, in the Virgin Islands, a higher recruitment success for Nassau grouper (*E. striatus*) on small artificial reefs than on natural substrates was revealed (Beets and Hixon 1994). Finally, average abundances of *Diplodus* juveniles on added Biohut habitats in marinas were twice as high as on nearby bare surfaces (Bouchoucha et al. 2016).

The efficacy of eco-engineering interventions for enhancing the ecological value of urban infrastructures is likely to vary across environments as well as the spatial and temporal scales of the intervention (Strain et al. 2018). Here, the efficiency of the Biohuts to host juvenile groupers seems to be site-dependent. Indeed, the Marchica lagoon is the only Mediterranean coastal lagoon that shelters many species of groupers (Pérez-Ruzafa et al. 2007). Among the 11 species of groupers known in the Mediterranean, eight species have been recorded in the western Mediterranean (Marginatus 2011; Bariche and Heemstra 2012), of which five have been recorded in the Marchica coastal lagoon, namely *Epinephelus aeneus* (Aloncle 1961), *Mycteroperca rubra* (Lozano

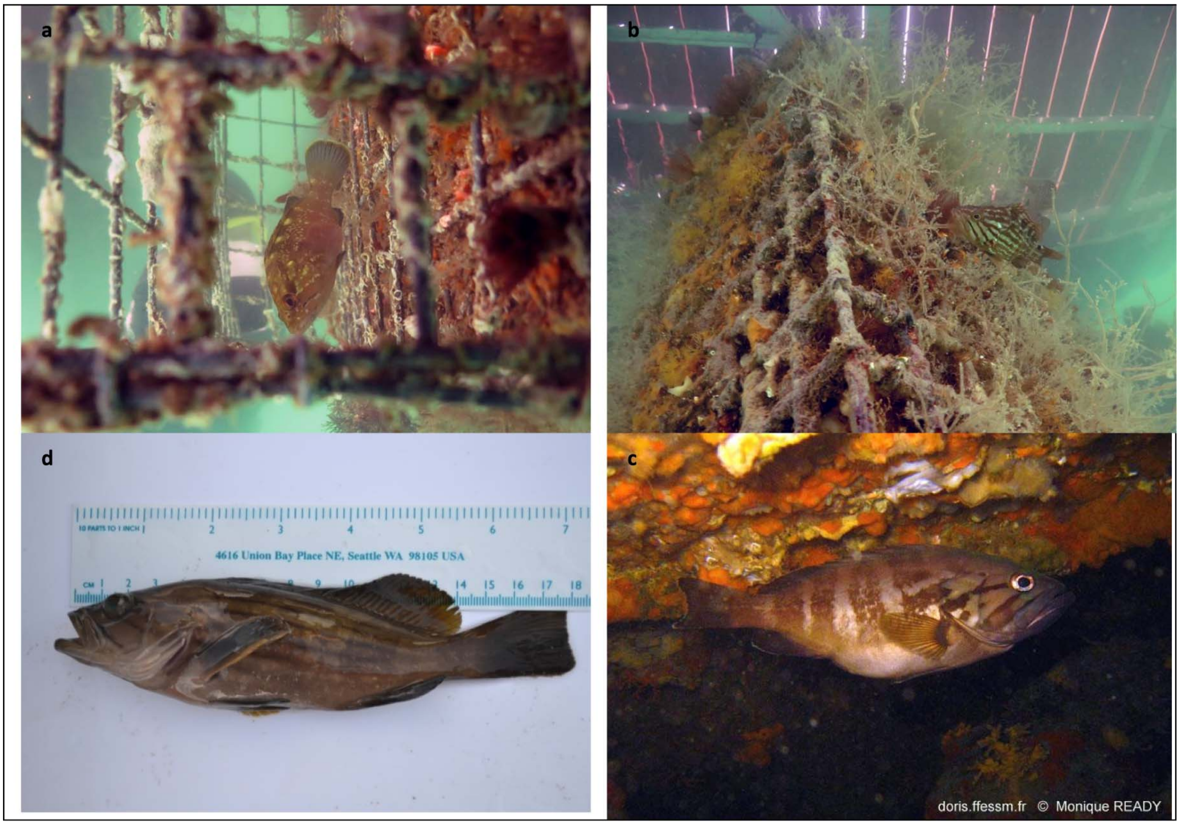

Fig. 3. Photos of the grouper species observed in the Marchica lagoon. (a) *Epinephelus marginatus*, (b) *Mycteroperca rubra*, (c) *Epinephelus caninus* and (d) *Epinephelus costae*.

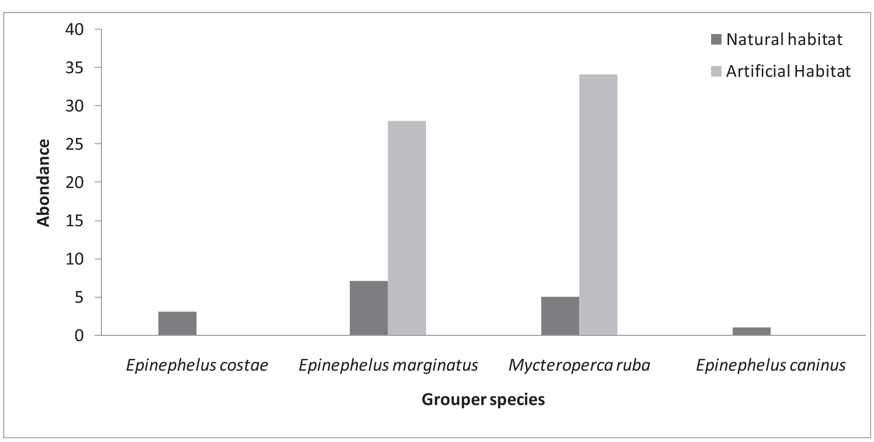

Fig. 4. Total abundance of groupers in the artificial (visual census, 50 x 4m^2) and natural habitats (32 purse seines, ~76,000 m^2) in the Marchica lagoon.

Cabo 1953; Aloncle 1961), *Epinephelus marginatus* (Lozano Cabo 1953; Aloncle 1961), *Epinephelus costae* (this study) and *E. caninus* (this study). The two latter species were recorded here for the first time in the Marchica lagoon. Moreover, in this study, all the groupers have a length not exceeding 20 cm and are all immature individuals, suggesting that the lagoon act as a nursery. This is a second unique attribute of this site. The presence of several grouper species at the juvenile stage suggests a high potential nursery function in this lagoon. Therefore, the Moroccan Mediterranean coast can play a key role in the population dynamics of groupers at the western Mediterranean Sea scale. Recent data evidenced the dual arrival routes of dusky groupers along the French coast from Tunisia in the eastern Mediterranean and from Morocco in the western Mediterranean (Bodilis et al. 2003). In the context of climate change, increasing temperatures can partly explain this settlement success in Northern Mediterranean. Recent observations in the presumed coldest zone (Lion Gulf) seem to confirm this hypothesis (Mercader et al. 2016).

Since the creation of the Grouper Study Group (GEM - Groupe d'Étude du Mérou: Non-Governmental Organization which brings together a global community of biologists, photographers, journalists, divers, underwater fishermen and managers) in 1986, and the listing of some grouper species on the International Union for the Conservation of Nature (IUCN) Red List, there has been abundant scientific work done on the biology and ecology of grouper species. This research and its resulting knowledge is essential for the implementation of effective actions with regard to the management and preservation of groupers especially the dusky grouper *E. marginatus.* The dusky grouper was included in several International Conventions (Berne Convention, Annex3; Barcelona Convention, Protocol for Mediterranean Biodiversity, Annex3) and was listed as endangered by the IUCN (classified as "ENA2d", i.e., a taxon currently facing a very high risk of extinction in the wild as a consequence of its over-exploitation in most Mediterranean countries) in 1996 and by the European Centre for Nature Conservation (ECNC, 1998) (De Almeida Rodrigues Filho et al. 2009). The most common actions are legislative tools and the creation of marine reserves. Indeed, MPAs have proven to be an efficient tool for grouper conservation (Zabala et al. 1997; Guidetti and Sala 2007; Di Franco et al. 2009). The few long term surveys conducted in Mediterranean MPAs, such as at Port-Cros (Harmelin and Robert 2001; Harmelin 2013), the marine reserve of Cerbère-Banyuls (Lenfant et al. 2003) and on the Maures coast (Cottalorda et al. 2013), indicate an increase in dusky grouper abundance. However, juvenile grouper settlement is less important in these areas (e.g. 12 immature dusky groupers (*Epinephelus marginatus)* were observed in 2001 along 7 km of coast line in the marine reserve of Cerbère-Banyuls – France, North-Western Mediterranean Sea) (Lenfant et al. 2003) than in the Marchica lagoon, where exceptional levels of settlement occur, especially in Biohuts.

Subsequently, to reinforce the role of MPAs in grouper population re-colonization, it is crucial to consider all the habitats frequented, such as the shallow rocky bottoms and, in our case, the Marchica lagoon, which sheltered the juvenile stages during their development. The recent development of marine ecological restoration, among other actions, has led to the deployment of artificial microhabitats (Biohuts) with the aim of restoring nursery function through habitat complexification. The first deployments have been undertaken in marinas (Bouchoucha et al. 2016) and commercial ports (Mercader et al. 2017). Our study showed that the Biohuts hosted a high concentration of juvenile dusky and comb groupers in comparison with natural habitats (Fig. 4). Similar numbers of very young juveniles were recorded in the same year in Biohuts placed in marinas and ports and in a natural nursery on French Mediterranean coasts (Mercader et al. 2016). Dusky grouper juveniles observed in marinas and ports demonstrate opportunistic behaviors, which could be similar in lagoons. Biohuts can be considered as a reservoir for the emblematic dusky grouper and are suitable to reinforce the nursery function of this coastal lagoon. In addition, they can act as a support in the creation of small marine reserves that can provide for the long-term recovery of some endangered species (Afonso et al. 2011).

Ultimately, human populations on coastlines will continue to increase, with concomitant coastal construction projects and their associated negative ecological impacts. Marine facilities should be carefully planned, and eco-engineering principles should be combined with ecological processes to create more environmentally-friendly urban environments (Chapman and Underwood 2011), thereby reducing environmental impacts (Pastro et al. 2017).

Acknowledgements

This work was undertaken in the framework of an international cooperation between Le Conservatoire du Littoral, Agence de l'Eau Rhône-Méditerranée-Corse, the Ecocean Society, University Mohammed V in Rabat, Institut National de Recherche Halieutique, Observatoire de la Marchica and Fondation Mohammed VI pour l'Environnement. Mohamed Selfati would like to thank the Agence de l'Eau Rhône Méditerranée Corse and the Ecocean Society for their financial support. The authors are also grateful to the local artisanal fishermen for their help in the field work. The authors are very grateful to two anonymous reviewers as well as to Associate Editor Amanda Bates for their kind and helpful contributions. Many thanks to Mike Reed, who kindly corrected and improved the English of the manuscript.

References

Afonso, P., Fontes, J., Santos, R.S., 2011. Small marine reserves can offer long term protection to an endangered fish. Biol. Conserv. 144, 2739–2744.
Aloncle, H., 1961. La pêche dans la "Mar Chica" de Mellila. Bull. Inst. Pêches Marit. Maroc. 7, 13–32.
Andrello, M., Mouillot, D., Beuvier, J., Albouy, C., Thuiller, W., et al., 2013. Low connectivity between Mediterranean marine protected areas: a biophysical modeling approach for the dusky grouper Epinephelus marginatus. PLoS One 8 (7), e68564. http://dx.doi.org/10.1371/journal.pone.0068564.
Bariche, M., Heemstra, P., 2012. First record of the blacktip grouper Epinephelus fasciatus (Teleostei: Serranidae) in the Mediterranean Sea. In: Marine Biodiversity Records, Page 1 of 3. vol. 5 Marine Biological Association of the United Kingdom (Published online).
Beck, M.W., Heck Jr., K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoschino, K., Minello, T.J., Orth, R.J., Scheridan, P.F., Weinstein, M.P., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633–641.
Beets, J., Hixon, M.A., 1994. Distribution, persistence, and growth of groupers (Pisces: Serranidae) on artificial and natural patch reefs in the Virgin Islands. Bull. Mar. Sci. 55 (2–3), 470–483.
Bergen, S.D., Bolton, S.M., Fridley, J.L., 2001. Design principles for ecological engineering. Ecol. Eng. 18, 201–210.
Bishop, M.J., Mayer-Pinto, M., Airoldi, L., Firth, L.B., Morris, R.L., Loke, L.H.L., Hawkins, S.J., Naylor, L.A., Coleman, R.A., Chee, S.Y., Dafforn, K.A., 2017. Effects of ocean sprawl on ecological connectivity: impacts and solutions. J. Exp. Mar. Biol. Ecol. 492, 7–30.
Bodilis, P., Ganteaume, A., Francour, P., 2003. Recruitment of the dusky grouper (Epinephelus marginatus) in the Northwestern Mediterranean Sea. Cybium 27 (2), 123–129.
Bohnsack, J., Bannerot, S.P., 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. In: Technical Report 41. NOAA.
Bouchoucha, M., Darnaude, A.M., Gudefin, A., Neveu, Verdoit-Jarraya, R.M., Boissery, P., Lenfant, P., 2016. Potential use of marinas as nursery grounds byrocky fishes: insights from four Diplodusspecies in the Mediterranean. Mar. Ecol. Prog. Ser. 547, 193–209.
Browne, M.A., Chapman, M.G., 2011. Ecologically informed engineering reduces loss of intertidal biodiversity on artificial shorelines. Environ. Sci. Technol. 45, 8204–8207.
Browne, M.A., Chapman, M.G., 2014. Mitigating against the loss of species by adding artificial intertidal pools to existing seawalls. Mar. Ecol. Prog. Ser. 497, 119–129.
Bruslé, J., 1995. Synopsis, of biological data on the groupers Epinephelus aeneus (Geoffrey Saint Hilaire, 1809) and Epinephelus guaza (Linnaeus, 1758) of the Atlantic Ocean and Mediterranean Sea. FAO Fish. Synop. 129, 1–69.
Bruslé, J., Bruslé, S., 1975. Ovarian and testicular intersexuality in two protogynous Mediterranean groupers, Epinephelus aeneusand Epinephelus guaza. In: Reinboth, R. (Ed.), Intersexuality in the Animal Kingdom. Springer-Verlag, Berlin, pp. 222–227.
Bruslé, J., Bruslé, S., 1976. Contribution àl'étude de la reproduction de deux espèces de mérous (Epinephelus aeneus et Epinephelus guaza) des cotes de Tunisie. In: Revue des Travaux de l'Institut de Péches Maritimes de Nantes, 39, No. 3, pp. 313–320.
Bulleri, F., Chapman, M.G., 2010. The introduction of coastal infrastructure as a driver of change in marine environments. J. Appl. Ecol. 47, 26–35.
Chapman, M.G., Underwood, A.J., 2011. Evaluation of ecological engineering of "armoured" shorelines to improve their value as habitat. J. Exp. Mar. Biol. Ecol. 400, 302–313.
Chauvet, C., 1987. Croissance et sexualité du mérou: l'avis d'un scientifique. In: Apnea No. 10, pp. 8–9.
Chauvet, C., 1988. Etude de la croissance du mérou *Epinephelus guaza* (Linné, 1758) des cotes tunisiennes. Aquat. Living Resour. 1 (4), 277–288.
Chauvet, C., Francour, P., 1990. Les mérous *Epinephelus guaza* du parc national dePort-Cros (France) Aspects socio-démographiques. Bull. Soc. Zool. Fr. 114 (4), 5–13.
Chauvet, C., Barnabé, G., Bayle Sempere, J., Bianconi, C.H., Binche, J.L., Francour, P., Garcia-Rubies, A., Harmelin, J.G., Miniconi, R., Pais, A., Robert, P., 1991. Recensement du mérou *Epinephelus guaza* (Linnaeus, 1758) dans les réserves et parcs marins des côtes méditerranéennes françaises. In: Boudouresque, C.F., Avon, M., Gravez, V. (Eds.), Les Espèces marines à Protéger en Méditerranée. GIS Posidonie Publication, Marseille, pp. 277–290.
Chiappone, M., Sluka, R.D., Sealey, K.S., 2000. Groupers (Pisces: Serranidae) in fished and protected areas of the Florida Keys, Bahamas and northern Caribbean. Mar. Ecol. Prog. Ser. 198, 261–272.
Clewell, A.F., Rieger, J., Munro, J., 2000. Guidelines for developing and managing ecological restoration projects. In: Publications Working Group. Society for Ecological Restoration.
Clynick, B.G., 2008. Characteristics of an urban fish assemblage: distribution of fish associated with coastal marinas. Mar. Environ. Res. 65, 18 − 33.
Coleman, M.A., Connell, S.D., 2001. Weak effects of epibiota on the abundances of fishes associated with pier pilings in Sydney Harbour. Environ. Biol. Fish 61 (3), 231–239.
Cottalorda, J.M., Seytre, C., Casalta, B., André, M., Francour, P., 2013. Seconde mission d'inventaire du peuplement de mérou brun Epinephelus marginatus sur le littoral des Maures. Mission du 28 au 30 septembre 2012. In: Rapport et Convention Groupe d'Etude du Mérou & Observatoire marin du littoral des Maures. GEM, Université Nice Sophia Antipolis et EA 4228 ECOMERS publ, pp. 1–36.
De Almeida Rodrigues Filho, J., Gomes Sanches, E., De Oliveira Garcia, C.E., Vianna Pannutti, C., Figueiredo Sebastiani, E., Guimaraes Moreira, R., 2009. Threatened fishes of the world: Epinephelus marginatus (Lowe:1834) (Serranidea: Epinephelus). Environ. Biol. Fish 85 (4), 301–302.
Derbal, F., Kara, M.h., 1995. habitat et comportement du mérou Epinephelus

marginatusdans la région d'annaba (algérie). Cah. Biol. Mar. 36, 29–32.
Di Franco, A., Milazzo, M., Baiata, P., Tomasello, A., Chemello, R., 2009. Scuba diver behaviour and its effects on the biota of a Mediterranean marine protected area. Environ. Conserv. 36 (1), 32–40.
Duarte, C.M., Chiscano, C.L., 1999. Seagrass biomass and production: a reassessment. Aquat. Bot. 65, 159–174.
Duarte, C.M., Dennison, W.C., Orth, R.J., Carruthers, T.J., 2008. The charisma of coastal ecosystems: addressing the imbalance. Estuar. Coasts 31, 233–238.
Fischer, J., Lindenmayer, D.B., 2007. Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265–280.
Francis, R.A., Lorimer, J., 2011. Urban reconciliation ecology: the potential of living roofs and walls. J. Environ. Manag. 92, 1429–1437.
Francour, P., Ganteaume, A., 1999. L'arrivée progressive de jeunes mérous (*Epinephelus marginatus*) en Méditerranée nord-occidentale. Mar. Life 9, 37–45.
Froese, R., Pauly, D., 2014. FishBase. Available at. www.fishbase.org.
Goeden, G.B., 1982. Intensive fishing and “keystone” predator species: ingredients for community instability. Biol. Conserv. 22, 273–281.
Gönenç, I.E., Wolflin, J.P., 2005. Coastal lagoons. In: Ecosystem Processes and Modeling for Sustainable Use and Development. Boca Raton, London New York Washington.
Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M., 2008. Global change and the ecology of cities. Science 319, 756–760.
Guidetti, P., Sala, E., 2007. Community-wide effects of marine reserves in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 335, 43–56.
Harmelin, J.G., 2013. Le mérou brun et le corb: deux Grands Témoins de 50 ans de protection du milieu marin dans le Parc national de Port-Cros (France, Méditerranée). Sci. Repts of Port-Cros natl Park, Fr. 27, 263–278.
Harmelin, J.G., Harmelin-Vivien, M., 1999. A review on habitat, diet and growth of the dusky grouper, Epinephelus marginatus(Lowe, 1834). Mar. Life 9, 11–20.
Harmelin, H.G., Robert, P., 1992. Mérou brun. Ses origines, sa vie, sa protection. Océanorama 18, 3–7.
Harmelin, J.G., Robert, P., 2001. Evolution récente de la population du mérou brun (Epinephelus marginatus) dans le Parc national de Port-Cros (France, Méditerranée). Sci. Rep. Port-Cros Natl Park, Fr. 18, 149–161.
Harmelin, J.G., Bachet, F., Garcia, F., 1995. Mediterranean marine reserve: fish indices as tests of protection efficiency. Mar. Ecol. 16, 233–250.
Heemstra, P.C., Randall, J.E., 1993. Groupers of the world (Family serranidae, subfamily epinephelinae). In: An Annotated and Illustrated Catalogue of the Grouper, Rockcod, Hind, Coral Grouper and Lyretail Species Known to Date. FAO Fish. Synop., 125, 382 p. FAO, Rome.
La Mesa, G., Louisy, P., Vacchi, M., 2002. Assessment of microhabitat preferences in juvenile dusky grouper (Epinephelusmarginatus) by visual sampling. Mar. Biol. 140, 175.
La Mesa, G., Di Muccio, S., Vacchi, M., 2006. Abundance, size distribution and habitat preferences in the grouper assemblage of the Ustica marine reserve (SW Mediterranean). Cybium 30 (4), 365–377.
La Mesa, G., Molinari, A., Gambaccini, S., Tunesi, L., 2011. Spatial pattern of coastal fish assemblages in different habitats in north-western Mediterranean. Mar. Ecol. 32, 104 − 114.
LaPoint, S., Balkenhol, N., Hale, J., Sadler, J., Ree, R., 2015. Ecological connectivity research in urban areas. Funct. Ecol. 29, 868–878.
Lenfant, P., Louisy, P., Licari, M.L., 2003. Recensement des mérous bruns (Epinephelus marginatus) de la réserve naturelle de Cerbère-Banyuls (France, Méditerranée) effectué en septembre 2001, après 17 années de protection. Cybium 27, 27–36.
Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312, 1806–1809.
Lozano Cabo, F., 1953. Notas sobre una campana de prospeccion pesquera en la Mar Chica de Melilla. In: Boletin del Instituto Espucol de Oceanografia. NO 64, Madrid.
Marginatus, 2011. Journal annuel du Groupe d'Etude du Mérou (www.gemlemerou.org), n° 11. pp. 1–8.
McKinney, M.L., 2008. Effects of urbanization on species richness: a review of plants and animals. J. Urban Econ. 11, 161–176.
Mercader, M., Foncuberta, A., Mercière, A., Saragoni, G., Boissery, P., Bérenger, L., Dubas, R., Lecaillon, G., Pastor, J., Lenfant, P., 2016. Observation of juvenile dusky groupers (*Epinephelus marginatus*) in artificial habitats of North-Western Mediterranean harbors. In: Marine Biodiversity. Oceanarium, pp. 1–2. http://dx.doi.org/10.1007/s12526-016-0498-x.
Mercader, M., Mercière, A., Saragoni, G., Cheminée, A., Crec'hriou, R., Pastor, J., Rider, M., Dubas, R., Lecaillon, G., Boissery, P., Lenfant, P., 2017. Small artificial habitats to enhance the nursery function for juvenile fish in a large commercial port of the Mediterranean. Ecol. Eng. 105, 78–86 (ISSN 0925-8574).
Moreau, S., Peron, C., Pitt, K.A., Connolly, R.M., Lee, S.Y., Méziane, T., 2008. Opportunistic predation by small fishes on epibiota of jetty pilings in urban waterways. J. Fish Biol. 72 (1), 205–217.
Parrish, J.D., 1987. The trophic biology of snappers and groupers. In: Polovina, J.J., Ralston, S. (Eds.), Tropical Snappers and Groupers: Biology and Fisheries Management. Westview Press, Boulder, Colorado, pp. 405–463.
Pastro, G., Dias, G.M., Pereira-Filho, G.H., Gibran, F.Z., 2017. The consequences of small-scale variations in habitat conditions driven by a floating marina on reef fish assemblages of SE Brazil. Ocean Coast. Manag. 141, 98–106.
Pérez-Ruzafa, A., Mompeán, M.C., Marcos, C., 2007. Hydrographic, geomorphologic and fish assemblage relationships in coastal lagoons. Hydrobiologia 577, 107–125.
Reñones, O., Goñi, R., Pozo, M., Deudero, S., Moranta, J., 1999. Effects of protection on the demographic structure and abundance of Epinephelus marginatus(Lowe, 1834). Evidence from Cabrera Archipelago National Park (West-Central Mediterranean). Mar. Life 9, 45–53.
Ruiz, F., Abad, M., Olías, M., Galán, E., González, I., Aguilá, E., Hamoumi, N., Pulido, I., Cantano, M., 2006. The present environmental scenario of the Nador Lagoon (Morocco). Environ. Res. 102, 215–229.
Seaman, W., 2007. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia 580, 143e155.
Smith, C.L., 1961. Synopsis of biological data on groupers (Epinephelusand allied genera) of the Western North atlantic. In: FAO Fish. Biol. Synop., 23, 61 p. FAO, Rome.
Strain, E.M.A., Olabarria, C., Mayer-Pinto, M., Cumbo, V., Morris, R.L., Bugnot, A.B., Dafforn, K.A., Heery, E., Firth, L.B., Brooks, P.R., Bishop, M.J., 2018. Ecoengineering urban infrastructure for marine and coastal biodiversity: which interventions have the greatest ecological benefit? J. Appl. Ecol. 55, 426–441.
Thompson, R., Munro, J.L., 1978. Aspects of the biology and ecology of Caribbean reef fishes: serranidae (hinds and groupers). J. Fish Biol. 12, 115–146.
Zabala, M., Garcia-Rubies, A., Louisy, P., Sala, E., 1997. Spawning behavior of the Mediterranean dusky grouper Epinephelus marginatus (Lowe, 1834) (Pisces, Serranidae) in the Medes Islands Marine Reserve (NW Mediterranean, Spain). Sci. Mar. 61, 65–77.