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EVALUATION OF IMPACT OF ARTIFICIAL REEFS ON ARTISANAL FISHERIES: NEED FOR COMPLEMENTARY APPROACHES*

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ABSTRACT

In a general context of fisheries decline due to overfishing and to other phenomena such as climate change, it appears to be crucial to implement a sustainable management of natural resources by finding a balance between conservation and exploitation purposes. Artificial reefs (ARs) have recently become one of the existing management tools, often in combination with fishing quotas or marine protected areas. To evaluate the effectiveness of the studied ARs, different methods have been used: (i) visual census by SCUBA diving (AR scale), (ii) fisheries landings survey (local scale) and (iii) external fish tagging (regional scale). Underwater visual census (UVC) showed a significantly higher species richness and density in ARs than in the control site. Abundance, biomass and LPUE data (Landings Per Unit Effort) issued from artisanal fisheries landings survey were not significantly different around the AR system from other fishing grounds of the French Catalan coast. The tagging experiments on *Diplodus sargus* suggested that the connectivity of demersal fish populations must be taken into account to evaluate the influence area of ARs and thus their indirect impacts on artisanal fisheries. The present study highlights the interest of combining methods covering different spatial scales in order to evaluate direct and indirect impacts of ARs on artisanal fisheries. Methods for the evaluation of AR efficiency are discussed.

RESUMO

Dentro do atual contexto de redução nos estoques de peixes ligados à sobrepesca, e também à outros fenômenos tais como as mudanças climáticas, é indispensável implementar um plano de gestão durável para os recursos pesqueiros, conciliando sua exploração e conservação. Os recifes artificiais (RAs) tem surgido nos dias atuais como uma importante ferramenta de gestão, freqüentemente combinada à cotas de pesca ou áreas marinhas protegidas. Com a finalidade de avaliar a eficiência dos recifes artificiais, utilizou-se os seguintes métodos: i) censo visual direto através de mergulho autônomo com escafandro (na escala dos recifes artificiais); ii) monitoramento dos desembarques da pesca artesanal (na escala espacial local); e iii) marcações externas (em escala regional). As contagens realizadas através de mergulho mostraram que densidade e riqueza são significativamente mais elevadas nos recifes artificiais do que na área controle. A abundância, biomassa e os DPUE (Desembarques por unidade de esforço) provenientes do monitoramento dos desembarques da pesca artesanal, não foram significativamente diferentes entre as zonas de pesca do entorno dos recifes artificiais e as outras zonas de pesca da costa catalã francesa. Os resultados dos experimentos de marcação do sargo, *Diplodus sargus*, sugerem que a conectividade das populações de peixes demersais devem ser consideradas para avaliação das zonas de influência dos recifes artificiais e de seus impactos indiretos sobre a pesca artesanal. O presente estudo evidencia a oportunidade em combinar métodos que cubram diferentes escalas espaciais, a fim de avaliar os impactos diretos e indiretos dos RAs sobre a pesca artesanal. Os métodos para avaliar a eficiência dos recifes artificiais são também discutidos.

Descriptors: Artificial reef, Artisanal fisheries, SCUBA visual census, Landings survey, Visual tagging.
Descritores: Recifes artificiais, Pesca artesanal; Censo visual por mergulho autônomo, Monitoramento de desembarques, Marcação visual.

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INTRODUCTION

In a general context of the decline of fisheries due to overfishing (LAUCK et al., 1998; CASTILLA, 2000; AGARDY, 2003; PAULY; WATSON, 2003) and to other phenomena such as climate change, it is crucial that the sustainable management of natural resources by finding a balance between conservation and exploitation should be implemented. In the Mediterranean Sea, artisanal fisheries have been particularly impacted by the decline of fish stocks (LLEONART; MAYNOU, 2003; COLLOCA et al., 2004) as a result of the high fishing pressure and the increase in the price of petrol over the past decade. Different management tools such as fishing quotas (PAULY, 2009), marine protected areas (HARMELIN, 2000; CLAUDET; PELLETIER, 2004; ASHWORTH; ORMOND, 2005; CLAUDET et al., 2006) and, more recently, artificial reefs (BAINE; SIDE, 2003) have already come into use.

Although the principle of attracting fish with different immersed objects has been known since the 18th century (MEIER et al., 1989), artificial reefs (AR) have only truly been used as a management tool since 1980. Today, ARs are used to increase local fish production (BOHNSACK et al., 1994; RELINI et al., 1994; GROSSMAN et al., 1997; PICKERING; WHITMARSH, 1997; RAMOS et al., 2006) but also to mitigate the impact of wastewaters (ANTSULEVICH, 1994; LEIHONEN et al., 1996) and aquaculture (ANGEL et al., 2005; GAO et al., 2008) and to restore damaged habitats (CLARK; EDWARDS, 1994; PICKERING et al., 1998; REED et al., 2006). Numerous studies have since focused on the evaluation of the efficiency of ARs as management tools of local resources, using different methodological approaches. Most of these studies have used scientific fishing surveys to define the potential impact of ARs on artisanal fishery catches (SANTOS; MONTEIRO, 2007), or direct visual censuses by SCUBA diving (LEITAO et al., 2009).

In France, the first large-scale AR deployment project was initiated along the Mediterranean coast by the authorities in 1985. Due to swell and the silting up of the artificial structures on the French Atlantic coast, most of the ARs deployed in France are currently located along the Mediterranean coast, in the Gulf of Lions (BARNABÉ et al., 2000). Important AR projects have been undertaken since 2000 (at the 'Prado' in the bay of Marseille and further west along the 'Côte Bleue') with two major goals: conservation of fish stocks and boosting of the artisanal fisheries catch. The AR system studied was created in 2004, in line with this new policy pursued by the Cepralmar, the regional organisation of Languedoc-Roussillon (south-west French Mediterranean region), responsible for the sustainable management of resources and the maintenance of local artisanal fisheries. A five-year study of these reefs was initiated one year after the immersion of the AR sets.

The main aim of this study was to evaluate the effect of a recently deployed AR system on fish community structure and to observe how this pattern is reflected in artisanal fishery catches. The underwater visual census (UVC) was adopted to provide information concerning fish assemblages and a fisheries landing survey was undertaken to test the direct influence of the AR system on artisanal fisheries. The landings per unit effort (LPUE) were analysed for different locations depending on the substratum type and provided a variability analysis of catches on a local scale. A visual tagging experiment of a target species (*Diplodus sargus*) was used to provide insight into the relationship between AR habitats and the natural ecosystem.

MATERIAL AND METHODS

Study Site and Artificial Reef System

The present study focuses on an artificial exploitation reef system located along the French Catalan coast, in the NW Mediterranean Sea (Fig. 1.A). This AR system is located along a spatially heterogeneous coastline, representing the natural and artificial fragmentation of marine ecosystems. The sandy Catalan coast is bordered in the north by Cape Leucate, in the south by the rocky Vermeille coast and is dotted with isolated natural rocky reefs and artificial structures such as the AR system studied. This AR system was installed in 2004, off the coast between Leucate and Le Barcarès, on a sandy substrate and is composed of 6 reef groups referred to as "villages". These villages run parallel to the coastline along the 15 and 30 m isobaths (Fig. 1.B) and consist of 28 sets of concrete reefs each. Reefs sets are placed 50 m apart, with a village occupying a total area of 120 000 m^2 (400 m long × 300 m wide). Three different structures are used: culvert reefs, box culvert reefs and chaotic clusters, distributed in the "villages" according to the scheme represented in Figure 1.C. This study was carried out on four chaotic cluster reefs in each of two of these "villages", Z3 (17.5 m deep) and Z5 (18 m deep). A natural rocky reef, located 8 km north of Z3 and 11 km north of Z5, was selected as control site.

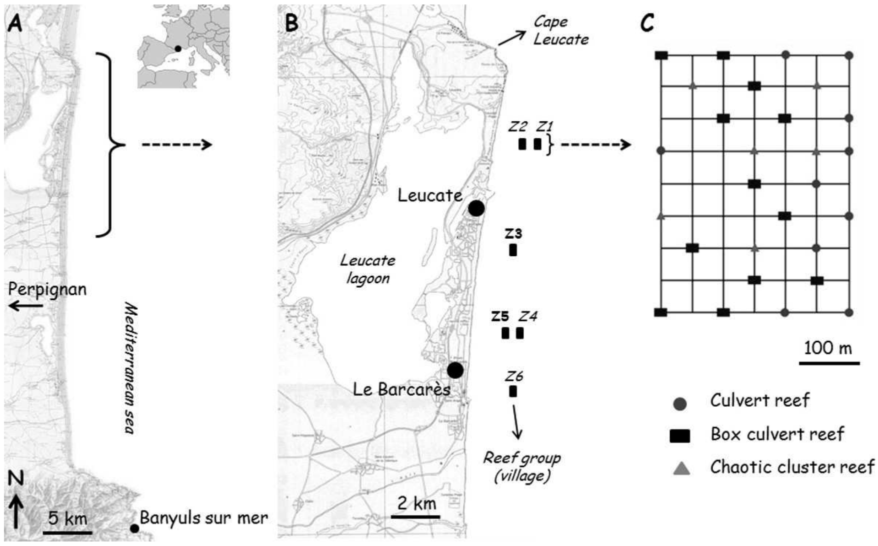

Fig. 1. A. Study site and location; B. Position of the 6 reef groups which constitute the studied AR system; C. Scheme of the positioning of the reef sets in an AR village.

Data Sampling and Analysis

UVC. The number of individuals per fish and invertebrate species was recorded at ARs and control sites by a SCUBA visual census in spring 2007. To avoid bias due to the high relative abundance of fish species belonging to the Blennidae and Gobidae genera, these species were excluded from analyses. Visual censuses were performed along a 40 m by 5 m (200 m²) transect (HARMELIN-VIVIEN et al., 1985) in four zones with similar depth to the AR systems, selected randomly at the control site. The visual census method was adapted to the specific design of the AR structures, with a complete inventory of each reef set (84 m²) performed by one diver. The fish count was performed in three steps, in order to observe species of different mobility. Species were recorded in the following order: (1) highly mobile fish species, (2) species near the reef and (3) species inside reef cavities. Density data (individuals per m²) were used in analyses to compare UVC counts between AR and control sites. Prior to data analysis, species richness and densities were log-transformed to reduce the weighting of abundant species and increase that of rarer species. Fish assemblage structure of the different locations was compared by a similarity analysis using the PRIMER software package (CLARKE; WARWICK, 2001). The Bray-Curtis similarity matrix was used to generate a hierarchical cluster analysis. The major fish species contributing to dissimilarities among locations were identified by a similarity percentage analysis (SIMPER). A one-way ANOVA followed by a *post-hoc* Tukey test was performed on richness and densities to test the differences among locations (significance threshold: $p < 0.05$).

LPUE. A survey of artisanal fisheries landings along the French Catalan coast (between Leucate and Port-Vendres) was undertaken in spring 2007 (April to June). During this survey, gear type, fishing location, species richness, abundance and weight were recorded. Biomass, fishing effort and LPUE (Landings Per Unit Effort) were calculated for nine different identified spatial areas. These nine areas were distinguished according to substrate type and relative position (Table 1). With the GPS position of gear deployment location, the biomass and LPUE data were geo-referenced on a map of the study site and analysed with a geographical information system (GIS). Average abundances, biomasses (kg) and LPUE ($g\ m^{-2}\ h^{-1}$) of the nine fishing locations were calculated and compared by separating the two principal gear types, gillnets and trammel nets.

Tagging. A visual tagging experiment was carried out in summer 2006 on 54 individuals of white seabream (*Diplodus sargus*) associated with the ARs. Fish were captured at night by divers using landing nets and were externally tagged with T-bar anchor tags (FD-68BC, Floy Tag®) below the dorsal fin. Some recapture data were obtained by professional and recreational fishermen´s tag returns but mostly through regular recapture dives. The capture and recapture locations of tagged fishes were identified on a GIS map of the study site in order to obtain the displacement distance and the number of days between recaptures was calculated.

Table 1. Definition of the nine fishing locations according to substrate type and distance to coast.

Fishing locations	Substrate type
CL - Cap Leucate	rocky substrate – Mediterranean coralligenous assemblage
AR - AR system	artificial hard substrate
IR - Isolated rocky reefs	rocky substrate
LL - Leucate lagoon	sandy to muddy substrate
NS - Northern sandy coastal area	sandy to muddy substrate
CS - Central sandy coastal area	sandy to muddy substrate
SS – Southern sandy coastal area	sandy to muddy substrate
OS – Offshore (beyond 3 miles from the coast)	sandy to muddy substrate
RC - Rocky coast (‘Vermeille’ coast)	rocky substrate– Mediterranean coralligenous assemblage

RESULTS

UVC. We identified 29 commercial fish and 6 commercial invertebrate species during the SCUBA visual census at the three study sites. The species recorded at each site are listed in Table 2. The hierarchical cluster analysis showed a distinct separation between the species assemblage structure of the control site and the AR sites (Z3 and Z5), with less than 10% similarity (Fig. 2). However, no significant difference was detected between the two AR sites. A one-way ANOVA on species richness and density showed a significant difference between locations, with p-values of 0.032 and 0.000 respectively (Table 3). Density at the control location was significantly lower than that in both AR villages (p-value = 0.000). Villages Z3 and Z5 had mean densities of 1.28 ind m^{-2} and 2.12 ind m^{-2} respectively, more than 10-fold lower than the density at the control location (Table 3). Species richness was only significantly higher in Z3 than at the control location (p-value = 0.036). No significant differences in species richness were observed between AR villages Z3 and Z5 (p-value = 0.614; Table 4.A; Table 4.B). The dissimilarity percentages and the list of the most important species contributing to differences between locations are summarised in Table 5. The dissimilarity percentage between the control location and the two AR locations reached 90 % for Z3 and 92% for Z5. Between Z3 and Z5 the dissimilarity percentage of the species assemblage reached 55%. The bogue *Boops boops* was the species contributing most to dissimilarity between assemblages, with a dissimilarity percentage exceeding 22% for all locations. Common two-banded and white seabreams also contributed greatly to the dissimilarity percentage among locations (Table 5).

LPUE. During the fisheries landings survey in spring 2007, 90 species were identified including 9 invertebrate and 6 elasmobranchii species. Of the 35 species counted by UVC, all were present in artisanal fishery landings except the bastard grunt *Pomadasys incisus*, the black squat lobster *Galathea squamifera* and the two shrimp species *Palaemon serratus* (common prawn) and *Stenopus spinosus* (Mediterranean boxer shrimp). The distribution of abundance, biomass and LPUE data for the different fishing locations is shown, respectively, in Figure 3.A, B and C. The results of one-way ANOVAs on abundance, biomass and LPUE among the different fishing locations for trammel net and gillnet catches are summarised in Table 6. The one-way ANOVA and the post-hoc Tukey analyses revealed no significant differences between locations, regardless of the type of gear used.

Table 2. List of fish and invertebrate species at each location. AR corresponds to both ARs systems, Z3 and Z5 together. The non-commercial species are marked with a star.

	C	Z3	Z5	AR
Atherina sp.	-	+	-	+
Boops boops	-	+	+	+
Chromis chromis	+	+	-	+
Conger conger	+	+	+	+
Coris julis	+	-	-	-
Ctenolabrus rupestris	+	+	+	+
Dicentrarchus labrax	-	+	+	+
Diplodus annularis	-	+	+	+
Diplodus puntazzo	+	-	-	-
Diplodus sargus	+	+	+	+
Diplodus vulgaris	+	+	+	+
Mullus surmuletus	+	+	+	+
Oblada melanura	+	+	+	+
Pagellus acarne	-	+	+	+
Phycis phycis	-	+	+	+
Pomadasys incisus	-	+	+	+
Sarpa salpa	-	+	-	+
Sciaena umbra	-	-	+	+
Scorpaena notata	-	+	+	+
Scorpaena porcus	+	+	+	+
Serranus cabrilla	+	+	+	+
Serranus hepatus	+	-	-	-
Sparus aurata	-	+	-	+
Spicara maena	-	+	-	+
Spicara smaris	-	-	+	+
Spondyliosoma cantharus	-	+	+	+
Symphodus tinca	+	-	-	-
Trachurus sp.	-	+	+	+
Trisopterus sp.	-	+	+	+
Galathea squamifera	-	-	+	+
Octopus vulgaris	-	+	+	+
Palaemon serratus	-	-	+	+
Palinurus elephas	-	+	+	+
Portunus puber	-	+	+	+
Stenopus spinosus	-	+	-	+

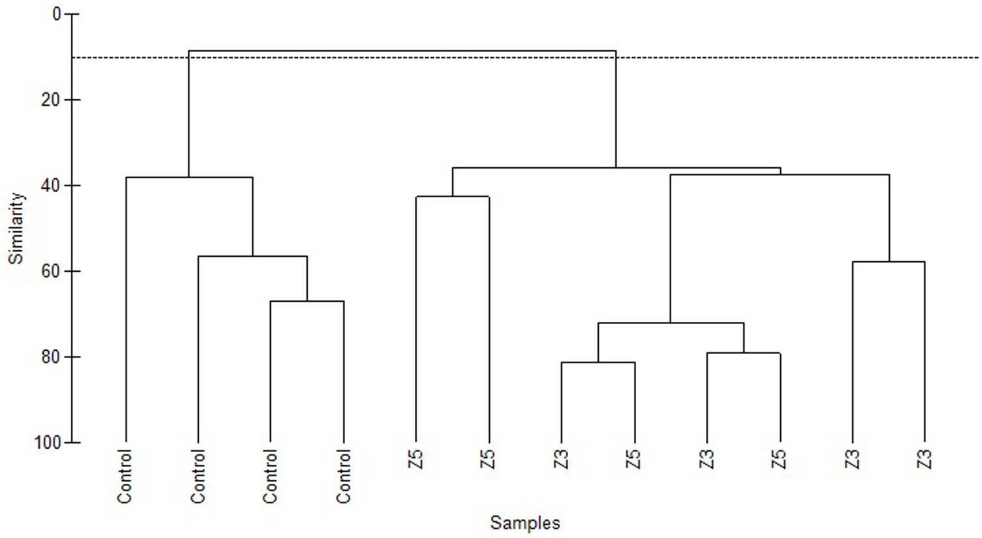

Fig. 2. Hierarchical cluster analysis (group average) of all samples for the three different locations: control site, Z3 and Z5.

Table 3. Mean value and standard error of species richness and density for the control site, Z3 and Z5.

	Abundance		Richness		Density (ind m^{-2})	
	mean value	SE	mean value	SE	mean value	SE
control	24.25	3.69	5.75	0.46	0.1212	0.0184
Z3	178.50	34.34	13.25	0.25	2.1250	0.4088
Z5	147.80	33.85	12.75	1.797	1.2827	0.1663

Table 4. One-way ANOVA and post-hoc Tukey test comparing species richness and density between control location (C) and both AR systems Z3 and Z5. Significance levels: *p < 0.05; **p < 0.01; ***p< 0.001; ns: not significant (p > 0.05).

	Richness			Density		
	F	P		F	P	
Among locations	5.143	0.032	*	26.521	0.000	***
Pairwise tests						
C vs Z3		0.036	*		0.000	***
C vs Z5		0.080	ns		0.001	***
Z3 vs Z5		0.867	ns		0.614	ns

Tagging. Of the 54 white seabreams tagged on the ARs, 5 individuals were recaptured (Table 7), representing a recapture rate of 9%. Three were found by divers on different chaotic cluster reefs from those where they were captured, 5 and 20 days after capture (Table 7). The two other fish were recaptured by fishermen. One moved toward the Leucate channel of the Leucate lagoon (Fig. 4) and the other moved 20 km north to Port La Nouvelle (Fig. 4, Table 7).

Table 5. SIMPER analysis comparing the species assemblages of the three different locations. Dissimilarity percentages between locations and the contribution of each species to dissimilarities are reported in the first column. The non-commercial species are marked with a star.

	Dissimilarity (%)
C vs Z3	**92.91**
Boops boops	21.90
Diplodus sargus	16.99
Pomadasys incises	14.73
Diplodus vulgaris	7.29
Mullus surmuletus	6.95
Dicentrarchus labrax	6.75
C vs Z5	**90.00**
Boops boops	24.24
Dilpodus sargus	13.27
Trachurus sp.	8.47
Diplodus annularis	7.84
Mullus surmuletus	7.63
Serranus cabrilla	7.07
Conger conger	5.97
Diplodus vulgaris	4.44
Z3 vs Z5	**54.62**
Boops boops	23.81
Diplodus vulgaris	12.20
Dilpodus sargus	8.34
Trachurus sp.	7.71
Mullus surmuletus	7.53
Pomadasys incisus	7.07
Dicentrarchus labrax	6.04
Diplodus annularis	5.07

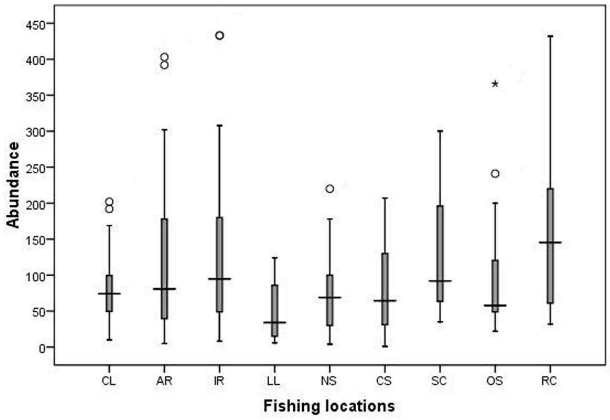

Fig. 3.A. Box-plot representing the median, quartiles and extreme values of abundance data for the 9 different fishing locations.

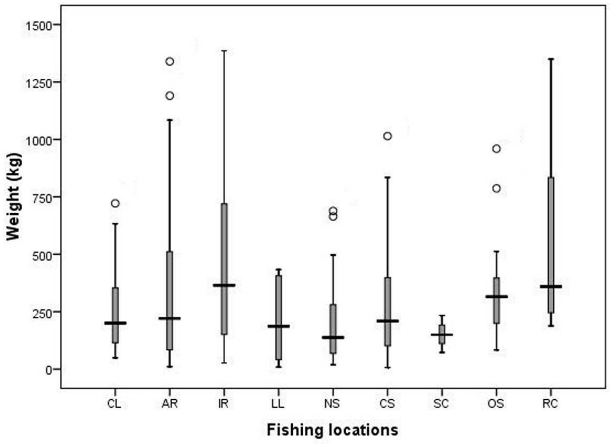

Fig. 3.B**.** Box-plot representing the median, quartiles and extreme values of biomass data (kg) for the 9 different fishing locations.

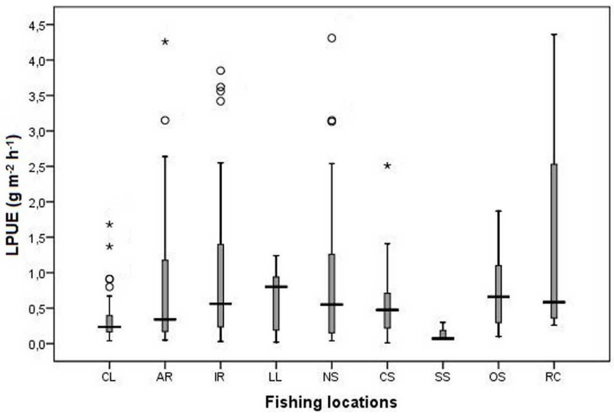

Fig. 3.C**.** Box-plot representing the median, quartiles and extreme values of LPUE (g m^{-2} h^{-1}) data for the 9 different fishing locations.

Table 6. One-way ANOVA comparing abundance, biomass and LPUE among the 9 different fishing locations for trammel net and gillnet catches. Significance levels: ns: not significant ($p > 0.05$).

	Abundance			Biomass (g)			LPUE ($g\ m^{-2}\ h^{-1}$)		
	F	P		F	P		F	P	
Trammel net	1.494	0.189	ns	1.210	0.309	ns	1.365	0.238	ns
Gillnet	0.629	0.752	ns	1.898	0.067	ns	1.610	0.129	ns

Table 7. Recaptured white seabreams which were tagged on the ARs of Leucate and Le Barcarès.

Recapture location	Tagging date	Recapture date	Capture depth (m)	Recapture depth (m)	Distance (km)	Time (day)	Size (mm)	Recapture method
AR	31/08/2010	19/09/2010	17	17	0,2	20	385	Diving
AR	31/08/2010	04/09/2010	17	17	0,2	5	350	Diving
AR	31/08/2010	04/09/2010	17	17	0,2	5	208	Diving
Leucate channel	04/09/2010	14/09/2010	17	2	6,7	11	210	Long-line
Port La Nouvelle	19/09/2010	03/10/2010	17	2	20	15	220	Gillnet

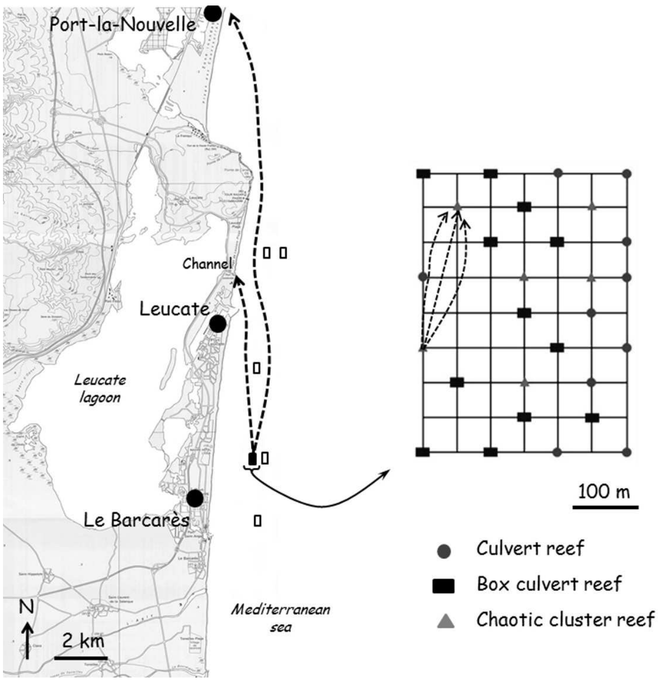

Fig. 4. Displacements of the recaptured tagged white seabreams (dotted line) outside of the AR villages and inside the village between reef sets.

Discussion

As observed in many AR studies (ALEVIZON; GORHAM, 1989; FABI; FIORENTINI, 1994; GROSSMAN et al., 1997; FABI et al., 2004; ARENA et al., 2007; SANTOS; MONTEIRO, 2007; DUPONT, 2008), the fish assemblages associated with the AR structures studied were significantly different from those associated with the control site, especially regarding the increased fish densities on ARs compared with those of the control site. The comparison between AR villages Z3 and Z5, located at a similar depth but at different distances from the control location, provides evidence that the distance to the closest natural rocky reef (control location) is not a factor influencing fish assemblages (richness and density). Under a purely attraction hypothesis of fish from natural rocky reefs to the artificial reefs, one would probably have seen an abundance gradient according to distance from the control location. The ARs of Leucate and Le Barcarès were thus probably not attracting fish away from the control location at Cape Leucate.

Out of the 35 invertebrate and fish species recorded during UVC, only 13 were present at the control site. None of the invertebrate species identified by the census were seen at the control location. However, the dissimilarity analysis of the species assemblages of the different sites showed that the species contributing most to dissimilarity were those present at all locations but in different proportions. Excluding the bogue *Boops boops*, whose high contribution to the dissimilarity percentage of the community assemblage was due to its gregarious behaviour and is not necessarily linked to the substrate type, the species contributing most to dissimilarity between locations is the white seabream *Diplodus sargus sargus* followed by the common two-banded seabream *Diplodus vulgaris*. The low abundance of common two-banded and white seabreams at the control location explains the important contribution of these species to the dissimilarity of species assemblages between control and AR locations. According to the FAO statistics (FAO, 2004), the white and the common two-banded seabream are two of the most commercially important species in southern Europe's fisheries.

This UVC study provides evidence that the AR studied is colonised by fish and invertebrates of greater or lesser commercial value. The high abundances of some demersal fish species on the ARs compared to those at Cape Leucate explain the differences in the community structure between the artificial and natural hard bottoms. As in many studies (CHARBONNEL et al., 2002; SHERMAN et al., 2002; BROTTO et al., 2006; GROBER-DUNSMORE et al., 2008; LAN et al., 2008), higher fish densities can be related to the higher structural complexity of the habitat, providing better shelter (EKLUND, 1997). The high fish abundance and the high contribution of commercially valuable fish species (sparids) on the ARs of Leucate and Le Barcarès highlight the potential role of these artificial structures for fisheries enhancement.

During the fisheries landing survey of spring 2007, 90 species were recorded, out of the 300 fish, crustacean and mollusc species identified in the Gulf of Lions (ALDEBERT, 1997). Despite the small sampling area and the selectivity of fishing gear, nearly a third of the species richness of the Gulf of Lions was sampled by the artisanal fishing survey. The Mediterranean fisheries, except for large pelagics, are characterised by fragmented fleets with a large number of landing points and multispecies catches (LLEONART; MAYNOU, 2003), explaining in part the high species richness observed in our study. Furthermore, the area studied is a highly heterogeneous environment, composed of a rocky coast in the north, partly surrounded by *Posidonia oceanica* seagrass meadows and a sandy coast in the south, interspersed with artificial and natural hard bottoms. This mosaic of substrates could probably play a role in the high species richness observed in the study area (GRATWICKE; SPEIGHT, 2005).

All but four species sampled by UVC were also identified in the fisheries landings. The four species observed only by UVC are rare species, including the bastard grunt *Pomadasys incisus* (PASTOR et al., 2008) and small crustaceans such as the Mediterranean boxer shrimp, *Stenopus spinosus*, and the black squat lobster, *Galathea squamifera*, mostly living in cavities, all of low commercial value and thus not targeted by fishing gear. Contrary to what might have been expected from the UVC results, the analyses of the fisheries data show no significant differences between catches made around the ARs and those from other fishing locations.

The underwater visual census method (UVC) is mostly used in AR research to describe the community structure associated with artificial vs. natural habitats (BAYLE-SEMPERE et al., 1994; BOMBACE et al., 1994; COLL et al., 1998; SEAMAN JR.; JENSEN, 2000; CHOU et al., 2002; ZALMON et al., 2002; ARENA et al., 2007; DUPONT, 2008). In fact, this method provides an insight into the fish community directly associated with the artificial or natural hard bottoms, by the sampling of demersal and benthic species which are not necessarily available to fishing gear. As a complement to the UVC method, the LPUE data provide information on the direct effects of fish community structure on fishing yield, with a greater selectivity for pelagic and demersal species from homogeneous grounds (GODOY et al., 2002; ZALMON et al., 2002). The differences in the results of the LPUE and the UVC surveys demonstrate the need for insight into both the fish population dynamic and the fisheries dynamic, for the better understanding and management of the resources.

The absence of significant differences between catches off Cape Leucate and in the AR system could be due to the patchy distribution of reef sets and the high structural reef complexity. The most commonly used types of fishing gear in the study zone are gillnets and trammel nets, which cannot be used close to rocky bottoms and especially not on high relief bottoms. For this reason most nets are deployed at least at 200 m from the hard bottom structures. A study by Alevizon & Gorham (1989) showed an increase in local resident reef fishes associated with ARs but no effect on fishes dwelling in nearby non-reef habitats which would have been more available to net gear. Unpublished scientific fishing surveys performed using two different kinds of fishing gear, long-line and nets, showed differences in the catchability of seabreams close to the ARs studied. Long-lines seem to be much more efficient fishing gear on the ARs of Leucate and Le Barcarès. As indicated by Leitao et al. (2009) for the Algarve, long-line fishing has been widely abandoned by local artisanal fishermen on the French Catalan coast, in favour of easy to operate net gear.

Despite the reward offered for the capture of tagged white seabreams, only two fish were returned by fishermen. A study by Abecasis et al. (2009) with capture-mark-recapture experiments on white and two-banded seabream showed similar difficulties with the return by fishermen, with a recapture rate between 3 and 4 %. Although it may be time consuming, regular recapture dives at strategic sites seem to be a good alternative for the recapture of tagged seabreams and in order to avoid the loss of information on these individuals. Despite the few recaptures, the tagging experiment indicated the connectivity between artificial reef sets within the same "village" as well as between the AR and habitats outside this area. The displacement of one of the recaptured seabreams to the Leucate channel, could show the potential role of the adjoining lagoon as a feeding habitat (KJERFVE, 1994; MACI; BASSET, 2009). Since the white seabream is one of the species contributing most to differences in fish density between the control location and the AR system, this preliminary study emphasizes the necessity of considering the life-history connectivity of fish populations and their habitat usage in order to better understand the role of these artificial structures in fish habitats and the processes driving the increase of fish abundance close to ARs. According to Sheaves (2009) 'life-history connectivity' is the sum of all migrations and dispersals among multiple habitats necessary to the fulfilment of the fish´s life cycle, such as spawning migrations, dispersal of eggs and larvae, migrations to join the adult population or feeding migrations and migrations to refuge habitats. Recent advances in tagging with electronic devices limit the difficulties of studying the spatial dynamics of highly mobile reef-fishes, as shown for the common two-banded and white seabream by Abecasis et al. (2009). Further research on habitat use and displacement patterns of white seabreams would thus be required to better understand the role of ARs in the habitat of coastal fishes and to find an adequate way to evaluate the indirect impact of ARs on fish production.

As an overall conclusion, we may say that the AR system of Leucate and Le Barcarès is efficient for fish aggregation, including that of commercially valuable species. However, fishing yield is not enhanced by the proximity of the ARs as compared to that of other fishing locations. This preliminary study highlights the importance of using complementary approaches to evaluate the impact of ARs on artisanal fisheries. The results of the tagging experiment of white seabreams show the importance of considering the 'life-history connectivity' of fish populations to evaluate the area of influence of these reefs and to study the impact of ARs on artisanal fisheries.

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