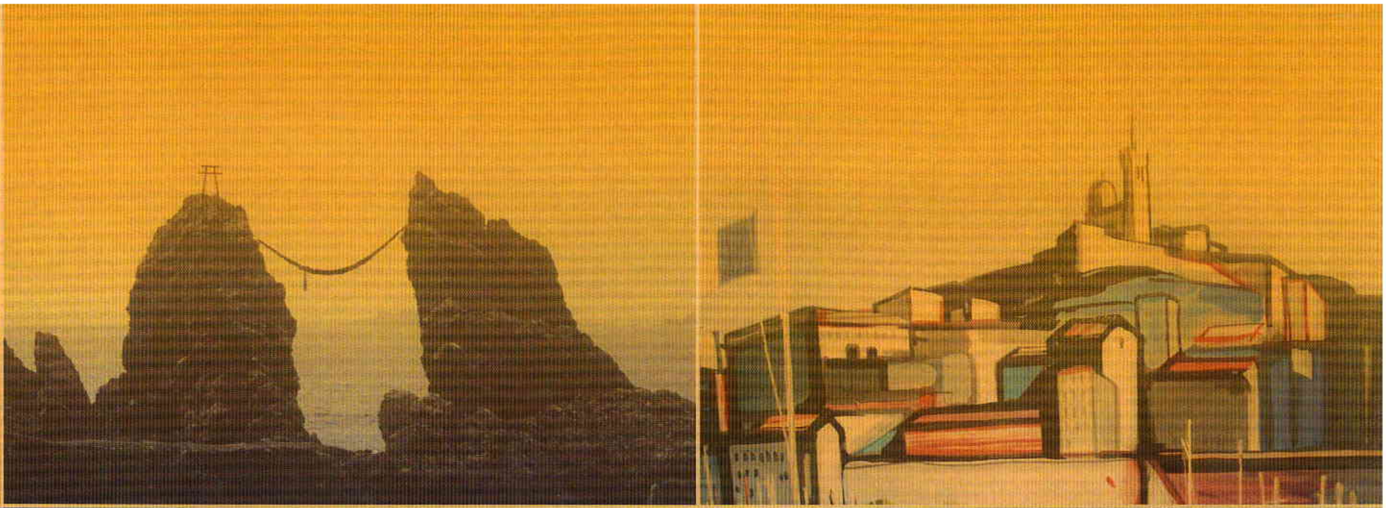

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Artificial Reefs in the Cote Bleue Marine Park: Assessment After 25 Years of Experiments and Scientific Monitoring

Eric Charbonnel and Frédéric Bachet

Abstract The Côte Bleue Marine Park (PMCB) was one of the precursors in France concerning the deployment of artificial reefs (AR). For 25 years, the Park has led several varied operations by using different kinds of modules: between 1983 and 2004, seven types of architecture for production reefs and five architectures for protection reefs were studied, for a total AR volume of 4,884 m^3, and represent an investment of €480,000.

The purpose of the AR deployment policy of the Park was to experiment and test various types of modules, during small-scale operations, but including several phases of immersion and scientific field surveys. These experiments allowed development of the conception of modules and adapting them to the local context, targeting several objectives. Moreover, they are used to support small-scale artisanal coastal fishing by two complementary aspects:

(1) The promotion of biological production in impoverished seabeds and sustaining professional artisanal fishing, with 2,684 m^3 of modules arranged in chaotic heaps in five areas, and increasing the biodiversity and the available fishing resources.
(2) The protection of priority natural habitats (*Posidonia* meadows and coralligenous rocks) and to manage and share both resources and fishing grounds among fishermen, with 326 heavy obstacles designed to protect against illegal trawling within the 5.5 km offshore limit. These 2,200 m^3 of anti-trawling reefs are spread along 17.5 km, creating barriers perpendicular to the coast. Since they have been installed, a significant decrease in illegal trawling has been observed.

In the Côte Bleue Marine Park, the two categories of AR (production and protection reefs) are interrelated in the two protected marine areas (integral reserves of 295 ha where all kinds of fishing activities, scuba diving, and mooring are prohibited).

These management tools have worked in an additional way and contributed to the preservation of the traditional small-scale fisheries in the Côte Bleue territory (for about 60 fishermen) at a time when these fishing activities are decreasing in the nearby zones.

1 Introduction

The Côte Bleue Marine Park ("Parc Marin de la Côte Bleue", or PMCB) was one of the precursors in France concerning the deployment of artificial reefs (AR). For 25 years, AR deployments have concerned both ecological aspects and promotion of fisheries and resources, with two complementary kinds of AR: protection reefs against illegal trawling on the coastal band and production reefs, for a gross volume of 4,884 m^3. The aims of this paper are to provide some assessments of the experiments conducted; to describe some aspects of AR as tools for integrated management of marine resources and sustainable fisheries; and to confirm the crucial influence of reef design, architecture, and layout on the biological effectiveness of AR.

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2 Presentation of the Côte Bleue Marine Park

The PMCB, located east of Marseille (Fig. 1), was created in 1983 with the same objectives as terrestrial natural parks: (1) protection of the natural environment, (2) preservation of traditional fisheries and participation in better management of resources, (3) increasing public awareness and education about the environment, and (4) promotion of experiments and research.

The PMCB is a public institution involving five cities of the coast "Côte Bleue" (Martigues, Sausset-les-Pins, Carry-le-Rouet, Ensuès-la-Redonne, and Le Rove), local governments ("Région Provence Alpes Côte dAzur," "Département des Bouches du Rhône"), and professional organizations of fishermen ("Comités Locaux des Pêches Maritimes" and "Prudhomies" of Marseille and Martigues).

The PMCB operates along the 40-km coastline of "Côte Bleue" up to 4 km offshore, between the gulf of Fos and Marseille. The Park manages two marine protected areas (MPA), no-take zones where all kinds of fishing activities, diving, and anchoring are prohibited: the Carry-le-Rouet reserve (85 ha protected since 1983) and Cap-Couronne reserve (210 ha protected since 1996; Fig. 1). For 25 years, the PMCB has led several programs of AR deployment, at an experimental scale, for a gross volume of 4,884 m^3. The two categories of AR used (production and protection reefs) are interrelated in the two integral reserves. Additionally, they work in an additional way towards the improvement of marine biodiversity and fishing resources.

Since the creation of PMCB 25 years ago, educational training has been created for schooled children, with activities at sea during 4 days per school. More than 22,000 children have attended these sea programs. Since 1994, an underwater pathway in MPA has welcomed the public during visits organized by the Park in the summer.

3 Description and Objectives of Artificial Reef Deployment

For 25 years, the Park has led several and varied operations by using different kinds of modules: between 1983 and 2004, seven types of architecture for production reefs and five architectures for protection reefs were studied (Fig. 2), for a total AR volume of 4,884 m^3, and represent an investment of €480,000 (Table 1). Professional fishermen are often the originators of AR projects, which can involve funding of up to 50% by the EU (EFF, European Fisheries Fund) and local governments. The goal of the AR deployment policy of the Park was to experiment and test various types of modules, during small-scale operations, but including several phases of immersion and scientific field surveys. These experiments allowed development of the conception of modules and adapting them to the local context and targeting multiple objectives. Moreover, they are used to support small-scale artisanal coastal fishing by two complementary aspects:

(1) The promotion of biological production in impoverished seabeds and sustaining artisanal fishing,

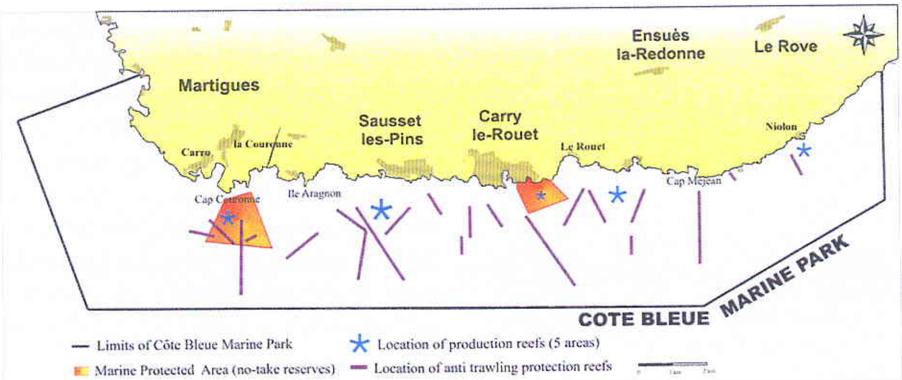

Fig. 1 Presentation map of the Cote Bleue Marine Park territory: a concession of 9,873 ha delivered on December 15, 2003 along 40 km of coastline to 4 km offshore, between Marseille and Fos

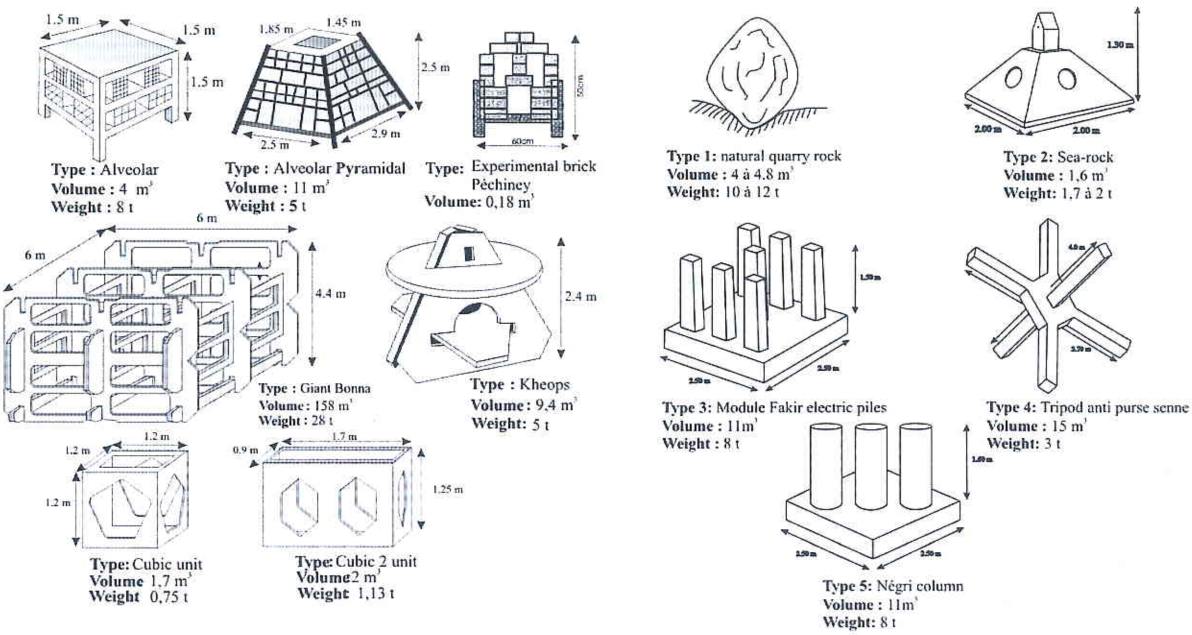

Fig. 2 Presentation of the two main categories of artificial reefs used in the Parc Marin de la Côte Bleue: on the left, seven models of production reefs (the small cubic modules are deployed into chaotic heaps) and on the right, five kinds of antitrawling reefs deployed one by one

Table 1 Description of artificial reef deployments on the five areas of the Côte Bleue Marine Park

Areas/volumes (m^3 of A. Reef)	Year of deployment	Description of artificial reefs
Niolon-Le Rove, 319 m^3	1985, 1989	– 319 m^3 of production reefs, with three types (83 small cubic modules of 1.7 m^3 + ten cubic modules of 2 m^3 + one large unit of 158 m^3)
Ensuès-la-Redonne, 677 m^3	1985, 1989	– 546 m^3 of production reefs (112 small cubic modules of 1.7 m^3 + 20 cubic modules of 2 m^3 + two large units of 158 m^3)
	1990	– 131 m^3 of protection reefs (17 quarry rocks of 11 t (4.4 m^3) + 36 pyramidal "sea-rocks" of 1.56 m^3, weight 2 t)
Carry-le-Rouet(no take reserve of 85 ha), 1,093 m^3	1983	– 225 m^3 of production reefs (36 alveolar modules, among 27 table unit of 4 m^3 and nine pyramidal unit of 13 m^3)
	1986,1990	– 190 m^3 of protection reefs (36 quarry rocks of 11 t (4.4 m^3) + 20 pyramidal "sea-rocks" 1.56 m^3 of 2 t)
	2000	– 678 m^3 of protection reefs (40 heavy column modules of 12.5 m^3 weight 8 t + 12 tripods antipurse senne 14.8 m^3 of 3 t)
Sausset-les-Pins, 1,442 m^3	1985, 1989	– 1,241 m^3 of production reefs (195 small cubic modules of 1.7 m^3 + 60 cubic modules of 2 m^3 + five large units of 158 m^3)
	1986,1990	– 201 m^3 of protection reefs (30 quarry rocks of 11 t (4.4 m^3) + 44 pyramidal "sea-rocks" 1.56 m^3 of 2 t)
Martigues-Couronne (no-take reserve of 210 ha), 1,205 m^3	1996–1997	– 1,001 m^3 of protection reefs (91 "Fakir" electric piles of 11 m^3)
	1997	– 148 m^3 of production reefs (87 small cubic modules of 1.7 m^3)
	2004	– 56 m^3 of experimental reefs (six modules "Khéops" of 9.4 m^3)

with 2,684 m^3 of modules arranged in chaotic heaps on five sandy areas, destinated to create new habitats similar to natural rocky reefs with high structural complexity for fish fauna and intended to increase the biodiversity and the available fishing resources.

(2) The protection of priority natural habitats (*Posidonia oceanica* meadows and coralgal banks called "coralligenous"), with 326 heavy obstacles designed to protect against illegal trawling within the 5.5 km offshore limit. These 2,200 m^3 of anti-trawling reefs are spread along 17.5 km of barriers stretching off the coast, arranged in perpendicular lines, and insure the protection of bottom nets and long lines from being damaged by trawlers and consequently reduce conflicts among fishermen and allow them to share the fishing grounds and resources.

There is no particular regulation on the majority of reefs. Most ARs are open to fishermen (both professional and recreational) and divers, except those located inside the two no-takes reserves, where fishing is prohibited. It represents 16% of the volume of production reefs and 26% of the number of protection reefs.

Several kinds of modules were tested (Fig. 2), both for production and protection effects. Most of the production reefs are composed of small concrete cubic modules of 1–2 m^3, gathered into chaotic piles of 60–100 m^3, and also bigger units (158 m^3) inspired by Japanese technology, but having a very low habitat complexity.

Concerning antitrawling reefs, five kinds of modules were used in the PMCB (Fig. 2). First experiments were conducted in 1986 with heavy quarry rocks, the first trial in the Mediterranean Sea. To be efficient, these protection reefs have to weigh a minimum of 8 t. These reefs are deployed one by one, separated from each other by 50–200 m. They are being arranged by lines, creating barriers perpendicular to the coast (17.5 km of barriers within the 3 km area, Fig. 1).

4 Main Results of Scientific Monitoring

After 25 years of AR experimentation in the PMCB, there is a wide variety of kinds of reefs (production, protection), module architecture, depths, environmental conditions, management rules (inside/outside MPA), etc. Several scientific monitorings were organized, using underwater visual census techniques, adapted to the specificity of AR (Charbonnel et al. 1997).

4.1 Protection Reefs

The most characteristic example of a successful protection reef is shown in Fig. 3, with the path of illegal trawling plotted before and after reef deployment, and the creation of the no-take reserve in Cap-Couronne (1997). The result has been a decrease of fishing pressure on the coastal band by removal of illegal

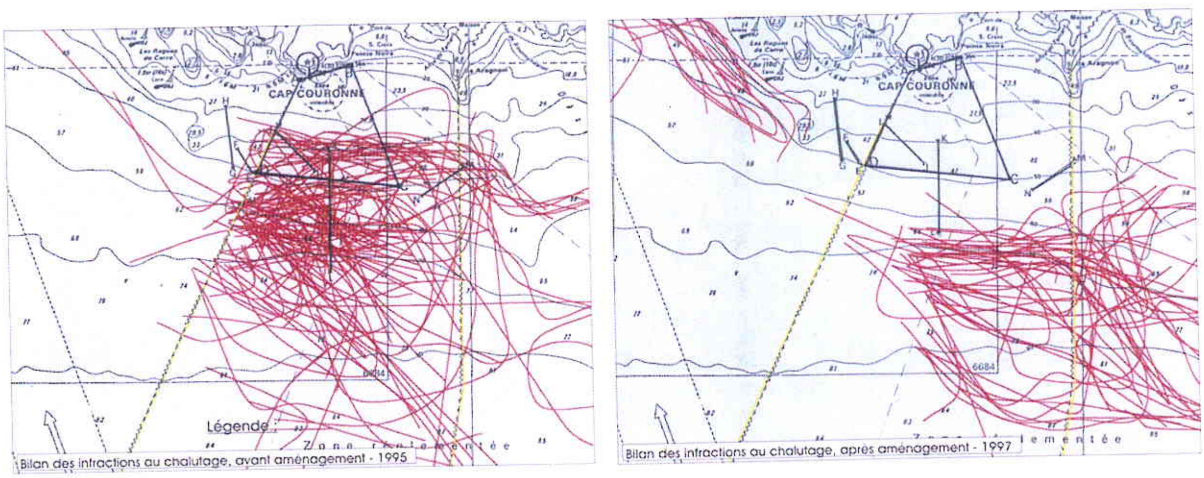

Fig. 3 Results of protection reef efficiency; on the left, before and, on the right, after reef deployment in the Parc Marin de la Côte Bleue, around the vicinity of Cap-Couronne integral reserve (red lines correspond to illegal trawling paths within the 5.5 km area)

Table 2 Evolution of the fish assemblages on two reef types (large unit of 158 m³ and small cubic units of 1.7 m³ deployed into chaotic heaps of 119 m³) for the area of Sausset-les-Pins between 1987 and 2000 (Charbonnel et al. 2000)

Reef type (volume: unit/reef)	Large unit (158/158 m³)			Cubic unit in chaotic heaps (1.7/119 m³)		
Year of survey	**1987**	**1993**	**2000**	**1987**	**1993**	**2000**
Total number of species	24	24	31	28	35	41
Mean number of species	7.3	8.0	11.5	10.8	13.6	16.8
Density without pk (individual/m³)	0.12	0.14	0.32	0.93	1.52	1.04
Total density (individual/m³)	–	11.8	7.2	–	27.7	76.4
Biomass without pk (g/m³)	5	21.5	12.4	116	306	155
Total biomass (g/m³)	–	269	108	–	2,918	2,396

Pk = planktivorous species (*Chromis*, *Boops*, *Spicara*) and *Coris julis*; – = data unavailable

trawling activities offshore. The efficiency of anti-trawling reefs allowed a better sharing of space and resources among fishermen by supporting traditional small- scale fisheries (bottom gillnet and trammel net, hook on line) with much more selective techniques (catching only adults and thus facilitating conservation of fishing resources), whereas trawlers caught all-sized species, particularly juveniles, who had not yet reproduced. This is a crucial point in the stock dynamics of necto-benthic species: mortality because of catching juveniles is the principal factor of the falling of catches.

The other essential effect of protection reefs is to preserve the most productive and fragile natural habitats (*Posidonia* meadows and coralligenous banks) from mechanical destruction by trawlers. These damages have important ecological and economic repercussions, because these habitats serve for spawning, nurseries, recruitment, and feeding areas for most part of the exploited resources.

4.2 Production Reefs

Concerning production reefs, monitoring showed that the fish assemblages associated with AR are similar in species composition, density, and biomass to those occurring on natural reefs made of rocky bottoms, and most often with superior performance because of the multimodal aspect and higher heterogeneity (Charbonnel et al. 2000, 2002). Availability of shelters may be more important, because food resources are generally not limited, because most species feed on the surrounding natural habitat. Colonization of AR can proceed quickly (2–3 years), but maturation of reef assemblages can take many years, and some reefs still show evolution after 10–15 years of deployment (Table 2, Fig. 4). Duration of assemblage maturation depends on the size and complexity of the AR.

For example, on a small AR of 150 m³ in Cap-Couronne (Fig. 4), the specific richness of fish assemblages increased regularly between 1995 and 2004, from 7 to 29 species (TNS, total richness) and from 2.6 ± 0.9 to 15.7 ± 2.1 species per census (MNS). Biomass was multiplied by a factor of 46: from 2.2 kg in 1995 (before reef deployment) to 100.7 kg in 2004.

The monitoring on Sausset AR between 1987 and 2000 showed that colonization can proceed over a longer period of time before reaching the maximum carrying capacity. The specific richness still increased on both reef types (total richness × 1.3 to 1.5, mean richness × 1.6) on these ARs aged 11–14 years in 2000 (Table 2). Fish assemblages are increasingly complex, and this

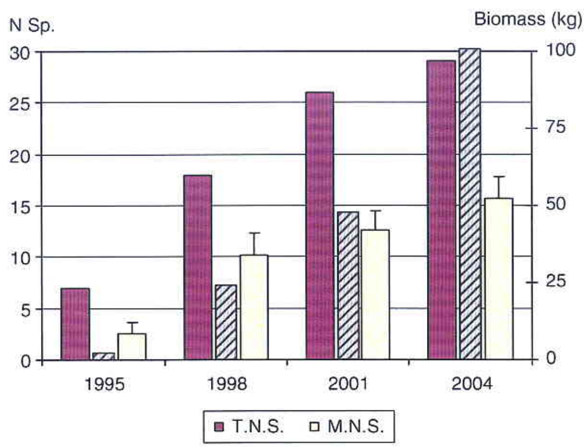

Fig. 4 Evolution between 1995 (before reef deployment) and 2004 of the specific richness of fish assemblages [total number of species (TNS), mean number of species (MNS) per census and standard deviation],and biomass (hatched) on a 150 m³ artificial reef located in the integral reserve of Cap-Couronne (Jouvenel et al. 2006)

process of slow colonization continues, with turnover and the appearance of new species, as well as a higher proportion of permanent species (based on their frequency of occurrence), suggesting a higher temporal stability of the species assemblage; especially chaotic heaps of small cubes offer numerous small interconnected chambers.

After 13 years, by comparing 2000 to 1987, the density and the biomass have also increased over time, according to the available resources. The best results were obtained in the 1993 survey, particularly connected to the abundance of Sparids. By comparison, the monitoring in 2000 was conducted with low temperature, inducing rarefaction of Sparids, and a decline in density and biomass when removing planktivorous species and wrasse *Coris julis*.

The structure of fish assemblages clearly differed according to the reef type: cubic units offer more complex habitats, with greater diversity in size of shelters. This model of AR presents a greater species richness (×1.5) and greatly increased density (×10) and biomass (×22) compared to a large unit reef (see Table 2) with vast undivided empty chambers, which are ineffective, because they have no natural equivalent.

This example and other French field work showed that reef design is a crucial factor in AR effectiveness. AR architecture and layout should be adapted according to the behavior and the habitat requirements of targeted fish species.

Research and experiments are necessary to improve reef efficiency, in relationship with studies of natural habitat effects. A reef aimed at maximizing its associated biodiversity and fish fauna should be heterogeneous and should have a high structural complexity.

The use of a mixture of different kinds of materials of different sizes and void spaces deployed in irregular piles facilitates the creation of a network of complex cavities of small interconnected chambers, which appear to provide benefits for many fish species – both predators and preys – that may find features in the multimodal pattern that suit their specific requirements (Charbonnel et al. 2002).

The reef architecture and module design determine not only the global performance of the reef (species richness, abundance, and biomass), but also the identity of species that are particularly fitted for exploiting this new resource.

It is important to notice that ARs worked as MPAs and have similar "reserve effects" with:

(1) Increasing biodiversity and global species richness, because of higher frequency of rare target species
(2) Increasing abundance of individuals, particularly those of species targeted by fishing
(3) Recovery of balanced demographic structure, with a higher frequency of large individuals, which are potential spawners

All these phenomena are similar to those observed in marine reserves (Francour 1994; Harmelin et al. 1995; Harmelin 1999; Charbonnel et al. 2000, 2001), and the same supposed beneficial effects on fish numbers seen in the peripheral area can be attributed to AR. The increase in the mean individual weight suggests that reef maturation induces an increase in the stock of large adults (Charbonnel et al. 2000).

There is also an evident ecological benefit, because spawning productivity of larger individuals is much higher than that of small ones.

Finally, similar to reserves, ARs also have a refuge function by virtue of their physical presence, without imposing the need for any particular protective management, such as fishing restrictions.

5 Conclusions

In the Côte Bleue Marine Park, the two categories of AR combining production and protection effects are not dissociable from of the two MPAs (no-take reserves). These are complementary tools, used in an additional way. All these management tools have contributed to the preservation of the traditional small-scale fisheries on coastal bands of the PMCB, using selective techniques. They have allowed maintaining the same number of artisanal fishermen for 25 years (about 60) at the same time that these fishing activities are decreasing in nearby zones, in a general context of full exploitation of resources.

AR may constitute a response to numerous problems concerning coastal resources, overexploitation of fisheries and ecosystem degradation. AR and MPA (particularly no-take zones) represent efficient tools for marine resources management and can maintain a sustainable development of fisheries and fishermen. In a general context of high fishing pressure, AR and MPA are good tools for the organization and management of activities on the coastal band. Because of the lack of respect of regulations and lack of repression, the PMCB implemented antitrawling reefs, which have been very efficient and allowed a better sharing of space and resources because of the decreasing fishing pressure on the coastal band with the removal of trawling activities offshore. These protection reefs are good tools for the preservation of priority habitats as defined by Natura 2000.

However, ARs are not a miracle tool. They represent only one facet of the overall management, which must take into account all phases of the life history of the over-fished species and more especially their spawning areas and nurseries. In the actual context of rule changes in Europe, with new management of fisheries (Common Fisheries Policy, CFP) and the implementation of the ecological network Natura 2000, ARs are well-adapted tools for integrated management of coastal marine resources and sustainable fisheries.

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