MARINE PROTECTED AREAS: A TOOL FOR COASTAL AREAS MANAGEMENT

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Abstract

Marine biodiversity is threatened by human impact. Though few marine species are regarded as being extinct due to Man, many species are critically endangered (e.g. the monk seal Monachus monachus), endangered (e.g. the Mediterranean giant limpet Patella ferruginea) or vulnerable, i.e. dwindling rapidly, although not threatened with extinction in the immediate future (e.g. the large mollusk Pinna nobilis). There are also threats to ecosystems (ecodiversity), such as, in the Mediterranean, the Lithophyllum byssoides rim and the seagrass Posidonia oceanica meadow. Marine Protected Areas (MPAs) were initially established to protect biodiversity via the removal of human exploitation and occupation. However, since the 1970s, the notion of MPA has moved on to a more general concept of nature conservation, then to a more dynamic one of nature management, within the framework of sustainable development. Today, the aims of MPAs are therefore six-fold: nature conservation, public education, reference areas for scientific research, tourism, export of fish eggs, larvae and adults to adjacent areas and finally management of the various uses of the sea (e.g. commercial fishing, recreational fishing, pleasure boating and tourism) in such a way that they do not conflict with each other or with conservation aims. Mediterranean MPAs, especially the Port-Cros National Park, illustrate the fact that they are rather characterized by the management of human activities than by a set of prohibitions and that there is no negative interaction between biodiversity conservation and artisanal fishing (i.e. small-scale commercial fishing), at least in the way it is done (i.e. with additional constraints to general regulations: mesh size, prohibition of trawling and long-lining, etc.). Consequently, MPAs are generally of benefit to the economy (e.g. commercial fishing and tourism industry), not only within MPAs but also in adjacent areas. They therefore constitute a powerful tool for integrated coastal management.
1. Introduction

The erosion of biodiversity (e.g. species diversity and ecosystem diversity) constitutes a major concern, both in the terrestrial and marine realm. The establishment of protected areas banning human activities was, from an historical point of view, the earliest response to their impact.

Today, especially with regard to the marine environment, the approach has totally changed. In the present paper, on the basis of examples mainly drawn from the experience of a Mediterranean Marine Protected Area (MPA), the Port-Cros National Park, we show that the efficiency of MPAs does not lie in the \textit{a priori} prohibition of human activities but in their management, in such a way that they no longer conflict with each other or with nature conservation goals.

In the mind of the general public, MPAs are still often perceived as areas preserved from human presence. Here, we show that they actually constitute powerful economic tools, both for artisanal (i.e. small-scale) commercial fisheries and for the tourism industry.

2. The need for Marine Protected Areas

2.1. Marine biodiversity

\textbf{Biological diversity} (biodiversity) means the variety among living organisms from all sources including, \textit{inter alia}, terrestrial, marine and other aquatic ecosystems and the complexes of which they are part. This includes: diversity within species, diversity between species, genera, families, phyla, etc., diversity between ecosystems, diversity between landscapes and functional diversity. Ecosystem diversity is often referred to as "ecodiversity". Within species diversity, one may distinguish \textbf{point diversity} (species number within a sample), \textbf{\(\alpha\) diversity} (species number within a habitat or ecosystem in a given region), \textbf{\(\beta\) diversity} (the species turnover between adjacent habitats or sections of coastline), \textbf{\(\gamma\) diversity} (the number of species of a region, either defined on a political, geographical or biogeographical basis) and \textbf{\(\epsilon\) diversity} (the number of species of a large geographical area, e.g. the Mediterranean basin) [62, 63]. There is no link between these levels of species diversity. For example, \(\alpha\) diversity may be high and \(\gamma\) diversity low. Human impact may locally increase \(\alpha\) diversity while diminishing \(\gamma\) diversity [81].

The overwhelming value of biodiversity, as an indication of environmental health and for the functioning of the biosphere, is now widely recognized, not only by academic scientists, but also by the mass media, decision makers and public opinion [82, 116].

Unfortunately, marine biodiversity has received only a very small fraction of the attention devoted to terrestrial environments. Not only do the species definitely recorded clearly represent only a small part of those that actually occur [46, 88, 107, 108], but the present status (how many? where? on the increase or on the decrease?) of most of them is poorly known [20, 23], with the exception of a few emblematic taxa (e.g. sea mammals, sea turtles, seagrasses, some fishes).

Rating the relative importance of human impact on biodiversity requires that the time needed for the impact to be reversed be taken into account (Alexandre Meinesz \textit{in} [24]): one day to one month, one month to one year, one year to ten
years (e.g. most of pollution events, including oil spills), ten years to one century (e.g. destruction of long-living species), one century to one millennium (e.g. destruction of the seagrass *Posidonia oceanica* meadow in the Mediterranean Sea) and finally more than one millennium, i.e. irreversible at human scale. Coastal development, species introduction and species extinction are so the greatest cause of concern, due to their irreversibility [25, 114].

### 2.2. Erosion of marine species diversity

The realization that marine species may become extinct is relatively recent. For example, in 1809, the French naturalist Jean-Baptiste de Lamarck wrote: "*Animals living in the water, especially the sea waters, are protected against the destruction of their species by man. Their multiplication is so rapid and their means of evading pursuit or traps are so great that there is no likelihood of his being able to destroy the entire species of any of these animals*" (translated from French). Along the same lines, in 1883, Thomas Huxley said (Address to the International Fisheries Exhibition in London): "*Any tendency to overfishing will meet with its natural check in the diminution of the supply (...), this check will always come into operation long before anything like permanent exhaustion has occurred*" [26, 61, 141]. Yet several marine species had already become extinct by that time (see below).

Species are classified as follows: extinct, extinct in the wild (only present in zoos or botanical gardens), threatened (either critically endangered, endangered, vulnerable or rare), of lower concern (i.e. whose populations seem to be in a normal state) and data deficient (i.e. whose present day status is unknown) [86, 87].

Modern day **extinctions** (neoeextinctions) are for the most part due to human impact, as opposed to geological "natural" extinctions (paleoextinctions) [43]. A taxon is considered to be extinct when there is no reasonable doubt that the last individual has died, i.e. when individuals have not been located in the wild over a period of 50 years [86, 110].

Recent extinction rates in well documented groups (mammals and birds) are one hundred to one thousand times faster than the average background rates [10, 108]. Looking towards the immediate future, likely extinction rates of a factor of ten thousand above background can be expected. This represents a sixth great wave of extinction, fully comparable with the five major mass extinctions (the "Big Five") of the geological past: late Ordovician, late Devonian, late Permian, late Triassic and end-Cretaceous. However, this time it is different in that it results from the activities of a single other species, rather than from external environmental changes [16, 17, 108].

In contrast with terrestrial environments, very few marine species are regarded as being extinct. Examples are the Rhodobionta *Vanvoorstia hemetiana*, the eelgrass limpet *Lottia alveus*, the rocky shore limpet *Colisella edmitchelli*, the periwinkle *Littoraria flavescens*, the horn snail *Cerithidea fuscata*, the Galápagos damselfish *Azurina eupalama*, the auk *Pinguinus impennis*, in the North Atlantic ocean (extinct in 1844), Steller's sea cow *Hydrodamalis gigas* in the eastern Pacific (extinct in 1768) and the Caribbean monk seal *Monachus tropicalis* [11, 40, 43, 65, 105, 115, 123, 141].

However, it is of interest to note that, if the definition of extinct species is applied (species that have not been located in the wild over a 50 year period), there
may be hundreds of species of invertebrates or macrophytes that have not been recorded since the 19th century or the early 20th century. Are these species extinct, or is it simply an artefact due to the poor knowledge of many groups of marine organisms? We may have lost many more species than we suspect ("cryptic extinctions" [43]), and the expected extinction of the systematists will not make it easy to answer this question. As foretold by Carlton [43], "the future historians of science may well find that a crisis that was upon us at the end of the 20th century was the extinction of the systematist, the extinction of the naturalist, the extinction of the biogeographer – those who would tell the tales of the potential demise of global marine diversity".

The Mediterranean monk seal Monachus monachus was formerly widespread around the whole Mediterranean Sea, the Black Sea and the Western Atlantic. It has become extinct in most of its range area. To date, according to the WWF, it is one of the ten species in the world that are most threatened with extinction (critically endangered species). It shares this status with inter alia the tiger Panthera tigris, the giant panda Ailuropoda melanoleuca, the Javan rhinoceros Rhinoceros sondaicus and the Indus river dolphin Platanista minor. During the last 25 years, the total number of monk seals has dropped from 1,000 to about 300 individuals, and of these 150-200 (a rather optimistic census) are in the Mediterranean [3, 102, 103, 128, 131]. The reasons for the monk seal's decline are (i) the reduction of its natural habitat (beaches, caves) because of coastal development and tourism [119], (ii) overfishing of the fish stock on which it feeds, which leads to individuals being scattered and stealing fish from fishers' nets [31, 32], and (iii) its being destroyed by fishers [89]; this destruction is a consequence of the previous point. Despite hundreds of public awareness leaflets, legal protection in most of the Mediterranean countries and an impressive series of international Conventions aimed at its protection (e.g. Washington, Bern and Barcelona Conventions), the monk seal is still on the decline in the Mediterranean. This emphasizes the limited efficiency of legal protection of a species, when habitat and feeding resource are not preserved. The only site where a small population is on the increase is the Portuguese Island of Madeira, within a Marine Protected Area [42, 48, 124].

**Endangered species** are species which have disappeared from fairly extensive sectors and are threatened with extinction. However, in contrast with critically endangered species, strong protection measures are likely to save them. For example, a mollusk, the giant limpet Patella ferruginea, is on the brink of extinction. Formerly widespread throughout the western Mediterranean, where it is an endemic, it now only survives in sparse populations in Corsica, Sardinia, Tunisia, Algeria and southern Spain [30, 95, 96, 97, 126, 145]. Its decline has accelerated over the last 15 years. The reason for the disappearance of this large species (sometimes over 10 cm in diameter), which lives in the midlittoral zone (i.e. slightly above mean sea level), is its being gathered by humans either for consumption or for use as bait. In addition, individuals are male up to 4 cm in diameter and then become female; human gathering mainly hits larger individuals, i.e. female ones [57]. Finally, juvenile individuals often settle on adults, so that gathering adults may also remove juveniles [94]. In the Scandula marine Reserve (Corsica), the decline of Patella ferruginea is still going on (Table I). The reason might be that the prevailing current, running south to north, which comes from areas devoid of giant limpets, does not brings larvae into the reserve. As far as larvae produced by the individuals harbored by the reserve are concerned, they are
swept along by the current to outside the reserve [98]. The fate of *P. ferruginea* illustrates the fact that protection of the habitat may prove to be inefficient, if the size of the protected area is small, which is the case of the Scandula marine Reserve.

Table I. Decline over time of the mean density of the giant limpet *Patella ferruginea* in two sites of the Scandula marine Reserve (Corsica). md = missing data. From [98].

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean number of individuals per 100 m of shoreline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northern shore of Gargallo cape</td>
</tr>
<tr>
<td>1983</td>
<td>md</td>
</tr>
<tr>
<td>1984</td>
<td>56</td>
</tr>
<tr>
<td>1987</td>
<td>md</td>
</tr>
<tr>
<td>1992</td>
<td>24</td>
</tr>
</tbody>
</table>

**Vulnerable species** are species which are still relatively common but whose populations are dwindling rapidly, although not threatened with extinction in the immediate future. Examples of species experiencing a steady and severe decline, at least in some parts of the Mediterranean, are the Stramenopiles (*Fucophyceae*) *Cystoseira amentacea*, *C. mediterranea*, *C. spinosa* and *C. zosteroides* [9, 13, 18, 38], the Mollusks *Pinna nobilis*, especially in the north-western Mediterranean [146], *Luria lurida* and *Zonaria pyrum*, the seahorses *Hippocampus ramulosus* and *H. hippocampus* [38, 106], the dusky grouper *Epinephelus marginatus* in the north-western Mediterranean [44] and the sea-turtle *Caretta caretta* [64].

The noble pen shell *Pinna nobilis* is the largest Mediterranean mollusk: it can reach a size of up to 100 cm and its life span exceeds 20 years [146, 147, 152]. In the north-western Mediterranean, large adults are exceedingly rare, with mean densities of less than one individual per hectare [134]. The reasons for the decline of *P. nobilis* are: (i) Collection by divers for souvenirs. (ii) Gathering for human consumption (locally) and to feed fishes in fish farms (in Turkey). (iii) Breaking of shells by trawling. (iv) The decline of its main habitat, the meadows of the seagrass *Posidonia oceanica* (see below) [38, 146, 152].

The dusky grouper *Epinephelus marginatus* is unquestionably the most popular of littoral fish along the western Mediterranean coasts [70]. In the north-western Mediterranean, from Catalonia to Italy, it was common until the 1950s, but subsequently underwent a dramatic decline. In the 1980s, a very few individuals (only adults) survived in this area, probably migrants from southern areas [44]. Spear fishing and life traits were clearly the main reasons for this local near-extinction: (i) *Epinephelus marginatus* is rather easy to spear, due to its escape behavior to crevices, and is therefore very vulnerable to spear fishing. (ii) It is a long living species: up to 50 years. First sexual maturity is reached when individuals are 5 years old (40-50 cm long). (iii) It is a protogynous hermaphrodite. Young individuals are female. Sex reversal occurs mainly when they are 14-17 years old (80-90 cm long): so older individuals are male. (iv) Finally, spawning is a very complex process which requires many individuals (reproductive aggregations) [38, 39, 44, 150, 151]. Since the late 1980s, some marine protected areas (MPAs; e.g. Medes Islands, Port-Cros, Scandula and Lavezzi Islands) have made possible the recovery of dense populations of *E. marginatus*, harboring both females and males, so that since the early 1990s,
spawning events have been not uncommon within these MPAs. In addition, the spear fishing of this species has been prohibited in France since 1993. Since then, juveniles and subsequently adult dusky groupers have been observed outside the MPAs. Spear fishermen often say: "The dusky grouper's recovery is not a consequence of the banning of spear fishing, but of the current warming of the Mediterranean Sea". The surface temperature of the Western Mediterranean did indeed rise (0.5-1.0°C) between the early 1960s and the late 1990s [19]. However, the dusky grouper was fairly common along the French coasts before the current warm climatic episode, which means that warming cannot explain its recovery, even if it may contribute to enhancing it.

2.3. Erosion of the marine biodiversity

In the Mediterranean, the main threatened communities are the intertidal rims built by Lithophyllum byssoides (Rhodobionta), the Neogoniolithon brassica-florida (Rhodobionta) reefs, the vermetid (Gastropoda) platforms, the subtidal Posidonia oceanica seagrass meadow, several particular types of the Posidonia oceanica meadow (in particular barrier-reefs) and the coralligenous, a deep scaphilid community built by encrusting calcareous Rhodobionta [28, 33, 34, 92, 112, 114].

The Lithophyllum byssoides rim is sensitive to pollution (especially hydrocarbons). The rims have died in French Catalonia, in the area of Marseilles (France) and in the Gulf of Palermo (Sicily): bio-erosion (perforating organisms) no longer being compensated for by bio-construction, the rims are progressively eroded and end up disappearing [93, 135]. Bearing in mind the slowness with which they are built up, this disappearance must be considered irreversible from the human point of view (even when the causes of its death are believed to have been removed).

Vermetid platforms are vulnerable to domestic pollution, low salinity rainwater and oil slicks. Sediment laden waters, as a consequence of coastal development (urbanization or construction of coastal roads), may kill vermetid formations by siltation [28, 92]. In addition, over-frequent walking over by tourists and amateur fishermen damage the vermetids [28].

The Posidonia oceanica meadows have dwindled considerably, in particular in the vicinity of the large urban centers. They are dwindling both at their lower limit (rising because of the water turbidity and the resulting deficit in light) and at intermediate depths. In Italy, Ligurian meadows have lost about 10-30% of their surface area [21]. In the Alicante region (Spain), 52% of the surface area has been lost [130]. In Marseilles (France), close to 90% of the meadows mapped by Marion in 1883 [104] have today disappeared. The causes are as follows [33, 34, 120, 121]: (i) Industrial and urban pollution (P. oceanica is very sensitive to this), in particular detergents and nutrients [6]. (ii) Turbidity, in reducing the limpidity of the water and the penetration of light to the deep. Phytoplanktonic blooms, whose intensity is accentuated by eutrophy, have the same impact. The result is a rising of the lower limit. (iii) Mooring of small boats [27]. (iv) Trawling. In the area of Alicante (Spain), it is responsible for almost half the surface area diminution in the meadow [130]. (v) Coastal development: ports, artificial beaches and reclamations over P. oceanica meadows [113]. (vi) Alteration of the sediment flow. A groyne perpendicular to the coastline results in relation to coastal drift in upstream hypersedimentation and a shortage in sediment (with baring of the rhizomes) downstream. The average maximum growth of orthotropic rhizomes being around
5-7 cm per year [29], the vegetative apexes are buried and die if the annual sediment input exceeds 5-7 cm. On the other hand, the bared rhizomes are vulnerable to water movement and to trawling. In both cases, the *P. oceanica* meadows can be destroyed.

Reduction in limpidity in waters (pollution, turbidity) and silting constitute the main threats to the *coralligenous community*. It is worth adding, locally, the over-frequent visits by scuba divers: erosion by contact of coralline Rhodobionta and Bryozoa (*Retepora* in particular), non-intentional breaking of gorgonians by beginners and deliberate tearing off of the red coral *Corallium rubrum* and the gorgonians *Eunicella* and *Paramuricea* [71, 76, 142].

Outside the Mediterranean, major threats concern tropical mangroves and coral reefs [58, 141, 143].

3. The early concept of protected areas

![Diagram](image)

**Fig. 1.** Protected areas (e.g. 1 through 3) seen as "islands" of nature and tranquility surrounded by incompatible resource uses. Black arrows: negative impacts.

Until the late 1960s, the key concept behind protected areas was that they were areas not materially altered by human exploitation or occupation, and that steps should be taken by the competent authority to prevent or eliminate exploitation or occupation. So protected areas were seen as "islands" of nature and tranquility surrounded by incompatible resource uses [109, 127]. Yet such an "island" mentality is fatal in the long term because protected areas will not be able to conserve biodiversity if they are surrounded by degraded habitats that limit gene-flow, alter nutrient cycles, provide invasive species and cause regional climate change which may ultimately lead to the disappearance of these "island parks" (Fig. 1) [109].

Invasive species clearly illustrate this problem. The park boundary of the Port-Cros National Park (France) offered no protection from the immigration of *Caulerpa taxifolia* (Chlorobionta, Plantae), once it was present along the coasts of the French Riviera [35, 49, 137, 138].

4. The modern concept of protected areas

Since the 1970s, the notion of protected areas has moved on to a more general concept of nature conservation, then to a more dynamic one of nature
management. Protected areas therefore need to be part of a broader regional approach to land (and sea) management [2, 26, 109, 127]. Furthermore, it is recognized that conserving nature requires a flexible approach in which local people should not to be excluded a priori. This new perspective was first given full legitimacy in the World Conservation Strategy [85] and was developed into practical advice at the 3rd World National Parks Congress, held in Bali, Indonesia, in October 1982. The title of the congress proceedings ("National parks, conservation and development: the role of protected areas in sustaining society") gives a clear indication of the new direction being advocated [109]. This approach (sustainable development) was then popularized and formalized at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992: "That range of activities and development which enables the needs of the present generation of humans and all other species to be met without jeopardizing the ability of the biosphere to support and supply the reasonably foreseeable future needs of humans and all other species". Sustainable development is thus a 4-corner concept (Fig. 2)

![Diagram of the 4-corner concept of sustainable development](image)

Fig. 2. The 4-corner concept of sustainable development. There is a symbiosis between meeting the needs of humans and those of other species, i.e. meeting the needs of other species helps supply those (economic, sociological and cultural) of humans.

Nowadays, the aims of the Marine Protected Areas (MPAs) are six-fold. (i) To set up conservatories for threatened species and habitats. (ii) To provide sites for public education on the environment (e.g. underwater nature trails, public information leaflets). (iii) To provide reference areas for scientific research. (iv) To provide attractive landscapes for tourism (bathing, pleasure craft, snorkeling, diving). (v) To establish no-take areas where fish density and sex-ratio make mating and spawning possible, and which subsequently export eggs, larvae and adults to surrounding unprotected areas and therefore enhance catches by fishermen. (vi) To manage the different uses of the sea (e.g. commercial fishing, recreational fishing, pleasure boating and tourism) in a rational way, so that they do not conflict with each other or with conservation aims [2, 26, 52, 56, 101, 140, 144].

Marine Protected Area are often perceived by the public at large as well as by the stakeholders and other users of coastal areas as a burdening collection of prohibitions. Possible constraints generated by a MPAs are as follows: (i) Prohibition of non-commercial collecting of fauna and flora. (ii) Prohibition of spear fishing. (iii) Prohibition of recreational angling. (iv) Prohibition of all forms, or only some forms (e.g. trawling), of commercial fishing. (v) Prohibition of scuba diving. (vi) Prohibition of pleasure craft mooring and anchoring. (vii) Prohibition
of boating. (viii) Prohibition of bathing [24]. According to these constraints, 5 levels can be distinguished (Table II). Usually, the area of a MPA is zoned in such a way that most MPAs include several levels (Fig. 3). It is worth noting that, even when there are no apparent differences in the regulations existing inside (level 1) and outside (level 0) an MPA, a major difference does exist: MPAs are usually the only sites where existing legislation is enforced (e.g. mesh size and prohibition of trawling close to the shore).

Table II. The levels of constraints outside (level 0) and within (levels 1 through 5) Marine Protected Areas. + = prohibited. - = non-prohibited. From [24].

<table>
<thead>
<tr>
<th>Prohibition</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection of fauna and flora</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+/- a</td>
</tr>
<tr>
<td>Spear gun fishing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recreational angling</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Commercial fishing</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scuba diving</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pleasure craft mooring and anchoring</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Boating</td>
<td>+/-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bathing</td>
<td>+/-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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</tbody>
</table>

(a) Depending upon local or national legislation. (b) Trawling sometimes prohibited.

Fig. 3. An MPA with zones at different levels of constraints (1 through 5).

In fact, with the exception of spear fishing, prohibitions usually concern only a small part of the MPA surface area. For example, if we consider the French Mediterranean Marine Protected Areas, commercial fishing is only banned in 7% of the total MPA surface area (Table III). This is the case in the Port-Cros National Park: artisanal fishing (i.e. small-scale commercial fishing) is possible in most of the area (1380 ha), with the exception of a few hectares (Fig. 4, 5) [26].
Fig. 4. Regulation in the Marine Protected Area of Port-Cros National Park (Provence, France, Mediterranean Sea). Spear fishing is prohibited in the whole area. Artisanal fishing authorized everywhere, with the exception of bathing areas. Constraints to artisanal fishing: general legislation + wider mesh size, limited number of gear types per fisher, prohibition of trawling and restriction of hook use (long-lining included) to some sites and places. From Parc national de Port-Cros in [26].

Fig. 5. Localization (red lines) of fishing nets in the Port-Cros National Park, between March and September 2001. Cumulated data from 63 daily surveys. From [41].
Table III. Main prohibited activities within French Mediterranean Marine Protected Areas, as a percentage of the total surface area (nearly 9,000 ha). From [79].

<table>
<thead>
<tr>
<th>Prohibited activity</th>
<th>Percentage of the total surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchoring of pleasure boats</td>
<td>7%</td>
</tr>
<tr>
<td>Artisanal commercial fishing</td>
<td>7%</td>
</tr>
<tr>
<td>Scuba diving</td>
<td>17%</td>
</tr>
<tr>
<td>Recreational fishing (angling)</td>
<td>20%</td>
</tr>
<tr>
<td>Recreational fishing (spear fishing)</td>
<td>100%</td>
</tr>
</tbody>
</table>

5. Marine protected areas and coastal management

As far as fisheries are concerned, Marine Protected Areas can provide four basic benefits [91, 148]: (i) Protection of critical functions (such as spawning grounds, feeding grounds), (ii) protection of specific life stages (juvenile settlement, nursery grounds), (iii) provision of spillover of exploited species and (iv) provision of dispersion centers for supply of eggs and/or larvae (stock enhancement).

5.1. Interactions between artisanal fishing and nature conservation

The question which arises is twofold. Firstly, taking into account the constraints that characterize the practice of artisanal fishing within an MPA like Port-Cros National Park, does this activity threaten one of the major MPAs' aims, nature conservation? Answering this question is of great concern since artisanal fishing is an activity that is profoundly rooted in Mediterranean customs and traditions. Secondly, do the constraints imposed on artisanal fishing hinder that activity, for example reduce the fishing effort, catch per unit effort (CPUE) and/or catch per surface area unit?

Benthic ecosystems in the Port-Cros National Park are healthy and habitat diversity is well preserved: e.g. meadows of the seagrass Posidonia oceanica, the coralligenous and sea-cave communities, and Cystoseira forests [5, 15, 73, 74, 83, 100]. Species diversity of macrophytes, invertebrates and fish is high [14, 55, 69, 80, 83, 118]. Of course, natural fluctuations may affect these populations, as a result of e.g. warm water episodes and diseases [7, 36, 59, 76, 122]. As far as emblematic species are concerned, the brown meager Sciaena umbra is not uncommon (1-4 individuals/ha) though less abundant than in other Mediterranean MPAs [75]. The population of the dusky grouper Epinephelus marginatus is in steady expansion1 (Table IV) [72, 77, 78]. The mean density of the noble pen shell Pinna nobilis is 9-11 individuals/ha (adults), with much higher density, 100 individuals/ha, within its preferred habitat, the Posidonia oceanica meadow [111]. In non-protected areas of the north-western Mediterranean, mean adult density is less than one individual per hectare [134]. The success of Port-Cros as a hot-spot for scuba diving confirms the quality of its species, habitat and landscape (seascape) diversity, in particular fish density, which is particularly appealing for divers. All in all, on the basis of present day knowledge of Port-Cros biodiversity, it cannot be claimed that artisanal fishing, in the way it is done (see caption to Fig. 4), seriously hinders one of the aims of the MPA, biodiversity conservation.

1 Clearly, the prohibition of spear fishing, together with restriction of long-lining and the banning of trawling play a major role in the expansion of Epinephelus marginatus population.
Table IV. Patterns of change over time of the population (number of individuals) of the dusky grouper (*Epinephelus marginatus*) of the Port-Cros National Park (ca 14 km², France, Mediterranean Sea), censused visually by snorkeling and scuba diving. md: missing data.

<table>
<thead>
<tr>
<th>Year</th>
<th>Gabinière Island</th>
<th>Other sites</th>
<th>Total</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>7</td>
<td>8-11</td>
<td>15-18</td>
<td>unpublished data in [72]</td>
</tr>
<tr>
<td>1983-1987</td>
<td>23-28</td>
<td>md</td>
<td>md</td>
<td>[139]</td>
</tr>
<tr>
<td>1988-1989</td>
<td>29-34</td>
<td>md</td>
<td>md</td>
<td>[66]</td>
</tr>
<tr>
<td>1993</td>
<td>34</td>
<td>52</td>
<td>86 (100*)</td>
<td>[72, 77]</td>
</tr>
<tr>
<td>1996</td>
<td>84</td>
<td>76</td>
<td>160</td>
<td>[72, 77]</td>
</tr>
<tr>
<td>1999</td>
<td>156</td>
<td>143</td>
<td>299</td>
<td>[77]</td>
</tr>
<tr>
<td>2002</td>
<td>210</td>
<td>200</td>
<td>410</td>
<td>[78]</td>
</tr>
</tbody>
</table>

*Estimate.*

To answer the question in reverse (i.e. do the constraints imposed on artisanal fishing within an MPA hinder that activity?) is more difficult. In the northwestern Mediterranean Sea, as well as in most coastal areas worldwide, quantitative data on artisanal fishing are scarce and quite difficult to compare, due e.g. to differences in the methods used, the sampling season, the type of gear taken into account, the target species and to the importance, usually unknown, of other catches (recreational fishing, trawling) and the target stock. In addition, the surface area of the regions studied is not a reliable datum, since it may include areas not suitable for artisanal fishing. In Port-Cros waters, the mean number of fishers was, in summer, 1.8/d in 2000 and 2.8/d in 2001 [41]. The fishing effort can be better estimated on the basis of the length of nets, or the number of 100 m net sections, per day and per ha (Table V). Comparison between Port-Cros MPA and the non-protected surrounding area shows that fishing effort is not lower, and may be higher, within the former than in the latter [41, Guerin, unpublished data]. As far as CPUE (catch per unit effort) is concerned, on the basis of available data, fish yield cannot be considered as lower at Port-Cros than in non-protected areas (Table V).

As a result, as far as the Port-Cros MPA is concerned, it seems that there is no negative interaction between biodiversity conservation and artisanal fishing within a MPA, at least in the way it is done there (see constraints in the caption to Fig. 4). This may be also the case in other Mediterranean MPAs (Table V).

5.2. Possible reasons for the absence of negative interaction

In the Mediterranean, which accounts for one third of total world tourism, recreational fishing catches, whether it be by spear fishing or angling, are far from negligible (2.8-8.4 t/km²/a; Table VI) as compared to those of the artisanal fishing industry (1.9-6.2 t/km²/a) [1, 18, 50, 51, 60], even if it must be emphasized that recreational fishing concerns a much smaller surface area than artisanal fishing. The overlap between the catches from spear fishing and angling is usually weak. In contrast, the overlap between recreational and artisanal fishing may be significant [51, but see 53].

At Port-Cros Island, spear fishing has been prohibited since the establishment of the National Park in 1963. Since 1999, angling has been prohibited from the coast to the offshore limit of the park marine area (East and South) and from the coast to 50 m offshore (North and West) (Fig. 4). If one considers catches from recreational fishing in other coastal areas, this prohibition can be seen to significantly relieve the fishing pressure on the Port-Cros fish stock.
Table V. Data on artisanal fishing in some localities of the French Mediterranean coast. Fishing effort: number of 100 m net sections per ha and per year (or day). CPUE: catch per unit effort, i.e. kg per 100 m of fishing net and per day (= per outing). md: missing data. upd: unpublished data.

<table>
<thead>
<tr>
<th>Locality</th>
<th>MPA</th>
<th>Surface area</th>
<th>Fishing effort</th>
<th>CPUE</th>
<th>Total catch</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Côte Bleue (Provence)</td>
<td>No *</td>
<td>13 km²</td>
<td>0.07 ha/d (summer)</td>
<td>0.7-2.5 kg/100 m/d (summer)</td>
<td>md</td>
<td>[53]</td>
</tr>
<tr>
<td>Côte Bleue (Provence)</td>
<td>No *</td>
<td>-</td>
<td>md</td>
<td>0.7 kg/100 m/d (summer)</td>
<td>md</td>
<td>[90]</td>
</tr>
<tr>
<td>Riau Archipelago (Provence)</td>
<td>No</td>
<td>21 km²</td>
<td>13.3 ha/a</td>
<td>md</td>
<td>md</td>
<td>[18]</td>
</tr>
<tr>
<td>Port-Cros (French Riviera)</td>
<td>Yes</td>
<td>14 km²</td>
<td>6.4 ha/a</td>
<td>1.2 kg/100 m/d (April)</td>
<td>19.3-1.2 kg/ha/a (April)</td>
<td>[51, 67, Guerin, upd]</td>
</tr>
<tr>
<td>Galeria-Ghiziroulate (Corsica)</td>
<td>Yes</td>
<td>md</td>
<td>md</td>
<td>1.1 kg/100 m/d (March)</td>
<td>md</td>
<td>[59]</td>
</tr>
<tr>
<td>NW Corsica</td>
<td>No *</td>
<td>md</td>
<td>md</td>
<td>0.9 kg/100 m/d</td>
<td>md</td>
<td>[136]</td>
</tr>
<tr>
<td>Lavezzi Islands (Corsica)</td>
<td>Yes</td>
<td>37 km²</td>
<td>7.9 ha/a</td>
<td>0.8-0.9 kg/100 m/d</td>
<td>md</td>
<td>[50]</td>
</tr>
<tr>
<td>Berlatozu arraitus (Corsica)</td>
<td>Yes</td>
<td>80 km²</td>
<td>1.4-2.9 kg/100 m/d</td>
<td>md</td>
<td>md</td>
<td>[5d]</td>
</tr>
</tbody>
</table>

* An MPA is present in the vicinity ("Parc Marin de la Côte Bleue"). * Calculated from the author's data. * Based upon [67]. * Year 2001. * Only target species. Conger conger and Muraena helena, for example, are not taken into account. * Under-evaluation: value based upon the fishing log books of 6 out of the 9 fishers who were observed fishing in Port-Cros waters.

Table VI. Catches from recreational fishing. The studied surface area or shore length are mentioned (in brackets). md: missing data.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Spear fishing</th>
<th>Angling from the shore</th>
<th>Angling from a boat</th>
<th>Total recreational fishing</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayol-Canadel (French Riviera)</td>
<td>1.3 (2.4 km²)</td>
<td>&lt; 0.1 (7.5 km)</td>
<td>0.2 (7.5 km²)</td>
<td>2.8</td>
<td>[45]</td>
</tr>
<tr>
<td>Port-Cros MPA (French Riviera)</td>
<td>Prohibited</td>
<td>0.2 (26 km)</td>
<td>0.4 (14 km²)</td>
<td>8.4</td>
<td>[47]</td>
</tr>
<tr>
<td>Riau Archipelago (Provence)</td>
<td>1.3 (8.5 km²)</td>
<td>0.1 (26 km)</td>
<td>1.3 (21 km²)</td>
<td>6.3</td>
<td>[51]</td>
</tr>
<tr>
<td>Riau Archipelago (Provence)</td>
<td>md</td>
<td>md</td>
<td>md</td>
<td>md</td>
<td>[22]</td>
</tr>
<tr>
<td>Cerbère-Banyuls MPA (French Catalaunie)</td>
<td>Prohibited</td>
<td>0.1 (5 km)</td>
<td>0.5-1.1 (5.8 km²)</td>
<td>4.5-5.1</td>
<td>[4]</td>
</tr>
</tbody>
</table>

* Exact value: 0.033 t/km/a. * At places where the different types of recreational fishing coexist, and assuming that angling from the shore concerns a 25 m wide littoral belt. * Calculated from the author's data. * Later on (1999), angling from the shore was banned and angling from a boat restricted to some areas (see Fig. 4). * A lower value is mentioned by [51], due to miscalculation.

Furthermore, it must be emphasized that an apex predator, the monk seal Monachus monachus, was formerly present in the area of Port-Cros National Park [102, 103]. In the absence of this fish-eating seal, a no-take area for artisanal fishermen would not represent a natural environment since the seal's preys could proliferate and cause a shift in the natural equilibrium. Fishermen may therefore contribute to mitigating the ecological impact of the monk seal's local extinction.

Finally, the actual implementation of the general legislation within an MPA, and the additional fishing constraints specific to the MPA (wider mesh size, banning of trawling, etc.), put an end to overfishing increase the fish stock and subsequently catches [e.g.149].
5.3. Marine Protected Areas enhance fishery yield in adjacent areas

A large number of littoral fish species undergo a sex change over time. Some of these are male when young, then become female. In contrast, others are initially female and subsequently become male. A consequence of these features is that, in overfished populations (Fig. 6, left), one of the sexes can either become scarce or even absent. In addition, large individuals may be lacking; the number of eggs laid by fish steadily increases with size and age, so that a young female may lay up to 200-fold less eggs than an old one. Within MPAs (Fig. 6, right), the simultaneous presence of females and males makes sexual reproduction possible and old females are present. In addition, in some species, nuptial pairing not only involves a mating pair but also requires the participation of a large number of individuals, both adults and juveniles, a process only possible when fish density is high and all age classes are present (i.e. diversified demographic structure). As a consequence, MPAs export huge amounts of eggs and larvae to neighboring areas (Fig. 6, left and center). Furthermore, due to overpopulation, individuals continuously leave the MPA to occupy unprotected adjacent areas (spillover), where they can be caught by fishermen. In this way, MPAs can substantially contribute to maintaining profitable yields in the regional fishing industry [8, 12, 37, 68, 91, 117, 125, 148]. In the Mediterranean, it has been estimated (or hypothesized) that a large number of small MPAs, 200 to 1000 ha, spaced 10 to 20 km apart, has a more positive effect than a few very large MPAs [24].

![Diagram of fish reproduction](image)

Fig. 6. Reproduction of fish, as a function of the population demographic structure in an overfished area; a Marine Protected Area (MPA) and an adjacent area. The MPA exports adults (spillover), eggs and larvae. From [37], redrawn.

Is this a more or less theoretical view, or does this work? Many concrete examples suggest that this definitely works. In Spain, three years after the establishment of the Tabarca no-take MPA (Alicante, Mediterranean), catches of high selling price fish species (e.g. Sparus aurata) increased twofold (Fig. 7) [129]. On St Lucia (Caribbean), the Soufrière Marine Management Area was set up in 1995. It encompassed a network of no-take areas (35% of coral fishing grounds). Six years later, in 2001, catch per unit effort
(CPUE) increased by 80% for small traps and by 36% for large traps; mean catch per trip increased respectively by 90% and 46%, though fishing effort remained stable [140].

![Graph showing catches by year](image)

Fig. 7. Left: Catches of artisanal (commercial) fishing in an overfished area near Alicante (Spain). Center: catches in the remaining fished area after the establishment of a no-take MPA. Right: change over time of catches of Sparus aurata. Arrow: the year of establishment of the MPA. From [129], redrawn.

The effectiveness of **larvae exportation** by a MPA was evidenced by Francour and Le Diréac'h ([in 79]) downstream of the Scandula MPA, Corsica (Table VII). The analysis of harvesting models shows that no-take MPAs are part of an optimum harvest designed to maximize yield [e.g. 68, 117].

Table VII. Evidence of fish larvae (*Diplodus annularis*) exportation from the Scandula MPA (Corsica, Mediterranean Sea). From Francour and Le Diréac'h ([in 79]).

<table>
<thead>
<tr>
<th>Current</th>
<th>Locality</th>
<th>Protection level</th>
<th>Mean juvenile density/10m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Gallizia Gulf</td>
<td>Unprotected</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>Elba Bay</td>
<td>MPA (no recreational fishing)</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Gargalu</td>
<td>No-take MPA</td>
<td>0.34</td>
</tr>
<tr>
<td>South</td>
<td>Portu Gulf</td>
<td>Unprotected</td>
<td>0.22</td>
</tr>
</tbody>
</table>

### 5.4. Marine protected Areas: a tool for integrated coastal management

Within an MPA, the zoning of the human activities, i.e. the separation of conflicting activities in specialized zones (e.g. bathing, scuba diving, pleasure boat mooring, recreational fishing) makes it possible to manage user conflicts and results in an optimization of human activities for the benefit of both stakeholders and nature conservation (Fig. 8). In this way, an MPA constitutes a scale model of what should be a regional integrated coastal management policy, including MPAs and unprotected areas.

Obviously, MPAs, together with regional integrated management of user conflicts, result in economic benefits, both for fishermen and the tourism industry, in such a way that there should no longer be a need to try to set off environmental values against economic values [8, 24, 129, 132, 133, 148]. For example, it has been estimated that the tiny (20 km² of land and sea) Port-Cros National Park, French Riviera, produces, directly and indirectly, a mean annual turnover of 300 M€ per year [26, 84]. The total gross revenue generated by the Bonaire Marine
Park (Caribbean Sea) was estimated at 23 M€ per year in 1991. This Park also generated substantial employment with up to 750 local workers and 240 foreign workers in park associated activities [91]. In Australia, the Great Barrier Reef attracts about 1.8 million tourists valued at over SA 1 000 million per year, compared to estimates of SA 360 million for the annual worth of Great Barrier Reef fisheries [91].

![Diagram](image)

Fig. 8. Integrated management of user (yellow boxes) conflicts and nature conservation within a Marine Protected Area, the Port-Cros National Park. Red arrows: negative interactions. Blue arrows: positive interactions. Black arrows: management. 1: Dissemination of introduced species (e.g. Caulerpa taxifolia); 2: Localization of introduced species stands; 3: Impact of mooring (e.g. on the seagrass Posidonia oceanica and the coralligenous community); 4: increase of fish stock; 5: competition for fish stock harvesting; 6: effect on scuba divers safety. From [26].

6. Conclusions

The concept of sustainable development means that there is a symbiosis between supplying the needs of humans and nature conservation. Accordingly, man, especially local people, should not be excluded *a priori* from Marine Protected Areas (MPAs).

Although present day scientific data related to MPAs deal more with nature conservation than with the economy, there is growing evidence that MPAs constitute a powerful tool not only for natural heritage conservation but also for economic development (tourism industry, artisanal fisheries) and regional integrated management of user conflicts, at least in temperate and warm seas.

The *à la mode* new concept of the Ecosystem Approach of Fisheries (EAF) may be considered as an offshore generalization of the MPA's experience and success story worldwide.

Many more MPAs should therefore be set up, for the benefit both of nature conservation and of economic development.
7. Acknowledgements

The authors are indebted to Nicolas Gérardin and Philippe Robert (Port-Cros National Park) for providing regulation data concerning the Port-Cros National Park, and to Michael Paul for improving the English text.

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