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SPECIES-BASED OR ECOSYSTEM-BASED APPROACHES TO CONSERVATION PRACTICES: LESSONS FROM THE PORT-CROS NATIONAL PARK (SOUTH-EAST FRANCE, MEDITERRANEAN SEA)

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BIOLOGICAL INVASIONS
CONSERVATION
CONTROL OF INVASIVE SPECIES
ECOSYSTEM-BASED APPROACH
MANAGEMENT
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ABSTRACT. – For almost 60 years, the management policy of the Port-Cros National Park (PCNP) has steadily progressed, in phase with human impacts, changes in doctrines and goals in the field of nature conservation, what was socially acceptable at a given time, a very active Scientific Council and a gradual shift from species-centered to ecosystem-based management. Here, we illustrate problems faced by a national park, together with responses or practices that are suited, or not, to an ecosystem-based approach. PCNP's doctrine has been to explain that the abundance of species fluctuates naturally, and that we must not be too hasty to intervene, that nature sometimes does things better than humans, that a national park is neither a zoo nor a botanical garden, and the purpose is not to artificially increase the species diversity. The management approach of the PCNP can constitute a source of lessons for nature protection and management.

INTRODUCTION

In the 18th century, and for centuries earlier, the prevailing approach to nature was human-centered (Boudouresque *et al*. 2020). The French naturalist Buffon felt only contempt for the environments that we now refer to as 'natural' (Buffon 1764, 1767). It is clear that, for Buffon, the ideal nature was represented by the royal gardens of Versailles, its fountains and canals, and its adjacent forest dedicated to royal hunts. This vision of nature prevailed until the 19th century. During the first two-thirds of the 19th century, the philosophy of Saint-Simon, by promising the happiness of humanity through the scientific domestication of nature, helped to reinforce this vision. In Europe and North America, the 'Acclimatization Societies', which were set up in the 19th century and persisted until the mid-20th century, aimed to make Western nations profit from the natural wonders of the world, by introducing them to Europe and North America (*e.g*., Matagne 1999, Planhol 2004, Faget 2007, Luglia 2014). The human-centered vision of nature persisted until the 20th century, in the guise of a dichotomy between useful species (for man) and pests (competitors of humanity); official lists of pests, the destruction of which was recommended, were published by European government bodies (De la Blanchère 1878, Faget 2016). It is worth noting that the interest for humans is today taken into account through the concepts of ecological goods and ecosystem services: the natural processes and component that benefit human needs (Costanza *et al*. 1997, 2014, Nordlund *et al*. 2016). The Japanese Satoumi approach based upon traditional use of the coastal waters by local people in the Edo period (1600-1868 CE) and still in use, may, in a way, be considered as a modern form of the human-centered approach (Berque & Matuda 2013, Henocque 2013, Yanagi 2013). The paroxysm of the human-centered approach was the eradication of predators (wolves, coyotes, grizzly bears), in the 19th century, in the famous Yellowstone National Park (USA). This destruction was not only the result of a naive approach by creationist do-gooders (carnivores are evil and were sent by God to punish men), but also of a naive approach to ecology. Predators are essential for the good health of their prey (see the Healthy Herd Hypothesis) and, in their absence, the Yellowstone ecosystem has collapsed. It was not until the middle of the 20th century that they were successfully reintroduced or

naturally came back, partly restoring the natural character of the Yellowstone National Park (Brussard 1992).

From the 19th century on, and especially during the last decades, environmental protection and conservation have been mainly centered on the species, or on sets of species, corresponding to the specialization of taxonomists: bats, birds, sea mammals, flowering plants, etc. Of course, these taxonomists were also, in general, environmentalists, in the sense that they were also interested in habitat (a notion which should not be confused with that of the ecosystem). Together with artists, they played a major role in the emergence of the concept of nature protection (Matagne 1999, Jaffeux 2010). Species have been divided into two broad categories. On the one hand, outstanding species, including species with 'heritage' value, which deserve attention; on the other hand, the 'ordinary' species. The notion of outstanding species, together with its heritage value, is a fuzzy concept (Gauthier *et al*. 2010, Astruch *et al*. 2012, Boudouresque *et al*. 2020). It covers: (i) rare species (either threatened or not). (ii) Threatened species, according to the IUCN Red List criteria, or IUCN-like criteria at a regional scale. The IUCN Red List is often irrelevant: the IUCN is dominated by terrestrial lobbies (*e.g*., birds, bats, flowering plants) or terrestrial-like lobbies (*e.g*., sea mammals, marine turtles); as pointed out by Thibaut *et al*. (2016a) and by Verlaque *et al*. (2019), many marine species, such as the brown algae (kingdom Stramenopiles) *Cystoseira* and *Sargassum*, although on the brink of extinction and despite being the focus of extensive scientific literature, and fully meeting the IUCN criteria, are still considered by the IUCN as DD (Data Deficient) or NE (Non-Evaluated). (iii) Species protected by national or international legislation; unfortunately, protection is sometimes irrelevant and dependent upon taxonomic lobbies (Thibaut *et al*. 2016a, Mammides 2019, Verlaque *et al*. 2019); the seagrass *Cymodocea nodosa* (Ucria) Ascherson is protected in France, while it is an opportunistic species, that benefits from habitat degradation and climate warming, and is currently in expansion. The seabird *Larus michahellis* (Naumann, 1840) is also protected, while its proliferation is due to human impact and threatens a number of other seabirds[1]. (iv) Charismatic species (including iconic species) are lovable and/or aesthetically pleasing species that enjoy a coefficient of sympathy from the general public (whether threatened or not, whether or not they play an important functional role in the ecosystem) (Dubois *et al*. 2017, Thibot et al. 2018). Dolphins are the perfect example; the common bottlenose dolphin *Tursiops truncatus* and the striped dolphin *Stenella coeruleoalba* (Meyen, 1833) are far from being threatened; there is no evidence that their populations are declining at a global scale (LC – Least Concern) and in Europe (DD – Data Deficient) (but see Baş *et al*. 2017 for *Tursiops truncatus* (Montagu, 1821)); they may even benefit locally from human impact (*e.g*., the decline of their competitors, such as sharks) (Cagnolaro & Notabartolo di Sciara 1992, Gannier 1995, Aguilar 2000, IUCN SSC Cetacean Specialist Group 2007, Baş *et al*. 2017, Braulik 2019). Whatever their actual population status, national legislations fully protect all Mediterranean dolphins.

Managers, stakeholders and environmentalists worldwide often prioritize the species-centered approach (or 'species-by-species' approach). The protection of an iconic and endearing species is obviously easier than that of tiny zooplankton species, or of parasites, although the latter may play a far more important role than the former in the functioning of 'healthy' ecosystems (Combes 2001). Within the framework of the Habitat Directive (1992) and of the Natura 2000 network of nature protection areas of the European Union (EU), the species-centered approach has been widely favored compared to the ecosystem-based approach, despite the name given to the Directive. It is worth highlighting that 'habitats', as understood by some managers, have nothing in common with ecosystems: they just correspond to the phytosociological units (Magnoliophyta) or species assemblages housing the species of interest. However, 'species-by-species' management is unrealistic, particularly when the emblematic species are either predators or prey. Obviously, the protection measures cannot lead to the increase in numbers of both predator and prey populations. The issue is that the management of natural habitats has often been driven by environmentalist 'lobbies', solely on the basis of taxonomical considerations. As every taxonomist specialist group focuses on its specific type of organism (*e.g*., marine mammals, turtles and tortoises, birds, iconic fish such as the dusky grouper *Epinephelus marginatus* (Lowe, 1834), flowering plants), the management of natural habitats sometimes results in a layering of taxon-focused protection measures. All in all, the management of natural habitats is often reminiscent of the tale of the blind men examining the elephant (Boudouresque *et al*. 2020).

With the ecosystem-based approach (EBA), we moved from the notion of species, which of course play a role in an ecosystem, to that of an ecosystem in which species participate and interact. The distinction may seem tenuous. However, it is a true revolution, as important as the shift from the human-centered approach, which characterized the 18th century and is illustrated by Buffon (1764, 1767), to the species-centered approach. The EBA has several strong points (Boudouresque *et al*. 2020). (i) It allows the inclusion of humans in the functioning of the ecosystem, in a natural way, thus evolving from the notion of ecosystem to that of social-ecological system. Humans are no longer set aside but are within the system. (ii) While the species-centered approach often just con-

[1] *Larus michahellis* is subject to a somewhat hypocritical system of 'adaptive management': although remaining protected, its populations are 'regulated' by officially mandated officials.

siders a collection of remarkable taxa, the EBA requires the construction of a framework corresponding to a conceptual model of the ecosystem. In this model, there are grounds for including even the unremarkable species (*i.e.*, species that are not rare, or threatened, or iconic). (iii) The conceptual model makes it possible to link the species together, following a network of interactions (predation, parasitism, mutualism), and to better interpret the possible fluctuations in their numbers. (iv) The conceptual model can be a stepping-stone towards analytical or numerical modeling, where flows (*e.g.*, C, N, P) between compartments are quantified. (v) The EBA also highlights the importance of tackling the coupling between adjacent ecosystems (including benthic and pelagic, terrestrial and marine ecosystems). (vi) The EBA enables the development of environmental quality indices that are much more significant and reliable than indices based on one or a few species: see *e.g.*, the Ecosystem-Based Quality Index (EBQI) for the *Posidonia oceanica* seagrass ecosystem (Personnic *et al*. 2014, Boudouresque *et al*. 2015). (vii) Invasive species constitute one of the most worrying aspects of global change, and the Mediterranean Sea is the area worldwide most hit by non-indigenous species (Galil 2008, Katsanevakis *et al*. 2013, Maxwell *et al*. 2016, Boudouresque *et al*. 2017a). Invasion issues are usually studied and managed in a single-species context: the interaction between an invasive species and a native one, the impact of an invasive species on point or alpha species diversity, etc. In fact, invasive species rarely act in isolation, but in packs; invasive species rarely have an impact on a species alone, but on entire communities; therefore, understanding their role and impact can only be achieved in the context of the whole ecosystem (Boudouresque *et al*. 2005a, 2011). (viii) Human activities (*e.g.*, fisheries, contamination) do have an impact on particular species; however, it is only within the framework of the whole ecosystem, and within its functional compartments, that these effects can be understood, managed and if possible mitigated (*e.g.*, Halpern *et al*. 2010, Cresson *et al*. 2014, Giakoumi *et al*. 2015, Ourgaud *et al*. 2015, Kincaid *et al*. 2017). Ecosystem-Based Fishery Management (EBFM) is obviously part of the EBA (*e.g.*, Rice 2005, Tudela & Short 2005).

The Port-Cros National Park (PCNP, Provence, France, Mediterranean) was established in December 1963 (Augier & Boudouresque 1973, Boudouresque 1976, Bougeant 1990). It encompassed the Island of Port-Cros and the neighboring island and islets (Bagaud Island, La Gabinière Islet and Le Rascas Islet), *i.e.*, the Port-Cros Archipelago, situated about 8 km off the continental coast of eastern Provence (Fig. 1). Together with the land areas of the island and islets, the PCNP included a 600-m wide belt of sea, corresponding to 1300 ha in surface area, surrounding the archipelago (Boudouresque *et al*. 2013). The

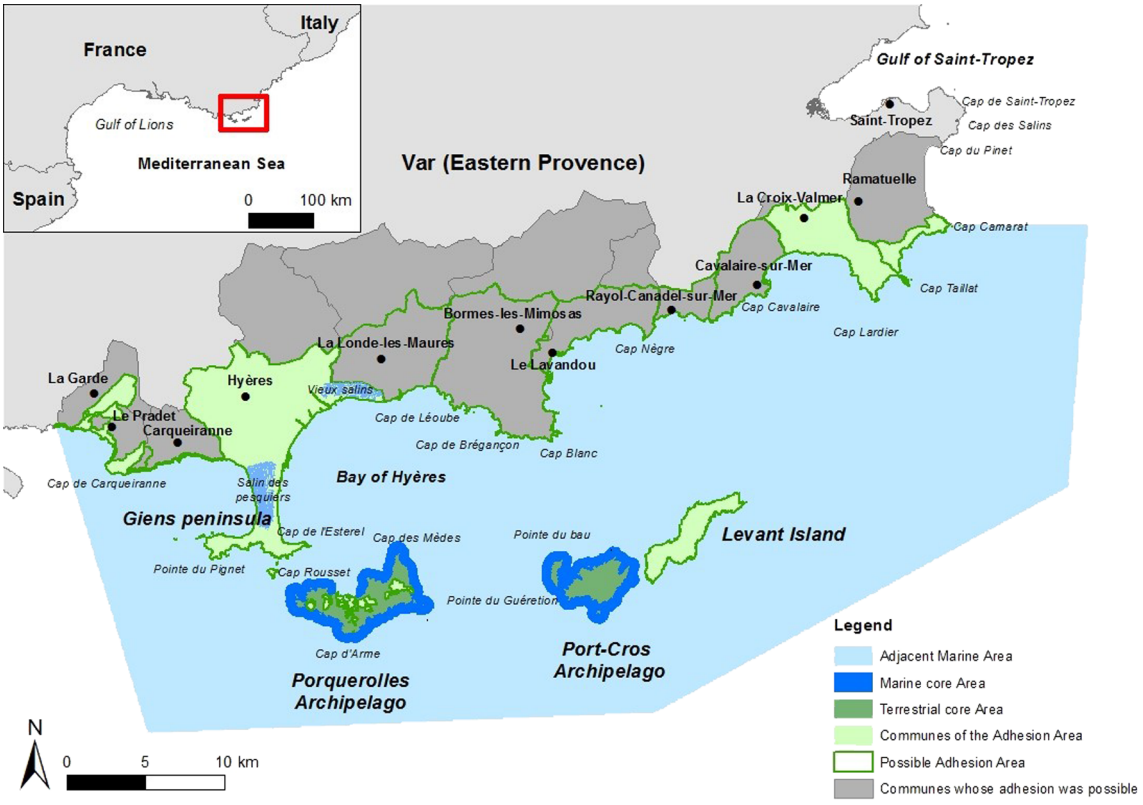

Fig. 1. – Map of the new Port-Cros National Park (N-PCNP), established in 2016. The initial PCNP, established in 1963, was restricted to the Archipelago of Port-Cros.

PCNP is one of the oldest terrestrial and marine national parks in the Mediterranean area. The oldest one is the Mljet National Park (Croatia), founded in November 1960, which stretches over 5,400 ha, including a marine area extending 500 m from the coastline (Kružić 2002).

Progressively, the PCNP has been entrusted with the management of an increasing number of territories outside the initial territory of 1963. Since 1985, the PCNP has managed the land (~950 ha), bought by the French state in 1974, situated on the neighboring island of Porquerolles. Since 1984, the park has managed the lands of the *Conservatoire de l'Espace Littoral et des Rivages Lacustres* (CERL) (Conservatoire of coastal areas and lake shores) situated at Cap Lardier, and since 1997 those situated on the island of Porquerolles (Grand Langoustier) and the Giens Peninsula (Escampobariou). Since 1999, the PCNP has run Natura 2000 for the islands of Port-Cros and Porquerolles and is the operator of Natura 2000 for the island of Le Levant and the salt marshes at Hyères. Since 2004, the PCNP provides technical and scientific support to the *Métropole Toulon Provence Méditerranée* (MTPM) for the management of the CERL territories of Les Pesquiers and Les Vieux-Salins (Barcelo & Boudouresque 2012, Astruch *et al*. 2018, 2019, Barcelo *et al*. 2018).

Following the redefinition of the national parks by French legislation in 2006, the PCNP engaged, between 2012 and 2016, in a major redefinition and extension of its territory; the new Port-Cros National Park (N-PCNP), established in 2016, includes the Port-Cros and Porquerolles Archipelagos as core areas (both terrestrial and marine), a vast Adjacent Marine Area (AMA – *Aire Maritime Adjacente*) including the Gulf of Hyères and extending seawards to the edge of the continental shelf, and a discontinuous continental area, the Adhesion Area (AA – *Aire d'Adhésion*) including five *communes* (municipalities; the *commune* is the smallest territorial division in France) (Fig. 1; Barcelo & Boudouresque 2012, Astruch *et al*. 2018, Barcelo *et al*. 2018). The *communes* of the AA have voluntarily joined the National Park, through the signing of a charter, which defines the objectives of the National Park regarding the conservation of the natural and cultural heritage and sustainable development (Thompson *et al*. 2011, Sellier 2015, Astruch *et al*. 2018, Hogg *et al*. 2018). In contrast, some *communes* of the Potential Adhesion Area (*Aire Optimale d'Adhésion*) did not wish to be part of the N-PCNP (Fig. 1).

The core area of the N-PCNP is therefore constituted by the archipelagos of Port-Cros and Porquerolles, off the coast of Provence. For almost 60 years, the management policy of the PCNP (initially restricted to the Port-Cros Archipelago) has steadily progressed, in phase with (i) changes in doctrines and goals in the field of nature conservation; (ii) what was socially acceptable at a given time; (iii) a very active scientific research background and a level of knowledge unique for Mediterranean protected areas (Farsac *et al*. 2013); (iv) improved governance, involving inhabitants, users and stakeholders (Hogg *et al*. 2016, Barcelo *et al*. 2018); and (v) a gradual shift from species-centered to ecosystem-based management. The PCNP Scientific Council, active, realistic and therefore respected and listened to by managers and stakeholders, has played an important role in this process (Barcelo *et al*. 2013a, Boudouresque *et al*. 2013).

Here, on the basis of several examples, we critically analyze earlier and recent issues faced by the PCNP, the N-PCNP and its Scientific Council, together with responses or practices that are suited, or not, to an ecosystem-based approach (EBA) (Tables I, II). It is worth noting that it was not our intention to provide a comprehensive list of the management issues faced by the PCNP and the N-PCNP over almost 60 years. Maintenance and restoration of the architectural heritage (forts dating from the 16th and 17th centuries), archaeological excavations and exploration of wrecks, such as that of *La Baleine* in the Bay of Port-Cros (*e.g*., Guérout 1981, Caron 1983, Brun 1997, Long 2004, Ruitton *et al*. 2004), have not been considered. In addition, park management cannot be considered as limited to the chosen examples and the provided possible responses; scientific investigation, long-term monitoring of species, ecosystems, human uses, landscapes and seascapes are also part of the management process. For example, the mapping of the localization of fishing gear by PCNP and N-PCNP officials is pivotal for the updating of the fishing charter and the management of the artisanal fishery (see below). Finally, doing nothing is still a management response, often the best one, although sometimes difficult to explain to the public at large and policy makers who ask for visible actions (Pont 2003, Schnitzler *et al*. 2008). In any case, consideration should be given to past mistakes in any humility, firstly because it is easy to judge the past in light of today's knowledge and paradigms, and secondly because the truths of today will probably not be those of tomorrow.

SPECIES-BY-SPECIES MANAGEMENT ACTIONS THAT COULD BE CONSIDERED TODAY AS INAPPROPRIATE

The digging of a pond in the western part of Porquerolles Island is an example of the management errors driven by taxonomic lobbies, here the bat lobby (Fig. 2, Table I, T14). The probable goal was to increase the insect resource for bats (Éric Serantoni, pers. comm.), to the detriment of protected plants, which does not matter to bat lovers. It is important to note that at the time, in 2002-2003, the Scientific Council had not been consulted by the scientific service of the PCNP regarding this operation.

In the heart of the village of Porquerolles, in a cellar (known as the *'cave à vin'* – wine cellar), a colony of 65 individuals of the Geoffroy's bat *Myotis emarginatus*

Table I. – Management issues and responses from the PCNP and N-PCNP in the terrestrial realm (numbered T1 through T26). 'No' means that the management suggestion was not implemented, either because it was considered unnecessary or because it was deemed unrealistic, by the Scientific Council and/or by the management team of the PCNP. It is worth noting that Porquerolles has been managed by the PCNP since 1974, but it has only belonged to the national park (N-PCNP) since 2012. PC: Port-Cros Archipelago. PQ: Porquerolles Archipelago.

Nr, Dates	Management issue	Responses, results and comments	References
T1 1970 to 1975	Degradation of the habitat of the Tyrrhenian painted frog *Discoglossus sardus* (PC)	Construction of low walls across valleys to retain water. Failure: ponds quickly filled	Hervé Bergère (pers. comm.)
T2 1970s	Landscape enhancement? (PQ)	Plantation of ice plants *Carpobrotus* sp. on the back beach of Plage d'Argent	Nicolas Gérardin (pers. comm.)
T3 1974	An inappropriate initiative by a State official (not a PCNP staff member) at a loss – what to do with a gift from the President of an Asian country to the President of the French Republic – and said to have been responsible for the release of 3 individuals of the Sika deer *Cervus nippon* (one male and two females) (PQ)	Up to about 20 individuals. Gradual eradication by the ONCFS (Office National de la Chasse et de la Faune Sauvage – *National Office of Hunting and Wildlife*). Last sighting in 2016	Cheylan (1984), Cheylan & Geoffroy (2020), Alain Barcelo (pers. comm.)
T4 1975	Extinction of Hermann's tortoise *Testudo hermanni* (PC)	Reintroduction of 46 individuals. See text for details	Besson (1975)
T5 Early 1980s	Providing shade for beach-goers on the Plage du Sud? Restoration of the supposed original features of the island landscape? (PC)	Plantation of Italian stone pines *Pinus pinea*	Hervé Bergère (pers. comm.)
T6 1982 to present	Degradation of the vegetation of the back beach (Plage du Sud) by tourists (bathers) (PC)	Construction of a low wall (1982), then installation of split stake fences (*ganivelles*) between 2002 and the present	Hervé Bergère (pers. comm.)
T7 Mid-1980s	Landscape enhancement (PC)	Plantation of ice plants *Carpobrotus* sp. in the village of Port-Cros (Port-Cros Island)	Nicolas Gérardin (pers. comm.)
T8 1995?	Worrying decline of 4 rare and protected species of Magnoliophyta (PC and PQ)	The authors suggested clearing, thinning of vegetation and nitrogen supply via anthropization. Some brushcutting operations carried out (PQ)	Médail *et al*. (1995)
T9 1995 to 2003	Too many footpaths: trampling, increased risk of fire, risk for hikers in the event of fire (PC)	Half a dozen paths closed	Hervé Bergère (pers. comm.)
T10 1995 to present	Worrying proliferation of invasive plants (e.g. *Carpobrotus* spp., *Cortaderia selloana, Lonicera japonica*)	Experimental manual control of *Carpobrotus* spp., *Senecio angulatus, Salpichroa origanifolia*, etc.	Aboucaya (2013)
T11 1997-1998 to 2007	Rescue of 40 individuals of Hermann's tortoise *Testudo hermanni* kept by a resident of Saint-Tropez (eastern Provence) who was leaving the region (PQ)	Enclosure construction and feeding (lettuce, fruit)	Nicolas Gérardin (pers. comm.)
T12 2001	Predation of eggs and larvae of *Discoglossus sardus* by the introduced mosquitofish *Gambusia holbrooki* (PC)	Eradication of *Gambusia* by poisoning (rotenone)	Lim & Dauba (2001), Duguet *et al.* (2019)
T13 2002	Demolition of the cellar which housed a colony of the bat *Myotis emarginatus*, in the heart of the village (PQ)	Construction of a tower specially designed to house the bats. See text for criticism	Médard *et al* (1999), Quekenborn *et al.* (2004)
T14 2002 or 2003 to present	Unknown	Digging a pond to increase the insect resource for bats (PQ)	Éric Serantoni (pers.comm.)
T15 2003: No	Conservation of bat species (PC)	The authors suggested fitting out the buildings to enhance the abundance of bats	Stoecklé (2003)

Table I. Continued.

Nr, Dates	Management issue	Responses, results and comments	References
T16 2003 to present	Possible decline of shearwater (*Puffinus yelkouan* and *Calonectris diomedea*) (PC, PQ)	Setting up of artificial nest-cavities. Poor success: available nests are not a limiting factor. See text for criticism	LPO *et al.* (2007), Bourgeois *et al.* (2015)
T17 2002 to 2011	Predation of feral cat *Felis catus* on adult Mediterranean shearwater *Puffinus yelkouan* (PC, PQ)	Eradication of feral cats by cage traps: 112 cats caught and transferred to the mainland. Increase (by 1.5) of the reproductive bird population (PC)	Tranchant & Vidal (2003), Bourgeois & Vidal (2008), Bergère (2009), Médail *et al.* (2013) Clelia Moussay (pers. comm.)
T18 2004	Extinction of the ocellated lizard *Lacerta lepida* (PQ)	The extinction is natural (disappearance of suitable habitats). No management action suggested	Cheylan & Cluchier (2004)
T19 2006 to ?	Determine numbers, social structure and spatial distribution of visitors (bikers, boaters, divers, etc.)	Setting up of the 'Observatoire Bountîles'	Le Berre *et al* (2013), Brécard & De Luigi (2016)
T20 2007: ?	Predation of birds by the European hedgehog *Erinaceus europaeus,* non-indigenous in Porquerolles (PQ)	Suggested control of hedgehogs by trapping. See text for comments	Legrand *et al.* (2007)
T21 2011?	Beach erosion and beach-dune ecosystem impoverishment due to removal of *Posidonia* dead leaves (*banquettes*) (PC, PQ)	Manual removal of human-generated waste matter (*e.g.*, plastic and metallic debris, processed wood). No removal of *banquettes* and natural driftwood	Serantoni (2015), Boudouresque *et al.* (2016, 2017b)
T22 2011 to present	Over-frequentation and carrying capacity (PC, PQ)	Impact on the well-being of visitors, on safety (risk of fire, injured visitors) and on national park officials workload	Bergère & Le Berre (2011), Jolivet (2018), Deldrève & Michel (2019)
T23 2011 to present	Invasion by two exotic species, the ice plant *Carpobrotus* spp. and the black rat *Rattus rattus* (PC)	Co-eradication of *Carpobrotus* spp. and *Rattus rattus* (traps and bromadiolone)	Bourgeois *et al.* (2005), Passetti *et al.* (2012), Médail *et al*. (2013), Braschi *et al*. (2017), Buisson *et al.* (2018)
T24 2012 to present	Invasion by the Argentine ant *Linepithema humile* (PC and PQ)	Preventing its spread to remote areas of the islands, and to still non-colonized islets and Bagaud Island	Berville *et al.* (2012)
T25 2018	Light pollution (PQ)	Four bat species are good indicators of light pollution, which should be reduced	Geoffroy *et al.* (2018)
T26 2015 to present	Natural arrival of wild boar *Sus scrofa* on Port-Cros, Bagaud and Porquerolles Islands (PC and PQ)	Control *via* trapping and hunting. See text for comments	Cheylan & Geoffroy (2020), Hervé Bergère (pers. comm.)

Table II. – Management issues and responses from the PCNP and N-PCNP in the marine realm (numbered M1 through M20). 'No' means that the management suggestion was not implemented, either because it was considered unnecessary or because it was deemed unrealistic or unethical, by the Scientific Council and/or by the management team of the PCNP. It is worth noting that Porquerolles has been managed by the PCNP since 1974, but It has actually only belonged to the national park (N-PCNP) since 2016.

Dates	Management issue	Responses, results and comments	References
M1 1963 to present	Over-exploitation of fish	Ban on spear fishing and trawling	Boudouresque (1976)
M2 1970: No	Erosion of the *Posidonia oceanica* barrier reef in Port-Cros Bay by boats trying to cross it to reach the beach (PC)	The installation of a line of buoys and a rope across the bay was recommended (1970)	Augier & Boudouresque (1970a)
M3 1970s to present	Prevent anchoring by leisure boats and *P. oceanica* meadow degradation, setting up of dead weights, chains and mooring buoys (PC)	The impact of dead weights and chains was worse than that of anchors (Fig. 3). Should be removed. Dead weights were left in place while chains were removed	Robert (1983), Hervé Bergère (pers. comm.), Jean-François Magréaud (pers. comm.)
M4 Between 1982 and 1987 to present	Erosion of the *Posidonia oceanica* barrier reef of Port-Cros Bay by boats trying to cross it to reach the beach (PC)	The installation of a line of buoys and a rope across the bay of Port-Cros	Stéphane Penverne (pers. comm.)
M5 1985 to present	Setting up of artificial reefs, to improve fish stocks and artisanal fishery (La Palud, PC)	See text for criticism	Charbonnel *et al.* (2001)
M6 1987	Local extinction of the giant limpet *Patella ferruginea* (French continental coasts) (La Palud, PC)	Reintroduction of individuals from Corsica (Scàndula) to the Rascas Islet, Port-Cros Archipelago. Failed, see text for comments	Laborel-Deguen (1988), Laborel & Laborel-Deguen (1991)
M7 1989 to present	Only research goal. Cuttings of *P. oceanica* transplanted from 12 populations (Algeria, France, Greece, Italy, Spain and Turkey) (PC)	See text for criticism	Meinesz *et al.* (1993)
M8 1993 to present	Degradation of the *Posidonia oceanica* meadow by anchoring (PC)	Prohibition of anchoring in two areas of the Port-Cros Archipelago (Fig. 7)	Ganteaume *et al.* (2005)
M9 1994 to present	The attractiveness of the seascapes and the density of emblematic fish generate a risk of over-frequentation and habitat degradation (PC)	Each scuba diver must sign the diving charter each year and abide by its rules (*e.g.*, no feeding, no anchoring, mooring on specific buoys, no beginners)	Robert (2013a)
M10 1999 to present	Reconcile artisanal fishing with the protection of natural habitats, in the context of MUM management (PC)	The fishing charter is more restrictive that national and local regulations (see text)	Boudouresque *et al.* (2004), Cadiou *et al.* (2009), Robert (2013a)
M11 2002	Extinction of *Zostera noltei* and *Cymodocea nodosa* in the lagoon of the *Posidonia oceanica* barrier – reef (PC)	Transplantation of 71 cuttings of *C. nodosa* collected in the Bay of Port-Man, 10 m depth. Successful	Meinesz *et al.* (2005), Goujard *et al.* (2010)
M12 2003: No	Overfishing of *Homarus gammarus, Palinurus elephas* and *Maja squinado*?	No proposal	Noël 2003
M13 2004	Degradation of the *Posidonia oceanica* meadow by anchoring and dead weights (see M2) (PC)	Setting up of ecological mooring (Harmony®) in the Bay of Port-Cros	Francour *et al.* (1997), Hervé Bergère (pers. comm.)
M14 2009 to present	Presence of the invasive macroalga *Caulerpa taxifolia* (PC and PQ)	Manual, sometimes chemical, eradication. Successful (PC)	Cottalorda *et al.* (2011, 2012), Esposito *et al.* (2012), Barcelo *et al.* (2013b)

Table II. Continued.

Dates	Management issue	Responses, results and comments	References
M15 2010	Regression of shallow *Cystoseira* spp. in Provence	Installation of zygote traps (10 cm x 10 cm x 5 cm cement blocks) in littoral rockpools. Failure. See text for comments	Robvieux (2013)
M16 2012 to present	Promoting 'reserve effect' (PQ)	Regulating amateur fishing and leisure boating, according to a zoning system for the marine core area	Barcelo *et al.* (2018)
M17 2015 to present	Promoting 'reserve effect' and artisanal fishery (PQ)	Setting up of a No-Take-Zone (*zone resource*) in the south-eastern part of PQ	Rincé *et al.* (2015), Astruch *et al.* (2016, 2017), Barcelo *et al.* (2018)
M18 2016: No	Overgrazing of *Cystoseira brachycarpa* forests (PC)	Limitation of herbivorous populations (sea urchins *Paracentrotus lividus* and teleost fish *Sarpa salpa*)	Thibaut *et al.* (2016b)
M19 2018-2019	Mass mortality of the fan mussel *Pinna nobilis*	No transplantation of individuals to deeper areas, but physical protection of surviving individuals from anchoring and nets	Catanese *et al.* (2018), Cabanella-Reboredo *et al.* (2019)
M20 2018-2019	Oil spill of the CSL Virginia	Warning of the Scientific Council and the director of the N-PNPC against over-cleaning. See text for comments	Boudouresque *et al.* (2019b, c)

Fig. 2. – An artificial pond, on Porquerolles Island, dug in the early 2000s, possibly to provide an insect resource for bats. Photo © Charles-François Boudouresque.

(Geoffroy, 1806) had been established (Table I, T13). This bat species, which feeds primarily on spiders and flies, is an anthropophilic and cave-dwelling species; it is listed in the Annex II of the Habitats Directive of the European Union (Médard *et al*. 1999, Médard & Muratet 2000, Flaquer *et al*. 2008). The cellar was destroyed in 2002; a tower (Tour du Palmier), with a shelter, was specially designed and built to house the colony of bats (Quekenborn *et al*. 2004). Unfortunately, the bats preferred to settle in the stairwell of an apartment building, which caused nuisance for the inhabitants. Some individuals have taken up residence in a ruined fort, the Galéasson (Clélia Moussay, unpubl. data). It took three years for the colony to 'adopt' the tower. In Port-Cros Island, Stoecklé (2003) suggested fitting out buildings either recent, ancient or abandoned ruins, with shelters and water supply systems purpose-designed to enhance the colonies of bats. However, the Scientific Council firmly rejected these proposals, and the ruined Sardinière farm, when restored (in 2011-2012), was not equipped with features intended to increase bat populations (Table I, T15).

The establishment of artificial nest-cavities (artificial burrows) for two species of shearwater, *Puffinus yelkouan* (Acerbi, 1827) and *Calonectris diomedea* (Scopoli, 1769), also typically resulted from the species-by-species approach to management (Table I, T16). These two species may be locally in decline (Courbin *et al*. 2018), but are not classified as threatened (LC in the IUCN Red list of threatened species). Although natural nest-cavities are not a limiting factor (only 33 % are occupied), 95 artificial nest-cavities were installed in Porquerolles, Port-Cros and Bagaud Islands, between 2003 and 2013, in an attempt to increase the nesting population (Bourgeois & Vidal 2007, Bourgeois *et al*. 2015). Very few of the artificial nests have been occupied (none at Bagaud Island) and the number of fledgling chicks from these nests has been insignificant (LPO PACA *et al*. 2007); Bourgeois *et al*.

(2015) expressed more optimistic conclusions, although upon examination of their data, these can be challenged. Either way, whether it was a failure or a rather questionable success, that does not change the fundamental question: the role of a National Park is neither that of a zoo, nor a facility for breeding a species, even if it was threatened elsewhere (which, moreover, is not the case here).

Hermann's tortoise *Testudo hermanni* (Gmelin, 1789) had thrived at Port-Cros Island until the middle of the 19th century. Its extinction would have been caused by man (Jahandiez 1914). A first reintroduction project was rejected by the Scientific Council of the PCNP, in 1970. A second project was subsequently approved and 46 individuals were released in 1975 at two sites, Vallon de la Solitude and Plateau de la Marma (Table I, T4) (Besson 1975). The reintroduction was done using individuals donated by residents of the Massif des Maures (eastern Provence) (Cheylan 1983). At that time, the complex genetic structure of Hermann's tortoise populations was unknown; in fact, the populations of Provence and Greece belong to distinct haplotypes (subspecies? distinct species? see *e.g.*, Fritz *et al*. 2006 and Nivelle 2017, for discussion); however, the Hermann's tortoises, which were marketed in France and kept by local inhabitants, generally belonged to the oriental (Greek) haplotypes. It is therefore probably oriental haplotypes that have been reintroduced in Port-Cros, rather than the native western haplotype. The re-introduction seems to have been unsuccessful in the long term (Cheylan 1983). However, this example highlights the need to be extremely cautious when reintroducing species. Similarly, in Porquerolles, 40 Hermann's tortoises, abandoned by a resident of Saint-Tropez (Provence), were housed in enclosures and fed for several years (Table I, T11). Obviously, the role of a protected area is not to take over the role of the societies for the prevention of cruelty to animals (such as the *Société Protectrice des Animaux* in France and the Royal Society for the Prevention of Cruelty to Animals in England and Wales).

To prevent anchoring by leisure boats and degradation of the *Posidonia oceanica* meadow (Augier & Boudouresque 1970a, b, Boudouresque *et al*. 1995, Cossu *et al*. 2006, Boudouresque *et al*. 2012, Rouanet *et al*. 2012), 27 concrete deadweight, connected by chains, and mooring buoys, were set up in the Port-Cros Bay in the 1970s (Table II, M3) (Jean-François Magréaud, pers. comm.). In fact, the impact of dead weights and chains was worse than that of anchors (Fig. 3) (Robert 1983, Boudouresque *et al*. 2012, Robert 2013b). The Scientific Council of the PCNP therefore recommended the removal of dead weights and chains, and their replacement by 'ecological moorings' (Harmony® or Harmony-like). However, the removal of the dead weights would have aggravated the damage: it was decided to leave them in place and to remove only the chains, in 1982-1983 (Jean-François Magréaud, pers. comm.). Subsequently, ecological moorings (Harmony®) were set up in 2004-2005 (Jean-François Magréaud and Hervé Bergère, pers. comm.). These moorings, which appear to have been a success, are still in place.

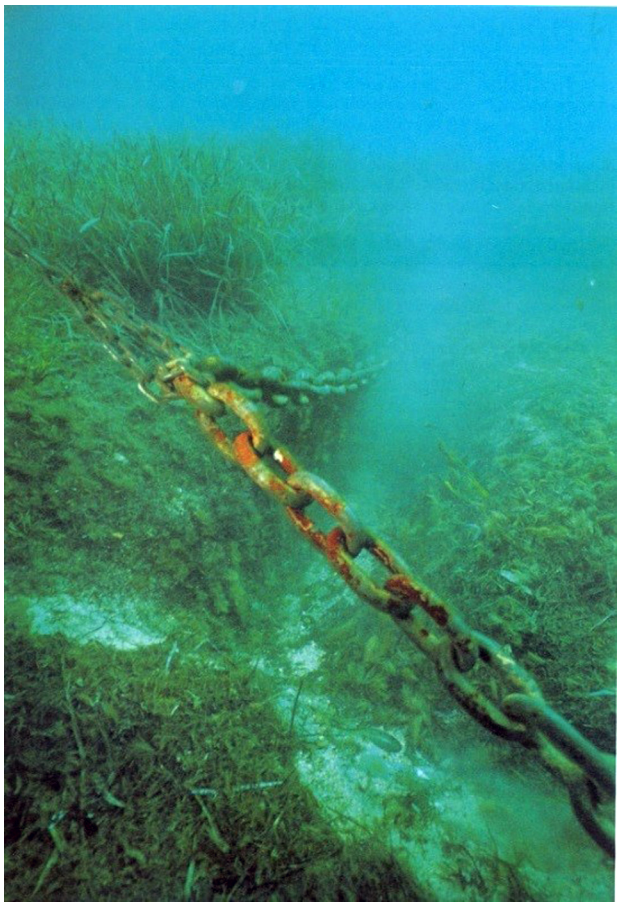

Fig. 3. – Furrow dug in the *matte* of a *Posidonia oceanica* meadow by a mooring chain of a mooring. Anonymous photo.

Fig. 4. – Four cement blocks (10 cm × 10 cm × 5 cm) in a rock pool on Port-Cros Island, with a *Cystoseira crinita* forest. They were intended to trap *Cystoseira* zygotes. Photo © Thierry Thibaut.

The installation of cement blocks in littoral rock pools (Pointe de Malalongue, Pointe du Tuf, Port-Man Bay) was intended to trap zygotes of several *Cystoseira* species (Fucales, Phaeophyceae), such as *C. crinita*, *C. barbata* and *C. foeniculacea* (Robvieux 2013) (Fig. 4; Table I, M15). These species are declining in Provence, French Riviera, French Catalonia and other Mediterranean areas (Thibaut *et al*. 2005, 2015, Blanfuné *et al*. 2016). However, this is not the case at Port-Cros Archipelago (Thibaut *et al*. 2016b). The operation was a failure: no seedling of *Cystoseira* was observed on the blocks after the reproduction period, and the winter storms have washed away or thrown onto the coastal rocks 80 % of the blocks, which were not attached to the substrate (Robvieux 2013). Not only was the operation a failure, but also it is likely that these blocks, during storms and before being washed away, damaged the healthy *Cystoseira* stand. This operation is therefore emblematic of inappropriate actions for the protection of the environment: (i) the role of the PCNP is not to cultivate species, even if they are threatened elsewhere; (ii) very inexpertly designed operations can be counterproductive, and contribute to threats to healthy populations.

The case of the European hedgehog *Erinaceus europaeus* Linnaeus, 1758 in Porquerolles Island deserves special discussion (Table I, T20). The species is native and is widespread in Western Europe. However, it seems to have been originally absent, or became naturally extinct, from a number of small offshore islands, including Porquerolles (Legrand *et al*. 2007). In the latter, it was first observed in 1984 (Cheylan 1984), perhaps deliberately introduced, near the village, and subsequently spread to the whole island. Its diet is diverse, mainly constituted of plants and arthropods, but it can also prey on birds nesting on the ground. Three bird species, reared and released to the wild for hunting purposes, are particularly concerned (Tranchant *et al*. 2002, Legrand *et al*. 2007): (i) the pheasant *Phasianus colchicus* Linnaeus, 1758, native to Asia, was introduced to Europe in the ancient Greece era; (ii) Reeve's pheasant *Syrmaticus reevesii* (J. E. Gray, 1829), native to China, was introduced in Europe in the late 19th century; (iii) the red-legged partridge *Alectoris rufa* Linnaeus, 1758, is native to Europe (Peterson *et al*. 1993, Pascal *et al*. 2006). For three other bird species, the threats are more putative (Legrand *et al*. 2007): the Mediterranean shearwater *Puffinus yelkouan*, Cory's shearwater *Calonectris diomedea*, and the nightjar *Caprimulgus europaeus*. Finally, predation by hedgehog may putatively concern the corn bunting *Emberiza calandra* Linnaeus, 1758; however, this species is far from being threatened in Europe (Legrand *et al*. 2007). It is worth noting that the European hedgehog *Erinaceus europaeus* is a protected species in Europe. All in all, the destruction of a protected species (the hedgehog), native to Europe and the absence of which from Porquerolles could be relatively recent, in order to protect the hunting of non-native species, as pointed out by Legrand *et al*. (2007), can hardly be considered as a priority management response from N-PCNP.

The wild boar *Sus scrofa* Linnaeus, 1758 is native to Eurasia, including Europe. Its abundance in southern France is currently on the increase (Cheylan & Geoffroy 2020). Several causes can account for its proliferation; this is mainly due to the increase in the surface area of forest and maquis due to the severe reduction of agro-silvopastoral practices in Mediterranean France, but also the elimination of predation by the wolf *Canis lupus* Linnaeus, 1758, feeding in winter by hunters (in French: *agrainage*), climate warming that reduces the natural winter mortality and increases the breeding potential, etc. The wild boar is a good swimmer, able to naturally reach not too distant offshore islands. From the late 19th century, it had been absent from Port-Cros Island, but it perhaps (probably?) thrived in the island during the long time periods when Port-Cros was not permanently occupied by man. It was first sighted on Port-Cros Island in 2008; since 2015, a permanent population of wild boar has naturally colonized Port-Cros Island and Porquerolles Island (Table I, T26). In Port-Cros, it has been blamed for digging up the soil, in search of food, and as a result degrading some populations of rare and protected plants, notably geophytes, and of the rare and locally endangered Sardinian frog (*Discoglossus sardus*) located in some temporary ponds. The so-called 'negative' effects of wild boar must be compared with the 'positive' effects of wild boar, which are part of an ecosystem approach: (i) aeration of the soil; (ii) the return of coprophagous insects, eliminated by chemical vermifuges used for domestic livestock; boar droppings have become a real refuge for many of these endangered insects everywhere (Philippe Ponel, unpubl. data). These coprophagous insects are also widely exploited by bats; (iii) the return of necrophagous insects, for example *Necrodes litoralis* Linnaeus, 1758, specialized in large corpses. However, the permanent inhabitants of the island were disturbed by its unfamiliar presence and possible danger for people, including tourists. The Scientific Council of the N-PCNP was of the opinion that the role of a National Park is not to combat a natural process, and its impact on associated species (even if they are rare and protected plants), which would be in accordance with an ecosystem-based approach; however, taking into consideration the fact that the wild boar is not a threatened species, and that the well-being of inhabitants is an important feature of the N-PCNP governance, it was not opposed to the control of the wild boar, *via* trapping and hunting. This attitude is consistent with the principles for ethical wildlife control (Sellier 2015, Dubois *et al*. 2017). About 200 individuals have been killed in 2018 and 2019 (Hervé Bergère, pers. comm.).

The attempt to reintroduce the giant limpet *Patella ferruginea* Gmelin, 1791 to Port-Cros, from individuals from northern Corsica, can be *a priori* considered a good idea (Laborel-Deguen 1988, Laborel & Laborel-Deguen

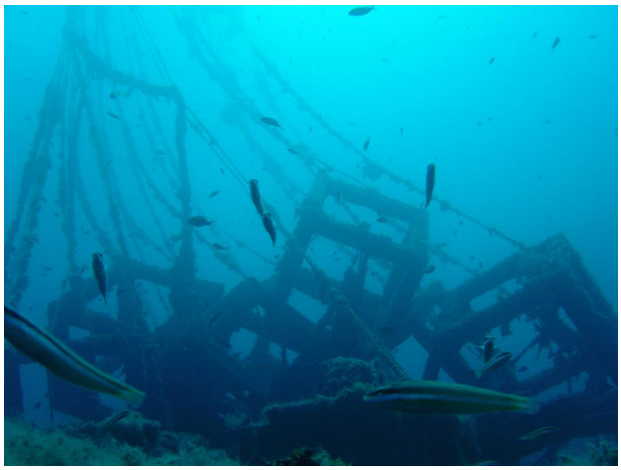

Fig. 5. – The setting up of artificial reefs. La Palud, Port-Cros Island. Photo Philippe Robert © Port-Cros National Park (PCNP). Courtesy of the PCNP.

1991, Laborel-Deguen & Laborel 1991a) (Table II, M6). The species, which is long-lived and can reach a diameter of 11 cm, is a western Mediterranean endemic which has been present in the whole western basin of the Mediterranean. It dwells in the midlittoral zone and has been harvested by humans since the Neolithic period (Espinosa & Ozawa 2006, Colonese *et al*. 2011). It has become extinct in most of its original range, *e.g*., in Provence and French Riviera (Laborel-Deguen & Laborel 1991b). The attempt does not seem to have been successful in the long term; the survival rate was 57 % after one day, 27 % after one year, 12 % after two years (Laborel-Deguen 1988, Laborel-Deguen & Laborel 1991a). The few very isolated individuals that have been observed in the Port-Cros archipelago, far from the Rascas islet, probably do not come from the small-reintroduced population, but from larvae from Corsica drifting with the currents (Meinesz *et al*. 2001).

In 1989, 278 cuttings and seedlings of the seagrass *Posidonia oceanica* originating from 12 populations in different parts of the Mediterranean (Algeria, France, Greece, Italy, Spain and Turkey) were transplanted to La Palud Bay (Port-Cros Island), at 11 m depth (Table II, M7). The goal was solely scientific: to check whether or not the morphological differences between these strains would be conserved when cultivated together in the same area and the same habitat (Meinesz *et al*. 1993). The choice of the Port-Cros National Park was purely technical: the ban on fishing in La Palud Bay (Astruch *et al*., 2018) guaranteed that this underwater 'botanical garden' would not be disturbed by fishing gear. Today, at a time when biological invasions, including gene pollution, are considered as one of the most worrying environmental issues (Carlton & Hodder 1995, Schmitz & Simberloff 1997, Boudouresque *et al*. 2017a), it is difficult to understand why such a scientific experiment was authorized within a national park.

Is the goal of a national park the artificial increase in fish stocks, via artificial reefs? (Fig. 5, Table II, M5). The shutdown of sewage, and therefore the increase in domestic pollution, would have the same effect (see *e.g*., Ourgaud *et al*. 2015). In fact, the installation of these artificial reefs corresponded to a demand from artisanal fishers, and it facilitated the subsequent establishment of the fishing charter (Robert 2013a, b). In addition, the goal was solely experimental (Charbonnel *et al*. 2001). The outcome could therefore be positive.

MANAGEMENT ACTIONS THAT CAN HAVE RELEVANCE IN THE CONTEXT OF ECOSYSTEM-BASED MANAGEMENT

The Tyrrhenian painted frog *Discoglossus sardus* Tschudi *in* Otth, 1837 is a species occurring in Corsica, Sardinia and on several small islands: Port-Cros, Le Levant (Provence), Giglio, Montecristo and Monte Argentano (Tuscany) (Knoepffler 1962). The species is not threatened in Corsica and Sardinia: it is listed by the IUCN as being of 'Least Concern' (LC) (Andreone *et al*. 2009). However, isolated populations on small islands can be more vulnerable and they could represent distinct conservation units. On Port-Cros Island, a small dam (30 m long, 6 m high) was built in the Vallon de la Solitude to create a water reservoir intended to irrigate crops, now abandoned, located downstream. This reservoir is used by *D. sardus* for its reproduction. The mosquitofish *Gambusia holbrooki* Girard, 1859, deliberately introduced in 1992, threatened the eggs and larvae of *D. sardus*; it was therefore eradicated in 2001 by poisoning (rotenone) (Lim & Dauba 2001, Duguet *et al*. 2019) (Table I, T12). The eradication was successful: it has never reappeared there (Hervé Bergère, pers. comm.).

The eradication of feral cats *Felis catus* Linnaeus, 1758 in Port-Cros (Table I, T17), predators of introduced rats together with the native Mediterranean shearwater *Puffinus yelkouan*, has been a success, insofar as it made it possible to improve the numbers and the reproductive success of the Mediterranean shearwater (Tranchant *et al*. 2002, Legrand *et al*. 2008). It also gave rise to a process of reflection on the functioning of the ecosystem and the interactions between cats, black rats *Rattus rattus* Linnaeus, 1758 (main prey of cats, with shearwater) and shearwater, a possible prey of rats (Bourgeois *et al*. 2005, Bergère 2009, Zarzoso-Lacoste *et al*. 2009, Médail *et al*. 2013). The management of the cat-rat-shearwater 'triangle' can be described as typical of an ecosystem-based management approach, and is consistent with ethical principles (see Dubois *et al*., 2017).

The co-eradication of the ice plant *Carpobrotus* spp. and of the black rat *Rattus rattus* on Bagaud Island is also part of an ecosystem-based approach, since there are mutualistic interactions between ice plants and rats

(Bourgeois *et al*. 2005); in addition, all the compartments of the ecosystem were studied, before and after eradication (Table I, T23). Such a multidisciplinary approach has never been implemented in the context of the eradication of invasive species (Tranchant *et al*. 2002, Médail *et al*. 2013, Berville *et al*. 2015, Braschi *et al*. 2017, Buisson *et al*. 2018). Of course, the risk that co-evolution between black rats and native species, such as the European leaf-toed gecko *Euleptes europaea* (Gené, 1839), would have resulted in an adaptive equilibrium, putatively disrupted by the eradication, especially in the case of reinvasion by a different population of black rats, should be carefully considered (Delaugerre *et al*. 2019).

The control of invasive species also occurs in the AA of the N-PCNP: *e.g*., (i) the destruction of the pond slider *Trachemys scripta* (Thunberg *in* Schoepff, 1792), a semiaquatic turtle native to southeastern United States and northern Mexico, which threatens the native European pond turtle *Emys orbicularis* Linnaeus, 1758 in the Vieux Salins saltmarsh of Hyères (Lascève 2014, Perrot *et al*. 2016); (ii) the uprooting of *Caulerpa taxifolia* at Le Pradet (eastern Provence) (Pironneau *et al*. 2014, Pironneau & Ringwald 2015, Barcelo *et al*. 2016).

There has been a myth, both among the public and among the first scientists working on this insular area, that the forest on the island of Port-Cros was an 'original and pristine forest', in a way a primary forest. In fact, the island has undergone strong human impact throughout its history, and especially over the last centuries: cultivation, massive deforestation to fuel a caustic soda plant or to export charcoal, overgrazing, etc. The holm oak *Quercus ilex* Linnaeus forest is therefore relatively recent and terrestrial ecosystems, their flora and fauna, are in a dynamic of rapid evolution (Médail *et al*. 2013). In contrast to the natural evolution of ecosystems over time, to 'freeze' landscapes in a state that is only a snapshot, fixed by the fragile memory of the observer, is a temptation that characterizes many environmentalists and even scientists. The PCNP, except perhaps at its very beginnings (Table I, T5, T8), did not fall into this trap, based on an archaic, naive and even completely wrong notion of biodiversity (see Boudouresque 2014 for the biodiversity concept). 'Opening' the habitats, in order to artificially increase the species richness, has not been the doctrine of the PCNP, N-PCNP and its scientific Council (see below for discussion). The best solution is probably to include natural disturbances as promoter of the patch dynamic of these terrestrial ecosystems (Médail *et al*. 2013).

The ecosystem constituted by the dune, the beach and the overlying layer of *Posidonia oceanica* dead leaves (*banquette*) (hereafter dune-beach-*banquette* ecosystem) harbors a unique fauna and flora and has a very high heritage value, in addition to providing valuable ecosystem services (Médail *et al*. 2013, Serantoni 2015, Boudouresque *et al*. 2017b). For the supposed pleasure of tourists, *banquettes* are removed from most Mediterranean beaches, treated as a waste and thrown on the garbage dump. This removal has dire ecological and economic consequences: the destruction of the ecosystem, erosion of the beaches, catastrophic attempts to restore them *via* riprap or sand replenishment; as the fate of beached dead leaves is to return sooner or later to the sea, and to feed (organic carbon, nutrients) coastal ecosystems, their destruction deprives coastal areas of fish, available to artisanal fishers (~35 kg wet mass of fish per metric ton of *banquette*) (Boudouresque *et al*. 2016). In addition, it seems that this 'tourist demand' is rather something dreamed up by tour operators and ill-informed mayors: even when uninformed, and massively when properly informed, tourists do not ask for the removal of the *banquette* (Boudouresque *et al*. 2017b). The PCNP strategy has been, in the core areas of Port-Cros and Porquerolles Archipelagos, to leave the *banquette* and the natural driftwood, to manually clean the beaches of human-generated waste matter (*e.g*., plastic and metallic debris, processed wood) and to inform the general public about the ecological and economic issues (Fig. 6, Table I, T21) (Serantoni 2015). This concept of 'ecological beach', born in Port-Cros, is currently gaining ground in the Mediterranean (Borrello *et al*. 2019, Astier *et al*. 2020; Rotini *et al*. 2020).

Fig. 6. – Natural driftwood, on the beach of L'Oustaou de Diéu (Porquerolles Island), after an episode of extreme flooding (Spring 2012), left in place. Photo © Charles-François Boudouresque.

The management of the artisanal fishery around the Port-Cros Archipelago can be referred to as an ecosystem-based approach (Table II, M10). For most environmentalists, many stakeholders and some managers, the paradigm of a Marine Protected Area (MPA) is the banning of all human activities, mainly artisanal fishery (No-Take Zones, NTZs) (Boudouresque *et al*. 2005b). In fact, how 'natural' NTZs really are can be challenged. In the Mediterranean Sea, some major top predators, such as the monk seal *Monachus monachus* (Hermann, 1779), and sharks are locally or functionally extinct, respectively. Under these conditions, considering that the catch by an extinct population of monk seal was of the same order as

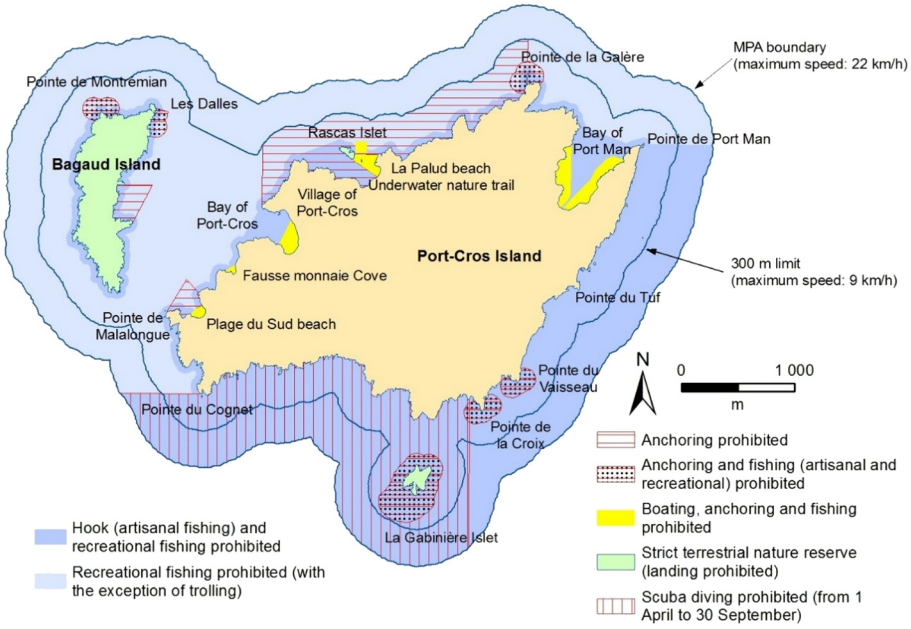

Fig. 7. – Artisanal and recreational fishing regulations within different areas of the Port-Cros Archipelago MPA. Areas where anchoring, artisanal and recreational fishing are prohibited are reserved for diving. 2014 edition.

the current catch by fishers, the complete ban on artisanal fishing (small-scale fishing) could generate an artificial deficit in top predators (Boudouresque *et al*. 2004, Ferretti *et al*. 2008, Astruch *et al*. 2018, Boudouresque *et al*. 2019a). In contrast to the NTZ management, the management of the marine area of the Port-Cros Archipelago MPA can clearly be assigned to the MUM type (Multi-Use Management). It is characterized by complex zoning of the MPA (Fig. 7; see discussion for the complexity of this zoning), based on the uses, conservation goals for the habitats and ecosystems and clearly displayed priorities (artisanal fishing rather than recreational fishing); step by step, recreational fishing has been banned in the whole of the MPA, which favors artisanal fishers and helps them to bear the constraints of the fishing charter (see below) (Le Diréach *et al*. 2018, Boudouresque *et al*. 2019a). To be authorized to fish inside the Port-Cros Archipelago, each fisher has to sign the fishing charter each year and to abide by its rules. The charter is more restrictive than national regulations and the regulations of the local *prud'hommie des pêcheurs* (fishers' guild), *e.g*., maximum length of the vessel, mesh size, length of fishing nets, maximum soak times, number of hooks and traps. The charter is updated annually, based on scientific monitoring and in consultation with the fishers (Boudouresque *et al*. 2004, Cadiou *et al*. 2009, Robert 2013a, b). It is important to note that these regulations, together with the general regulations of the PCNP and of the N-PCNP (*e.g*., ban on trawling, spear fishing, angling) are strictly enforced. The MUM strategy, as opposed to the NTZ strategy promoted by conservationist NGOs (Non-Governmental Organizations), is gaining ground today in the world of conservation (see *e.g*., Burbano *et al*. 2020). Of course, the MUM strategy can include NTZs in the framework of the zoning, such as the '*zone ressource*' of the Porquerolles Archipelago (Rincé *et al*. 2015, Astruch *et al*. 2016, 2017, Barcelo *et al*. 2018) and the six areas of Port-Cros Island surrounding diving spots where artisanal and recreational fishing are banned, so constituting actual NTZs (Fig. 7, Table II, M17).

A mass mortality event has since 2016 been affecting the emblematic fan mussel *Pinna nobilis* Linnaeus, 1758, throughout the Mediterranean (Table II, M19) (Vásquez-Luis *et al*. 2017, Cabanellas-Reboredo *et al*. 2019). It is due to a unicellular haplosporidan parasite, *Haplosporidium pinnae*, probably introduced from the northwest Pacific (Catanese *et al*. 2018). On the basis of a hypothetical assumption that resistance to the parasite would be better at low temperature and therefore at depth, some researchers have proposed transplanting individuals to deep water areas. Some MPAs have viewed this proposal favorably (Parc National des Calanques, western Provence) or even implemented it (Observatoire Marin du Golfe de Saint-Tropez, eastern Provence). The Scientific Council of the PCNP opposed this proposal, which had no scientific basis; in addition, transplantation would increase mortality, by stress or by predation in the new area (De Gaulejac & Vicente 1990, San Martín 1995, Reveret *et al*. 2015; but see Bakran-Petricioli *et al*. 2019). On the other hand, the PCNP has implemented *in situ* physical protection, by means of exclusion zones from anchoring and fishing nets, of surviving individuals, probably resistant to the parasite, and likely to found new populations.

Over-frequentation is increasingly an issue worldwide in protected areas. The impacts of over-frequentation not only concern landscapes, seascapes, emblematic species and the functioning of ecosystems, but also the well-being of inhabitants, visitors and park officials, the overall safety (risk of fire, evacuation of injured visitors, etc.) and the

effectiveness of the surveillance by officials of protected areas of environmental offences (Table I, T22) (Bergère & Le Berre 2011). The definition of a carrying capacity is however a complex issue, and the N-PCNP has carefully addressed the question (Wagar 1964, 1974, Deldrève & Michel 2019). As pointed out by Lindberg *et al*. (1997), the question is not '*How many is too many?*' but '*What are the desired conditions?*' The extent to which the local police can, or should, play a role in the protection of natural areas from damage caused by a large number of visitors, in the context of French legislation, has been explored by Jolivet (2018); this author suggested improvements to the present legislation[2]. Improvements in the management of tourism by the local 'business ecosystem' (Porquerolles), or its restructuration, have also been suggested (Van der Yeught 2018).

On October 7th, 2018, the ro-ro ferry *Ulysse* collided with the *CSL Virginia*, 28 km northwest of the Cap Corse (Corsica) (Table II, M20). A maximum of 600 m^3 (the capacity of the fuel tanks, if full) of fuel leaked out from the tanks of the *Virginia*. Most of this oil (90 %) was recovered by spill response vessels, according to the French Navy authority (Boudouresque *et al*. 2019b, c). Evaporation further removed about 30 % of the remaining oil (Philippe Cuny, pers. comm.). This oil spill (40 t?) is therefore negligible when compared with historical hazards which have hit European coasts, *e.g*., *Amoco Cadiz* (1978, Brittany, 223,000 t), *Haven* (1991, Genoa, Italy, 20,000 t), *Erika* (1999, Bay of Biscay, 19,000 t), and *Prestige* (2002, Galicia, 60,000 t) (Marchand *et al*. 1979, Cognetti & Cognetti 1992, Le Moigne & Laubier 2004). Winds and currents pushed remaining oil slicks toward the coasts of Provence (Boudouresque *et al*. 2019b, c). Part of the areas fouled belongs to the core area (Archipelagos of Port-Cros and Porquerolles) or to the transitional area (*Aire Maritime Adjacente*) of the N-PCNP. The Scientific Council of the N-PCNP and its director issued (23rd October 2018) a warning against the risks, for the natural environment and the ecosystems, of an over-reaction and the use of heavy and intensive cleaning methods on the rocks and beaches; they recommended *e.g*., (i) no use of chemicals (*e.g*., dispersants, detergents); (ii) no hot water high pressure washing (HWHPW), with the exception of rocky areas accessible to pedestrians, close to the beaches; (iii) no cleaning in areas of high ecological sensitivity such as *Lithophyllum byssoides* (Lamarck) Foslie rims; (iv) on beaches, taking care to remove as little sand as possible and leave as much wood as possible on the spot; (v) *Posidonia oceanica banquettes* of dead leaves, on beaches and rocks, should be preserved, with manual removal limited to surface layers exhibiting oil. The increase of ecological damage due to cleaning has been relatively well documented (*e.g*., Broman *et al*. 1983, Poncet & Le Bail 2001, De la Huz *et al*. 2005, Jézéquel & Poncet 2011). Unfortunately, the French authorities (*Préfet du Département du Var*) followed the recommendations of the ship's insurers and entrusted to a private company, internationally recognized for its expertise, the task of removing all traces of oil. While the territory of the core area of the PCNP was relatively spared from disproportionate cleaning, thanks to the intervention of the Scientific Council and the decisions of the PCNP's director, this was not the case for the rest of the area, which was intensively and disproportionately cleaned up, both in areas accessible to tourists in summer and in inaccessible areas. Rocks were stripped of the whole of the mediolittoral and supralittoral ecosystem (Cyanobacteria, lichens, *Littorina*, *Euraphia*, *Chthamalus*, *Patella*, etc.) *via* HWHPW, *P. oceanica banquettes* were totally removed, regardless of whether or not oil patches were present on the upper layer of dead leaves, etc. These *banquettes* are of paramount importance for coastal ecosystems and provide a wide range of ecosystem services (Boudouresque *et al*. 2016, 2017b, Rotini *et al*. 2020). The result of this inappropriate over-cleaning is that a very minor oil spill, occurring 9 months before the next tourist season, was transformed by the polluters themselves (*via* the insurers), by carrying out a disproportionately large-scale cleanup operation, into an ecological disaster, for which natural ecosystem restoration will take at least 10 years (Boudouresque *et al*. 2019b, c). Obviously, the N-PCNP strategy can be referred to as ecosystem-based.

The legal policy implemented by the N-PCNP is also an illustration of an ecosystem-based approach. First of all, it should be recalled here that the law is not limited to regulation. For example, the legal policy is also concerned with claims for compensation for ecological damage (Martin 2020). In this regard, for some time now, the National Park has ceased to base its claims on the number of individuals of a species that have been destroyed or disturbed, but instead focuses on the resulting loss of ecosystem services on the one hand and, on the other hand, on the expenditure needed to support natural recovery of damaged ecosystems.

DISCUSSION AND CONCLUSIONS

The species-by-species approach to management is a convenient and recurrently tempting way to try to protect nature. It is convenient, because it is easily understood by the general public, because it does not require the study of the cascading consequences of the action on a given species, because it is far easier to implement than an eco-

[2] These improvements are underway. The French Senate unanimously voted to amend art.L.2213-4 of the General Code of Local Authorities, in order to authorize the mayor of the municipality to prohibit or regulate access to certain areas if such access is likely to harm the protection of the environment or the character of the site. The National Assembly must in turn soon examine this proposal.

system-based approach, and, last but not least, because it is strongly supported by 'taxonomic lobbies'. It is recurrent, since it dates back to the 19th century and continues to be the dominant practice of international NGOs and administrations, including in France the Ministry of the Environment and, to some extent, its official agency, the OFB *(Office Français de la Biodiversité*), although the EBA is currently gaining ground within the OFB. The requirements of the French Ministry of the Environment have sometimes borne more resemblance to accountancy practices than to scientific ones: how many species (even casual or observed once) are there in your protected area? Is this number on the increase when compared with that of the previous year? Is it higher than in the adjacent non-protected area? (implying: if so, your management is good). Of course, this criticism is something of a caricature: officially, 'and habitats' is always added to the essential inventory of species; but it sometimes seems rather like a kind of ecologically correct polite formula.

This accountants' concept of environmental management is often associated with a simplistic, and even erroneous, vision of biodiversity, where biodiversity is viewed as the number of species. The higher the number of species, the better the status or the health of a habitat is considered to be. Disturbances are wrongly thought to reduce the number of species, while in reality they often increase it (see *e.g.*, Ourgaud *et al*. 2015). In most cases, the highest number of species is reported for intermediate levels of disturbance (IDH – Intermediate Disturbance Hypothesis and DEM – Dynamic Equilibrium Model) (*e.g.*, Lubchenco & Menge 1978, Huston 1979, Valdivia *et al*. 2005, Svensson *et al*. 2009). In fact, biodiversity is a complex multidimensional concept, defined by at least five scales (evolutionary, functional, organizational, spatial and heterogeneity scales) and more than a hundred metrics. These metrics can give apparently contrasting responses, when they are in fact complementary (Sala & Knowlton 2006, Boudouresque 2014, Boudouresque *et al*. 2017a).

The species-by-species approach does not take into account natural fluctuations in the numbers of a species within an ecosystem, as a function of predator-prey cycles, parasite-host cycles, natural inter-annual fluctuations of climate, or threshold effects of physical-chemical and biological parameters that make a population or an ecosystem shift from one state to another (regime shift or phase shift; see *e.g.*, Cury & Shannon 2004, Boudouresque *et al*. 2005a, Litzow & Cianelli 2007). Control of supposed harmful species, in order to increase prey populations, often backfires, with a further unexpected decrease in prey populations (Doak *et al*. 2008). We must not be to hasty to intervene as soon as a species declines or another species proliferates; ecosystems are in constant evolution, contrary to what the old climax concept suggested. This is particularly true for the terrestrial ecosystems of Port-Cros Island, which are slowly recovering

Fig. 8. – In the background, the 'bats tower' (Tour du Palmier) in the village of Porquerolles. The half-moon opening at the top of the tower is the entrance to the shelter specially built to house a colony of Geoffroy's bat *Myotis emarginatus*. Photo © Charles-François Boudouresque.

after the very strong human impact of the 19th century, that is to say almost yesterday (Médail *et al*. 2013). This is also true for marine ecosystems, even if it seems at first glance less apparent: effluent from a caustic soda plant, relocated from Marseille because it was too polluting, overfishing by artisanal fishers, extirpation of large and emblematic fishes by spear fishers, the extermination by fishers of a top-predator, the monk seal *Monachus monachus*, supposed to be a fish thief, marked the 19th and 20th centuries, before the creation of the PCNP (Marchessaux 1989a, b). The steady but slow recovery of emblematic fish populations, such as the dusky grouper *Epinephelus marginatus* and the brown meagre *Sciaena umbra* Linnaeus, 1758, illustrate a recovery process still in progress (Harmelin & Marinopoulos 1993, Harmelin & Ruitton 2007, Harmelin *et al*. 2010, Harmelin 2013).

Each 'taxonomic lobby' wishes to favor its group of taxa, to increase the abundance of individuals and its species richness. There is certain logic in increasing the numbers of a 'threatened' species, which also benefits from broad support from the general public. However, 'threatened' species are not always actually threatened: they can even be proliferating thanks to humans; they may be fortunate to belong to an emblematic and lovable taxon. For example, Geoffroy's bat *Myotis emarginatus*, for which a tower with artificial shelter ('Tour du Palmier') was specially built in the village of Porquerolles (Fig. 8, Table I, T13), is far from being a threatened species: its abundance is stable, close to a natural state, and it is classified as LC (Least Concern) in the IUCN Red List (Hutson *et al*. 2007). Taxonomic lobbies also do not consider the possible impact of the increase of their beloved taxon on other taxa. When 'bat lovers' asked the PCNP to promote the abundance of bats through shelters and water supply systems, they were not asked about the effect of their proliferation on other species using the same food

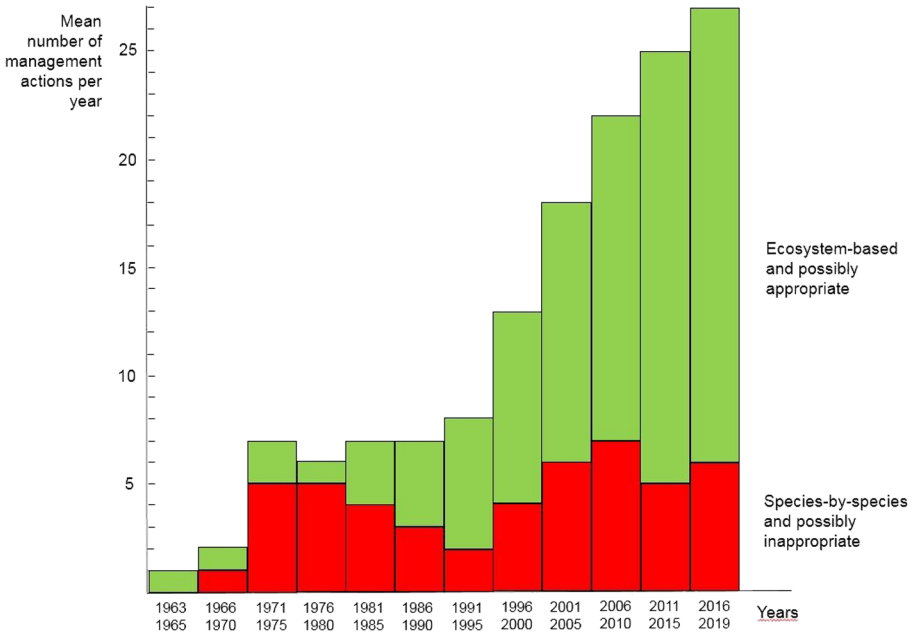

Fig. 9. – Mean number of management actions, species-by-species and possibly inappropriate and ecosystem-based and possibly appropriate, over time. Data from Tables I and II. Many management actions, both appropriate (*e.g.*, T21 and M1) and inappropriate (*e.g.*, T16 and M7), are long-lasting and therefore appear over several time periods.

resource, nocturnal insects (*e.g.*, the Tyrrhenian painted frog *Discoglossus sardus*, shrew, the European leaf-toed gecko *Euleptes europaea*, birds, etc.) (Table I, T15). It is difficult to explain to the general public, and to journalists who have almost always a literary rather than scientific culture, that national parks are neither botanical gardens nor zoos, and that a natural ecosystem can be poor in species. The general public and journalists are often confused and incredulous when they are told that the most effective way to increase the number of species is to open paths and agricultural plots in the forest, to create garbage dumps and to spread fertilizer (see *e.g.*, Landrieu & Gilg 2010, Boudouresque 2014).

In an admirable outburst of anger against taxonomic lobbies and their simplistic view of biodiversity, Landrieu & Gilg (2010) wrote: *'To make us believe that we must cut down forests to open the environment to more species of birds, flowers and butterflies and that, by doing so, we are helping to increase biodiversity, there no, I do not agree! If we let ourselves be guided by the sole objective of the maximum number of species, which leads to increasing the 'species richness' of a site and not its 'biodiversity', the ultimate destiny of the manager could be the maintenance of botanical gardens and zoos! When the environment is naturally forest, it is forest species that constitute biodiversity. Our role is to improve if necessary the functionality of this environment, its 'state of conservation'. It's the ecosystem that decides its biodiversity, based on ecological potential, resources, colonization, dispersal of species. We must beware of 'overselling' biodiversity, by trying, for example, to change a forest environment that is naturally 'poor' in species, into an environment that is artificially rich*' (translated from French by the authors) (see also Pavé 2019). It is worth noting that the so-called species poverty of the 'closed' natural forest environments is an idea propagated by the lobby of flowering plant taxonomists; for insect specialists, the closed forest environments exhibit on the contrary an incredible species richness: saprophagous, saproxylophagous, phytophagous, predators of litter, old wood, old bark, mosses, tree cavities, etc.

Supporters of the species-by-species approach sometimes claim that they are also thinking at ecosystem level, because they consider the habitat of the species. Habitat is generally defined on a descriptive basis, the composition in species, phytosociological in terrestrial environment, fauna and flora in marine environment (*e.g.*, Molinier 1960, Pérès & Picard 1964, Corine 2020). So it is a kind of vicious circle. Of course, habitat is not the ecosystem; habitat and ecosystem are completely different concepts; the habitat is a descriptive concept (physical-chemical characteristics, lists of species), while the ecosystem is a functional concept (the interactions of species between them and with the environment).

Doing nothing is often the best management response, although sometimes difficult to explain to the public at large and policy makers avid for visible actions (Pont 2003, Schnitzler *et al.* 2008). Unfortunately, national authorities, in particular in France (Ministry of the Environment, *Agence de l'Eau*), often favor visible actions (artificial reefs, transplantation, artificial restoration, etc.), excessively expensive, generally ineffective and even seriously destructive of the natural environment, while the use of the budgets for the reduction of impact would have been one or two orders of magnitude more effective.

With the exception of an initial 'teething phase', and of the Island of Porquerolles before it officially became

part of the core of the Port-Cros National Park, the PCNP, the N-PCNP and its Scientific Council often avoided the trap of interventionism. Step by step, the National Park has undoubtedly moved away from a species-by-species culture towards an ecosystem-based approach (EBA) (Fig. 9). Possible biases are (i) that ancient inappropriate actions (1963-1985) could have been omitted and (ii) that the effects of ancient inappropriate actions (*e.g.*, the 'bat tower' and the artificial reef, not removed) have persisted to this day; the trend towards an ecosystem-based approach is therefore probably more marked. However, while it is easy to criticize a species-by-species approach to management, with its contradictions and with its absurd, caricatured, sometimes grotesque errors, it is much more difficult to apply an EBA to management. Obviously, it is far easier to describe the ups and downs of a species than to understand the terrifying complexity of the functioning of an ecosystem. In addition, understanding the functioning of an ecosystem requires a multi-disciplinary team, therefore more funding, longer time series, while being handicapped by a lesser understanding on the part of the general public and managers. Finally, if the inappropriate actions of the past are easy to criticize in light of today's ecology and current concepts of nature conservation, it should be recognized that the evidence of today will probably appear ridiculous in 50 years. If our actions or our inaction lead to the disappearance of a species, and if our successors have maintained the cult of the rare and patrimonial species, they will severely criticize our errors of appreciation and management.

The complexity of the marine zoning of the Port-Cros archipelago MPA is a reflection of and the result of the MUM doctrine and almost 60 years of progress in management thinking. Although it has proven to be quite effective, in terms of governance (Sellier 2015, Barcelo *et al*. 2016, 2018, Deldrève & Michel 2019), the protection of ecosystems (Personnic *et al*. 2014, Thibaut *et al*. 2017; but see Astruch *et al*. 2012) and the maintenance of sustainable human activities (artisanal fishing, diving, pleasure boating) (Boudouresque *et al*. 2004, Cadiou *et al*. 2009, Robert 2013a, Le Diréach *et al*. 2018), its complexity makes it difficult for users to read and makes its implementation by the park guards difficult and time consuming.

International literature on the issue is often produced by theorists with no hands-on experience of the reality and governance of a protected area. It is also produced by tricksters who 'sell' paper parks (no reference! It would be inappropriate). It is important here to emphasize that the PCNP and the N-PCNP are among the ~10 % of effective parks (Meinesz & Blanfuné 2015), where the legislation is more or less correctly implemented and respected, taking into account the very many constraints imposed on the manager and the difficulty of convincing the judicial institutions of the importance of protection issues.

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