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Biodiversity Management in a Mediterranean National Park: The Long, Winding Path from a Species-Centred to an Ecosystem-Centred Approach

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Abstract: The Port-Cros National Park (PCNP), established in 1963, was one of the earliest terrestrial and marine parks in the Mediterranean Sea. From 2012, it engaged in a major redefinition and extension of its territory (N-PCNP—New Port-Cros National Park). This case is particularly interesting insofar as the protected area has been competently and efficiently managed since its creation, and protection and management measures have been strictly implemented: in the Mediterranean, the PCNP has often been considered as a benchmark. Here, we critically analyse almost 60 years of the management of the biodiversity and the human uses, with their share of successes and failures, certain operations which are today regarded as errors, and a doctrine today of a priori non-interventionism, in contrast to the doctrine in vogue in the early years. Of particular interest is the change in outlook with regard to actions favouring flagship species, such as building a tower for bats, setting up artificial nests for seabirds, and constructing an artificial reef at sea. The question of the natural arrival of the wild boar, a native species, and the hostility of the public and some species-centred scientists, is particularly instructive. We analyse these changes in the light of the ongoing trends in concepts in ecology and nature conservation, and the shift from a species-centred to an ecosystem-centred approach. It is worth emphasizing that a critical review of almost 60 years of management is a very rare exercise in a national park anywhere in the world.

Keywords: artificial reefs; bats; biodiversity; management; mediterranean; protected areas; Port-Cros National Park; *Sus scrofa*; threatened species

1. Introduction

Protected areas are powerful tools for the conservation of ecosystems, the promotion of their return to a supposed 'natural' state (if they have deviated from it because of humans), the protection of threatened species, the promotion of environmental education and scientific research, and sometimes the preservation of cultural heritage; in addition, in the marine realm, protected areas are also an efficient tool for enhancing fisheries in adjacent areas by exporting adult individuals (spillover), larvae and eggs (e.g., [1–6]).

The fact that the total protected surface area should be much larger than it is today [7] is not the sole issue to be considered in the management of protected areas. Staff and budget

capacity are the strongest predictors of conservation efficiency: Marine Protected Areas (MPAs) with an adequate staff and budget capacity have a positive ecological impact three times greater than MPAs with inadequate capacity ([8], but see [9]). However, it is not only the protected surface area and the resources available that matter: in fact, especially in the marine realm, most MPAs are actually so-called 'paper parks' or 'mist parks'. Paper parks are fictitious protected areas: lines on an official map without park wardens, management plans, a scientific council, or even a park director. Mist parks are protected areas intended to fulfill the international commitments of countries; they often cover vast areas, have a real existence (director, premises, officials), but do not implement any real management measures involving, where necessary, constraints for some of the users [9–14].

In any case, there are today no—or very few—truly natural ecosystems left, especially in the terrestrial realm: the development of agriculture and pastoralism, and the extirpation of a significant part of the megafauna in Eurasia, America and Oceania, have deeply disrupted the functioning of ecosystems (e.g., [2,14–21], but see [22]). With regard to the marine realm, in the Northern Adriatic Sea, Lotze et al. [23] reconstructed past changes in marine food webs and ecosystem functioning over 100 000 years, from prehumans and hunter-gatherers to the medieval, modern and global periods: the changes were extremely far-reaching. At the scale of the world ocean, a similar attempt concerning large animals (mammals, birds, turtles and fish) evidenced generalized and dramatic declines from historical abundance levels [24]. For example, the right whale *Eubalaena glacialis* and the grey whale *Eschrichtius robustus* may have occurred, and may even have been not uncommon, in Roman times in the Mediterranean Sea, but are absent today [25]. The North Atlantic Ocean has lost 90% of its predatory fish biomass these past 100 years, and marine mammals can no longer be used as scapegoats by fishers and fishery managers to explain the decline of the resources, which are actually due to the fishers themselves [26].

A key issue is the question of the baseline [24,27]. How were the ecosystems before human-induced disturbances? What is a healthy ecosystem? Taking into consideration the natural trajectory of change of an ecosystem due to climate episodes (e.g., the Medieval Warm Period and the Little Ice Age), does the baseline make sense, as it is continuously shifting? What about the current human-induced global warming? [27–33].

In this article, we make the most of the benefit of almost 60 years of experience of the Port-Cros National Park (PCNP; Provence, France, the Mediterranean), one of the oldest parks which is both terrestrial and marine, with the aim of tackling the changes in paradigms, the possible management failures (in the light of the current concepts) and the obvious successes. We also analyse the slow transition from management based on species to management based on ecosystems, with its trail of misunderstandings, whether among the general public, among certain scientists, or sometimes even among the PCNP agents. On the other hand, the analysis of the quality of governance, although it is an important issue (see e.g., [34–37] which is closely linked to management, falls outside the scope of this study.

2. The Three Steps in the Approaches to Biodiversity Management

2.1. The Human-Centred Approach

The term biodiversity has only been formally defined since the end of the 20th century, and its meaning has since changed; however, the concept dates back earlier. Here, we are using biodiversity in its current meaning (see e.g., [38,39]).

The first approach to biodiversity management was human-centred. This approach was dominant for most of human history, from hunter-gatherers to early farmers up to the industrial revolution [21,40]. It is well illustrated by the writings of the influential French naturalists Buffon [41,42], and more locally Gourret [43], for the Provencal Mediterranean. Buffon felt only contempt for the environments that we now refer to as 'natural': a good environment was useful to humans, and was a showcase of the power of man and his dominion over nature and beasts. Gourret was merciless towards species which were harmful to fishermen, such as dolphins, and also porpoises, sharks and octopuses. Their

harmfulness justified the methods dedicated to destroying them, even those we would today qualify as cruel; Gourret's enthusiastic writing about the ways to get rid of dolphins could even be qualified as sadistic.

The human-centred vision of nature persisted until the 20th century, based on the dichotomy between useful species (for humans) and pests (competitors of humanity); official lists of pests, the destruction of which was recommended, were published by various European administrations [44,45]. For instance, birds of prey were on the pest lists, as they were considered to be competitors having an impact on the availability of commercially valuable or emblematic species for farmers and hunters. This approach was not only oversimplified but also biased. In fact, it has been shown that predators have a positive impact on their prey, directly or indirectly (see the Healthy Herd Hypothesis) [40]. In a way, the modern concept of ecosystem services (e.g., [46–52]) fits into the logic of the human-centred approach to nature, though it is much more complex and integrated. The integrated management of man and nature throughout the application of the theories of natural capital and ecosystem services could even be considered as a fourth level of management.

2.2. The Species-Centred Approach

The second approach to biodiversity management is species-centred. This approach culminated in the 20th century, but remains the dominant approach among the general public and environmental-management state agencies. Some species are 'outstanding', or have a 'heritage interest', and therefore deserve special attention. These are rather vague concepts (see e.g., [53–56]).

The criteria for the definition of outstanding species are diverse, including (i) rare species, at least in the region considered. (ii) Threatened species: the notion of threat can be defined according to the criteria of the IUCN Red List, but it is often defined in a more empirical way, at the regional level. Species which are extensively studied by scientists, and which are relatively easy to assess (e.g., birds, bats, turtles, fish, flowering plants), are more likely to be considered as threatened than taxa which are not supported by a large community of scientists and are difficult to identify (insects, sponges and algae, for example). Mediterranean macroalgal species on the brink of extinction (e.g., *Cystoseira, Ericaria, Sargassum*) are not even cited on the IUCN Red List, or only as DD (Data Deficient), even though there is abundant and consistent literature regarding their precarious status [57–60]. The valuable concept of 'IUCN Green Status of Species', which aims to assess the effect of conservation measures on threatened species [61], has not been tested on marine invertebrates, plants and macroalgae. (iii) Protected species are species which are protected at the regional, national or international level, or which are included within the annexes of the European Union (EU) directives or international agreements, e.g., the Bern Convention and the Barcelona Convention. It is worth noting that the protection status often does not so much reflect real threats, but often rather the sympathy that the species attracts. For example, all dolphin species are protected today, including *Tursiops truncatus* and *Stenella coeruleoalba*, for which there is no evidence that their abundance is below the baseline, and which might even have benefited from human action, which has eliminated some of their competitors [62–64]. (iv) Iconic (or charismatic, flagship) species are species that arouse the sympathy of the public, either because of their beauty [65], their intelligence, or an image acquired through films. In the PCNP, the dusky grouper *Epinephelus marginatus* and the meagre *Sciaena umbra* are iconic species. (v) Ecosystem engineers are organisms that directly or indirectly modulate the availability of resources (other than themselves) to other species by causing physical state changes in biotic or abiotic materials; autogenic engineers change the environment via their own physical structures, i.e., their living and dead tissues; allogenic engineers change the environment by transforming living or non-living materials from one physical state to another, via mechanical or other means [66,67]. In the PCNP, the holm oak *Quercus ilex* in the terrestrial realm, the seagrass *Posidonia oceanica,* and the stramenopiles *Cystoseira, Ericaria, Gongrosira* and *Sargassum* in the marine realm are

autogenic engineers. (vi) Key species (sometimes named keystone species) are species with a strong impact on their community or ecosystem, which is greater than that which might be expected from their abundance alone; in addition, they are major interactors with many links to other species, such as all of the herbivores [53,54,68]. There have been attempts to hierarchize concerns on the basis of some of these criteria (e.g., biogeographical rarity, local rarity and threats) (e.g., [69]).

A given outstanding species can belong to one or several of the above-mentioned categories. This is the case of the dolphin *Tursiops truncatus*, which is at the same time a protected species, an iconic species and a key species. Interestingly, within one century, dolphins have shifted from the status of a pest, which implied destruction by all means, to the status of an iconic and protected species. Flagship species are not always good indicators or umbrella species: their conservation can be very expensive (at the expense of less charismatic species); furthermore, management regimes focused on two flagship species can conflict [53].

2.3. The Ecosystem-Centred Approach

With the ecosystem-centred approach, we move 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-centred approach, which characterized the 18th century, to the species-centred approach.

The ecosystem-centred approach has several strong points [40,53,70,71]. (i) It allows the inclusion of humans in the functioning of the ecosystem, in a natural way, thus evolving from the notion of the ecosystem to the social–ecological system. Humans are no longer set aside, but are within the system. (ii) While the species-centred approach often only considers a collection of outstanding taxa, the ecosystem-centred approach requires the construction of a framework corresponding to a conceptual model of the ecosystem. In this model, there are grounds for the inclusion of even the 'ordinary' species (i.e., species that are neither rare, nor threatened, nor iconic). Species which are not outstanding (the 'ordinary biodiversity') often play a more important role in the functioning of ecosystems than outstanding species. (iii) Building a conceptual model makes it possible to link the species together, following a network of interactions (e.g., predation, parasitism, mutualism), and to better interpret the possible fluctuations in their abundance. (iv) The conceptual model can be a stepping-stone towards analytical or numerical modelling, where flows (e.g., C, N, P) between compartments are quantified. (v) The ecosystem-centred approach also highlights the importance of tackling the coupling between adjacent ecosystems (including benthic and pelagic, terrestrial and marine ecosystems). (vi) The ecosystem-centred approach 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 [72–77]. (vii) Terrestrial and marine invasive species constitute one of the most worrying aspects of global change, and the Mediterranean Sea is the area impacted most by non-indigenous species [78–81]. Invasion issues are usually studied and managed in a single-species context, i.e., the interaction between an invasive species and a native one. In fact, invasive species rarely act in isolation, but in packs: invasive species rarely have an impact on one species alone, but rather on the entire community; therefore, the understanding of their role and impact can only be achieved in the context of the whole ecosystem [82,83]. (viii) Human activities (e.g., fisheries, chemical 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., [84–89]). Ecosystem-Based Fishery Management (EBFM) is obviously part of the ecosystem-centred approach.

3. A Brief History of the Port-Cros National Park

The Port-Cros National Park (PCNP, Provence, France, Mediterranean) was established in December 1963 [90] by a French decree (*Décret* 63-1235, 14 December 1963), in the framework of the French Law of 1960 (*Loi de création des parcs nationaux*; No 60-708, 22 July 1960). It encompassed the island of Port-Cros and the nearby island and islets (Bagaud Island, La Gabinière Islet and Le Rascas Islet), i.e., the Port-Cros Archipelago, situated about 8 km off the mainland coast of eastern Provence (Figures 1 and 2). In addition to the land areas of the island and islets, the PCNP included a 600-m wide belt of sea, corresponding to 1 300 ha in surface area, surrounding the archipelago [91,92]. The PCNP is one of the oldest terrestrial and marine national parks in the Mediterranean area.

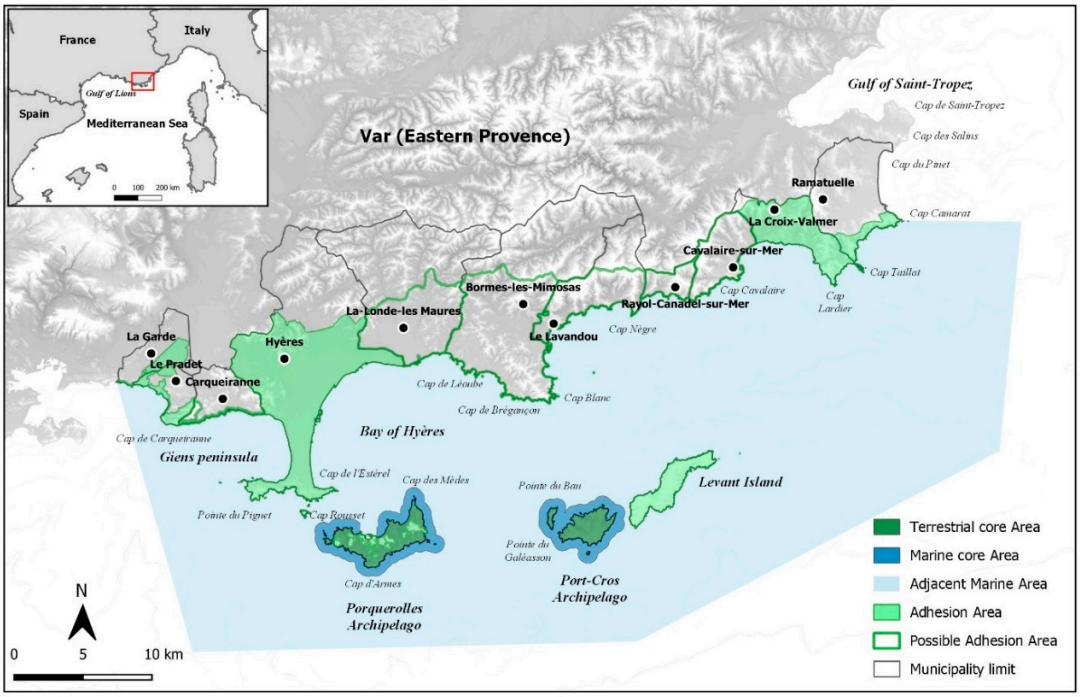

Figure 1. Map of the new Port-Cros National Park (N-PCNP) established in 2016. The initial PCNP, established in 1963, was restricted to the archipelago of Port-Cros. In the municipalities (*communes*) which joined—or not—the N-PCNP, part of the municipality's area is located outside of the Possible Adhesion Area.

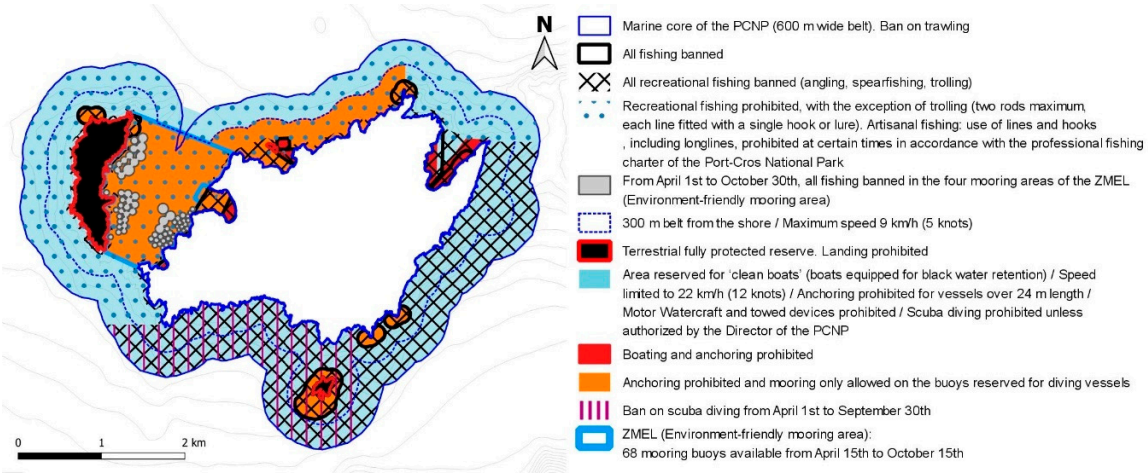

Figure 2. Boating, anchoring, scuba-diving, artisanal and recreational fishing regulations within different areas of the Port-Cros Archipelago (PCA) MPA (Port-Cros National Park). Other regulations are not shown on this map. Original drawing © Marie Clap (PCNP).

Progressively, the PCNP has been entrusted with the management of an increasing number of territories outside of its initial territory of 1963. The land (~950 ha) situated on the neighbouring island of Porquerolles (bought by the French State in 1971) was handed over for management to the PCNP. Starting in 1984, the PCNP also 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 EU Natura 2000 sites 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 has provided 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 [93–97].

Following the redefinition of the national parks by the French legislation of 2006 (*Loi N°* 2006-436, 14 April 2006), the PCNP was engaged—between 2012 and 2016—in a major redefinition and extension of its territory (*Décret N°* 2012-649, 4 May 2012); the new Port-Cros National Park (N-PCNP), established in 2016 (Figure 1), includes the Port-Cros and Porquerolles Archipelagos as core areas (both terrestrial and marine: 30 km^2), a vast Adjacent Marine Area (AMA—*Aire Maritime Adjacente*) including the Bay of Hyères and extending seawards to the edge of the continental shelf (1 186 km^2), and a discontinuous continental area—the Adhesion Area (AA—*Aire d'Adhésion*: 113 km^2)—including five municipalities (*communes* in French; Figure 1). The municipalities of the AA voluntarily joined the N-PCNP, 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 [20,94,97,98]. In contrast, some municipalities of the Possible Adhesion Area (*Aire Optimale d'Adhésion*) did not wish to be part of the N-PCNP yet.

4. Materials and Methods

We examined all of the literature we are aware of dealing with the Port-Cros National Park in its successive configurations (first the Archipelago of Port-Cros, then the territories managed by the PCNP, up to the N-PCNP, which includes the island and mainland territories). This literature was published in scientific journals (including the PCNP journal, *Scientific Reports of Port-Cros National Park*, 35 volumes of which have been published since its launch in 1975); it also includes unpublished reports (gray literature), kept at the PCNP headquarters (in Hyères-les-Palmiers) and in various libraries, including that of the MIO (Mediterranean Institute of Oceanography), at Aix-Marseille University [4,92,93].

We also examined the documents produced by the PCNP (in collaboration with its Scientific Council) aimed at defining a scientific strategy and management plans [99].

Finally, we examined the minutes of the meetings of the Scientific Council (SC)—set up in 1964 (the year following the establishment of the PCNP), and which has operated without interruption since then (1–2 annual meetings)—and of its Bureau (4–6 annual meetings) [91,100]. Of particular importance are the 'Opinions' (in French: '*avis*') delivered by the SC, either in response to a request from the Director (possibly passing on an administrative request), or by self-referral from the SC itself. Between 2008 and 2020, the SC delivered between 5 (in 2008) and 28 (in 2015) *avis* per year (mean: 18). Although an SC Opinion is not legally binding, it is worth noting that the vast majority of the opinions were followed by the PCNP Director.

The management operations to which we refer here were listed and detailed by Boudouresque et al. [92] in Table 1 of that article for the terrestrial realm, and in Table 2 for the marine realm. Additional management operations are listed hereinafter (Table 1). The level of public and/or social acceptability of the management operations is based on expert judgement (i.e., that of the authors), and is related to the time of the management operation: it may have changed over time.

Table 1. Management issues and responses from the PCNP and N-PCNP in the terrestrial realm (numbered T27 through T34) and the marine realm (numbered M21 through M29). These operations were not taken into account by Boudouresque et al. ([92]; see Tables 1 and 2 herein). PC and PQ refer to Port-Cros Archipelago and Porquerolles Island, respectively.

No, Dates	Management Issues	Responses, Results and Comments	References
T27 2004 to present	Cyclical outbreaks of the non-native black rat *Rattus rattus* threaten seabirds and are a nuisance for residents (PC)	Setting up traps around the village and seabird nesting sites	Hervé Bergère (pers. comm.)
T28 2000s	Low walls across valleys built in the 1970s to favour the Tyrrhenian painted frog *Discoglossus sardus* (T1) were ineffective and inappropriate (PC)	Removal of the low walls	Élodie Debize (pers. comm.)
T29 2002–2005	Decline of the European leaf-toed gecko *Euleptes europaea* (PC)	Clearing and thinning of the vegetation of Vallon de la Solitude. Renewed once, then discontinued	Élodie Debize (pers. comm.)
T30 2011–2012	Presence of the invasive black locust *Robinia pseudo-acacia* near the Vallon de la Solitude dam (PC)	Successful eradication	Élodie Debize (pers. comm.)
T31 2011–2013	Restoration of the La Sardinière farm, evidence of the agricultural past of PC	The SC rejected the proposal from bat specialists to install facilities for bats (shelters, waterers)	*Avis* 9/2010 of the SC
T32 2020	Natural arrival of the wild boar *Sus scrofa* (swimming) in the integral reserve of Bagaud Island (PC)	The wild boar is native and a key species in Mediterranean ecosystems: no reason to eradicate it	*Avis* 5/2020 of the SC
T33 2021	Weed control and fire risk, Plage d'Argent (PQ)	Use of four donkeys for environment-friendly weed control	*Secrétariat connaissance du patrimoine*, PCNP
T34 2021	Aging of the split stake fences (*ganivelles*) installed in 1982 (T6) to protect the vegetation of the back beach (Plage du Sud) (PC)	Renovation of the split stake fences	Élodie Debize (pers. comm.)
M21 1963 to present	Over-exploitation of sea urchins (*Paracentrotus lividus*) (PC)	Ban on sea urchin harvesting	Philippe Robert (pers. comm.)
M22 1984–1995	Rescue of the critically endangered Mediterranean monk seal *Monachus monachus*	Project of breeding in captivity of individuals from Cap Blanc (Mauretania), then release of the calves in an enclosed Port-Cros bay	Simon and Moutou [101], Boudouresque [102]
M23 2000s	Monitoring of water quality via *Mytilus galloprovincialis* ('mussel watch')	Cages containing mussels, placed without PCNP authorization, removed and destroyed by wardens	Andral et al. [103]
M24 2005	Specimens of the protected *Scyllarides latus* seized in commercial outlets (PC)	Released in the PCNP, La Palud Bay (Port-Cros Island)	Philippe Robert (pers. comm.)
M25 2010s	Monitoring of water quality via *Mytilus galloprovincialis* ('mussel watch')	Risk of contamination by non-indigenous species. Authorization refused	*Avis* 7/2018 of the SC

Table 1. *Cont.*

No, Dates	Management Issues	Responses, Results and Comments	References
M26 2018	*Pinna nobilis* transplant from shallow towards deep habitats in an attempt to thwart mass mortality due to *Haplosporidium pinnae*	Absence of a scientific basis for such transplantations. Authorization refused by the SC	Amalric and Leclerc [104]
M27 2020	Disposal and exploding of bombs and mines from World War II	Avoid PCNP waters, prior scaring of wildlife, less than 10–15 m depth	Unnumbered *Avis* of the SC of 3 March 2020
M28 2020 to present	Degradation of the *Posidonia oceanica* meadow by the anchors of pleasure boats (PC)	Setting up of a ZMEL (*Zone de mouillages et d'équipements légers*—environment-friendly mooring) in the Bagaud Pass: 68 mooring buoys	*Arrêté interpréfectoral* N° 039/2020 (PREMAR)/No DDTM/SML 001/2020 (PREF)
M29 2021	Decline of the populations of *Paracentrotus lividus* and other echinoderms	A moratorium on *P. lividus* harvesting would be acceptable, under certain conditions	*Avis* 1/2021 of the SC

Although scientific research is an essential tool for management (we only protect well what we know well) [105], and although the PCNP has—since its establishment—been a hotbed for scientific research [4,93], we have not considered here the research programmes.

5. Results and Discussion

5.1. Is the Marine Zoning Too Complex?

There are two types of MPAs: NTZ (No-Take Zones), where all human activities (fishing, scuba diving, anchoring, sometimes even sailing and bathing) are banned, and MUM (Multi-Use Management), characterized by the complex zoning of the marine part of the MPA, based on the co-existence of uses, conservation goals for the habitats and ecosystems, and clearly displayed priorities (e.g., artisanal fishing rather than recreational fishing). It is worth noting that, as far as the conservation of the natural heritage and the functioning of the ecosystems are concerned, MUM management, as enforced in the PCA (Port-Cros Archipelago) MPA, is at least as efficient as NTZ management [106,107]. In addition, it is compatible with sustainable fisheries in particular and sustainable development in general, and fits well with the concept of the socio-ecosystem [40].

Recreational fishing is almost completely prohibited in the PCA MPA, with the exception of trolling in its northern part (Figure 2), a form of fishing that does not target resident fish. Artisanal fishing is prohibited in 6.2% (PCA MPA; Marion Peirache, pers. comm.) and 9.9% (Porquerolles Island; Laurence Le Diréach, pers. comm.; see Figure 3) of the total area of the PCNP core areas.

A relevant question is whether this zoning is not too complex. A very complex zoning system is not only difficult to understand for the users but also difficult to enforce for the wardens. Nothing is worse than an unenforced or inapplicable law ([108] and Gilles Martin, unpublished data). However, it is worth noting that the respective regulations (for boaters, recreational fishers, etc.) are nowadays easily accessed with a QR code, and are on the PCNP web site (see, e.g., the leaflet edited by the PCNP [109]). Moreover, the use of GPS is now widespread. For a given user, the specific zoning and regulation is not so complex; Figures 2 and 3 are shown here for illustrative purposes only, superimposing a large number of uses (not even all) so as to illustrate the complexity of the zoning, but they were produced specially for this article; users will not find a map such as these on the internet or on the PCNP information sites, but rather specific maps which are easy to understand, corresponding to their specific use. In addition, this (complex) zoning, in the context of a MUM, is backed by charters for fishing and diving activities, such that its enforcement should become easier with time (which does not preclude any further

simplification). Within the framework of the historical PCNP, restricted to the Port-Cros Archipelago (PCA), this complex zoning seemed to work. However, the question deserves to be reconsidered within the framework of the N-PCNP. In any case, the proviso for any efficient nature conservancy is that the public who come to the core areas of the PCNP are aware that they are visiting a national park, a highly valuable and protected area; in that domain, we must admit that the communication offered by the tourism offices, who post mainly winter pictures (a period of low frequentation), or challenges on social networks to nominate the most beautiful beach, should provide a more useful contribution to the knowledge of the zoning and regulations.

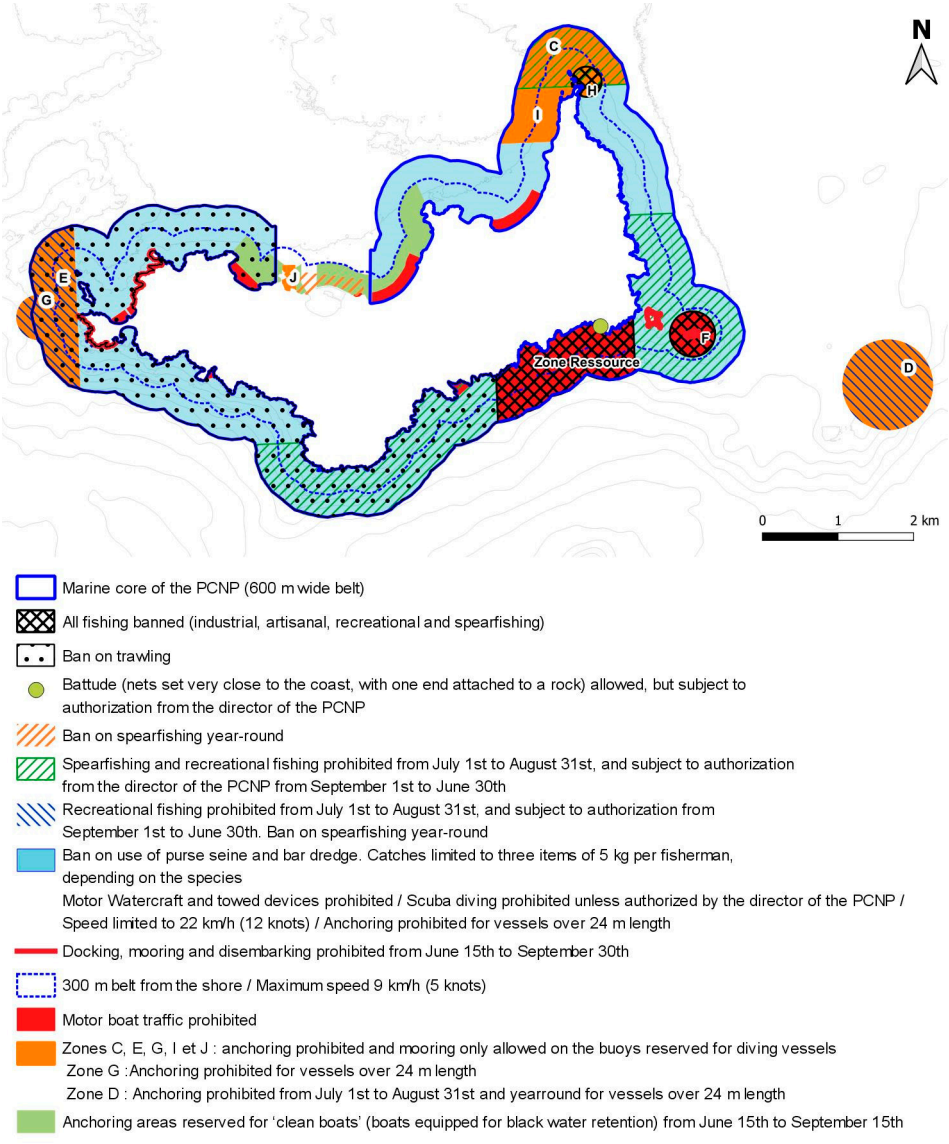

Figure 3. Boating, anchoring, scuba-diving, and artisanal and recreational fishing regulations within different areas (A through H) of the Porquerolles MPA (Port-Cros National Park). Other regulations are not shown on this map. Original drawing © Marie Clap (PCNP).

Finally, an important point concerning the apparent complexity of this legislation is that it reflects a long-term consultation, spread over decades in the case of the Archipelago of Port-Cros, with the different categories of users, at the same time as with the State authorities, who are at least as difficult to convince as users. This is called governance.

5.2. Should the Sea Urchin Paracentrotus Lividus and Other Macro-Herbivores Be Controlled?

The sea urchin *Paracentrotus lividus* is, together with the teleost fish *Sarpa salpa*, the main macro-herbivore species in the western Mediterranean Sea [110–114]. Although the former presents clear feeding preferences, it is highly opportunistic and is able to consume a wide spectrum of resources, from dead fish to sand [112,115,116]. It is mainly controlled by predator fish [117–120]. Overfishing may result in the proliferation of sea urchins and the formation of barren grounds, where Fucales (e.g., *Cystoseira, Ericaria* and *Gongolaria*) forests are extirpated and the vegetation is reduced to a carpet of encrusting corallines and low algal turf [75,121–123].

In the northwestern Mediterranean, where *P. lividus* is considered a delicacy, there is a popular belief among professional sea urchin harvesters regarding the historical depletion of stocks. This depletion is supported by scientific data for the short term (decades), but not for the long term (decades to centuries) [112,124]. The supposed 'golden age' could have been an artefact: a proliferation of *P. lividus* due to a peak in organic pollution together with the overfishing of their teleost predators [112]. Sea urchin harvesters argue for the seeding of juveniles born in hatcheries. Seeding has sometimes been carried out [125], but it has been criticized [126]: the natural situation in the Mediterranean is probably a scarcity of *P. lividus,* as evidenced by the Scàndula Nature Reserve in Corsica [14,127].

In the Port-Cros Archipelago MPA, the harvesting of *P. lividus* has been banned since the establishment of the PCNP (management: M21). Outbreaks and subsequent mass mortalities of *P. lividus* have been reported [128–130]. The decline of the barrier reef of *Posidonia oceanica* in the Bay of Port-Cros [131] and the near extinction of the infralittoral *Ericaria brachycarpa* (=*Cystoseira brachycarpa*) forests [132] have been attributed to *P. lividus* overgrazing. However, the teleost *Sarpa salpa*, which proliferates in some MPAs (see, e.g., [133–135]) may also have played a role, at least locally [136,137].

The SC was contacted in late 2020 by Porquerolles fishermen, who alerted them regarding the potential severe decline of their *P. lividus* harvests (management: M29). They were ready to accept a provisional ban for 2–3 years, to be included into the charter for fishery within the PCNP, provided that the SC would endorse and recommend it. A heated debate took place; however, the various data analysed by the SC (namely the monitoring of the Port-Cros and Porquerolles echinoderm populations spanning 1994–2019 [124]; see also other MPAs) did not provide an adequate basis to pinpoint the sole responsibility of the professional fishery in the sea urchin's population decline (which appears to extend to most of the echinoderms). As a result, the fishermen finally only suggested the reduction of the period for harvesting (to the first and last months of the currently allowed period), provided that it would also apply to the recreational fishery in the *Aire Marine Adjacente*.

5.3. Should Any Fishery Be Banned?

When the PCNP was established (then only the Port-Cros Archipelago), sea fishing (artisanal and recreational) was not prohibited. Only trawling, sea urchin harvesting and spearfishing were banned (management: M1 and M21). For some environmentalists, this was a major error that would hamper the renewal and growth of fish populations, an error which is now difficult to reverse. Subsequently, between 1990 and 2004, recreational fishing was prohibited step by step in the Port-Cros Archipelago MPA. It was shown that the uptake by recreational fishing was equivalent to that of the artisanal fishing [138,139]. This ban was, in a way, a trade-off with artisanal fishermen, who accepted a fishing charter with much more restrictive conditions than the French national and local regulations: a shorter soak time, a larger mesh size, a smaller number of traps, and a shorter length of nets, etc. [106,140–142]. Since 1999, artisanal fishing has been banned around six scuba diving sites in order to ensure the safety of divers (Figure 2). Overall, artisanal fishing is only prohibited in a small part (6.2%; 80 ha) of the MPA: bathing areas near beaches, areas reserved for scuba diving, and the area around the snorkeling trail in the Bay of La Palud (Figure 2).

There is a debate between those who think that no fishing, even if it is artisanal, should be allowed in a national park, and those who consider that artisanal fishing is part of the cultural heritage of the Mediterranean countries, and that the preservation of this cultural heritage is one of the goals of a national park.

According to Boudouresque et al. [139], an additional reason which is ecosystem-based justifies the presence of artisanal fishing, insofar as regulatory constraints keep fishing within moderate limits. Some top predators which were once present in the area, such as the monk seal *Monachus monachus*, are today locally extinct [143], and a number of shark species are today functionally extinct [144]. Where an ecosystem is truncated by the absence of some of its uppermost predators, artisanal fishing could play the role of a surrogate top predator [107].

5.4. Should the Natural Closure of the Terrestrial Vegetation Be Controlled?

Human influence is very ancient on Hyères Islands and since prehistoric times, certain islands (Porquerolles, Le Levant) have been occupied periodically and more or less intensively by humans [145]. Over the centuries, the impacts linked to deforestation, fire, cultivation and grazing, have been very significant, which has led to significant alterations of the landscapes, the functioning of ecosystems and their biodiversity [140].

The impacts described contradict the current view of the forest as an 'original and pristine forest' in Port-Cros, as was emphatically proclaimed in the 1930s by several writers, and even renowned naturalists and scientists such as Alfred Serge Balachowsky, professor at the National Museum of Natural History (Paris), who fervently advocated for the creation of a National Park in March 1963: "Today the island is the exact reflection of what it could have been before the presence of man, under the exclusive influence of natural balances". The absence of major disturbance for about three-quarters of a century in forest ecosystems and scrublands has resulted in the maturation of woody vegetation and an overall closure of open areas of lawns and low scrub (*Cistus* scrublands). Thus, in Port-Cros, between 1970 and 2004, the holm oak formation increased from 80 ha to 407 ha, while the mixed oak forest–maquis formation with *Quercus ilex, Arbutus unedo* and *Erica arborea*, which covered only 14 ha in 1970, represented 242 ha thirty years later [146]. The dynamic trajectory of the island bird population is also oriented towards a guild of forest birds marked by the appearance of medium-to-large species which are mostly frugivorous, as is characteristic of aging forests [147].

On the island of Port-Cros, a much-discussed aspect is that of the conservation and management of open areas of xerophilous lawns or low scrublands and their associated species, in particular vascular plants and photophilous invertebrates, which have been in constant decline for a century. The presence of cat thyme (*Teucrium marum*, Lamiaceae), a plant with a Tyrrhenian distribution—a characteristic species of open scrublands, on hot and sunny rocky soils—is a good indicator of the ancient extent of these heritage value ('patrimonial') habitats, as noted by Jahandiez [148]: "It literally covers Port-Cros and the Île du Levant, where its powerful smell of ether strikes the traveler disembarking in these places in June or July". Since then, cat thyme has become very scarce, and it is confined to a few relict open environments, particularly along tracks and trails [149].

As such, according to the principle of naturalness, should we not avoid carrying out any interventionist management and consider that these pioneer habitats are, by nature, doomed to disappear due to the normal plant dynamics? Or, on the contrary, should we adopt 'measured interventionism' by the deployment of the occasional clearing of limited areas, which would probably be insufficient to maintain these sunny environments and photophilous species? Should we go as far as major restoration or ecological engineering operations in an attempt to recreate significant areas of open environments on these islands, including some areas of dense scrub and maquis?

In the 1990s, the first recommendations of scientists were to act against this natural closure of the vegetation in order to "locally limit the expansion of banal species and populations which develop to the detriment of others of greater scientific and heritage

interest" [150] (management T8). However, this assertion is problematic because it classifies species according to subjective categories without functional significance and without an overall ecosystem approach. If we consider other taxonomic groups, the closure of vegetation and the maturation of forest stands in Port-Cros will promote the establishment and development of new guilds which are characteristic of old thermophilous forests, such as saproxylophagous Coleoptera, fungi, mosses and liverworts (e.g., *Cololejeunea minutissima*), or corticolous lichenic communities linked to old trunks [146]. In addition, these operations to open the environment are costly, complex and ultimately ineffective because the natural dynamics of the vegetation would imply the regular renewal of the cutting of emerging woody species. Rather than the solely taxonomic approach, it is therefore necessary to promote an ecosystem approach that is better suited for broader temporal and spatial dimensions. Maintaining, in a fixed manner, some transitory stages included within the ecological dynamics as a whole remains illusory, and is nonsensical from the ecological point of view [92,151]. It is necessary to integrate occasional disturbances such as clearings created by windfalls (*chablis* or *volis*) following the fall of old trees—an underestimated pivot of forest dynamics in Mediterranean forests [152]—or to accompany the natural arrival of a large mammal, the wild boar, which is seen only as a destructive element of a certain "heritage biodiversity", which remains to be demonstrated (see Section 5.6). These natural disturbances play a key role because they are part of the well-known process of 'patch dynamics', which was already formalized 35 years ago by Pickett and White [153]. Generally, in the framework of the PCNP and N-PCNP, we are indeed in favour of the free evolution of natural environments and vegetation (letting nature be natural), as long as the native species and processes are not altered by invasive alien taxa or exogenous disturbances. The example of the free evolution of terrestrial ecosystems in the Scàndula Nature Reserve (Corsica) is a very good illustration which shows that minimalist management is ultimately very efficient [14].

5.5. Should Natural Populations Be Enhanced?

The question of the assisted increase in populations of outstanding species (with heritage value) is recurrent in protected areas. For the strategy of species-centred management, the promotion of population growth made sense. The Salins des Pesquiers saltmarsh (Figure 1), for example, has been managed since its acquisition by the *Conservatoire de l'Espace Littoral et des Rivages Lacustres* (CERL) in 2001, almost as an ornithological park: everything was done to maximize the reproduction of the bird species and their diversity: water circulation, the level of water in the ponds, artificial nests, and the destruction of foxes accused of being predators of chicks, etc. [40,76,154,155]. An artificial platform was even built, using oyster shells, mussel shells and gravel, to facilitate the nesting of *Recurvirostra avosetta*, *Sternula albifrons* and *Chroicocephalus genei*, although these three bird species are considered to be LC (least concern) in the IUCN Red List [156].

In the first decades of the PCNP, the dominant approach was species-centred, and management was very logically performed on a species-by-species basis. Under these conditions, it seemed logical to enhance the populations of heritage species, either by releasing individuals or by improving their habitat. (i) The Tyrrhenian painted frog *Discoglossus sardus*, endemic to Corsica, Sardinia and some Tuscan islands, only occurs in mainland France on Port-Cros and Le Levant islands [157]. Low walls were constructed across the small valleys to retain water and supposedly improve its habitat (management: T1); this operation failed, as the ponds quickly filled with sediment. Subsequently, the walls were removed (management: T28). (ii) In response to the local extinction of Hermann's tortoise *Testudo hermanni*, individuals abandoned by private owners in Provence were released in Port-Cros and the Porquerolles islands. In Porquerolles, they were fed, in an enclosure, for 10 years (management: T4 and T11). The complex genetic structure of the Hermann's tortoise populations was then unknown; in fact, the populations of Provence and Greece belong to distinct haplotypes (see e.g., [158]). The Hermann's tortoises which were marketed in France and kept by local inhabitants generally belonged to the Oriental (Greek)

haplotypes; therefore, what were Oriental haplotypes were introduced to Port-Cros, rather than the native western haplotype, which is obviously inappropriate. (iii) A pond was dug at Porquerolles to increase the insect resource for bats (management: T14); at the same time, a tower was specially built to house a colony of the bat *Myotis emarginatus* (management: T13), due to the planned destruction of their actual (and artificial) habitat (a crumbling warehouse). No question was raised as to whether the increase in bat populations might not come at the expense of the insect populations (some insect species do have a heritage value) and of other consumers of nocturnal insects, such as *Discoglossus sardus* and shrews. In addition, the aesthetic and inspirational value of butterflies, or the symbolic—and in some places religious—value of dung beetles should be considered. At that time (early 2000s), the SC was just informed of the construction of the bat tower, and had not even been informed of the digging of the pond, both being located in Porquerolles, which was not officially part of the national park. (iv) The Mediterranean slipper lobster *Scyllarides latus* is a protected species in France (*Arrêté* of 26 November 1992) [159]. Its capture and marketing are therefore prohibited. Live individuals, seized in commercial outlets, were released in Port-Cros in 2005 (management: M24, Table 1) (Philippe Robert, pers. comm.). (v) The giant limpet *Patella ferruginea* once occurred in Provence, where it is locally extinct. Individuals originating in the Scàndula Nature Reserve (Corsica) were reintroduced to Rascas Islet (Port-Cros) [160] (management: M6). The operation failed. A handful of individuals have been observed around the Archipelago of Port-Cros, several hundred metres or a few kilometres away from each other. One hypothesis is that they come from larvae resulting from the dense populations which remain in Corsica (Capicorsu and Scàndula) and carried by the Mediterranean Northern Current; the Port-Cros individuals, present in the Port-Cros Archipelago, constitute what is called a 'pseudo-population'.

5.6. The Natural Arrival of the Wild Boar Sus Scrofa

The wild boar *Sus scrofa* is native to Eurasia, including Europe. In southern France (Provence and Occitania), its abundance has fluctuated since at least the 18th century, with low points close to local extinction and high points such as the current proliferation [161]. Several causes can account to this proliferation: (i) the increase in the surface area of forest (from 13% in the late 18th century to 46% today) and *maquis* due to the severe decline of agro-silvopastoral practices; (ii) the elimination of its predation by the wolf *Canis lupus*; (iii) the feeding of the boar in winter by hunters (in French: *agrainage*); and (iv) climate warming, which reduces the natural winter mortality and increases the breeding potential [161,162].

The wild boar is a good swimmer, and is able to naturally reach islands not too distant from the mainland. From the late 19th century, when Port-Cros Island was almost completely forest-cleared for agricultural purposes, it was absent from the island, but it probably thrived in the island during the long time periods—for centuries or millennia—when Port-Cros was not permanently occupied by man. It was first sighted on Port-Cros Island in 2008; since 2015, permanent populations of wild boar have naturally colonized Port-Cros Island and Porquerolles Island [161]. Its presence on Bagaud Island was repeatedly reported during recent years, but the permanent occupancy of this island is not attested, probably as a result of freshwater scarcity.

In Port-Cros, the wild boar 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 (e.g., the narrow endemic *Romulea florentii*), and of the rare and locally endangered Sardinian frog (*Discoglossus sardus*) located in some temporary ponds. It has also been blamed for the reduction of the abundance of the snake *Malpolon monspessulanus* [163]. The so-called 'negative' impact of wild boar must be compared with its 'positive' effects, which are part of an ecosystem approach: (i) the aeration of the soil; (ii) the reactivation of the soil seed bank, including bulbs; and (iii) the return of coprophagous insects which were eliminated by chemical vermifuges used for domestic livestock, as boar droppings have become a real refuge for many of these endangered insects everywhere (Philippe Ponel, unpublished data in [92]). These coprophagous insects are also widely exploited by bats.

(iv) Another positive is the recovery of necrophagous insects, for example *Necrodes litoralis*, which is specialized in large corpses.

Most of the members of the SC of the N-PCNP are of the opinion that the role of a the National Park is not to combat a natural process or its impact on associated species (even if they are rare and protected plants), which is consistent with an ecosystem-based approach; in addition, they take into account the fact that if rare plants (e.g., *Romulea florentii*) are present today, it is because they have resisted the presence of wild boar—occasionally or permanently—for millennia. In the same way, if the snake *Malpolon monspessulanus* is still present, while unable to swim across several kilometres of sea and therefore to recolonize islands if it is becoming extinct, it is because it resisted the presence of wild boar over millennia under natural environmental conditions (an obvious fact which is not considered by Ballouard et al. [163]). However, taking into consideration the fact that the wild boar is not a threatened species, and that the well-being of the inhabitants is an important feature of the N-PCNP governance, the SC was not opposed to the control of the wild boar, via trapping and hunting (management: T26 and T32). About 275 individuals had been killed by 2018 ([161]; Élodie Debize, pers. comm.). This attitude is consistent with the principles for ethical wildlife control [97,164], although the presence of several dozen hunters taking part in periodical beats in the core area of a National Park is still questionable from an ethical point of view.

5.7. The Control of Marine Invasive Species

MPAs are not islands of nature surrounded by incompatible resource uses [3,17,165,166]. Introduced species do not respect the limits of MPAs [167–169].

Elton's theory of ecological resistance (ERT—[170]) in the mid-20th century, which claimed that high species diversity and the lack of disturbance were factors of resistance to introduced species, has now been abandoned in the marine realm, and is seriously challenged in the terrestrial environment. The reality is even exactly the opposite: habitats with high species diversity are those most affected by biological invasions, and disturbances generally increase (not reduce) species diversity (Biodiversity Increasing Invasibility Hypothesis—BIIH) [38,39,171–173].

A number of invasive species occur in both the marine core areas (Port-Cros Archipelago and Porquerolles Island) and the PCNP Adjacent Marine Area (AMA). The most worrying species are the macroalgae *Caulerpa taxifolia, C. cylindracea* and *Womersleyella setacea* [174–176].

Controlling invasive species is usually very difficult once they are established, unless eradication is implemented very quickly [17,177,178]. The solution is to prevent their arrival, which requires the support of appropriate and effective legislation. France is unfortunately a 'bad pupil' in Europe because of the power of the officials of the Ministry of the Environment, who do not implement, or implement very late, both French Laws and EU Directives, perhaps because they are unduly influenced by the arguments of animal shops, garden centers and aquarium trade lobbies [60,179].

The control of *Caulerpa cylindracea* and *Womersleyella setacea* is, unfortunately, impossible nowadays. In contrast, the PCNP set up an efficient strategy for the containment of *C. taxifolia* (M14). Annual campaigns dedicated to locating and uprooting *C. taxifolia* have been carried out since 1994; they have been successful. In addition, by association with volunteers and scuba-diving clubs, they can be assimilated to citizen science and play a role in raising public awareness [180–186].

5.8. The Control of Terrestrial Invasive Species

Four terrestrial invasive species have particularly attracted the attention of managers and the Scientific Council: the ice plant *Carpobrotus* spp., the Argentine ant *Linepithema humile*, the common wall gecko *Tarentola mauritanica,* and the black rat *Rattus rattus*. A fifth species, the red-eared slider *Trachemys scripta*, occurs in the saltmarshes of Hyères, in the Adhesion Area, where it has been the target of control by capture [187], but not in the core areas of the N-PCNP (Port-Cros Archipelago and Porquerolles Island).

The Argentine ant *L. humile* is a highly invasive species which is a major competitor of native ants and of other insects, and indirectly impacts native plants and cultivated plants of agricultural interest; it has been present since 2005 in the Archipelago of Port-Cros, and since 2006 in Porquerolles [188]. Since then, following several *avis* of the Scientific Council, the manager has inspected construction materials when they arrive on the islands from the mainland.

The gecko *T. mauritanica* is native to the western Mediterranean area of North Africa and Europe; its occurrence on Mediterranean islands, e.g., Porquerolles, where it arrived between 1985 and 2001, and Le Levant (N-PCNP), was due to human-induced introduction; it can be detrimental to the native *Hemidactylus turcicus* [189,190]. As for the Argentine ant, construction materials are inspected upon their arrival in the islands.

The black rat and the ice plant illustrate the phenomenon of the invasive meltdown, as defined by Simberloff and Holle [191]. There is a mutualistic symbiosis between them, with the rat dispersing the ice plant's seeds and the ice plant providing the rat with food and water. This efficient co-invasion threatened some species of rare flowering plants, such as *Romulea florentii*, together with seabirds, lizards and invertebrates. For this reason, the PCNP authorities, following the advice of the SC, decided in 2010 to proceed with the simultaneous eradication of the two species on the island of Bagaud, which is an integral reserve (Figure 2). In order to measure the consequences of the co-eradication, pre- and post-eradication monitoring was set up two years before the co-eradication, and 10 years after. The main taxa were thus the subject of monitoring, based on solid and replicable protocols. Thus, this project also had the consequence of setting up a long-term observatory of ecological changes, including climate warming, in this integral reserve [192–196].

This project raised several issues. (i) Considerable financial costs: more than €500,000 was spent in eradication operations for uneven results. If the extirpation of ice plants had a positive effect on the flora, and particularly on the invertebrates, it is obviously not the same for rats. (ii) The underestimation of the resilience of black rat populations: individuals appear to have escaped eradication operations, or have since recolonized the island, despite post-eradication biosecurity measures. (iii) The lack of knowledge of the composition and structure of the island's fauna and flora that preexisted on Bagaud Island before the very ancient appearance of the black rat and the more recent introduction of ice plant: the black rat would have arrived in the western basin of the Mediterranean 2200–2400 years ago [196]; the ice plant was much more recently introduced. How can we then speak of ecological restoration? (iv) Ethical issues may be raised by the destruction of several thousand rats. (v) Problems of social acceptance: it is the uninhabited island of Bagaud which has been the subject of the eradication project, while the proliferation of rats in Port-Cros represents a considerable nuisance for the inhabitants and for recreational boaters. This situation led the PCNP authorities to undertake occasional control operations of rats around the village of Port-Cros. The size of the Port-Cros area and the high tourist attendance make any rodent eradication project on this island illusory. (vi) The inconsistency of the decisions taken by the administration of the PCNP: while the arrival of rats transported by pleasure craft is a proven fact, the recent decision to organize mooring in the pass between Bagaud and Port-Cros islands by means of buoys (ZMEL; see Figure 2), some installed close to the coast of Bagaud Island, is likely to allow the recolonization of Bagaud by rats transported by pleasure craft.

5.9. Global Warming

Global warming is a very serious concern for all species and ecosystems on land and in the sea [197–199]. Protected areas are of course not spared by global warming. Southern species are currently spreading northwards in the Mediterranean [200–203]. The teleosts *Thalassoma pavo* (ornate wrasse) and *Sphyraena viridensis* (yellow barracuda), a top predator, are now common in the Port-Cros Archipelago. The Mediterranean parrotfish *Sparisoma cretense* has also been sighted there [204]. In contrast, species of cold affinities, such as the eelgrass *Zostera marina* and the teleost *Sprattus sprattus*, mainly occurring in the northern

Mediterranean, should see their range shrink, which at the moment, unexpectedly, is not the case [205–208].

Many authors have focused their attention on the physiological or geographical effects of warming on species. In fact, these effects are often limited at the scale of the ecosystem. It is less these effects than the effects of warming on the ecosystem itself that are decisive [209].

Stopping or slowing down global warming is obviously beyond the reach of the managers and the SC of a protected area; it is, of course, at global scale that actions should be taken, for example within the framework of the Paris Agreement, signed in 2016 [210]. However, a protected area can play a role, through environmental education, in raising public awareness of the issue of global warming and its consequences [211]; the PCNP is particularly active in this area. Nevertheless, it should be noted that global warming is often used as a convenient scapegoat by the local and State authorities: not much can be done at local scale without global scale action. However, for the moment, the impact of invasive species and overfishing is far greater than that of global warming [80,81]. At least in the case of overfishing, it is at the local level that we can act, which the State authorities may not wish to draw attention to.

5.10. Compensation of Ecological Damage and Conservation Easement

In relation to ecosystem-based management, recent developments in French law should be highlighted. Law n° 2016-1087 of 8 August 2016 for the recovery of biodiversity, nature and landscapes [212] has adopted provisions relating to the compensation of ecological damage, defining it as "non-negligible damage to the elements or functions of ecosystems or to the collective benefits derived by man from the environment". Several decisions have already been handed down on this basis at the request of the PCNP, which insists in each case submitted to the courts on the need to assess the damage by favouring the ecosystem approach as far as possible [108,213].

Another innovation of this same law was the introduction into French law (article L132-3 of the Environmental Code) of a legal instrument implemented in the USA since the early 1960s, the 'obligation réelle environnementale', which corresponds to what American law calls 'conservation easement'. A landowner agrees to impose certain obligations regarding what may and what may not be done on his property, on himself and on the property's successive owners during the term of the agreement. These obligations, which are granted to public or private persons acting to protect the environment, are intended to "maintain, conserve, manage or restore elements of biodiversity or ecological functions". This instrument has considerable potential, particularly for the protection of adhesion areas of national parks that do no benefit from the regulatory protection of the park's core areas [214]. Unfortunately, for the time being, the PCNP has not yet taken the necessary measures to implement this tool, despite the numerous recommendations made both at national level [215] and by the PCNP Scientific Council.

5.11. The Management of Biodiversity: Social and Public Acceptance

The perception of biodiversity is biased by the fact that it is often shaped by concepts dating back to the mid-twentieth century, while current paradigms are ignored to a greater or a lesser extent [216]. Taxonomic lobbies (e.g., bats, birds, flowering plants, marine mammals, snakes, turtles) obviously play a negative, counter-ecological role. For example, (i) the assimilation of biodiversity to the number of species, which is very reductive; (ii) the belief that the higher the number of species, the better; (iii) the belief that disturbed habitats are species-poor and of low interest; (iv) the belief that fire is *per se* an ecological disaster, whereas, if it is not too frequent, it fulfills useful ecological functions—at Cap Lardier (mainland Provence, N-PCNP), the 2017 fire caused massive germination of the Magnoliophyta *Anthyllis barba-jovis,* which is of heritage value, and the appearance of a fauna of xylophagous beetles; (v) the belief in the balance of nature; (vi) ignorance of natural fluctuations in populations; (vii) the popular but non-scientific belief that wild boar are invasive (see, e.g., [163]); and (viii) an implicitly fixist vision of the environment. These

biases affect the general public and the media, but also sometimes park officers, wardens and even scientists.

In this regard, the educational role of the Scientific Council (SC) is important. It is worth highlighting that, in the PCNP, many park officers attend the meetings of the SC and its Bureau. Although they do not vote, their participation is active and valuable: they ensure the feedback of information from the field (bottom-up), and at the same time they understand the positions and opinions of the SC, learn about new scientific paradigms, and then pass on the information (top-down) [91,102].

Fluctuations in the abundance of species often disturb managers, although they are often of natural origin.

The acceptance of management measures (which include 'doing nothing') by the general public (public acceptance) and by users (social acceptance) is an essential issue throughout the world. The protection of flagship species, especially if they are photogenic and likeable, is easier and better accepted than that of less aesthetically pleasing species, although the latter can actually play a much more important role in the functioning of the ecosystem. The interest of these species is that they act as umbrella species: their protection can result in measures that will help protect many other, less-charismatic species [164,217–220]. However, it is important that the management of such species remains a means, not an end. The acceptance of management measures can change over time, as is the case for the beneficial effect of MPAs on artisanal fishing and ecotourism, and for the necessary control of over-frequentation [142,221,222]. In contrast, implementing measures of the limitation of over-frequentation is a long-standing fight, because they fuel resentment in many users and stakeholder communities (e.g., recreational fishermen, scuba divers, bathers, visitors, the hotel business, boat trip owners) in most areas (e.g., [14,223–227]). However, the acceptability is increasing (e.g., in the PCNP; see [95,96,228]) of the enforcement of measures (in summer 2021) such as the limitation of the total number of passengers transported by ferry shuttles (including bookings for the boat trip), and the limitation of the number and identification of bicycles (Porquerolles Island).

5.12. The Change over Time of the Port-Cros Management Strategy

Obviously, many management operations which were carried out in the earliest days of the existence of the PCNP would not be carried out today (Figure 4): for example, the planting of exotic species (T2 and T7), the digging of a pond to increase the insect resource of bats (T14), the release into the wild of individuals of endangered species abandoned by their owners (*Testudo hermanni*, T4 and T11) or seized from traders (*Scyllarides latus*, M24), the transplanting of limpets (*Patella ferruginea*) from Corsica to restore the locally extinct population (M6), the clearing of vegetation to favour rare species (T8 and T29), the monk seal *Monachus monachus* project of *ex situ* breeding (M22), the establishment of an artificial reef in the Bay of La Palud (M5), and the implantation of cuttings of the seagrass *Posidonia oceanica* from distant Mediterranean areas such as Turkey, Greece and Algeria (M7).

In contrast, a number of management operations, which might have been carried out 20 or 30 years ago, are today clearly rejected by the SC and/or by PCNP officials, when they are considered. For example, take the rejection of the proposal of bat experts to create facilities for bats (shelters, waterers) when restoring the La Sardinière farm (T31, Table 1). The same applies to the rejection by the SC of the eradication of wild boar in the integral reserve of the Island of Bagaud (T32, Table 1).

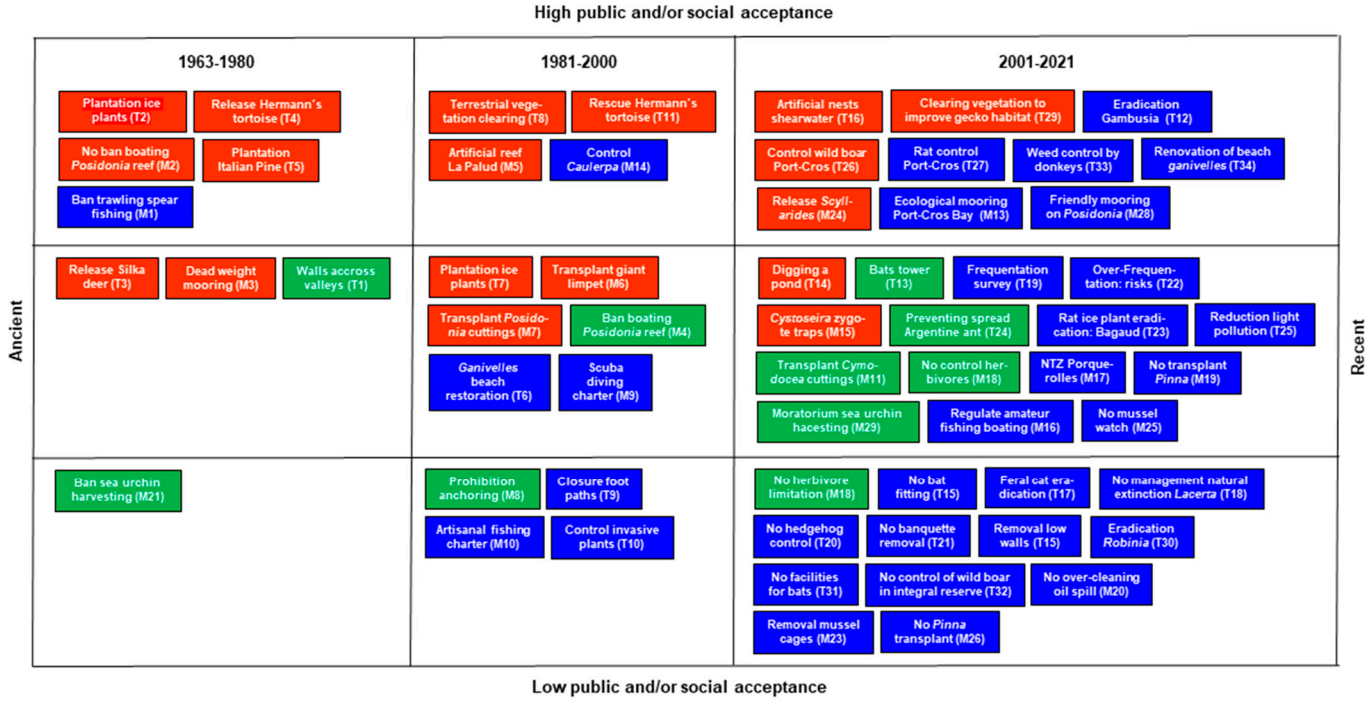

Figure 4. Some management operations within the core areas, terrestrial and marine, of the Port-Cros National Park, since its establishment (left to right), according to their public and/or social acceptability (top to bottom). The operations are in red, green and blue, according to their poor, medium and good compliance with current concepts of ecosystem-centred management, respectively. For details of terrestrial (T1 through T34) and marine (M1 through M29) operations, see Tables 1 and 2, respectively, in Boudouresque et al. [92], and Table 1 (in this article). Note that T3 was a decision external to the PCNP. M14 started in the 1990s, not in the 2000s, as is erroneously reported by Boudouresque et al. [92].

Without being strictly speaking ecosystem-centred, a number of current management operations are ecosystem-compatible, insofar as they benefit the whole ecosystem. For example, take the setting up of environment-friendly moorings in the Bagaud Pass (M28, Table 1). The growing use of EBQIs (Ecosystem-Based Quality Indices), which are not based upon a few emblematic species, but on the whole of the functional compartments of the ecosystem, to assess their health status, is also a step towards ecosystem-centred management [72,74–77,229].

The Scientific Council and the Scientific Department (today *Service Connaissance pour la gestion de la biodiversité*) of the PCNP often repeat: doing nothing sometimes constitutes a management action; nature often does things better than humans (see e.g., [15,230]. At first, the message was not always understood, but this understanding is progressing, slowly and with difficulty, but surely.

The shift from species-by-species management to ecosystem-centred management is not a linear and steady process. However, an examination of Figure 4 clearly shows the general trend. The red boxes (poor compatibility with ecosystem-centred management) are mainly on the left (ancient) and at the top (good public and social acceptability) (Figure 4). On the other hand, the blue boxes (good compatibility) are mainly on the right (recent) and at the bottom: their acceptability is often medium to low, despite their relevance. The ratio of blue to red boxes went from 0.2 in the 1960s and 1970s to 1.0 in the 1980s and 1990s, and finally to 4.3 since the 2000s (Figure 4). Although this may be partly due to the fragmentary inventory kept in the early period, and the fact that the administrative procedures were simpler, with decisions which were sometimes informal—thus not leaving any written trace—the increase in the number of management operations over time is spectacular, going from 5 to 20 on average per decade. This reflects the increased importance of management in the activities of the PCNP, and at the same time the increased involvement of the SC and the scientific department in management.

It is important to note that the ecosystem-centred approach does not mean rejecting the species-by-species approach. In reality, the two complement each other on a case-by-case basis. In addition, when outstanding species are critically endangered or on the brink of extinction, it is clear that specific management measures are warranted. In the marine realm, this may be the case for the monk seal *Monachus monachus*, which is now locally extinct, but which could return naturally (see [231]), as well as species of *Cystoseira* (*sensu lato*) and *Sargassum* (Stramenopiles) [58,59]. A concurrent/complementary species-centred approach can also be justified, both in the terrestrial and marine realms, when long-lived species are concerned.

6. Conclusions

For the general public and for many managers, species-by-species management based on emblematic species is much easier to understand and implement than the ecosystem-based approach. It is clear that a national park should not deprive itself of emblematic species in its publicity material. Hermann's tortoise *Testudo hermanni*, the silverbush *Anthyllis barba-jovis*, the dusky grouper *Epinephelus marginatus*, and the seagrass *Posidonia oceanica* are popular, friendly, high-profile species that attract the general public. Simply put, they must also serve as an introduction to a more ecological, more ecosystem-centred approach, which unfortunately is not yet the case in many protected areas (see e.g., Goldstein [70], at Yellowstone, USA), and which is only progressing slowly, even in the PCNP.

It is very difficult to make the general public, as well as experts who are passionately devoted to the taxon to which they are dedicated (e.g., bats, marine mammals, birds, turtles, flowering plants), whose competence is recognized and whose help is vital for the PCNP, understand that protected areas such as the PCNP are neither botanical gardens nor zoos. It is not their role to replace societies for the prevention of cruelty to animals (e.g., *Société Protectrice des Animaux* in France). In an ecosystem-centred approach, favouring a taxon because it is pleasant, provides services to humans (e.g., bees and bats), or is threatened elsewhere necessarily has an impact on other species or ecological compartments. Another difficulty is to find the right balance between the management measures the SC finds pertinent and beneficial (at the time the debate is opened), and the management measures that the users (including the permanent residents) wish for or recommend; from this point of view, the Müritz National Park in Germany constitutes an interesting case, with problems which are partly comparable to those of the PCNP [232].

To undertake a critical review of almost 60 years of management is a rare exercise in a national park. The Yellowstone National Park (USA), the birthplace of the idea of national parks, established in 1872, and the Kruger National Park (South Africa), offer a longer period of time for the performance of such introspection [70,233]. The Egadi Islands MPA (Italy) is an interesting case, insofar as three management and governance modes have followed one another: top-down management from 1991 to 2001, local management (by the municipality) from 2001 to 2010, and finally bottom-up management since 2010, in association with fishermen and users [234]. Unfortunately, this MPA has been a paper park since its establishment, so the comparison is worthless [234]. In most protected areas, the changes in management practices and their consequences have been studied as a function of a single parameter, e.g., the artisanal fishery management at Torre Guaceto (Italy) [235], and the reintroduction of wolves at Yellowstone [236]; the grey wolf *Canis lupus* was deliberately exterminated from the Yellowstone National Park in 1926, then successfully reintroduced in 1995–1996 [236–239]. Perhaps the analysis most comparable to that described here is that of Venter et al. [233] for Kruger National Park, covering 120 years, from the shameful initial removal of indigenous peoples to the current social-ecological approach and ecosystem-based management.

The case of Port-Cros is particularly interesting, insofar as the protected area has been competently and efficiently managed since its creation, and the protection and management measures have been strictly implemented. In the Mediterranean, the PCNP is often considered as a benchmark, on account of the commitment of its agents, in particular its

successive directors, through the effective and continuous support of its board of directors and the Ministry of the Environment, and because of the considerable work of its SC and Scientific department (*Service Connaissance pour la gestion de la biodiversité*), which enjoy the respect and recognition of administrative and political authorities, and of the general public. The PCNP has been a pathfinder in several domains, such as the introduction of snorkeling trails, the negotiation of fishing and diving charters (implemented at that time against the opinion of the Ministry of Environment), and the setting up of environment-friendly moorings, etc. The more risks one takes, the greater the risk of error or failure, such that it is a satisfaction to see operations flagged in green or even in blue in the early years (<2000, *a fortiori* < 1980) (Figure 4).

Of course, this review must take into account the change, over the past 60 years or so, of concepts of ecology, environmental protection and management. Something that seems inappropriate today may not have done so 60 years ago. We must consider with humility that what seems correct to us today may be regarded as mismanagement 60 years from now. In addition, we must consider that the efficiency of the management and that the coordination within the PCNP (wardens/Scientific Department/SC—Scientific Council) has increased during these 60 years. Some of the early operations, which we consider today as mismanagement, were initiatives of field agents, of which the Scientific department and/or the SC were not aware. Furthermore, the French law of 2006 conspicuously increased and made mandatory the role of the SC in the management of national parks. Regrettably, some operations which are considered today to be mismanagement were strongly supported by the SC, such as the transplantation of cuttings of *Posidonia oceanica* from a number of Mediterranean localities to Port-Cros Island (management: M7) and the setting up of artificial nest-cavities for shearwater *Puffinus yelkouan* and *Calonectris diomedea* (management: T16).

We believe that the introspective survey we present here may be useful for many protected areas around the world. They have been faced with similar problems and the same evolution of concepts. For these reasons, we have not eliminated from the analysis operations which may appear to be of minor importance today, but which may not have been at the time when they were implemented, or which may become relevant in the future.

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