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The management of Mediterranean coastal habitats: a plea for a socio-ecosystem-based approach

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Abstract. Biodiversity is often defined erroneously 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. Managers, stakeholders and environmentalists worldwide often prioritize the ‘species approach’. The protection of an iconic and endearing species is obviously easier than that of tiny zooplankton species, although the latter may play a far more important role than the former in the functioning of healthy ecosystems. The species- approach has been widely favoured compared to the ecosystem approach. However, ‘species by species’ management is unrealistic. The problem is that the management of natural habitats is often driven by environmentalist lobbies on the basis of taxonomy (e.g. mammals, turtles, birds, iconic fish, flowering plants, etc.) and disciplinary lobbies (biology, benthos, pelagos, contaminants, currents, etc.). Ecosystems are units of biological and spatial organization that include all the organisms, their interactions, the functional compartments they belong to, along with the components of the abiotic environment. The concept of the socio-ecosystem is useful insofar as it emphasizes the fact that man is part of ecosystems. Here, the authors make use of four case studies, in the Mediterranean Sea, in an attempt to demonstrate the interest of a comprehensive, socio-ecosystem-based approach, in the field of environmental management. They also highlight the importance of tackling the coupling between benthic and pelagic ecosystems and between terrestrial and marine ecosystems.

Keywords. biodiversity, environmentalist lobbies, management, Mediterranean, socio-ecosystem

1. Introduction

Biodiversity is often defined erroneously and in a simplistic way 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. 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. Lubchenko and 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, organisational, spatial and heterogeneity scales) and more than a hundred metrics. These metrics can give apparently contrasting responses, when they are in fact complementary (Sala and Knowlton, 2006; Boudouresque, 2014; Boudouresque et al., 2017a).

Humans have always sought to structure, organise and control the environment they are living in, exploiting or protecting. Terrestrial or marine managements practices have of course been adapted to these aims and to the epoch, with an outcome ranging from effective to mishandled and to counterproductive (Hardin, 1968; McNeely, 1996; Watson-Right, 2005). ‘Management’ is the buzzword for the proactive, modern aspect of this multi-millennial trend. Doing nothing also constitutes a management strategy.

Environmental issues have been addressed by Man through three different approaches: the ‘Human-centred’, ‘species-centred’ and the ‘ecosystem-centred’ approaches. The significance of the first, the Human-centred approach, is today not solely historical (the 18th and 19th centuries), since is still followed today in other forms. The second, the species-centred approach, characterized the 20th century and remains the current approach adopted in many countries and for several international agencies; it is supported by groups of experts working on a given taxon (hereafter ‘taxonomic lobbies’). Finally, the ecosystem-centred approach has made its appearance

recently, and it remains weakly established under the strong pressure of ‘taxonomic lobbies’. Yet the ecosystem-centred approach is the only one that can meet the challenges driven by global change and ensure the proper management of natural habitats.

The social-ecological system-based approach is based on the principle that humans have been part of ecosystems for hundreds of thousands of years, first as top-predators, then as farmers, in the context of mutualistic symbioses. Humans are part of the ecosystems, as a key species or as ecosystem engineer, and they have to a greater or lesser extent shaped all the ecosystems of the planet, including within national parks (Redman et al., 2004; Folke, 2006; Ostrom, 2009).

2. The Age of the Human-centred approach

The French naturalist Buffon (1707-1788) felt only contempt for the environments that we now refer to as ‘natural’. In his *Histoire Naturelle*, he speaks of ‘(...) a congested space, clogged up with old trees laden with parasitic plants, lichens, mushrooms, impure fruits of corruption (...), dead and stagnant waters, for lack of being led and directed (...); swamps covered with aquatic and foul-smelling plants, that feed only venomous insects and serve as a haunt for disgusting animals. Between these filthy marshes which occupy the low places, and the decrepit forests which cover the high lands, extend some sorts of moors, savannahs which have nothing in common with our grasslands; there, weeds overcome, oppress the good grasses’ (Buffon, 1764). Later, he wrote that *‘The raw nature is hideous and dying (...); let us animate these dead waters, making them flow; let’s form streams, canals (...); set fire to these old forests, already half-consumed; let us destroy with iron what the fire could not have consumed (...)’*¹ (Buffon, 1767). It is clear that, for Buffon, the ideal nature was depicted by the royal gardens of Versailles, its fountains and canals.

It is easy today to smile at this vision of nature: it was the one that prevailed until the 19th century, based on a Human-centred approach. 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. More recently, in a report to the US Congress dated 1948, that recommended draining the Florida wetland, we can read: *‘The Everglades are now suitable only for the haunt of noxious vermin, or the resort of pestilent reptiles’* (Fudge, 2001; Hollander, 2008; Faget, 2011).

The human-centred vision of nature persisted until the 20th century, in the form of the 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 administrations (De la Blanchère, 1878; Faget, 2016). Thus, birds of prey were on the pest lists, being considered competitors with an impact on the availability of commercially valuable or emblematic species for farmers and hunters. This approach was very simplistic. In fact, predators have a positive impact on their prey, directly or indirectly (Healthy Herd Hypothesis). For example, the Japanese authorities accused marine mammals for competing with fishers for fish resources, thus justifying hunting them; but actually, from the perspective not of a species-by-species approach, but of an ecosystem-based approach (see below), marine mammals favour fisheries (Gerber et al., 2009). 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 the modern form of the human-centred approach. Satoumi is defined as the human use and management of coastal seas for high productivity, while maintaining high biodiversity and sound marine environments, *via* human-shaped seascapes (Yanagui, 2010; Berque and Matuda, 2013; Henocque, 2013; Komatsu et al., 2017). The point of view of western fisheries scientists is another human centred approach, with roots in the late 19th century; to embrace the overwhelming size of the ocean, fisheries scientists turn towards mathematics, considering the catches as a compound effect of firstly fishing mortality and secondly natural mortality (see Fedor Baranov’s equation; Baranov, 1918). Many generations of fisheries scientists followed this pioneer, developing production models, refining their equations using population demography properties, until the need for an ecosystem-based approach to fisheries prevailed. It is worth noting that the interest for humans is today taken into consideration as ecological goods and ecosystem services: the natural processes and components that benefit human needs (Costanza et al., 1997, 2014; Nordlund et al., 2016).

3. The Age of the species-centred approach

From the 19th century on, and especially during the 20th century, a species-centred approach was developed. Species were divided into two broad categories. On the one hand, outstanding species, including species with heritage value (iconic species), which deserve particular attention; on the other, the ‘ordinary’ species. The

¹ Translated by the authors from the original French text.

notion of outstanding species is a fuzzy concept (Gauthier et al., 2010; Astruch et al., 2012; Brambilla et al., 2013) that covers:

(i) Threatened species. Species are classified, according to the IUCN (International Union for Conservation of Nature; IUCN, 2017), into nine categories: EX (extinct), EW (extinct in the wild – can survive in zoos or botanical gardens), CR (critically endangered – facing an extremely high risk of extinction in the wild), EN (facing a risk of extinction in the wild), VU (vulnerable – e.g. a population size reduction > 30 % over the last 10 years), NT (near threatened), LC (least concern), DD (data deficient) and NE (not evaluated). The categories CR, EN and VU are grouped under the name of ‘threatened species’. The classification of species within these categories is carried out by panels of experts, is regularly updated and can be considered reliable, according to current knowledge. For example, the seagrasses *Posidonia oceanica* and *Cymodocea nodosa* are ranked as LC, which is consistent with Boudouresque et al. (2009). At the national and regional scales, species are classified within these categories, ‘according to the IUCN methodology and approach’ but, perhaps because of greater pressure from the specialists of certain taxa (e.g. birds, bats, mammals, vascular plants), the classification is sometimes less rigorous. For example, in the Provence and French Riviera region (France), *P. oceanica* and *C. nodosa* are ranked as EN and NT, respectively (Noble et al., 2015), which seems very exaggerated (*P. oceanica*) or even wrong (*C. nodosa*); the latter species is rather expanding, taking advantage of global warming and the decline of *P. oceanica* (Boudouresque et al., 2009; Montefalcone et al., 2011; Pergent et al., 2012). In some cases, expert judgment is probably more relevant, or better supported, than the IUCN Red List. For example, the Mediterranean brown algae *Cystoseira crinita*, *C. squarrosa* and *Laminaria rodriguezii* are listed as ‘not evaluated (NE)’ in the IUCN Red List, while *C. crinita* is regarded as CE, near to regionally extinct, in French Catalonia and Languedoc (France) (Blanfuné et al., 2016a), *C. squarrosa* is regionally extinct along the French coast, with its last record in 1929 (Thibaut et al., 2015), and *L. rodriguezii* is endangered in the Adriatic Sea (Žuljević et al., 2016).

(ii) Rare species (either threatened or not). For example, the deep-dwelling needle-spined sea urchin *Centrostephanus longispinus* in the north-western Mediterranean; this species is not endangered, just naturally rare in the area, especially at depths accessible to scuba divers. It is quite abundant in some other areas (e.g. Eastern Mediterranean, Atlantic coast of Morocco, Senegal) (Francour, 1991; Templado and Moreno, 1996). Surprisingly, in the north-western Mediterranean Sea, one of its densest populations has been sighted on a wastewater pipe, near Marseilles (western Provence, France) (Bonhomme et al., 2014). Despite the lack of known threats or any clear decline in its population, the species is listed as threatened in French Red Lists and is strongly protected. It is worth noting that, in some cases, the extreme rarity of a species constitutes *per se* a threat. For example, the mollusc *Gibbula nivosa*, endemic to Malta Island (Schembri et al., 2007; Evans et al., 2010).

(iii) Protection status. Some species are protected by national or regional legislation. The protection status is highly dependent upon the visibility of the species (e.g. size), the sympathy it arouses (e.g. dolphins) and especially the influence of ‘taxonomic lobbies’ (e.g. birds, bats and sea mammals). In France, the seagrass *Cymodocea nodosa*, the sea urchin *Centrostephanus longispinus* and the dolphin *Stenella coeruleoalba* are strictly protected, while none of their populations are actually threatened or even in regression.

(iv) Lovable species (or charismatic species) are species that enjoy a coefficient of sympathy from the general public (whether threatened or not). Dolphins are the perfect example, even if they entered this category very late, after World War II (Faget, 2016). In the Mediterranean Sea, the short-beaked common dolphin *Delphinus delphis*, although listed as LC (Least Concern) worldwide, is considered as vulnerable (significant decline). In contrast, the common bottlenose dolphin *Tursiops truncatus* and the striped dolphin *Stenella coeruleoalba* are far from being threatened in the Mediterranean; their populations are in no way declining and may even benefit from human impact (e.g. overfishing and elimination of their competitors, such as sharks) to proliferate (Gannier, 1995). Whatever their actual population status, national legislations fully protect all Mediterranean dolphins. In Italy, the appeal of bird species better predicts their conservation status than the threats that are actually hanging over them (Brambilla et al., 2013). Some species are charismatic due to their role in enhancing seascapes, such as the gorgonians *Paramuricea clavata*, *Eunicella singularis* and *E. cavolini* (Astruch et al., 2012). Courchamp et al. (2018) drew attention to a perverse effect regarding charismatic species: the massive cultural and commercial visibility of some of them in the public sphere encourages the public to think that they are still common while some of them may be on the brink of extinction.

(v) Ecosystem engineers and key species. 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’ (Lawton, 1994). Key species are species that ‘have effects on ecosystems out of all proportion to their relative abundance’ (Bond, 2001). Within the scope of the ecosystem-based approach (see below), the ecosystem engineers and the key species are undoubtedly those most worth of consideration.

(vi) Indicators of environmental quality. In the Mediterranean Sea, the red alga (Rhodobionta) *Lithophyllum byssoides*, the brown alga (Stramenopiles) *Cystoseira* spp. and the seagrass (Magnoliophyta) *Posidonia oceanica* are usually regarded as indicators of good environmental quality; in contrast, most species of the genus *Ulva* (including enteromorpha-like *Ulva*) are linked to environmental stress (Gobert et al., 2009; Blanfuné et al., 2016b, 2017). Finally, some species displaying sensitivity to positive or negative thermal anomalies are indicators of global warming; e.g. the Chlorobionta *Caulerpa prolifera*, the expansion of which is favoured by warmer temperature, and in contrast the gorgonians *Paramuricea clavata* and *Eunicella singularis*, which are negatively impacted by warm episodes (Perez et al., 2010; Garrabou et al., 2002; Boudouresque et al., 2017b).

Managers, stakeholders and environmentalists worldwide often prioritize the species-centred 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-centred approach has been widely favoured compared to the ecosystem-centred approach, despite the name given to the Directive. Beyond this Directive, the ‘species by species’ approach can be found at all levels of the environmental management process, including fishery management, before ecosystem-based fishery management (EBFM) came to the fore (see below). 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 problem is that the management of natural habitats has often been driven by environmentalist ‘lobbies’ on the basis of taxonomy alone. As every taxonomist specialist group is focusing on its specific type of organism (e.g. marine mammals, turtles and tortoises, birds, iconic fish such as the grouper *Epinephelus marginatus*, flowering plants), the management of natural habitats often results in a layering of taxon-focused protection measures. Disciplinary (e.g. biology, benthos, pelagos, contaminants, currents, modelling) groups of specialists also drive the management of natural habitats. All in all, the management of natural habitats is often reminiscent of the tale of the blind men examining the elephant.

4. The revolution of 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. The distinction may seem tenuous. However, it is a true revolution, as important as the shift from the human-centred approach to the species-centred approach.

Humans are often rightly viewed as a disturbance by ecologists and environmentalists. However, at least in some cases, social-ecological systems including humans could be closer to ‘natural’ ecosystems than ecosystems excluding humans, such as the No-Take Zones (NTZs) of Marine Protected Areas (MPAs). A good example, is the Mediterranean monk seal *Monachus monachus* and artisanal fisheries. Until the 1950s, the archipelagos of Port-Cros and Porquerolles (eastern Provence, France) hosted a monk seal colony. Taking into account the mean daily food ration of the species, mainly fish (Marchessaux, 1989; Ballesteros, 2012), the possible size of the colony, and the tightly restricted way fishing is practised in the Port-Cros MPA (Cadiou et al., 2009; Astruch et al., 2018), it has been suggested that artisanal fishers may contribute to mitigating the ecological impact of the local extinction of this top predator, making the social-ecological system closer to a ‘natural’ one than a NTZ deprived of both top predators and fishers (Boudouresque et al., 2004). Ideally, the return of the top predators (e.g. monk seal, sharks) would of course be preferable; but the size of MPAs is almost always much smaller than their home-range. Further examples are provided by the Ecosystem-Based Fishery Management and the Ecosystem Approach to Management (see e.g. Tudela and Short, 2005; Halpern et al., 2010; Kincaid et al., 2017).

The ecosystem-centred approach presents several strengths. **(i)** It allows the integration of humans in the functioning of the ecosystem, in a natural way, thus passing from the notion of ecosystem to that of social-ecological system. Humans are no longer set aside from a number of species, the system, but within the system. **(ii)** While the species-centred approach often just considers a collection of remarkable taxa, the ecosystem-centred approach requires the construction of a framework, 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, and to better interpret the possible fluctuations in their numbers. In addition, the conceptual model, within the framework of the Vertical Diversity Hypothesis (VDH), takes into account top-down and bottom-up processes within the ecosystem (e.g. Wang and Brose, 2018). **(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 (Pethybridge et al., 2018). **(v)** The ecosystem-centred approach also highlights the importance in tackling the coupling between adjacent ecosystems (including benthic and pelagic, terrestrial and marine ecosystems). In

addition, the life range of many species, e.g. spawning areas, nurseries, feeding and resting areas, spreads over several adjacent ecosystems (Cheminée et al., 2014). **(vi)** The ecosystem-centred approach makes it possible to build environmental quality indices that are much more significant and reliable than indices based on one or a few species (generally belonging to the same higher taxon; e.g. teleosts, or Magnoliophyta) (Personnic et al., 2014; Ruitton et al., 2014; Boudouresque et al., 2015; Rastorgueff et al., 2015; Thibaut et al., 2017). **(vii)** Invasive species constitute one of the most worrying aspects of global change (Maxwell et al., 2016; Boudouresque et al., 2017a). The Mediterranean Sea is the area worldwide most hit by non-indigenous species, with 500-1 000 introduced species (Ribera and Boudouresque, 1995; Galil, 2008; Katsanevakis et al., 2013). Invasion issues are usually studied and managed in a single-species context: 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 given species, but on entire communities; therefore, understanding their role and impact can only be achieved in the context of the whole ecosystem (Boudouresque et al., 2005, 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; Sala et al., 2012; Giakoumi et al., 2015; Ourgaud et al., 2015; Kincaid et al., 2017). Ecosystem-Based Fishery Management (EBFM) is obviously part of the ecosystem-centred approach (e.g. Rice, 2005; Tudela and Short, 2005). **(ix)** By definition, the concept of ecosystem services can only be understood, assessed and managed at ecosystem level.

5. Case studies

Hereafter, we will use four Mediterranean case studies to demonstrate the interest of a comprehensive, social-ecological system-centred approach in the field of environmental management and the sustainability of fisheries. These case studies are **(i)** the salt marshes of Hyères, where the management is mainly species-centred, or more specifically bird-centred, **(ii)** the Biguglia lagoon, a nature reserve, where the conservation should be planned not only at the scale of the lagoon, but also at the scale of the adjacent wetland and the watershed, through an ecosystem-centred and integrated approach, **(iii)** a coastal pelagic social-ecological system (the Gulf of Lions), where modelling has been developed, within the aim of the sustainable management of fisheries, and **(iv)** the MPA of the Archipelago of Port-Cros (National Park), where the aim of a social-ecological system-based management process is clearly proclaimed.

The salt marshes of Hyères. Salt marshes and brackish lagoons are part of an ecological continuum, a functional unit, that corresponds well to the concept of a social-ecological system. Between the 16th century and 1995, the salt marshes of Hyères (900 ha; eastern Provence, France) were profoundly altered by humans for the exploitation of salt, turning them into salt evaporation ponds: ensembles of canals and of shallow pans used to evaporate brine. Evaporation ponds and canals are still in place, so that even after salt production was discontinued, the Hyères salt marshes remain typical of a social-ecological system. Since 2001, the salt marshes of Hyères have belonged to the Conservatoire du Littoral (CL), a French public sector organisation (inspired by the British private charity National Trust NT; Legrain, 2000). The objectives of the CL are not to manage its territories as national parks, nor as natural areas (which would not make sense in the case of the salt marshes of Hyères, which are man-made), but to protect them from urbanization and to make them accessible to the public. These zones are therefore managed on a case by case basis, in cooperation with the municipalities (here, Toulon Provence Méditerranée) and local institutions (here, the Port-Cros National Park), without any general doctrine. In the case of the salt marshes of Hyères, the main aims are to conserve the heritage of the salt industry and preserve 'biodiversity'. Regarding biodiversity, it is clear that management policy is focused on birds, with a vision of biodiversity that is that of the 20th century: how many species? How many individuals? The more species and the more individuals, the merrier. The circulation of water, the management of locks and canals, the water level, everything is mostly managed to favour the maximum number of waterfowl species, and to match the specific needs of each of them. A pump has even been built to lower the water level according to the needs of each bird species. Artificial nests are set up to promote waterfowl reproduction. Since foxes are predators of eggs and waterfowl chicks, chickens have been used as bait, being raised and placed in traps to capture foxes which are then killed. Of course, foxes in particular, but predators in general, are part of a natural ecosystem, but the goal here, otherwise perfectly acceptable, is not to favour the wilderness of the salt marsh ecosystem, but to turn the salt marshes of Hyères into some sort of bird-centred animal park or zoo. Finally, the rise of the sea level and its consequences have not been considered. During the Last Glacial Maximum (LGM), ~20 000 years ago, the sea level was ~120-130 m below its current level. Since then, it has never stopped rising (Lichter et al., 2010; Faivre et al., 2013). Glacial cycles last about 100 000 years, with oscillations between cold glacial maximum and warm interglacial periods. The interglacial period we are in is not finished. At the end of the last interglacial episodes, the ice cap of Greenland completely melted, which led to a rise of the sea level of 6 to 9 m above the current one (DeConto and Pollard, 2016). So we can expect the same increase to occur within the next millennia

(2-3 millennia?), without taking into account any human impact. But greenhouse gases should accelerate this natural rise of the sea level, and even aggravate it, with the melting of the Antarctic ice cap. The management strategy for the Hyères salt marshes, which does not take into account their future flooding, may well turn out to be a very short-term strategy. A number of taxa have been studied and monitored. However, no attempt has been made to integrate them into functional compartments and within an ecosystem-based approach.

The Biguglia lagoon. Biguglia is a shallow, brackish, 1 460-ha coastal lagoon located close to Bastia city (Corsica). The lagoon is linked to the Mediterranean Sea through a long natural channel; marine water inputs are limited because the sea channel tends to close (due to the accumulation of sand); it receives freshwater from the rivers draining its 180 km²-watershed and from old artificial channels and pumping stations draining the agricultural plain, sewage plants and rainfall; freshwater inputs dominate the water budget and lagoon renewal is rapid (Garrido et al., 2016; Pasqualini et al. 2017). Biguglia lagoon was recognised as a very important site for waterfowl and was included in the RAMSAR list of wetlands of international importance. This lagoon has been classified as a Nature Reserve since 1994 and in the EU Natura 2000 network since 2006 (Special Protected Areas of the Bird Directive). Biguglia lagoon has a single owner (Haute-Corse *Département*) with a specific department dedicated to its management. Since 2006, the whole lagoon area and a small part of the fringing wetlands are no-entry zones with the exception of a small number of artisanal fishers who are allowed in for this traditional use. For 40 years, this confined ecosystem has increasingly been disturbed by eutrophication associated with an intensification of agriculture and an increase in the density of urban settlements in the watershed; the degradation of the water quality in Biguglia lagoon is reflected by a shift from a dominance of aquatic magnoliophytes in the 1970s to varying dominance of phytoplankton and opportunistic macroalgae in the early 2000s (Souchu et al., 2010; Pasqualini et al., 2017). The deterioration of the water quality led the managers of the Biguglia lagoon nature reserve to take action to improve the water quality; however, this has resulted in the progressive desalination of the lagoon, with in particular the marked development of freshwater species. Similarly, the alterations in the ecosystem have drastically facilitated the successful installation of opportunistic and invasive organisms, such as the phytoplankton *Prorocentrum minimum* and the ctenophore *Mnemiopsis leidyi* (Cecchi et al., 2016; Garrido et al., 2016). Such management actions can weaken the entire ecosystem and have a significant impact on fish resources and bird populations, which play a key role in the conservation of the lagoon. Ecological restoration efforts undertaken to improve the hydraulic management of the nature reserve must be accompanied by the reduction of nutrient inputs in the watershed, with calling for a perspective of the regional and local authorities that goes beyond the boundaries of the lagoon nature reserve: to include the adjacent saltmarsh and the watershed. In addition, lagoon conservation requires an integrated and multidisciplinary approach where the natural and social scientists work together (Robert et al., 2015).

The Gulf of Lions (GOL) is an important feeding area for many fish, seabird and marine mammal species. It is a highly productive system because of high nutrient inputs coming mainly from the Rhone River, upwelling activity, bottom morphology and water circulation (Agostini and Bakun, 2002; Petrenko et al., 2005; Hu et al., 2009). Many fish species of commercial interest have been intensively exploited on the GOL continental shelf for decades by the French and Spanish fleets, using multispecific gear such as trawl nets, purse seines and gillnets (Farrugio et al., 1993). Current analyses on the status of Mediterranean marine ecosystems suggest that most demersal and pelagic fish stocks are fully exploited or overexploited (Papaconstantinou and Farrugio, 2000). Fishing is one of the major drivers of ecosystem alteration in coastal areas (Jackson et al., 2001). It has various kinds of direct and indirect impact that interact with the impact produced by changes in natural and anthropogenic oceanographic features and disturbances (Hall, 1999; Christensen et al., 2003). The achievement of effective marine ecosystem-based management implies the regulation of the use of the living resources based on the understanding of the structure and dynamics of the ecosystem of which the resource is a part. Ecosystem modelling has been proposed as a tool to inform management decision making for marine fisheries (Cochrane and de Young, 2008). Ecosystem models facilitate the analyses of ecosystem structure and functioning. For a long time, fisheries have gradually replaced top predators, e.g. sharks (Ferretti et al., 2008). In the GOL, fishery impact analysis is particularly difficult as there are many types of gear catching many species. The effects of fishing gear are complex, according to the number of target and accessory species and the catch biomass (Bănaru et al., 2013). The highest impact on ecosystem functioning is caused by large benthic trawls. Multiple controls (bottom-up, wasp-waist, top-down) interact in marine ecosystems and only ecosystem approach may highlight their complex effects. Fisheries have a higher top-down effect on the system's vitality, resilience and organization, and finally on ecosystem health, than pollution and terrestrial inputs from agricultural activities discharged by river inputs. Fishery impact on the ecosystem should be related with socio-economic activities as fishers are a usual predator, in the framework of a social-ecological system, and the factors related to socio-economic constraints (market fish price, fuel price, international exchanges, concurrence by recreational fisheries and illegal fisheries, regulations, etc.) may not be predicted by ecological models alone.

The Port-Cros Archipelago. The Port-Cros National Park (PCNP) was established in 1963. It was the second marine and terrestrial national park in Europe, only preceded by the Mljet National Park, in Croatia. Originally,

PCNP, with its Marine Protected Area (~1 300 ha), was restricted to the Port-Cros Archipelago, ~8 km off the Provence mainland (France) (Barcelo and Boudouresque, 2012; Astruch et al., 2018). Within the MPA, the legislation is strictly respected, in contrast with the vast majority of Mediterranean MPAs, which are 'paper parks', the announced regulations being in no way enforced (Sala et al., 2012; Meinesz and Blanfuné, 2015). During the first decades following its establishment, the management of the PNPC was focused on iconic species, such as the seagrass *Posidonia oceanica*, the giant mollusc *Pinna nobilis* and the teleosts *Epinephelus marginatus* and *Sciaena umbra* (Harmelin et al., 2007; Harmelin and Ruitton, 2007; Astruch et al., 2012; Rouanet et al., 2015). Subsequently, an original management system, the so-called MUM (Multi-Use Management), was implemented gradually, based on a social-ecological system approach. In contrast with most MPAs, which are based upon the dichotomy between areas where all fishing is prohibited (No Take Zones, NTZs; the core area) and areas where the 'ordinary' legislation of the country is implemented (the buffer zone), artisanal fishing is not only authorized but even welcome (Boudouresque et al., 2004; Cadiou et al., 2009; Astruch et al., 2018). The PNPC MPA is characterized by a complex zoning system, to avoid user conflicts involving different human activities, while making them compatible with healthy ecosystems close to what is supposed to be 'natural' (the baseline); for example, trawling, spear fishing and recreational fishing have been banned, while artisanal fishing was allowed, provided it fell within a restrictive framework (fishing charter, mesh size of nets, length of nets, size of boats, etc.), adjusted each year and intended to adjust catches, stock and quality of ecosystems (Boudouresque et al., 2004; Cadiou et al., 2009; Boudouresque et al., 2013; Barcelo et al., 2013; Astruch et al., 2018). Overall, the management of the marine part of the PCNP nowadays fits rather well into a social-ecological system approach.

6. Discussion and conclusion

In the past, only physical, chemical, biogeochemical and microbiological variables were considered to measure the status of the marine environment in EU marine waters; they were assessed in isolation and set against thresholds; if the values were below the thresholds, the state of the environment was regarded as very good or good. However, as stressed by Boero (2016), these stressors can act in synergy: all values can be below thresholds, but acting together, they might alter the functioning of the ecosystem. The Marine Strategy Framework Directive (MSFD) of the EU corresponds to the ecosystem-centred revolution; the Good Environment Status (GES) is assessed on the basis of the state of biodiversity and ecosystem functioning. Most of the eleven descriptors prescribe that each of them should not impair the functioning of ecosystems (Boero, 2016).

It is important to emphasize that the three approaches, the human-centred approach, the species-centred approach and the ecosystem-centred approach, are not contradictory, but complementary. Over time, they added up, not replaced. In the same way, the radio did not replace printed documents, television did not eliminate the radio and the internet did not eliminate printed documents, radio and television. In addition, the ecosystem approach cannot exist without knowledge of the species. As far as the knowledge of the species is concerned, it cannot exist without the specialists of taxa (fish, birds, crustaceans, etc.), because nobody today can master the whole of the taxonomy of the Living world. In this sense, the current decline, some say extinction, of taxonomists, is a central problem in ecology (Boero, 2010).

The ecosystem approach has become, within a few years, a trendy concept. Dozens of publications mention it, implicitly or explicitly: an ecosystem-based approach to fisheries, an ecosystem-based approach to management, etc. Yet, reading some of these works, one wonders where the ecosystem is? The ecosystem approach is simply an imprecation, a kind of umbrella, a magic word. The same can be said of the social-ecological system approach. It is time today to give real meaning to the ecosystem-based approach, and more particularly to the social-ecological system-based approach.

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