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Four decades of research on the Medes Islands

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Summary. It has been over thirty years since the publication of the first major study about the natural environment of Medes Islands. The data collected in that first study entitled *Els sistemes naturals de les illes Medes* (*The natural systems of Medes Islands*) and the conclusions drawn from its analysis revealed the biological characteristics of this archipelago and led to a proposed set of measures to ensure its preservation as a natural area of extraordinary importance. One of these adopted measures was the creation of the Medes Islands Marine Protected Area in 1990. Protection rules derived from this measure have allowed researchers to develop a number of studies on several species inhabiting these islands (mostly in the submerged parts of the ecosystem) and to continuously monitor the evolution of the associated natural systems and the impact of human activities (fishing, diving, nautical tourism, etc.), both to the whole ecosystem and to very important and characteristic species including Neptune grass *(Posidonia oceanica)*, Mediterranean violescent gorgonian (*Paramuricea clavata*), red coral *(Corallium rubrum)* and Mediterranean dusky grouper *(Epinephelus marginatus)*. The results of these studies performed on Medes Islands during the four previous decades suggest that only through continuous monitoring and data collection, and further analysis, is it possible to define the appropriate regulations to ensure the protection and preservation of natural areas at risk of being altered by human activities, preservation measures that promote the development of new studies and the improvement of the knowledge of the functioning of natural systems. [**Contrib Sci** 11:75-83 (2015)]

Introduction

In 1984 the book *Els sistemes naturals de les illes Medes* ("The natural systems of Medes Islands") was published [32]. It was a very extensive volume of more than 800 pages, forty-two chapters, and around twenty plates and unfolding maps. The book , compiled from the work of fifty-four authors, explained the whole body of knowledge to date on the physical environment, botany, fauna and communities, both terrestrial and marine, of the small archipelago of the Empordà region (Catalonia) at that time.

Keywords: Medes Islands · reserve effect · frequentation effect · benthic communities · demersal communities

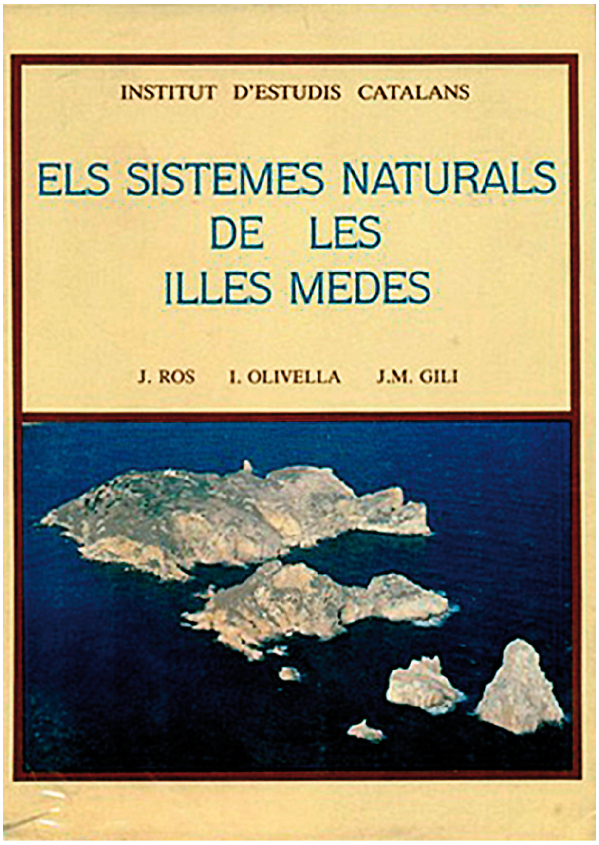

Fig. 1. Front cover of the book *Els sistemes naturals de les illes Medes* ("The natural systems of Medes Islands").

That work, promoted by the Catalan Institution of Natural History (ICHN) and published by the Institute for Catalan Studies (IEC), was an absolutely and completely new experience for the time and was a notable achievement contributing to the knowledge of Mediterranean nature, especially of its marine benthic communities. *Els sistemes naturals de les illes Medes* raised the knowledge of the Catalan Mediterranean coastal biological populations to the same level of that of other countries of the region (France, Italy, the former Yugoslavia), and was the model for new studies developed in other Iberian coasts. This work was widely distributed to the main researchers on the Mediterranean benthic communities who, in a general way, praised its scope and comprehensiveness.

But the book was almost exclusively a descriptive catalog because only some incidental references were made to the functioning of the communities, and in these scarce instances, they were based on studies from other researchers, mainly from those studying similar communities in the French coasts.

During the decade of 1970 studies were mainly focused on identifying the organisms of Medes Islands and describing their surroundings, and discovering their patterns of organization in the communities and the terrestrial and marine landscapes. It was only in the 1980s that the study of the dynamics (biological, ecological) of those organisms started in full, largely through the scientific monitoring of the Marine Protected Area (MPA). This monitoring began in the 1990s with the help of experimental approaches, mainly *in situ* and *sub aqua*, aimed at resolving specific questions.

During the thirty years that have elapsed since the publication of the book, and with a view to the future, many of the scholars that assembled the first monograph as well as new ones added throughout the period, have studied the functioning of some of the most representative species and communities of Medes Islands, particularly the marine ones, with an emphasis on benthic and demersal communities. Investigations into functional ecology have exceeded the initial scope and have been integrated into broader contexts, both geographic and scientific. The results of these studies have been published on a regular basis on over half a hundred research papers, and a summary of some of these were published on a monograph on Medes islands thirty years after the first one [14].

The monitoring of the Medes Islands Marine Protected Area

Besides the rich land- and seascape and biodiversity of Medes Islands, other no less important aspects must be also considered as a stimulus for research during these years. First, the creation of the Fishing Reserve (1983) and the Marine Protected Area (1990). Second, the scientific monitoring of the results of the protection measures (and the effects of the visit to the protected area); this monitoring is, surely, the longer one done in a Marine Protected Area of all the Mediterranean Sea. And third, the synergistic effect of this monitoring on other research centered on the area of the Medes Islands and its surroundings.

A preserved area, whether marine or terrestrial, is a piece of biosphere relatively free of some of the impacts that human activities inflict on areas without protection, so it is possible to design some experiments with a reasonable expectation that their results will not be biased by the human influence. Also, when human pressures disappear, nature tends to quickly return to an almost natural state depending on the demographic dynamics of species, although this state has been questioned because of the many centuries of exploitation of the marine and coastal resources that have altered

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Fig. 2. View of Medes Islands archipelago from the coastal line of Montgrí. (Author: Vincent van Zeijst CC).

the communities [16,17]. That was why the continuous monitoring through time of the preservation effects quickly rendered dramatic results concerning the population recovery of some species previously exploited (mainly fish).

The synergistic aspect is related to the scientific monitoring of the preserved area. The logistical organization of the monitoring activities was used to develop most of the activities of several research projects centered on the preserved area; and vice versa.

Since it is not possible to manage a protected area when the results of the protection are unknown, repetitive and sustained scientific studies will be necessary to allow researchers to recognize potential problems and to inform about them to the protected area managers in order to modify the management if needed. Since 1990, and for fifteen years, a team of researchers basically from the Department of Ecology of the University of Barcelona developed an annual monitoring of the ecological dynamics of selected species and communities of the Medes Islands Marine Protected Area.

In addition to the reports of the monitoring to the administrative authorities [7,30,41] and the management recommendations included in these reports, the members of the monitoring team regularly advised the preserved area managers about several other related issues. Since 2005, monitoring has been made in a sporadic way and not always by the same researchers, so the methodology has been altered and, surely, also the usability of the time series data obtained until then. Recently the first team has begun again the monitoring in the area and the old and useful methodology applied anew.

Since the beginning, the monitoring of the Medes Islands Marine Protected Area has focused on determining the "zero point" (the situation before the protection, almost always referred to coastal non-protected areas ecologically similar to the islands) and to study both the potential changes resulting from protection (the so-called preservation effect) and the impact on biological communities from the increased number of boats, cruises, and especially scuba divers visiting the area (frequentation effect). This monitoring is essential to determine if the management of the preserved area is yielding the expected results as well as to offer to the managers of the area the recommendations to improve it based on scientific studies [11,23,26,31,41].

The effects of the fishing and shell fishing ban since the Fishing Reserve and the Marine Protected Area were established should be apparent soon after and should also be easy to define.

Both the relatively small size of the Medes Islands archipelago (21.5 ha) and its accessibility from the continental coast (only at about 1 km from the l'Estartit shoreline) attract large numbers of scuba divers from around the world every year. The number (both absolute and relative) of dives into these waters is the greatest of any Marine Protected Area in the Mediterranean, which generates a very high frequentation pressure. As a result of this large number of visitors, the erosive process (intentional or unintentional) of the sessile communities (such as gorgonians and the coralligenous in general) and the alteration of the behavior of fish to which food is often offered become very important. This frequentation effect, to which it must be added the anchoring of boats on fragile bottom (coralligenous, *Posidonia* beds) and, more recently, the poaching of fish and coral, must be adequately quantified.

Quantification of the effects

The Marine Protected Area monitoring design was made by considering several groups of studies and by planning a multilevel approach. On the one hand by analyzing species and communities that are important from the ecological and/or

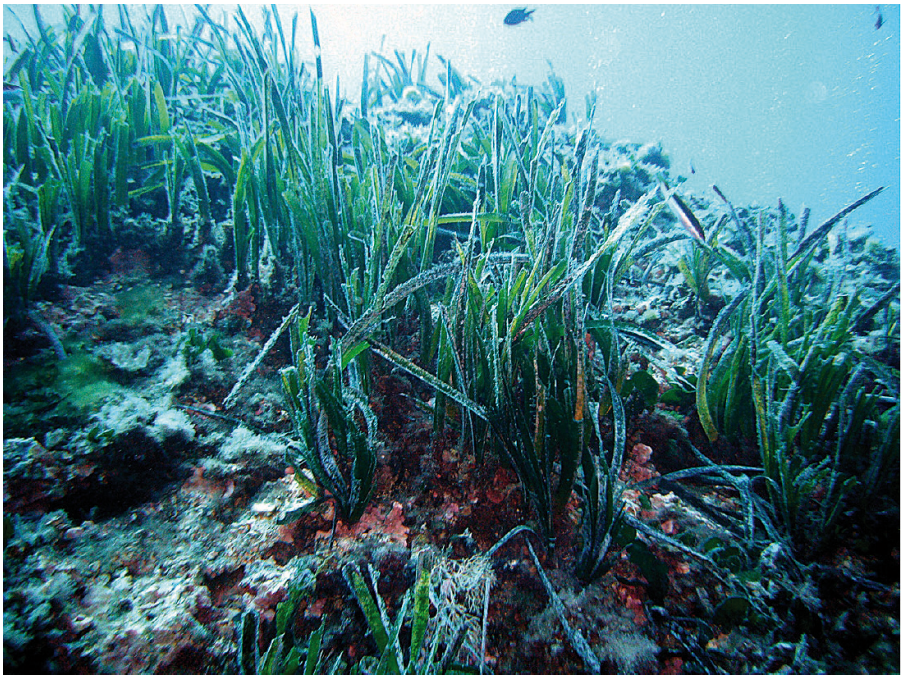

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Fig. 3. Underwater image of prairies of Neptune grass (*Posidonia oceanica*) (Author: Yoruno CC).

emblematic point of view, or that can work as biological indicators of general effects on the community and, on the other hand, trying to clearly differentiate the two aforementioned effects (preservation and frequentation) or some others if they exist.

Since the program's inception, uninterrupted studies have been ongoing and supplemented by more limited short-term studies of the following organisms and communities: seagrass prairies, especially the Neptune grass itself *(Posidonia oceanica)* and some associated species of animals; the macrophytic community (macroscopic seaweeds); the violescent sea-whip or chameleon sea fan *(Paramuricea clavata)*; sea urchins (especially *Paracentrotus lividus*); fishes, mainly the vulnerable species (*Epinephelus marginatus*, etc.); Mediterranean lobster *(Palinurus elephas)*; red coral *(Corallium rubrum)*; bryozoa or moss animals (especially *Pentapora fascialis*) as indicators of the erosive process in the coralligenous community; and, during the first years, before the official data on submarine frequentation being available, also their estimates. Of these organisms and communities, the species composition, abundances, sizes, age distribution and other demographic and biological variables were ascertained, always using bloodless methods.

The results of the monitoring during these years have been offered to the managers of the protected area in the form of annual reports and have been also published in several scientific articles.

Negative effects. Some submarine areas of the Medes Islands are being overwhelmed by the direct and indirect effects of massive numbers of visitors. They have been literally trampled, and the most emblematic benthic communities and species (coralligenous, sea fan communities, caves, red coral, calcareous algae, bryozoans) show clear signs of degradation. For the most visited areas, it has been estimated that damage caused to the violescent sea-whip *(P. clavata)*, a very slow growing cnidarian, by voluntary uprooting or by involuntary "trampling" could eliminate their populations in one or two decades. The permanent boat-traffic, dumped garbage, pollution, the anchoring effect on the prairie of *P. oceanica* —a system of anchoring buoys has been in place for some years, though it has been inadequately used—, the underwater poaching and illegal collecting of red coral, *C. rubrum*—although collecting this species is not legal inside the preserved area and, in any case, its size is clearly smaller than allowed elsewhere—are also threats to the integrity of this protected area that is suffering the effects of its fame.

Positive effects. The number of fish species—especially the more vulnerable to fishing—, the sizes of their populations as well as those of individual fish and the size of most species have increased, in some cases dramatically. The fish are less elusive, do not flee divers and even come close in search of food. The Mediterranean dusky grouper *(E. marginatus)*, European seabass *(Dicentrarchus labrax)* and gilthead

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Fig. 4. Detail of red coral (*Corallium rubrum*). (Author: SUBnormali Team CC).

bream *(Sparus aurata)*, among many other species that had become rare due to overfishing, are as abundant as they probably were before the practice of traditional fishing and underwater spearfishing and have reached sizes that veteran divers do not remember ever have seeing. Protected species therefore thrive.

Some studies have found that the ratio between large- or medium-size to small fish is too high and, although there are no reliable studies of this effect, this could indicate that the reserve is acting as disseminator of young fish to adjacent waters by the process of liberating larvae and juveniles to the surroundings of the protected area.

These positive effects, however, have another aspect perhaps more problematic. The recovery of territorial populations of species such as the Mediterranean dusky grouper *(E. marginatus)*, implies that the carrying capacity of the area has been reached: all territories are already occupied, and older males are evicted by the younger ones. Gilthead breams *(S. aurata)* exploit the mussels *(Mytilus edulis)* that grow on the rocks with higher effectiveness than humans did (when there was no ban on harvesting). Also, populations of sea urchins *(Paracentrotus lividus)*, quintessential herbivores, are reduced by predator fish, and their action on the algal mats has decreased to the point that the previous barren areas (areas depleted of carnose algae, where only calcareous and encrusting algae resisted the attack of sea urchins) are now luxuriant prairies of algae in much of the bottom on the Medes Islands, and are colonized by the host of invertebrates facilitated by its three-dimensional structure. But protection also helps herbivorous cow bream population *(Sarpa salpa)*, which has the opposite effect on algal communities.

Other research on Medes Islands

A new bionomic map (natural communities) of the submerged area of the Natural Park has been done, thirty years after the first one, and knowledge of the bottom has greatly improved due to the ongoing activities of research and monitoring throughout these years. While, in general, the available resources for exploration of the seabed of the islands have allowed a more precise knowledge of the natural heritage, it can also be said that the underwater landscape has changed relatively little, if the mentioned changes as a result of protection and the effects of mass mortality episodes are excluded. Indeed, the comparison of photographic transects made along bathymetric gradients of the seabed of Medes Islands for over two decades has enabled us to detect some of these changes [21].

The Medes Islands archipelago has become, over these four decades and due to the good knowledge of its biological

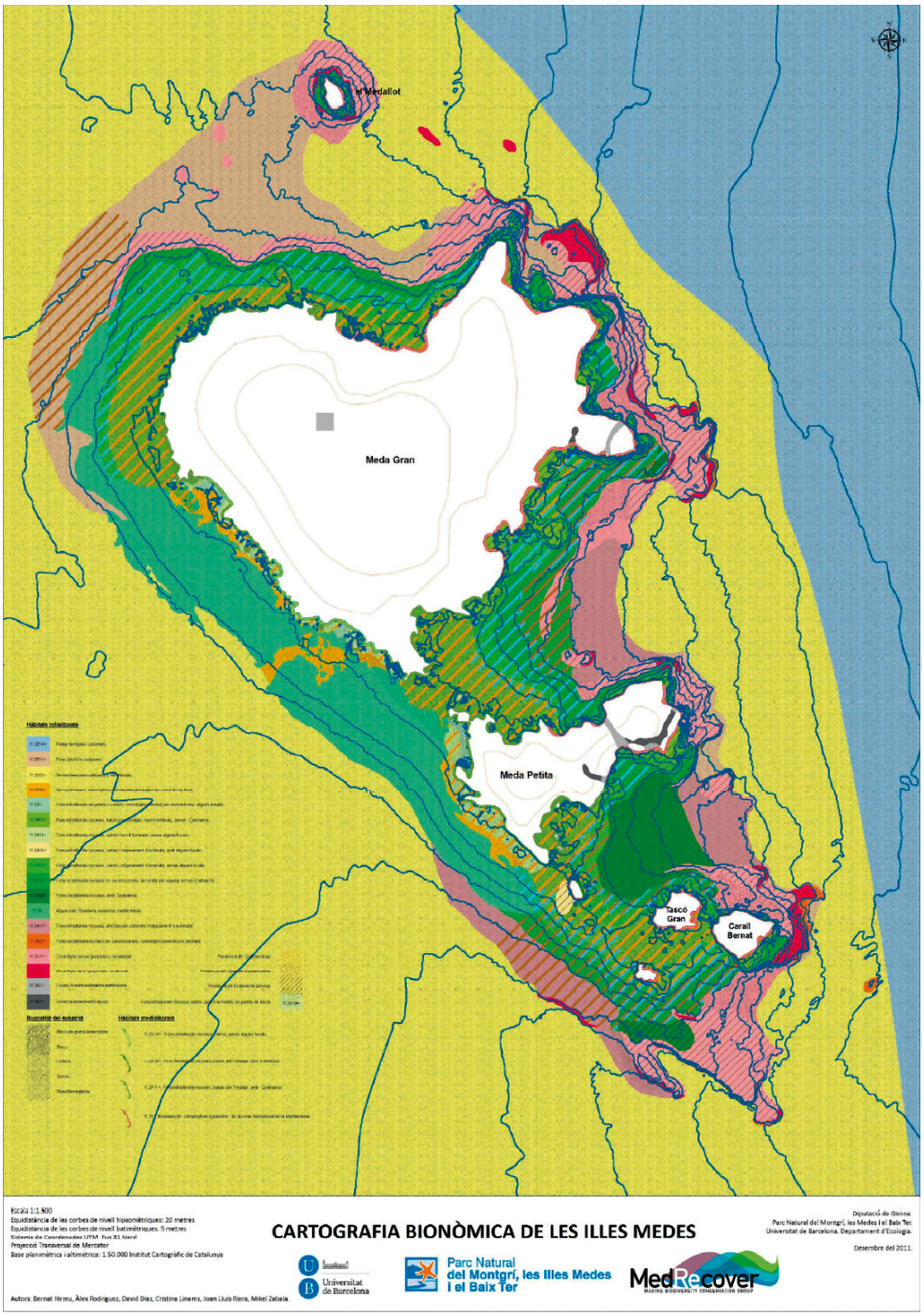

Fig. 5. Bionomic cartography of Medes islands. (Courtesy of B. Hereu, et al., 2012).

communities, a reference point for research on marine ecology in the Mediterranean and other places. Among these areas of research, we can mention the following:

· Distribution of certain species, both to small- and medium scales, and over time, in response to environmental factors.

· Trophic ecology (diet, prey capture, and feeding in different groups of invertebrates and vertebrates).

· Trophic interactions among groups, cascade effects, and developmental models.

· Complete energy balance (reproductive effort, growth rate, food, excretion, respiration) of different benthic species.

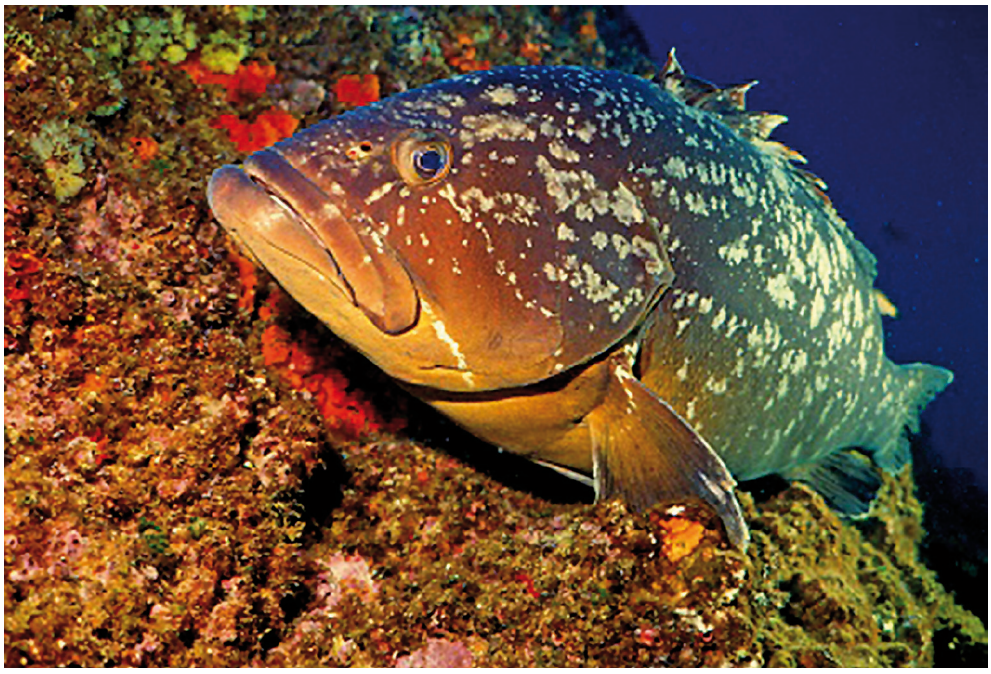

Fig. 6. Image of Mediterranean dusky grouper *(Epinephelus marginatus).* (Author: Parent Géry CC).

· Integrated studies of unique ecosystems, including caves and seagrass beds.
· Biomass and production at the scale of the ecosystem.
· Production and physiology of macrophytes.
· Demography: growth, natural mortality, changes in the size structure (age), reproduction and recruitment, partial mortality, fusions and fissions (in colonial organisms) demographic control *in situ*, demographic models.
· Population structure, feeding, reproduction and recruitment, demography, genetics, etc., of selected species: red coral *(C. rubrum)* and the violescent sea-whip *(P. clavata)*.
· First stages of the ecological succession; dynamics of the communities in the long term.
· Photographic series of permanent plots: sequential comparison for short periods (annual). Long-term analysis of photographic series (decadal).
· Characterization of the environment (physics, chemistry, geology and biology of the water column; interaction with currents; studies at very high resolution, in time and space, to understand environmental characteristics at micro-scale).
· Biochemical composition (identification of molecular signals as indicators of the state of health: stress proteins).
· Episodes of mass mortality of suspensivores (gorgonians, sponges, bryozoans, bivalves, etc.), at Medes Islands and in other Mediterranean locations. Monitoring of thermal change.
· Recovery of populations (gorgonians, coral)
· Ichthyoplankton in the surroundings of the islands.
· Approach to the integrated knowledge of the underwater caves of the islands, with original experimental designs to study both its physical and environmental frameworks and the organisms inhabiting them [9,42].
· Work on populations of Mysidacea daily entering and leaving the caves and collaborating to the transport of organic matter into them [4,5,27].
· Studies on the so called midlittoral *trottoir,* where very detailed studies were made on a small scale of its inhabitants [3].
· Use of biochemical techniques to determine the biological status of some species, such as sea fans [35].
· Detailed studies on the biology and ecology of some species of gorgonians and hydrarians [1,2,36].
· Structure and dynamics of the population of key marine reserve species (fishes and lobsters) [16,18,19].
· Assessing the effectiveness of Marine Reserves [38,63].
· Comparative studies with populations of sea fans, sponges and algae from other localities, either Mediterranean or not [8,12,15,18–20,24,25,28,29,33,39].

The scientific monitoring of the protected area of Medes Is-

lands has not only acted synergistically to promote the development of research, but has also been serendipitous in the sense that has allowed unexpected findings. One is the episode of red coral *(C. rubrum)* poaching, precisely in one of the monitored plots, which allowed to estimate the damage done and advise authorities; another is the observation for the first time in such a northern latitude of the Mediterranean as Medes Islands, of the spawning behavior of the Mediterranean dusky grouper *(E. marginatus)* [43,44], probably caused by the warming of water due to climate change.

While it can be said that benthic communities and fish have been well studied in the Medes Islands Marine Protected Area, it has not been the same with planktonic communities and biological processes in the water column. There are, however, some studies of particular interest because they are related to aspects studied in other areas, such as planktonic larval stages of fish [37]. Much remains to be done to improve the knowledge of the dynamics of particulate matter, of organic matter and its transport and deposition, although some preliminary studies indicate that Medes Islands is a high productivity area in a Mediterranean context [34].

Recently, we have considered the islands and the protected area as a model for managing other marine protected areas in the Mediterranean, either from increases in fish populations and biomass [13] or as an artisanal fisheries zone [38,39] and, even with a broader perspective, considering the continental shelf outside the islands [6,10,22].

The future

The research carried out on the seabed of Medes Islands and their environment, gradually changed from biotic inventory to bionomic cartography, and this, to monitor the response of some selected species and communities to the protection measures (and some of their social and economic consequences, such as the dramatic increase in the appeal of the islands to local and foreign divers and tourists in general). Meanwhile, several studies had been started trying to elucidate the biology and ecology of selected species, the dynamics of populations and communities, and the interaction between organisms and their environment. Has the potential of the area to supply new lines of research (or old ones, but with a different approach) been exhausted over these four decades? We do not think so.

Research in the protected area of Medes Islands (and, for some years, also of the immediate Montgrí coast) will not end. By definition, scientific research is the permanent replacement of paradigms, all of them with a limited validity.

Competing interests. None declared.

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