A conceptual framework for the integral management of marine protected areas

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A general conceptual framework for the management of marine protected areas (MPAs) was developed. The driver-pressure-state-impacts-response (DPSIR) framework was used to determine the elements affecting MPAs. The developed evaluation framework helped to select an appropriate suite of indicators to support an ecosystem approach, an assessment of the MPAs functioning and policy decisions. Gaps derived from the management and policy responses in the MPAs were also outlined. It was concluded that the DPSIR framework can help to simplify the complexity of MPA management. This document is a tool for policy makers, scientists and general public on the relevance of indicators to monitor changes and MPAs management.

1. Introduction

The marine system is arguably more complex than any other ecosystem with highly interrelated processes between its physical, chemical and biological components. Its study and management requires information on all processes and an understanding of the structure and function of the systems. In addition, the increasing amount of national, supra-national and global legislation and agreements, is producing the necessity to develop tools for the sustainable use of the marine environment, in particular management for conservation and biodiversity in order to protect habitat integrity. This calls for multi-disciplinary approaches to marine protected areas research and resource management.

From the First World Conference on National Parks, when countries were invited to create marine protected areas and parks, the number of MPAs and surface protected has increased [1]. The spatial extent of marine areas protected globally has grown at an annual growth rate of 5.2%, over the last two decades, which have been established with different aims. Approximately 2.2 million km², equivalent to 0.6% of the world’s oceans and 1.5% of the total marine area under national jurisdiction, are currently protected [2]. In general, MPAs have been proposed throughout the world as an optimal way to protect marine ecosystems [3–5]. The effectiveness of a MPA, among other many things, is related with its management. This should include defined objectives and goals from the outset, site selection, zoning, planning and implementing a surveillance and enforcement system, as well as monitoring actions [6]. In order to determine the validity of MPAs as fisheries management tools is essential to evaluate the MPA performance by means of continuous monitoring.

Indicators are increasingly being developed and used as management tools to address environmental issues [7–10], they are also used to assess the effectiveness of the actions and policies implemented, by measuring progress towards environmental targets [8,11]. In this sense indicators can contribute in the monitoring of the effectiveness of MPAs. Indicators are variables used to quantify or qualitatively describe phenomena that are not directly easily measured, but which society considers valuable to monitor...
over time [12,13]. The paradox is that while the scientific community is mostly working on very detailed and narrower aspects, the managers require a holistic and ecosystem approach, not necessarily at a very high level of detail [14]. The selection of a set of indicators must provide information that can be clearly understood by managers and stakeholders, providing them with a base for decision making.

However before selecting and choosing indicators it is necessary to clearly define cause–effect relationships, and to establish a framework from which the indicators can be selected. One of the techniques available in defining indicators is the driver–pressure–state–impact–response (DPSIR) conceptual framework, initially developed by the OECD (Organisation for Economic Co-operation and Development). The DPSIR scheme of indicators is a flexible framework that can be adapted to the necessities of specific programmes to stress the different indicator types. It has been widely used for different purposes, for the implementation of the European Water Framework Directive [15–17], coastal zone studies [10,18–26] and in fisheries management [14]. This methodology works well at simplifying the complexity of environmental management and makes easier communication among policy makers, scientists and the general public, improving the cooperation among them. It allows a better understanding between the results from an action developed and the effects produced in the different system components (e.g. the fisheries, the socioeconomics).

1.1. Problems facing MPAs management

Many calls have become for the further designation of MPAs, understanding as an MPA as those that present conservation as resource protection objectives, included all the categories defined by the IUCN [27], recommending that 20–30% of the area of each marine habitat should be designated as no-take area by 2012 [28]. MPAs reflect the extension of scientific and ethical concerns for the wider health of marine ecosystem conservation, including their component populations and habitats, the processes that sustain them and the functions they provide, having beneficial effects for habitat–specific species associated with sensitive grounds [29] or very sedentary species [30]. However, many authors argue that MPAs are not a fishery panacea [31] basically because few data sustain positively their potential to promote sustainable fish stock yields. Nevertheless these authors are not referring to multiple-use zones, but huge areas with some kind of management [32].

In general MPAs have been sited at intrinsically ecological rich places based more on opportunistic human factors than on relevant ecological and/or socioeconomic features such as: currents structure, habitat requirements, inter-specific processes, fishing effort distribution, effects of MPA location, size and design [33], resulting in a very heterogeneous pool of small reserves along the coast and a number of very large high seas reserves within the EEZs countries. This heterogeneity is also reflected in the management implemented and, therefore, in its results, being difficult post-comparisons to deduce general trends derived from the effects of protection. Moreover, many of the objectives assigned to MPAs have not been tackled, resulting in a very narrow use of methodological approaches and study subjects (Ojeda-Martínez, unpublished data). Another problem facing MPAs management is the lack of coordination at different levels. Although some authors advocated [34] or interpreted [35] this increase of MPAs as a network in some regional areas (e.g. the Mediterranean Sea), the fact is that they are not working like it. There lacks a minimum of coordination on their functioning, even among MPAs depending on the same institution. Furthermore, fewer than 10% of MPAs that exist today achieve their management goals and objectives [2,13], and in many cases, the effects resulting from the protection are not duly disseminated, creating uneasiness in many stakeholders and users. Furthermore, there are few studies and mainly located in some areas that analyse management by itself, relating the investment (in terms of budget, staff, time of surveillance, etc) in the MPA with those elements that theoretically should be affected by the protection [13,36]. Therefore MPAs management needs to look towards an integrated governance approach that recognizes the interdependences of the different elements, and the need to know and manage the effects of each activity affecting the MPA. With typical small MPAs the activities and management of the surrounding and upstream areas are major factors and if these – including particularly their impacts and sustainability in relation to the designated area – are not studied, the prospect of integration is remote.

The purpose of this document was to identify, define and discuss the ecological, socioeconomic and related essential variables that can potentially be used as indicators, in order to assess the effectiveness of MPAs as a policy response to conserve and restore fisheries and marine biodiversity. The specific goals include: a) to select the main components of the marine biodiversity affected by fisheries and tourism, including their descriptors and their derived consequences; b) to define a conceptual framework relating the selected components; c) to propose a set of variables that can potentially be used as indicators at each level in the DPSIR framework.

2. Methodological approach

2.1. Establishment of an expert panel

The methodological approach of this research started with the establishment of an expert panel formed by scientists belonging to EMPAFISH project (http://www.um.es/empafish/). This group was formed by experts in: fisheries, MPAs, marine ecology, mathematics, statistics and multi-criteria analysis. The expert panel, such as those proposed for other purposes [5,37,38] was formed by a principal committee which led the process. This principal committee analysed different methodological approaches and selected the DPSIR framework, among all of them. The main objective of the expert panel was to define a conceptual framework which improved the understanding of the complexity of linkages and feedbacks between the causes and effects within environmental issues in MPAs. Also look for management gaps and identify variables as potential indicators, with the help of the conceptual framework defined. This process lasted about eleven months, weekly meetings were held by the expert panel, while more frequent ones, were held by the principal committee, until the development of the conceptual framework and the indicators definition.

2.2. Participation process

The first step of the participation process (Fig. 1) was to define the key elements that are those components of the ecosystem that are susceptible to be affected by any of the elements generated by human activity, particularly from fishing and tourism as the main driving forces affecting the environment. As the objectives of the project were to assess the effectiveness of MPAs as management tools, the responses on the framework were defined as the actions arising from the existence of such figures of protection. Cause-effect diagrams were developed and were broken down into the different elements within the DPSIR framework. Each element was studied in detail, based on the experience of the expert panel and on a deep search in the bibliography, including every cause or factor that interacted with the element. Identification according to the DPSIR framework was done to establish at which level of the
framework the elements were found (driving forces, pressures, states or impacts). Every management action associated with MPAs was identified and broken down into different parts, introducing them in the conceptual framework and connecting as responses to the driving forces, pressures, states or impacts. In this phase gaps in the overall responses of the MPAs management were identified towards the different levels of the framework. The search for all possible indicators associated with each element of the model was the next step.

3. MPAs DPSIR framework

The first results were the definition and selection of the key elements, the driving forces and the responses. Key elements were defined as those components of the ecosystem that are susceptible to be affected by any of the elements of the DPSIR framework. They play an important role in the DPSIR framework, as cause–effect diagrams are based on the relationships between these elements and the system studied. The key elements selection is an important part of the framework and managers are mostly interested, in them, as they need to define effective actions in prevention, restoration and control. For the general conceptual framework, the key elements selected were; species and habitats protected by European directives (Habitats Directive, Barcelona Protocol concerning Specially Protected Areas and Biodiversity in the Mediterranean, OSPAR Convention and those featured in the IUCN red list); target commercial species; ecological process developed (e.g. recruitment, biological production, species interaction, genes transfer) and socioeconomic processes (e.g. incomes, socioeconomic resources, demography). Fishing and tourism sectors were chosen as driving forces. Driving forces: are understood as the factors that cause changes in the system; they can be

![Fig. 1. Scheme of the participation process to develop the DPSIR conceptual framework and its application to the management of a marine protected area.](image)
social, economical or ecological and can have positive or negative influences on pressures. These economical areas were chosen as they are mainly the sectors that generate activities affecting most MPAs in developed countries, although this can be different in underdeveloped countries [14]. Responses: that are the efforts made by society as a result of the changes manifested, can be any legal measure that is done to manage the marine environment as e.g. fishing gears banned and artificial reef installation. Because of the objectives in the conceptual framework, the responses were the MPAs, as indicators and gaps for MPAs present and future management must be found. In order to make policy recommendations for the management of MPAs and the selection of indicators, it is first necessary to describe the present state of the marine environment, its pressures and its management. Once the links between driving forces, pressures (that are the human activities that directly affect the system), states (are the condition of the system at a specific time and is represented by a set of descriptors of system attributes that are affected by pressures) and impacts (that are the effects on human health and/or ecosystems) are clear, policy responses can be formulated.

3.1. The fishing sector as driving force: pressures, states and impacts

Fishing incorporates different types of fishing gears and therefore the fishing sector driving force has been divided into sub-driving forces, taking into account the different fishing gears (Fig. 2). Depending on the type of fishing gears used, the fishing activities affect the marine environment in different ways. Each sub-driving force embraces the different types of fishing using the different gears considered. The number of fishing boats/year can be a good example of a driving force parameter as it reflects the fishing activity round MPAs (Fig. 3). Several actions contribute to generate pressures on the system, the pressures were chosen as they affected our key elements. The different fishing gears cause similar pressures over the key elements and the states, its measure is what makes pressures different. Fishing has an environmental effect on many coastal areas [34,39] and it can exert pressure over the marine environment in a number of different ways: i) Extraction or harvesting on the resource at a higher rate than its capacity to regenerate is the most direct pressure (e.g. the sighting of professional fishing activities/year (Fig. 3), reflects the pressure exerted in the MPA boundaries or close to them, being a good indicators). This is not only unsustainable in economic terms, but also has significant effects elsewhere in the ecosystem. Generally, impacts are the causes that evoke responses and fishing activities usually cause a decrease in the abundance, biomass and size of commercial and non-commercial species [34,40–43], the measure of these parameters being a good indicator (e.g. species biomass as a state indicator (Fig. 4) and big Sparidae biomass as an impact indicator (Fig. 5). As the target species declines due to over fishing, others became more dominant and the whole structure of the ecosystem and typically the fishery targets altered. Stocks are over exploited so there is a decrease in total catch of the initial high trophic level target species, but as in the case of some low trophic level target species, fishing down the food chain can for a time increase total catch. ii) The effect of fishing gear on the non-target species, communities and habitats (e.g. total or partial broken of species like Pinna nobilis or coral species, and discards), that produces substantial habitat destruction by trawl and dredge gears on first use and destruction of the seabed ecosystem with little recovery in
regularly trawled or dredged areas. Discards attract and increase the number of scavenger fish [44], invertebrates and seabirds [45], varying the relationships among ecosystem components. Depending on the type of gear used, the effect on species and habitats modifies the spatial structure in different ways. Other less aggressive gear, e.g. trammel nets, may also affect the target and non-target species, thus modifying the population structures. Some static fishing tackles do not exert this type of pressure [46–48]. iii) Waste, understood as detritus generated by the stakeholders, litter dropped from the deck, hydrocarbon emissions by boats, organic emissions and chemical pollution, is an indirect pressure produced by the fishing sector. Pollution although not an objective of fishing is a direct consequent operational pressure on the habitats and species affected. The major impact of inert solids waste is the mortality of species such as turtles that mistake plastics and other rubbish as jellyfish and ingest them. Hydrocarbons are also a problem as they are deposited on sessile and pelagic species, as well as birds. In the case of coral reefs and some sediment studies it has been shown that hydrocarbons can have long-term persistent effects killing invertebrates and inhibiting settlement of larvae to replace adults that have died. Inert solids are a problem for filter-feeding species whose filtering appendages can become obstructed resulting in death. Most species and habitats are buried by inert solids and hydrocarbons, killing them or limiting their vital functions, such as photosynthesis. iv) Lost tackles are also a hazard and dangerous to wildlife (fishes, marine mammals, turtles and birds). Lost gears may affect habitats, but in most cases they affect species, key species like turtles and sea mammals [49], can be totally or partially broken or trapped by them. Birds are also affected by lost gears, suffering amputations of wings and feet [50]. As animals are trapped, they die, which increases the scavenger presence modifying the inter-specific relations.

3.2. The tourism sector as a driving force: pressures, states and impacts

Ocean and coastal tourism is widely regarded as one of the fastest growing sectors of contemporary tourism [51], indeed tourism is the driving economic sector (Fig. 6) in many coastal zone areas because it is seen as a cost effective means of bringing development and foreign currency earning capacity to isolated areas and countries. Tourism is expected to continue to grow, and nowadays is producing a major environmental impact on many coastal areas. Nevertheless, the popularity of fishing, surfing, scuba diving, windsurfing, whale watching and yachting and selling of “sun, sand and surf experience”, drives the development of beach resorts and associated residential and commercial infrastructure (e.g. this driving force can be measured by the indicator of the evolution of the number of diving permissions in an MPA (Fig. 7). This brings increased pressure space and resource competition on coastal areas which may already be subject to highly concentrated use and infrastructure stress through agriculture, human

![Fig. 3. Driving force: temporal evolution in numbers of amount of professional fishing boats for the closest brotherhoods to Tabarca MPA [84]. Pressure: number of professional fishing activities close to the MPA, obtained by the Tabarca MPA surveillance. Data source: Tabarca MPA surveillance technical reports (TRAGSA, Secretaría de Pesca Marítima).]

![Fig. 4. State: total fish biomass sampled by UVC (underwater visual census), temporal trend and linear regressions within the MPA and in control areas (no protection), in Tabarca MPA.]}
settlements, fishing, urban, industrial transport and communications development [51]. Also this increases a whole of social and cultural impacts, derived from the abandonment of traditional economic activities, to adapt to new patterns of behaviour, use and consumption of resources and management of wastes [52]. Pressures of marine tourism can be broadly categorised as ecological, social and cultural: i) Angling from shore, angling from boat and spear fishing are very popular activities in most countries where they are practiced at recreational and competitive levels [43,53–55]. These activities are forbidden in most of the marine protected areas, but are allowed along the coast. However, there are still certain problems, such as the illegal selling of the catches or the resistance of spear fishermen to comply with protection measures, despite spear fishing could be policed and possession of spear fishing equipment could be a controlled activity. Although spear fishing is usually carried out at low intensity along all suitable
stretches of coast, (except during competition events), there is published evidence that, in the western Mediterranean, spear fishing can affect the composition of fish communities [56–59] and the structure of fish populations [60–62]. Conflicts between different user groups can arise because recreational fishing may take place in areas closed to commercial fishers and they may compete for the same resources. ii) Diving and snorkelling have been well studied overseas [63] and this pressure also generates most of the incomes of coastal areas e.g. the real number of divers in the MPA is an indicator to assess the pressure of this driving force (Fig. 7). A percentage of divers who swim too close of the bottom may break species [64]. Fragile branching corals are the most susceptible to breakage [65], bryozoans and sea fans have erosion problems due to this pressure [66]. Some studies on snorkellers have detected larger numbers of broken species in areas actively used by snorkellers, including snorkel trails, but the level of breakage levelled off quickly [65]. Other associated effects are changes in fish behaviour due to feeding [67]. iii) Tourism produces problems due to trampling [68–70] and illegal species collection in accessible rocky shore areas. It can provoke the replacement of low growth (e.g. Cystoseira spp) to rapid growth opportunistic species. Visitors usually collect key species which inserts pressure similar to the extraction done by recreational fishing. Furthermore, indirect effects include: erosion by trampling, gradual changes in vegetation structure and plant species composition as an adaptation to mechanical pressure. iv) Also visitors, divers, shipping and recreational fishing, generate waste in many other different ways, as happened in the fishing sector. v) Visitors need to have infrastructure built and they create a seasonal demand for resources [71]. In some cases, this expansion generates a need of complementery infrastructures (e.g. desalination plants, sewage plants, etc) to provide this demand (e.g. fresh water necessities in Mediterranean localities doubles during the tourist season incrementing subsequently the amount of sewage processing, that at the end is more important for near shore water, so does the amount of sewage processed [71]). Besides land-use, demand for resources and need for waste disposal facilities cause pressure on fresh water and natural coastal habitats. Uncontrolled development associated with tourism affects coastal ecology (e.g. varying the ecological balance through eutrophication, if adequate standards of design and implementation of sewage management are not adopted). Construction in coastal regions, sand erosion and instabilities in beaches, have destructive effects on fauna, flora and habitats and, in particular, on endemic species [72]. vi) Anchoring and mooring generate impacts associated with other pressures such as recreational fishing, shipping and diving and have been well studied [73]. A series of extensive impact assessments have found that pressures of moorings on the surrounding areas are minimal, apart from the ‘footprint’ under the moorings. Anchoring of both tourist and recreational boats is a significant issue in heavily visited sites [74]. Anchors and anchor chains are capable of breaking multiple species (e.g. coral colonies) at each drop and affect habitats like Posidonia oceanica meadows.
Driving Forces

<table>
<thead>
<tr>
<th>Type</th>
<th>Sector</th>
<th>Indicator</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>Fishing</td>
<td>Number of fishing boats</td>
<td>Temporal and/or spatial variations in the number of the professional fishing boats that fish on the Marine Protected Area (MPA) or its boundaries.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Fishing</td>
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<td>Temporal variations on the number of the people working for the fishing sector or industry. Principally people fishing.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Fishing sector</td>
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<td>Temporal variations of the profit of the fishing sector. Differences of the profit of this sector with the establishment of the MPA.</td>
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<tr>
<td>Fishing &amp; tourism</td>
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<td>GDP produced by the sector</td>
<td>Temporal distribution of the Gross Domestic Product (GDP) by the different sectors selected as driving forces.</td>
</tr>
<tr>
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<td>Number of investments done in the sector</td>
<td>Temporal and spatial number of investments done to improve the sector either fishing or tourism (in this case the driving forces).</td>
</tr>
<tr>
<td>Fishing</td>
<td>Fishing boats power</td>
<td>Power</td>
<td>Temporal variations of the power of the fishing boats that fish in the MPA or in its boundaries or the fleet that fishes close to it.</td>
</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Per capita income of the area</td>
<td>Per capita income of the area</td>
<td>Spatial and temporal distribution of per capita income in the area influenced by the MPA.</td>
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<tr>
<td>Fishing &amp; tourism</td>
<td>Per capita income of the sector</td>
<td>Per capita income of the sector</td>
<td>Per capita income of the fishing and tourist sector (in this case the driving forces) in the area influenced by the MPA.</td>
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<tr>
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<td>Fishing boats with a kind of gear</td>
<td>Fishing boats with a kind of gear</td>
<td>Number of fishing boats that use a determinate kind of gear.</td>
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<td>Spear fishing/coast</td>
<td>Number of people fishing with a spear by kilometres of coast influenced by the MPA.</td>
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<td>Angling/coast</td>
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<tr>
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<td>Fishing rods sold</td>
<td>Number of fishing rods sold per number of habitants in the area influenced by the MPA.</td>
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<tr>
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<td>Specialised shops</td>
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<tr>
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<td>Spear guns sold/habitant</td>
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<td>Diving clubs number</td>
<td>Temporal and spatial evolution of the number of diving clubs in the area.</td>
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<td>Diving incomes</td>
<td>Temporal and spatial evolution of the incomes produced by diving activities.</td>
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<td>Diving licences number</td>
<td>Temporal and spatial evolution of the diving licences in the area.</td>
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<td>Influx of visitants</td>
<td>Temporal evolution of the visitants.</td>
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<td>Guided activities in the area</td>
<td>Guided activities in the area</td>
<td>Temporal evolution of the number of the guided activities in the area.</td>
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<tr>
<td>Tourism</td>
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<td>Recreational boats sold</td>
<td>Temporal evolution of the number of recreational boats sold in the area.</td>
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<tr>
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<td>Jet sky sold</td>
<td>Temporal evolution of the number of jet sky sold in the area.</td>
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<td>Nautical activities offered</td>
<td>Temporal and spatial evolution of the number of nautical activities offered in the area.</td>
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<td>Hotel accommodation offer</td>
<td>Temporal and spatial evolution of the hotel accommodation offer in the area.</td>
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<tr>
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<td>Fishing ground</td>
<td>Area, were the fishing is exerted.</td>
</tr>
<tr>
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<td>Boats fishing/day</td>
<td>Boats fishing/day</td>
<td>Number of boats fishing.</td>
</tr>
<tr>
<td>Fishing</td>
<td>CPUE</td>
<td>CPUE</td>
<td>Catch Per Unit Effort (CPUE).</td>
</tr>
<tr>
<td>Fishing</td>
<td>Length of net</td>
<td>Length of net</td>
<td>Length of the net over a type of habitat.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Number of hooks</td>
<td>Number of hooks</td>
<td>Number of hooks over a type of habitat.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Fishing time</td>
<td>Fishing time</td>
<td>Fishing time.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Total Biomass extracted</td>
<td>Total Biomass extracted</td>
<td>Kilograms of biomass extracted when fishing by boat and by gear.</td>
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<tr>
<td>Fishing</td>
<td>Biomass extracted by specie</td>
<td>Biomass extracted by specie</td>
<td>Specie biomass (kilograms) extracted by boat and by gear.</td>
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<tr>
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<td>Individuals fished/total capture</td>
<td>Individuals fished/total capture</td>
<td>Kilograms of individuals from the same specie fished divided by the total capture in kilograms.</td>
</tr>
<tr>
<td>Fishing</td>
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<td>Number of species caught</td>
<td>Number of different species caught by gear.</td>
</tr>
<tr>
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<td>Hydrocarbons consumed</td>
<td>Hydrocarbons consumed</td>
<td>Litres of hydrocarbons consumed for fishing by boat.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Organic matter thrown</td>
<td>Organic matter thrown</td>
<td>Tons of organic matter thrown to the sea.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Gears lost</td>
<td>Gears lost</td>
<td>Number of fishing gears lost.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Tourist angling in coast</td>
<td>Tourist angling in coast</td>
<td>Number of tourist anglers along the coast (in km) per day.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Tourist angling in boat</td>
<td>Tourist angling in boat</td>
<td>Number of tourist anglers by boat along the coast (in km).</td>
</tr>
<tr>
<td>Tourist</td>
<td>Spear fishers</td>
<td>Spear fishers</td>
<td>Number of spear fishers along the coast (in km) per day.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Density of recreational fishers</td>
<td>Density of recreational fishers</td>
<td>Temporal density of recreational fishers.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Recreational fishing surface</td>
<td>Recreational fishing surface</td>
<td>Recreational fishing surface.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Recreational boats</td>
<td>Recreational boats</td>
<td>Number of recreational boats in a day along the MPA boundaries.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Boating or jet sky</td>
<td>Boating or jet sky</td>
<td>Number of motor boating or jet sky in a day in the MPA or influenced area.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Divers</td>
<td>Divers</td>
<td>Number of recreational divers in a day in the MPA or along its boundaries.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Visitants</td>
<td>Visitants</td>
<td>Number of visitants in a day in the MPA.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Littoral itinerary</td>
<td>Littoral itinerary</td>
<td>Number of visitants in a day in a littoral itinerary or route.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Hydrocarbons consumed</td>
<td>Hydrocarbons consumed</td>
<td>Hydrocarbons concentration (mg/l) consumed by boat in the closer ports.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Organic matter</td>
<td>Organic matter</td>
<td>Quantity in tonnes (Tn) of organic matter thrown by recreational boats</td>
</tr>
<tr>
<td>Tourist</td>
<td>Recreational boats</td>
<td>Recreational boats</td>
<td>Number of recreational boats (fishing boats + tourism boats + whale watching + ...).</td>
</tr>
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Pressures

<table>
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<tr>
<th>Type</th>
<th>Sector</th>
<th>Indicator</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>Fishing</td>
<td>Fishing ground</td>
<td>Area, were the fishing is exerted.</td>
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<tr>
<td>Fishing</td>
<td>Boats fishing/day</td>
<td>Boats fishing/day</td>
<td>Number of boats fishing.</td>
</tr>
<tr>
<td>Fishing</td>
<td>CPUE</td>
<td>CPUE</td>
<td>Catch Per Unit Effort (CPUE).</td>
</tr>
<tr>
<td>Fishing</td>
<td>Length of net</td>
<td>Length of net</td>
<td>Length of the net over a type of habitat.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Number of hooks</td>
<td>Number of hooks</td>
<td>Number of hooks over a type of habitat.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Fishing time</td>
<td>Fishing time</td>
<td>Fishing time.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Total Biomass extracted</td>
<td>Total Biomass extracted</td>
<td>Kilograms of biomass extracted when fishing by boat and by gear.</td>
</tr>
<tr>
<td>Fishing</td>
<td>Biomass extracted by specie</td>
<td>Biomass extracted by specie</td>
<td>Specie biomass (kilograms) extracted by boat and by gear.</td>
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<tr>
<td>Fishing</td>
<td>Individuals fished/total capture</td>
<td>Individuals fished/total capture</td>
<td>Kilograms of individuals from the same specie fished divided by the total capture in kilograms.</td>
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<tr>
<td>Fishing</td>
<td>Number of species caught</td>
<td>Number of species caught</td>
<td>Number of different species caught by gear.</td>
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<td>Hydrocarbons consumed</td>
<td>Hydrocarbons consumed</td>
<td>Litres of hydrocarbons consumed for fishing by boat.</td>
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<tr>
<td>Fishing</td>
<td>Organic matter thrown</td>
<td>Organic matter thrown</td>
<td>Tons of organic matter thrown to the sea.</td>
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<tr>
<td>Fishing</td>
<td>Gears lost</td>
<td>Gears lost</td>
<td>Number of fishing gears lost.</td>
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<td>Tourist angling in coast</td>
<td>Number of tourist anglers along the coast (in km) per day.</td>
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<tr>
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<td>Tourist angling in boat</td>
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<tr>
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<td>Spear fishers</td>
<td>Spear fishers</td>
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<td>Density of recreational fishers</td>
<td>Temporal density of recreational fishers.</td>
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<td>Recreational boats</td>
<td>Recreational boats</td>
<td>Number of recreational boats in a day along the MPA boundaries.</td>
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<tr>
<td>Tourist</td>
<td>Boating or jet sky</td>
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<tr>
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<td>Divers</td>
<td>Divers</td>
<td>Number of recreational divers in a day in the MPA or along its boundaries.</td>
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<tr>
<td>Tourist</td>
<td>Visitants</td>
<td>Visitants</td>
<td>Number of visitants in a day in the MPA.</td>
</tr>
<tr>
<td>Tourist</td>
<td>Littoral itinerary</td>
<td>Littoral itinerary</td>
<td>Number of visitants in a day in a littoral itinerary or route.</td>
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<tr>
<td>Tourist</td>
<td>Hydrocarbons consumed</td>
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<td>Hydrocarbons concentration (mg/l) consumed by boat in the closer ports.</td>
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<td>Tourist</td>
<td>Organic matter</td>
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<tr>
<td>Tourist</td>
<td>Recreational boats</td>
<td>Recreational boats</td>
<td>Number of recreational boats (fishing boats + tourism boats + whale watching + ...).</td>
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State

<table>
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<th>Type</th>
<th>Sector</th>
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<th>Definition</th>
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<td>Abundance</td>
<td>Abundance</td>
<td>Quantity of each key specie can be found in the MPA</td>
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<td>Biomass</td>
<td>Biomass</td>
<td>Weight of each key specie that can be found in the MPA</td>
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<td>Density</td>
<td>Abundance per unit area of key species are in the MPA</td>
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<td>Size structure</td>
<td>Size structure</td>
<td>Size distribution of the different key elements selected</td>
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<td>Diversity</td>
<td>Assemblage structure in the MPA</td>
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<td>Fishing &amp; tourism</td>
<td>Relative Abundance</td>
<td>Relative Abundance</td>
<td>Relative abundance of key species.</td>
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<td>Richness</td>
<td>Number of species.</td>
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<td>Sector</td>
<td>Indicator</td>
<td>Definition</td>
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<td>Relative abundance of the more abundant species</td>
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<td>Number of new individuals (juveniles) incorporated to a population</td>
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<td>Changes on the occupied surface</td>
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<td>Number of key species endangered by solid objects.</td>
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<td>Hydrocarbons concentration in the water column.</td>
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<td>Species broken</td>
<td>Number of species broken by anchoring or diving.</td>
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<td>Nests</td>
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<td>Temporal and spatial variations of the quantity of key species that are in the MPA boundaries</td>
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<td>Changes in covertures</td>
<td>Changes produced in the state of the key elements during the time a pressure is affecting them.</td>
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<td>Changes in community structure</td>
<td>Temporal and spatial changes in the community structure.</td>
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<td>Species size variation</td>
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<td>Temporal and spatial variations of the quantity of each key specie that can be found in the key MPA</td>
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<td>Temporal and spatial variations on the species composition structure in the MPA boundaries.</td>
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<td>Temporal and spatial variations on the number of the key species.</td>
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<td>Changes in dominance</td>
<td>Temporal and spatial variations on the abundance of the dominant species.</td>
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<td>Changes in sediment composition and/or quality.</td>
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<td>Temporal and spatial substitution of the species</td>
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<td>Changes in recruitment</td>
<td>Temporal and spatial variations on changes in the recruitment rate</td>
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<td>Breaking index</td>
<td>Temporal and spatial variations of breaking index of key species.</td>
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<td>Rugosity</td>
<td>Temporal changes in the rugosity of key elements</td>
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<tr>
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<td>Changes in habitat heterogeneity</td>
<td>Temporal and spatial habitat changes</td>
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<tr>
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<td>Changes in trophic levels</td>
<td>Temporal and spatial changes in trophic levels</td>
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<tr>
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<td>Opportunistic species</td>
<td>Appearance of opportunistic species.</td>
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<td>Sensitive species</td>
<td>Changes in sensitive species</td>
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<td>Variation of the targeted species size</td>
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<td>Variation of the targeted species weight</td>
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<td>Captures</td>
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<tr>
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<td>Recruitment rate</td>
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<td>Extracted biomass</td>
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<td>Opportunistic species evolution</td>
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<td>Evolution of the surface damaged by anchoring</td>
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<tr>
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<td>Diving activities</td>
<td>Evolution in the surface affected by the diving activities.</td>
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</tr>
<tr>
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<td>Whale watching</td>
<td>Temporal and spatial variations in whale watching</td>
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<tr>
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<td>Sea mammals</td>
<td>Number of impacts with sea mammals</td>
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<td>Trampling</td>
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<tr>
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<td>Water quality</td>
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<td>Responses Fishing</td>
<td>Marine Protected Area</td>
<td>Surface of the Marine Protected Area</td>
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<tr>
<td>Fishing &amp; tourism</td>
<td>Integral reserve</td>
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<td>Fishing &amp; tourism</td>
<td>Zoning surface</td>
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<td>Sport fishing surface</td>
<td>% of the total surface of the MPA limited for sport fishing.</td>
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<tr>
<td>Fishing &amp; tourism</td>
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<td>% of the total surface of the MPA limited for diving (recreational or scientific)</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget</td>
<td>Total budget invested in the MPA by the governments</td>
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</tbody>
</table>
3.3. Marine protected areas: a response

Responses are possible at all levels in the DPSIR framework, but at the pressure and state level, measures are technically and economically hardly feasible. MPAs were being proposed widely as a tool to manage marine biodiversity and fisheries, complementarily to other management measures [75].

The selection of a site for conservation management is only one of many elements in the building of a MPA. It requires goal identification, site survey and data collection, data analysis, and data synthesis and plan formulation, all of which apply to site selection as well as all other steps in a MPA programme. Experiences and processes all over the world demonstrate that MPAs are an effective management tool.

Some key experiences can be outlined from the US Florida Keys National Marine Sanctuary, which is administered by the National Oceanic and Atmospheric Administration (NOAA) in partnership with the Florida Department of Environmental Protection (FDEP).

<table>
<thead>
<tr>
<th>Type</th>
<th>Sector</th>
<th>Indicator</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget for surveillance</td>
<td>Temporal (annual, monthly...) budget for surveillance.</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget for each pressure</td>
<td>Temporal (annual, monthly...) budget invested to research each pressure</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget for educational programs</td>
<td>Budget invested in educational programs</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget for waste programs or actions</td>
<td>Budget invested in waste programs or actions</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Budget for anchoring points</td>
<td>Budget invested in anchoring points actions</td>
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<td>Fishing &amp; tourism</td>
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</tr>
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<td>Budget invested for each participant organisms or stakeholder.</td>
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<td>Budget invested in each research program developed for the pressures acting in the MPA.</td>
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<tr>
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<td>Budget invested for management and conservation of littoral itineraries.</td>
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<td>Temporal variations of the number of denounces for illegal fishing or illegal diving or illegal boating.</td>
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<td>Temporal and spatial evolution of the limitations or places for diving in the MPA or its boundaries.</td>
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</tr>
<tr>
<td>Fishing &amp; tourism</td>
<td>Meetings between the actors</td>
<td>Number of meetings between the actors.</td>
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<td>Fishing &amp; tourism</td>
<td>People working in projects</td>
<td>Variations on the people working on projects.</td>
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<tr>
<td>Fishing &amp; tourism</td>
<td>Legislation changes</td>
<td>Changes in laws, normative, restrictions and/or limitations.</td>
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In 1960 Floridians responded to early warning signs that the Keys’ marine environment was fragile – that its coral reefs, seagrass beds, mangrove islands and the fish, lobsters, birds, and other creatures that lived there were not infinite. Their concern led to the creation of the world’s first underwater marine park, the John Pennekamp Coral Reef State Park. In 1990 Congress designated the Florida Keys National Marine Sanctuary. It encompasses the goals of balancing the long-term health of the ecosystem with the economy it supports [76]. In Australia examples like the Great Barrier and Ningaloo Marine Parks can be found. Scattered over a distance of 2300 kilometres, from the middle of Australia’s eastern coast northwards to Papua New Guinea, lies the Great Barrier Reef. Not really a continuous barrier but a collection of about 3400 separates coral reefs, shoals and other formations, it is the largest system of coral reefs in the world and one of the main examples of protection, conservation and management. Australia had already taken action to protect coral reefs when it established the Great Barrier Reef Marine Park. The Marine Park is a multiple-use management approach which aims to achieve reasonable use consistent with conservation. The Great Barrier Reef Marine Park, approved in 1975 anticipated the 1981 World Conservation Strategy and it may be unique in providing specifically for conservation and reasonable use, or sustainable development of a large area of recognised conservational significance [77,78]. Another example in this region is the Ningaloo Marine Park in Australia that is managed to conserve a unique environment for the enjoyment of visitors. This area was in 1987 under the National Parks and Wildlife Conservation Act 1975 (NPWC Act). Its management plan sets out the main objectives for the park management, as conservation, recreation, science and education. This Park is protected to allow sustainable recreation for current and future generations. In the Mediterranean region MPAs have also been established to protect marine biodiversity and restocking commercial species, exhibiting a high heterogeneity in terms of zoning, management and results [35].

As these examples show the MPAs were chosen as tools to mitigate the impacts caused by different socioeconomic activities on marine resources, at least in some very representative areas. For this reason, MPAs and their related management activities should be considered, in this conceptual framework, as responses (e.g. this can be measured through the evolution of the budget and the number of surveillance hours as a management response indicator. Fig. 8). They were divided in two different stages: plan the uses and activities allowed or forbidden in the area of the reserve and management of the different activities planned to enhance different programs developed in the reserve.

3.4. DPSIR framework to select indicators

We linked the components of the DPSIR framework through cause–effect connections. Once these links were obtained, we defined parameters that could be measured to assess the protection effect for each of the components of the framework. In this way we obtained variables for the driving forces, pressures, states, impacts and responses for both, fishing and tourism sectors. Finally 149 variables were defined and classified within the DPSIR framework (Table 1). Here we present variables that have been defined for a general conceptual model for MPAs and that could be used as potential indicators, although they have to be adapted to each particular case study.

4. Discussion

A general conceptual framework using the DPSIR methodology to analyse the socioeconomic issues, environmental changes and policy responses of MPAs, was developed. This framework was developed through a participation process which involved an expert panel but must be used by managers and evaluated by the stakeholders implicated in the MPA. From this conceptual framework a set of variables for each DPSIR component were defined. These variables will be evaluated as indicators through criteria by a participation process which also involves managers. Also this framework helped us to analyse and find gaps on the management of an MPA. This general framework seems to be appropriated for the evaluation of the problems developed in an MPA.

To develop the conceptual framework, we used the DPSIR framework [8], among many other methodologies because it demonstrates and illustrates the complexity of linkages between the causes and impacts to managers, politicians, resource users and scientists. DPSIR also allows a holistic and multi-dimensional view of causal relationships. The DPSIR framework is an extended version of the Pressure-State-Response (PSR) approach, that is based on the idea that anthropogenic activities impact the environment and that adverse environmental impacts drive humans to control the pressures. It introduces two new concepts: human welfare and environmental quality and societal behaviour and economic pressures affecting the environment, incorporating them as “Driving Forces” and “Impacts”. This methodology also embraces the process of indicator linkages of environmental functions. Under DPSIR, environmental problems and solutions are simplified into variables that stress the cause–effect relationships between human activities that exert pressures on the environment, the condition of the environment and society’s response to the condition [14]. Other systematic conservation planning tools, like Marxan [79] and MarZone [80], consider biodiversity conservation and socioeconomic interests ad hoc to design networks of marine protected areas. These tools incorporate data to model predictions about the results of the management. The conceptual framework resulting from DPSIR methodology was proposed as a first step to define the condition of certain MPAs, enabling the use of further and more accurate tools. The incorporation of different approaches will increase the efficiency of designing marine protected areas that will satisfy biodiversity conservation goals and will be socioeconomically viable.

The conceptual framework can be applied to any case study and it should be used as a system guide for MPA planners and managers. For a right application of the conceptual framework to develop an ecosystem based approach management, species, habitats, the whole ecosystem, diverse and potentially conflicting uses, thus a diversity of stakeholders, for a certain case study must be contemplated. In this process, various stakeholders might have different conceptual frameworks to be, to the extent possible, reconciled and accommodated in a common conceptual framework. The exact composition of the framework can change in response to the concerned person and/or institution necessities. Thus, if this framework is applied and there exists local legislation, it must be considered. Diagrams represented here are a general example, applying them must be done with the legislation and specific characteristics of each MPAs. Also for each application there will be different problems, uses, necessities and stakeholders that must be considered when defining the DPSIR components and making the cause–effect diagrams.

The relationship between marine science and marine policy has historically been challenging, with examples from fisheries, water quality, whaling, and marine conservation readily available [81]. The challenging relationship has often been attributed to the form of interaction between marine scientists and those involved in policy-making [82]. It can also be argued that the MPA definition issue is a factor. Scientists and conservationists who focus only on MPAs as no-take reserves set up a counterpoint “game” with fishery interests who can spend energy resisting loss of fishing areas rather than investing research and resources into developing verifiability indicators and management measures for ecologically
sustainable fisheries. This well known divorce between science and management is reflected in, that most of science research does not respond to management necessities. This lack of response to MPAs management objectives is focused on gaps on research in determine fields such as: temporal data for states, and non-existence of data concerning responses and driving forces. The adoption of an objective-based management system for the marine environment and application of conceptual frameworks will require some adaptation and reconciliation by managers, scientists and stakeholders, as has been happening in several parts of the world for 10 or more years [83]. Social approaches and negotiation processes, and science as a trans-cultural and testable knowledge can play a role in this framework. This methodology will make management simpler to understand and will make easiest to spread it to stakeholders.

5. Conclusions

The DPSIR scheme of indicators is a flexible framework that can be adapted to the necessities of specific programmes to identify the different actors and processes affecting the MPA and surrounding areas. It allows a better understanding of the effects of management actions on the different system components (e.g. the fisheries, the socioeconomics), and hence is more suitable in the identification and analysis of indicators. Its structure can be used to select indicators as is being done in the implementation of e.g. European Water Framework Directive [15–17]. Moreover it can be a very effective tool to organize participation processes to better involve stakeholders, managers and scientists.

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