A critical look at the definition of indicators to assess the effectiveness of marine protected areas

Marine protected areas (MPA) have been created to protect threatened, rare species and/or preserve remarkable habitats. What are the results, have they succeeded in restoring biodiversity? Are the selected indicators suitable for the task? How can they be improved?

As we witness the rapid erosion of marine biodiversity, the decline of numerous fishery resources and the deterioration of marine habitats, particularly in coastal zones, marine protected areas (MPA) look increasingly like the best available solution for integrated management of coastal areas. In such a context, the scientific community recommends that at least 10 % of each of the planet's ecological regions be protected. With this in mind, most of the world's governments have committed to creating and running a coherent MPA network by 2012 (World summit on sustainable development, Johannesburg, 2002; Convention on biological diversity, 2004).

Backed by experience in estuary and lagoon habitats, and notably in the development of biotic indicators, the Cemagref Estuarine ecosystems and diadromous fish research unit in Bordeaux (EPBX) is deeply involved in supporting a number of initiatives to create MPAs (including the Gironde-Pertuis marine nature reserve project) and evaluating the effectiveness of existing MPAs (for example, the "Marine protected areas and fisheries management by optimisation of resources and ecosystems" project, or AMPHORE, which is funded by the French National research agency (ANR), see box ❶). This is the context in which we have chosen to critically examine the definition of indicators to assess the effectiveness of marine protected areas, based on our experience and on the questions and difficulties we have encountered.

Marine protected areas as management tools

In fundamental terms, a marine protected area (MPA) can be described as a demarcated area of sea in which a long-term biodiversity protection objective has been set. Such areas are selected according to the presence of rare or endangered species and/or remarkable habitats [1].

The creation in 1963 of the Port-Cros reserve (see photo ❶), Europe's first marine nature reserve (1 250 hectares of sea in the western Mediterranean), stemmed from the will to preserve its aesthetic value and ecological heritage (Neptune grass, coralline areas, rare and endemic species, etc.). Among other factors, the current project to set up the "Pertuis Charentais and Gironde Estuary" marine reserve was scientifically justified after cases of the endangered European sturgeon (Acipenser sturio) being fished accidentally were recorded.

The objective of protecting biodiversity is rarely exclusive, it is often combined with the objective of supporting local socio-economic development and/or managing resources, fisheries in particular, in a sustainable way.

A marine protected area was set up in the Northern province of New Caledonia not only to maintain outstanding marine biodiversity, but also to encourage the develop-

1. A habitat is deemed to be remarkable when it fulfils an important function for the ecosystem it harbours and is a point of convergence for scientific, ecological, economic and sociocultural issues.

❶ Alep pine in Port-Cros island (South of France).

ment of sustainable economic activities (ecotourism) and involve the local population in the site's management, so as to foster local awareness and adherence to the rules.

One of the key objectives of creating a marine reserve in the Iroise Sea was to refine the management methods applied and thus protect and even replenish certain fish stocks.

In such cases, various measures (e.g. scientific monitoring, an action programme, codes of conduct, protection of the maritime public domain, regulations, surveillance, public information, etc.) are taken to attain protection and management objectives.

As part of its remit to protect habitats and species, and because it is located in an extremely popular tourist spot, Port-Cros National Park has put in place a raft of legal provisions – for instance, to restrict the influx of tourists (yachting, scuba diving, fishing, etc.) – as well as technical and educational measures to explain the impact of tourism and the way habitats and species evolve.

Which indicator(s) illustrate what type(s) of MPA effectiveness?

To judge the effectiveness of MPAs and measures implemented to attain protection and management objectives, indicators must be defined and the data gathered (Jackson *et al.*, 2000; Niemeijer et De Groot, 2008). These indicators must serve not only to describe the habitat, biological populations, communities and the pressures to which they are subject, but also as assessment and decision-making tools. Recent studies have brought to light the inability of Shannon and Simpson diversity indices to reflect environmental or anthropogenic constraints, despite their common use in ecology (Danilov and Ekelund, 1999).

In addition, to be effective an indicator must fulfil several characteristics, i.e. it must be precise, robust, relevant and interpretable in management terms, so that it can be used alongside the objectives set (Jackson *et al.*, 2000).

Like the ecosystems that inhabit them, MPAs are complex systems that combine various objectives embodying different criteria. Like all tools for managing ecosystems from the perspective of their resources or natural habitats, management objectives address three key aspects, either implicitly or explicitly, namely ecological aspects, socio-economic aspects and issues of governance (Arkema *et al.*, 2006). The system's complexity and the diversity of objectives mean that these cannot be reduced to a single descriptor. It is therefore necessary to take a number of indicators into consideration and aggregate or combine them so as to make them comprehensible (Brind'Amour and Lobry, 2009).

In this context, the issue of indicator relevance becomes more significant when there are multiple objectives. Furthermore, an indicator is relevant only if it allows a decision to be taken in relation to a given objective. Therefore, there is no single measure of a MPA's effectiveness, but several categories of indicator tailored to assess the effectiveness of a given MPA in different fields.

❶ The contribution made to the AMPHORE ANR Biodiversity project by the Cemagref EPBX research unit

The AMPHORE ANR-Biodiversity project entitled "Marine protected areas and fisheries management by optimisation of resources and ecosystems" is geared toward demonstrating the effectiveness of marine protected areas for fisheries purposes:

- by defining biological, ecological, economic and social indicators and developing analytical methods to achieve this objective;
- by defining the decision-making processes that will condition the creation of MPAs as well as regional policies founded on the notion of an MPA network.

Backed by its experience in the development of fish-based indicators to assess the ecological state of transitional waters, the Estuarine ecosystems and diadromous fish unit of Cemagref in Bordeaux was able to contribute to this work. It did so by assisting in the process of selecting the most appropriate biological/ecological indicators and the methods used to analyse them, so as to assess MPAs in their capacity as fisheries management tools.

The indicators and methods employed to analyse the time trends selected were tested by the team using series of historical data on the ichthyofauna of the Gironde estuary. The aim was to assess their ability to diagnose the state of the ecosystem as a function of the fishing gear used and the spatial and temporal windows studied.

Thus, from a socio-economic perspective, to assess the impact of a MPA on the tourism sector, total revenue from tourism could be measured in an area (to be defined) around the MPA (activity indicator). Holidaymakers could be surveyed to measure their level of satisfaction (perception indicator). With issues of governance, these indicators could illustrate the strategic vision [2], for example, by investigating the existence of a management plan, common management objectives or even research activities. They may also serve as system efficiency indicators, by measuring decision-making times, the level of involvement of the different stakeholders, the enforcement and application of regulations, etc.

From a purely ecological perspective, the issue of MPA effectiveness remains fairly open. One key objective voiced by the majority of MPA managers, and which everyone agrees upon, is the conservation of biodiversity. Notwithstanding the assumption that all players agree on the definition of "biodiversity", the next step is to assess the expected impact of management measures on the biodiversity criteria selected and to define appropriate indicators. For instance, the variation over time of the number of fish species in the reserve, which is an indicator of stability/resilience [3], does not provide the same information as a comparison with the adjacent area, which gives an indication of both the MPA's attractiveness and net exports from the reserve to unprotected areas.

Fishery aspects encompass issues affecting both fisherman and resources. Thus, the effectiveness of MPAs in enabling eco-management of fisheries and generating an understanding of the precautions required must be measured based on biological, ecological, but also socio-economic indicators. In this case, the aim might be to assess the rise in profits from fishing as well as the increase in the biomass of commercially-fished species, both inside and outside the MPA, following the application of management measures within the protected area.

2. A strategic vision is defined as the wider, long-term outlook shared by the various different players with regard to co-management (and, in a wider sense, governance), where the emphasis is placed on what is needed to succeed.

3. A system's resilience refers to its capacity to return to its initial state after a disturbance.

Assessing difficulties

Difficulties encountered with the site effect and the refuge effect

One of the difficulties encountered when assessing the effectiveness of MPAs with respect to either ecological or socio-economic objectives resides in the consideration of spatial effects. Two types of effect are particularly difficult to grasp, the site effect and the refuge effect.

"Site effect" should be understood to mean the bias introduced by the fact that MPA sites are generally not selected at random. More often than not, they are selected because of the presence of remarkable habitats that it is desirable to preserve for their intrinsic heritage value (in conjunction with the Habitat directive, for example) or for the associated ecological functions they provide (migration corridors for remarkable migratory species, nurseries for commercial fish species, reproduction areas, etc.). As a result, the habitats and population fractions being protected are typical of the site selected. Thus, if a habitat is protected because it serves as a fish nursery, it will feature a higher density of juveniles. Similarly, the array of wildlife that inhabits Neptune grass is altogether typical and differs from that of other habitats that are not necessarily protected.

The refuge effect is another notable effect linked to MPAs. In some cases, fishery resources are evidently more abundant inside MPAs, where fishing may be regulated or prohibited, than outside them, where there are fewer restrictions on fishing. While this may seem obvious, it is nonetheless important. This refuge effect makes it considerably more difficult to assess the effectiveness of an MPA, notably for fishery-related purposes. Thus, the fact that the species targeted by fisheries are more abundant in a MPA is not necessarily an indicator of the effectiveness of spatial fishery management measures. Conversely, it can be a good indicator when it comes to species conservation and biodiversity. A positive reserve effect is usually produced by a combination of three separate effects, i.e. the refuge effect, the buffer effect (linked to seasonal or annual fluctuations in abundance that are less marked inside the reserve than they are outside it) and the spill-over effect (net exports of adults from the reserve to unprotected areas). These three objectives must be identified if we are to assess the effectiveness of the measures. In other terms, the ecosystem of an MPA is not isolated from other ecosystems and it is hard to estimate the effectiveness of MPAs without evaluating the ecological state of the ecosystem as a whole.

Both types of effect, among others, have an impact on the representativeness of indicators and raise the question of reference.

Indicator representativeness, an ever-evolving reference

Determining whether a positive effect or an improved state has been achieved requires the existence of a point of comparison or reference. In the specific case of MPAs, this reference may be spatial and/or temporal.

With a spatial reference, the aim is to compare a protected area with an unprotected area. Of course, for the comparison to be relevant, the ecosystems being compared must display similar ecological functioning. In particular, it is crucial that they offer the same ecological functions to the biological populations within them. Yet, as previously indicated, in many cases protected habitats are considered "remarkable". This sometimes makes comparisons difficult. How do we choose reference sites? On what spatial scale should we work to assess the effects at regional level, rather than just local level? In the case of coastal nurseries, for example, the effect expected from a fisheries perspective is invariably at a regional level.

This also adds methodological difficulties when it comes to indicators. For example, one indicator used to determine fishing's impact on a population is the average size of individuals in the population. Indeed, in traditional fisheries theory, the most commonly caught individuals are the largest, which therefore affects the average size of the population. Yet, coastal and estuary systems are the areas in which juveniles concentrate and, moreover, most scientific monitoring is geared towards keeping tabs on small individuals. In such cases, the average size observed is extremely sensitive to recruitment in the population being monitored. Furthermore, if the management objective is to favour the habitat's nursery function, a low average size would tend to indicate that the measure is having a positive effect.

Using a temporal reference is often a viable solution, if not an ideal one. Indeed, it requires that the dynamics of habitats, populations or essential processes, as well as their natural variability, be adequately taken into account. From an operational point of view, many years' worth of data may need to be collected to take into account interannual variability in highly dynamic and fluctuating habitats, such as estuaries. Another factor that we can no longer ignore is global change. The rising water temperatures recorded alter the dynamics of ecosystems and the composition of ecological populations. With most biological and ecological indicators, it is rather difficult to assess the impact of anthropogenic pressures in a context of long-term climate change. This is an aspect that has to be considered if we are to assess the impact of protection measures with any degree of accuracy.

Conclusion : toward the development of site-specific indicators

Thus, there is no universal set of indicators, their selection will depend on the context of an MPA, the functions it provides (e.g., nursery functions in the case of coastal and estuary MPAs, sea grass beds, etc.) and the objectives assigned to it (conservation of biodiversity, sustainable fishing, development of tourism or angling, etc.). Each context is clearly unique. Within the scope of the ANR GAIUS project, it has been proposed that site characterisation indicators be developed that will enable MPAs to be classified according to their environmental importance and functionality. For instance, these parameters would make it possible to create a typology of MPAs that would allow situations to be compared in relative terms, so as to better evaluate the effectiveness of measures.

But in order to better assess the effectiveness of a MPA, the issue of reference should ideally be considered prior to setting up protection measures. This will make it possible to avoid methodological bias when putting monitoring in place (standardisation of sample protocols, etc.) and to assess the effects in a context of global climate change (reference values, etc.).

The huge variety of objectives that may be assigned to MPAs brings about methodological difficulties relating to indicator combinations and raises the question of their compatibility. Thus, conflicts may arise between leisure activities and conservation. For instance, providing visitors with unrestricted access to the area may damage the habitat and its biodiversity (e.g., the impact of ship anchors, excessive use of the site by divers), which runs counter to conservation objectives.

Lastly, the creation of an MPA is tantamount to setting up spatial management measures. Yet, in many cases, in particular in a fisheries context, this alone is not enough. The current strategy of defining quantified objectives for MPA development in France and Europe is an ambitious one. However, although important, the protection of specific marine areas alone does not amount to a sustainable environmental policy. It will be truly effective only if it forms part of an overall biodiversity protection programme. ■

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