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10 - INDICATORS – Constructing and validating indicators of the effectiveness of marine protected areas pp. 247-290

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1. Introduction

Marine protected area (MPA) effectiveness is also termed MPA *management* effectiveness to emphasize that it pertains to how well the protected area is being managed, and primarily the extent to which it is protecting values and achieving the various goals and objectives for which it was created (IUCN-WCPA Guidelines, Hockings et al. 2006). Values include ecosystem services and functions, biodiversity, landscape and geomorphological features, as well as cultural, socio-economic, and research- and education-related aspects. Assessing MPA effectiveness has become a crucial issue as many MPAs are designed all over the world in response to international commitments regarding biodiversity conservation and resource management. Such strong commitments cannot be achieved through ineffective MPA, either because poorly enforced ("paper parks") or poorly designed. Pressure to evaluate management effectiveness is also increasing in a world where accountability and performance evaluation is more and more compelling.

While several previous chapters have focused on the assessment of MPA effects, I here consider the issues of assessment in the light of decision-support for MPA management. Rather than assessing MPA effects, the focus is thus on assessing MPA effectiveness with respect to intended management objectives.

MPA management can be envisaged at several scales. Locally, it pertains to the aim of complying with the objectives for which the MPA was designed. At an intermediate scale, there exist more and more government agencies that are in charge of managing the national network of MPA (although this might not be a network of MPA sensu stricto, cf. Chapter 6), e.g. the National Marine Sanctuary Program (NMSP) in the USA (http://sanctuaries.noaa.gov/science/welcome.html) and the French Agency for Marine Protected Areas in France (http://www.aires-marines.fr), and might require some evaluations at the network scale. Finally, at both national and international levels, global assessments may be needed for tracking progress toward agenda's objectives (Mora, MPA book). This chapter will mainly address the local scale, which forms the basis for the assessments at other scales.

Assessing MPA effectiveness here consists in providing reliable, and if possible quantitative, science-based advice for supporting management and decision-making. According to the IUCN World Commission on Protected Areas Guidelines, management effectiveness evaluation is defined as “the assessment of how well the protected area is being managed” (see above). A way to assess effectiveness lies in the provision and documentation of indicators able to track progress toward this achievement of MPA management objectives.

An indicator is commonly defined as a function of observations or of the outputs of a model, which value indicates the present state and/or dynamics of the system of interest (Food and Agriculture Organization 1999). Over the last decade, the term indicator has become very popular. A bibliographic search carried out in October 2009 on the key-words indicator, and marine environment or fish, showed that between 1980 and 2000, 751 peer-reviewed scientific papers referred directly to indicators of either marine environment or fish, whereas this number rose to 1331 papers between 2000 and October 2009. This increasing scientific production is obviously related to the growing social and institutional demand for environmental monitoring and assessment. Yet, there should be a distinction between indicators used mainly for scientific purposes, and indicators aimed at assisting and guiding management actions. As mentioned above, this chapter focuses on management-oriented indicators.

Constructing and validating indicators of MPA effectiveness implies to consider a range of candidate indicators, evaluate and compare their performance with respect to assessing MPA effectiveness. Indicator performance mainly lies in its sensitivity to the question addressed and in its statistical properties. In order to stress the importance of validating candidate indicators through performance criteria, I distinguish: i) metrics, values of variables observed or calculated at given spatial, temporal and socio-ecosystem scales, from a specific observation system or model; from ii) indicators, metrics displaying desirable performances for testing MPA effects. Therefore, not all metrics can lead to indicators.

This chapter will deal with the selection, test and validation of indicators of MPA effectiveness. Indicators will refer to all MPA management objectives encompassing biodiversity conservation, management of fisheries and other MPA-related uses, and other social and economic aspects including governance. In a first section, I will present a methodology for selecting and validating indicators. This methodology is currently being implemented in the research project PAMPA (http://www.ifremer.fr/pampa). In the following sections, each step of the approach will be discussed and illustrated through a number of case studies pertaining to French and European MPAs.

Section 1. State of the art on the evaluation of MPA effectiveness

Guidelines were produced quite early as to the design of MPA (Kelleher and Kenchington 1992, Kelleher 1999), as much effort was dedicated to the designation of new MPAs in the last decades. Today, thousands of MPAs exist across the world and this trend is still ongoing due to the commitments of many countries to reach the objective of establishing a consistent and comprehensive global network of MPA by 2012 (2002 World Summit, http://www.earthsummit2002.org).

Although the need for developing operational tools and guidance “to evaluate the ecological and management quality of existing Protected Areas (PA)” has long been acknowledged by conservation organizations such as the World Conservation Union (IUCN) (for instance at the 3rd World Parks Congress in Bali, Indonesia in 1982) , the issue of management effectiveness appeared much later in the work of the IUCN World Commission on PA . More recently, the Programme of Work for PA of the Convention on Biological Diversity (CBD, http://www.biodiv.org) called on parties to “develop and adopt appropriate methods and standards, criteria and indicators for evaluating management effectiveness and governance by 2008, and to assess at least 30% of their protected areas by 2010”.

In the marine environment, the question of MPA effectiveness has become stringent these last years not only due to the multiplication of MPA. At the World Park Congress in 2003, there has been a paradigm shift for protected areas where it was recognized that these are a crucial element of sustainable development and as such should contribute to globally agreed goals (IUCN 2003), making PA effectiveness a larger and even more compelling issue than it used to be. Also, in a number of cases, MPA are poorly accepted by local populations (see e.g. Christie 2004) or suffer from a lack of human and financial resources for management. These conditions compromise the success of the MPA in terms of both conservation and management of uses and governance. Such examples are also detrimental to the concept of MPA as a management tool for coastal ecosystems (Agardy *et al.*, 2003). In this respect, management effectiveness evaluations provide a mechanism to encourage accountability of MPA management and foster its acceptance by stakeholders and the public. According to Hockings *et al.* (2006), PA evaluation results are usually used for several purposes: i) to improve PA management performance through adaptive management; ii) to promote accountability and transparency; and iii) to assist effective funds and resource allocation within the protected area system.

Subsection 1.1. Scales, scopes and existing frameworks.

There are many frameworks for evaluating progress toward management objectives where management is taken in the wider sense, e.g. project management or environmental management. The well-known Pressure-State-Response (PSR) framework often referred to in sustainable development and in environmental assessment has initially been developed by the OECD to structure its work on environmental policies and reporting (OECD, 2003). This conceptual framework is related with other frameworks such as DSR (Driving force-State-Response), DPSR (Driving force-Pressure-State-Response) and DPSIR (Driving force-Pressure-State-Impact-Response) (e.g. Garcia et al., 2000). Pressure stands here for anthropogenic pressures upon the environment. State is reflected by indicator values. Response corresponds to the measures undertaken by society to reduce impacts revealed by State, and caused by Pressure. The advantage of this framework is to make anthropogenic pressures explicit, to link them with their environmental consequences reflected by State, and to consider remediation actions through Response. The DPSIR framework generalizes the PSR by considering in addition Driving forces which operate at larger scales and cause Pressures. The DPSIR framework is retained as a reference by the CBD and by related initiatives concerning biodiversity conservation.

Numerous management questions can be addressed within these general conceptual frameworks, which were designed to organize and categorize indicators and facilitate their use. Many indicator systems, i.e. sets of indicators, focusing on the environmental dimension of sustainable development use frameworks based on variations of the PSR model (UN Commission on Sustainable Development 2006).

In the more specific field of Protected Areas (PA), the IUCN overarching framework for assessing management effectiveness (Hockings et al. 2006) relies on the principle that management follows a cyclical process with six important components that should, ideally, all be assessed for effectiveness (Table 1). In 2006, the IUCN-WCPA listed numerous mechanisms for evaluating the effectiveness of PA management (MPA News, Vol. 7, n°10), among which Wells and Dahl-Tacconi (2006) described six mechanisms dedicated to MPA. These authors identified three kinds of approaches: broad scale, fine-scale and scorecard-based. Broad-scale approaches are derived from the World Heritage Management Effectiveness Workbook (http://www.enhancingheritage.net) and encompass a wide range of issues from planning to outcomes. Fine-scale approaches include the IUCN "How is your MPA doing?" (Pomeroy et al. 2004) and the Nature Conservancy 5-S framework (http://www.nature.org/files/five_s_eng.pdf), the latter being more focused on conservation issues, while the former addresses both biophysical, socio-economic and governance issues. Finally, the approaches based on scorecards are quicker, more qualitative and may allow comparisons between sites; but they are rather intended for general reporting purpose for funding bodies (http://www.icriforum.org/mpa/mpaeffectiveness.html). The evaluation system to be selected depends on: i) the scope of the evaluation, system-wide vs. site-specific, but also themes addressed; and ii) on the recipient of the report, e.g. funding bodies, policy makers, or stakeholders.

As mentioned in the introduction, the kind of assessment needed depends on both the spatial scale considered, and the scope and motivation of the evaluation process. On the one hand, funding bodies, policy makers and conservation lobbyists are more interested in highlighting problems, setting priorities and promote better management practices (Hockings 2006). Many countries and organizations are increasingly applying so-called headline indicators, i.e. a short set of indicators providing easily understandable signals to high-level policy makers and to the general public (UN Commission on Sustainable Development 2006). The World Bank-WWF Management Effectiveness Tracking Tool (Stolton et al. 2002) was developed to help monitoring progress in the achievement of their worldwide PA management effectiveness targets. As stressed in the cited reference, “it should not replace more thorough methods of assessment for the purpose of adaptive management”.

On the other hand, managers may wish to build on evaluation results to improve MPA performance and report to senior managers, the government or other stakeholders, either locally or at the national scale. Such evaluations focus on outcomes. For instance, each US National Marine Sanctuary documents so-called condition reports in order to serve as a tool to determine if it is achieving resource protection and improvement goals as reflected in NMSP performance measures (http://sanctuaries.noaa.gov/science/condition/faq.html). The reports are supporting documents during the Management Plan Review Process, but are also used for: i) reporting by policy makers, particularly within NOAA and the Department of Commerce; and ii) education and outreach. Condition reports follow the same approach and format; they are based on a set of 17 questions which is common to all MPAs and depict the status and trends of sanctuary resources. These questions relate to water, habitat, living resources, and maritime archaeological resources. Each question is answered using a qualitative “status and trends” reporting system. Additional text, tables and figures are provided to explain the basis for the judgment determining the status and trends. More specific questions are not discussed in these reports but rather used to document the answer to the set of general questions.

To date, the most complete contribution in terms of tools and guidance for the assessment of management effectiveness for existing MPAs was provided under IUCN auspices (Pomeroy et al. 2004; 2005). The MPA Management Effectiveness Initiative (MEI) formed in 2000 by IUCN-WCPA and by World Wildlife Fund with the main objective “to develop a set of marine-specific natural and social indicators to evaluate MPA management effectiveness”, based on both scientific and practitioner expertise. Results are presented in a guidebook aimed at helping managers and practitioners to better achieve the goals and objectives for which their MPA was created (Pomeroy et al. 2004) The approach relies on a four-step process: i) select the appropriate indicators; ii) plan and prepare for the evaluation; iii) collect and analyze data for the selected indicators; and iv) communicate and use evaluation results to adapt the MPA's management (Pomeroy et al. 2005). According to the IUCN-WCPA framework (see above), indicators to be considered pertain to context (where are we now?), planning (where do we want to be?), inputs (what do we need?), processes (how do we go about it?), outputs (what were the results?) and outcomes (what did we achieve?) (Table 1). The MPA MEI effort deliberately focused on output and outcome indicators. A survey of goals and objectives from MPAs around the world was first conducted. Goals and objectives are related to governance, biophysical and socioeconomic aspects. A review of the indicators used for the marine environment and for coastal communities led to identify over 130 indicators out of which 42 were retained and subsequently linked to one or several objectives (Table 2). For each indicator, a profile was defined in terms of measurability, resource needs, protocols, analysis and communication, and in a summary of strengths and limitations. Finally, 18 pilot sites volunteered to test the methodology over a period of eight months, enabling a revision of the guidebook. At the end of the project, the guide was deemed to be a useful instrument. It provides clear and easily understandable insight into the meaning and construction of indicators. Yet, as clearly stated by the authors, it is not prescriptive, nor is it an exhaustive state of the art on monitoring and assessment methods. Indicator performance, in particular in relation with design recommendations and data analysis, is not addressed, as it might be too technical. Likewise, it provides little guidance on indicator interpretation, with respect to resulting management actions.

The framework developed in the guidebook was implemented in a number of regions, e.g. in Central America (Corrales 2005), and in the Mediterranean (Port-Cros National Park 2007). The IUCN methodology is also recommended by the Western Indian Ocean Marine Science Association (WIOMSA) MPA Toolkit (http://www.wiomsa.org/mpatoolkit), a series of handsheets that was designed to support MPA managers in the WIO by providing them with a hands-on guide to a diverse array of topics, including among others the assessment of management success.

Subsection 1.2. Scientific contributions to assessing management effectiveness and constructing indicators.

Over the last two decades, there has been a wealth of papers dealing with the assessment of MPA effects, in particular for biodiversity conservation (Pelletier et al., 2005, see also Chapters 2 and 8), whereas fisheries-related effects have been documented more recently (see Chapter 9 and Pelletier et al. 2008). In searching the scientific literature for both MPA assessment and indicators, I found that between January 2000 and October 2009, eighty-four peer-reviewed papers and communications addressing MPA assessment could be listed, whereas over the same period, only fifteen papers mentioning indicators and MPA were listed. Out of these, very few addressed the definition of operational indicators for decision-support systems. Pelletier *et al.* (2005) reviewed a number of metrics used for the assessment of ecological, economic and social effects of MPAs, and examined their performance as potential indicators (see subsections 2.2 and 2.3). Pelletier *et al.* (2008) reviewed and compared MPA assessment methods for conservation and fisheries-related effects and confronted their ability to provide indicators for informing the decision process. The authors highlighted the gaps and challenges in this respect. Muthiga (2009) recently presented an application of Pomeroy *et al.* (2004) framework to Kenya's oldest MPA taking into account ecological, socio-economic and governance aspects of MPA effectiveness. Interestingly, results are presented under a conventional graphical display for each theme and summarized in a table that does not show management objectives. Biodiversity conservation objectives appeared to be generally met, but the objective of sustaining livelihood was not fully reached, and governance indicators showed the weakest scores.

In contrast, there are more papers proposing and discussing indicators of fishing effects (among others Trenkel and Rochet 2003; Daan et al. 2005; Jennings 2005).

In the fisheries management context, there are few descriptions of frameworks that involve both scientists, the fishing industry and managers, and can be used as decision-support system. This may probably be explained by the fact that many fisheries operate in international settings, where this kind of collaboration may be difficult to implement. For instance, in the Northeast Atlantic, scientific advice is still transferred to decision-makers via a number of complex stages involving a suite of expert groups and commissions. Trenkel *et al.* (2007) attribute this prescriptive approach to the fact that scientific advice is based on models and propose an indicator-based approach instead. It seems however that the assessment tool, although imperfect, is less to be blamed than the complexity and lack of flexibility implied by the process producing the advice and the lack of interaction between managers and scientists, including e.g. failure to clearly formulate management targets.

Issues in developing appropriate frames for decision-support systems for fisheries management have been discussed in Smith and Link (2005). The Australian Fisheries Management Authority (AFMA) is responsible for ensuring the sustainable and efficient use of federal fishery resources. The AFMA partnership model involves scientists, managers and the fishing industry (Smith et al. 1999). At a more general level, and in order to facilitate the implementation of the FAO Code of Conduct for Responsible Fisheries, the FAO proposed the Sustainable Development Reference System, a framework to develop a set of indicators for the management of capture fisheries with a tentative application to an Australian fishery (Garcia et al. 2000).

In summary, there exists substantial published guidance for MPA practitioners and managers to devise indicators of MPA effectiveness. The existing documents are remarkably easy to understand, and they deliberately excluded too technical issues from their scope of interest. Thus, there is a lack of guidance about efficient indicator estimation, sampling protocols, data analysis, indicator validation, and statistical issues of monitoring and assessment in general. On the other hand, there are a lot of contributions to the assessment of MPA effects in the peer-reviewed literature. Some of these contributions specifically address monitoring and assessment issues and provide some general recommendations for a correct assessment of MPA ecological effects, e.g. proper design, or importance of habitat considerations (Osenberg *et al.*, MPA book). However, it is difficult to derive concrete recommendations for the assessment of MPA effectiveness, in particular concerning monitoring protocols that are cost-effective and suited to MPA managers' constraints. Also, there is no published study dealing with the methodological issues of constructing indicators of MPA effectiveness. In this respect, there is thus room for further collaborative approaches involving managers and scientists. This is essential to properly address managers' needs, while sorting out questions which require scientific input. It is also needed to integrate managers' constraints in terms of funding and human resources, capacity and communication. In the next section, I present a framework that enables such an approach. According to subsection 1.1., it is thus a fine-scale approach to MPA evaluations for tracking achievements and progress toward management objectives (outcomes according to the IUCN framework). Objectives pertain to biodiversity conservation, management of fisheries and other uses, and governance. Hence the scope is close to that of Pomeroy et al. (2004).

Section 2. A collaborative approach between scientists and managers for selecting and validating indicators of MPA management effectiveness

Subsection 2.1. Metrics, indicators and performance criteria

A metric is defined as a function of experimental observations or model outputs; it is calculated at given spatial and temporal scales and at a given level of the socio-ecosystem of interest. The observation system or alternatively the model must be specified, as it determines distinct statistical properties and sampling costs. Examples are the percent coverage of seagrass observed at a given transect by underwater visual censuses (UVC), the number of boats observed over a given period of time in a given area, or the abundance of a fish species at the beginning of the year as calculated from a dynamic model.

An indicator is a metric displaying desirable properties for assessing management effectiveness. In practice it is deemed to perform well if it guides toward the appropriate decision while minimizing risks of error.

Performance criteria for indicators have been listed and discussed in a number of papers, both in environmental assessment (Kurz et al. 2001; Hilty and Merenlender 2000) and in fish stock assessment (Garcia et al. 2000; Rochet and Trenkel 2003, Trenkel and Rochet 2003). Rice and Rochet (2005) consider nine criteria to select indicators: concreteness, theoretical basis, public awareness, cost, measurement, historic data, sensitivity, responsiveness, and specificity. Garcia et al. (2000) list 13 criteria: policy priorities, practicality/feasibility, data availability, cost-effectiveness, understandability, accuracy and precision, robustness to uncertainty, scientific validity, acceptability to users/stakeholders (consensus among parties), and ability to communicate information, timeliness, formal (legal) foundation, and adequate documentation. Numerous criteria raise the problem of weighing and priorization. In addition, there should be some chronology in considering performance criteria. For instance, it is useless to consider communication issues, if the indicator is poorly linked with the question at stake.

Here, I will thus only consider two criteria that are determining for indicator performance, relevance and effectiveness (Nicholson and Fryer 2002). A metric is relevant when there is an unambiguous link between the metric and the effect it is supposed to indicate, and (if possible) when there are reference points for interpreting metrics values. A relevant metric is efficient if its statistical properties, and more generally its reliability, enable to reach a diagnostic about the effect of interest while minimizing associated errors.

Subsection 2.1. Formulation of management objectives and management actions

The first step in the process (Figure 1) is to formulate management objectives in an unequivocal and sufficiently precise manner, so that there is a common understanding of these objectives by managers and scientists. This enables to evaluate whether the evaluation of the degree of achievement of the objective calls for a scientific contribution, which is not always the case. For instance, reporting about MPA budget, enforcement means or other input indicators does not need scientific input or expertise. In contrast, reporting short-term outputs, results or long-term impact implies collecting data, analyzing and interpreting them, which may benefit from scientific contribution.

MPA management goals and objectives are in general described in a management plan, although this document does not always exist, or may be under construction. Guidelines for the desirable content of an MPA management plan may be found in Kelleher (1999); they include the clear specification of objectives and sub-objectives for each zone of the managed area. Yet, it happens that management plans are still missing or in construction, as its definition and writing is a comprehensive time-consuming process. In some cases, management plans may even be considered by managers as a tedious and mostly administrative task (Pelletier et al. 2005). This formulation is essential to define targets against which progress can be assessed (see also Claudet and Pelletier 2004). As stated by Dale and Beyeler (2001), the choice of ecological indicators is often confounded in management programs that have vague long-term goals and objectives.

A second important aspect to be specified relates to the management actions that can be undertaken by MPA managers. When dealing with indicators for guiding management decisions, potential management actions must be listed for each objective. If progress toward a given objective is not linked with a potential action, then reaching this objective is out manager's prerogatives. To mitigate this limitation, reporting by the manager to a higher authority may be considered as a management action.

It is essential that this first step stems from discussions and workshops involving both managers and scientists, because it will determine the orientation of the work to be achieved for designing indicators that match objectives and actions. It is also important as it forms the basis for collaborative work. This non-technical step thus enables to set up a common understanding of MPA management issues for both managers and scientists, including the setting up of a common semantic.

Subsection 2.2. Identification of relevant metrics

In a second step, it is necessary to identify a number of relevant metrics for each objective and related management action. The main constraint here lies in the means that are available to collect the information needed for calculating the metrics. When there were few MPAs, most data were collected by scientists directly or indirectly involved in the MPA. The number of MPAs has dramatically increased and often MPAs touch on various management objectives ranging from biodiversity conservation to coastal management in general, so that it is difficult to expect continuing supervision of MPA monitoring by scientists. In contrast, it is the scientist's duty to provide assessment tools that can be implemented with the existing staff capacities and financial resources. Therefore, the selection of relevant metrics must start from the data that can be collected at the MPA level, or that are available to the MPA manager, a high-level MPA agency, or through other – public or not – information systems.

As in the first step, this constraint is best accounted for through discussions with MPA manager or super-managers. Once the potential data collection systems are identified, relevant metrics are selected for each objective. In general, a large number of metrics can be calculated from a given data set, at no extra cost once the data are collected. But many of them are redundant, and scale issues are important. Conditioning the selection of most relevant metrics on management objective is important as conveying many results is not efficient for decision-support. Estimating the a priori relevance of metrics should be done by scientists. This is generally based on expert's opinion but Pelletier *et al.* (2005) provided a literature-based score of relevance for metrics aimed at assessing MPA ecological effects. Yet, this was only possible because the metrics had been used in many different situations, and between-case variability could be averaged out.

Subsection 2.3. Observation protocols and analysis of metrics

At this stage, an observation protocol a priori appropriate for estimating the selected metrics must be devised. Recall that the definition of the metric includes that of the observation system, therefore the challenge is to design a protocol that enables to estimate a set of values of the metrics from which the assessment of MPA performance can be achieved. There is a wealth of literature on appropriate designs for the assessment of direct MPA effects on biodiversity (Osenberg *et al*., MPA book; Stelzenmüller, and Pinnnegar, MPA book). Still, there is much less literature on how to best assess MPA effects on uses or the effects of uses on MPA effectiveness, although such approaches are developing since the human component is more and more accounted for in MPA management (and in coastal management in general).

Scientific papers often rely on the analysis of a number of metrics per taxa or species group, which variability is assessed in relation to protection status. More rarely, there is an attempt to provide a synthetic answer to questions such as: Is biodiversity maintained in the MPA? Are fish species sustainably exploited (but see Guidetti and Claudet), and if not how can the MPA contribute to this objective? More generally, there is a lack of overall diagnostic at the MPA level, although scientific studies are more logically oriented toward analytical approaches.

Most assessments of MPA effects have been carried out from the statistical analysis and modeling of field data. Yet, dynamic models are also used to quantify the consequences of MPAs on the dynamics of populations, communities and fisheries (Pelletier et al. 2008). They enable exploring management scenarios involving alternative MPA designs and other management policies. By construction, such a model must embrace the whole dynamic of the entity modeled, whether it is a species, a fish community, an ecosystem or a fishery. This concerns the spatial extent, the main drivers of the dynamics, and the interacting components. The direction and magnitude of changes in indicators may then be used to provide a system-wide assessment of MPA, the system involving the fishery or ecosystem where the MPA is located, which generally extends beyond its boundaries. Conversely, in such models, the link with observation protocols is less direct, as model parameterization and calibration generally depends on a large number of information and data.

Subsection 2.4. Interpretation of indicators

Assuming that metrics have been analyzed, interpreting indicators consists in gauging the value taken by the metrics with respect to the management objective at stake, if possible against a reference value. A reference point is a desired target or limit for an indicator (Sainsbury and Sumaila 2002). It may be expressed as the trend or value of the indicator associated with meeting the management objective (Jennings 2005). This trend or value may be a limit (threshold), a target, a direction and/or a time horizon to reach a given status. But a limit reference point can also be regarded in terms of risk and thus associated with an unacceptable outcome. The issue of reference points for MPA indicators was discussed in Pelletier et al. (2008). In the context of fisheries science, reference points have been used and discussed for a number of years (Caddy 1998; Collie and Gislason 2001; Hilborn 2002; Koeller 2003) and are commonly used in stock assessments and for scientific advice, e.g. ICES 2001; http://www.ices.dk/products/icesadvice.

In another context, for the assessment of water quality, the European Water Framework Directive (WFD) requires to define reference conditions with respect to the objective of a good status (including both Good Ecological Status (GES) and good chemical status) to be reached by 2015 (http://ec.europa.eu/environment/water/water-framework/objectives/index_en.htm). From an ecological point of view, these reference conditions correspond to reference values of various biological indicators observed in situ. Being based on monitoring data, water quality assessment does not differ from empirical assessments of MPA effects from a methodological standpoint.

Establishing reference points or values for indicators related to GES raises the same challenge for the WFD and for MPA. It is a largely multidimensional issue, subject in addition to possible irreversibility and shifting baselines problems (Knowlton and Jackson 2008). In this respect, considering trends and directions rather than distance to absolute values is likely to foster the achievement of targets by managers, because it is intuitive and less questionable. It also makes the assessment easier. There are however some advantages to defining references for MPA indicators. First, the trivial fact that MPAs have an inside and an outside facilitates the assessment of effects and the establishment of references for objectives linked to preservation within the MPA, particularly for no-take zones. Second, in the long-term, such areas may themselves become reference as control areas for the assessment of anthropogenic stressor effects, particularly fishing; although the restored ecosystem may be different from the pristine ecosystem due to irreversibility. Historical data coupled to monitoring before and after MPA establishment, may then help to understand the causes of ecological changes at several scales, both retrospectively and within the MPA.

Beyond gauging values or trends, the interpretation of indicators must lead to a management or a set of management actions. This is made possible because the potential management actions attached to a given objective have been previously listed (see subsection 2.1). Yet, further discussion is needed here to select the appropriate actions depending on indicator values, and this may require more than a single indicator (see section 3 for illustrations). Interpreting indicators thus requires that scientists assess values and trends with respect to reference points, and that managers link this assessment to management actions as a function of management priorities. Desirable targets, but also undesirable outcomes and corresponding management time frames must obviously be accounted for in this process.

Subsection 2.5. Validation of metrics as indicators

Validation is the process of checking if something satisfies a certain criterion. It implies one can document that the metrics is suited for its intended use, i.e. it is able to track progress toward the achievement of the corresponding management objective. In quality management systems, validation amounts to confirming that stakeholder's or user's needs are satisfied.

Validating metrics as indicators of MPA performance has been overlooked in the past, in relation to a lack of interest for the use of indicators for decision-support. It can be achieved in various ways. On the one hand, one might apply the metric in a variety of contexts and case studies, and check how well it performs, to ensure that the metric is not too specific and relatively robust in coping well with variations (sometimes unpredictable ones). On the other hand, one could imagine resorting to more formal validation methods. For a statistical model, validation means that model assumptions are met. If the model is used to analyze a metric, it means that variations of the metrics can be analyzed and interpreted from the model. In addition it is necessary to ensure that the metric would lead to the same response if it were calculated from an independent data set drawn from the same population. In the case of quantitative metrics and when a sufficient number of observations is available, this can be achieved by computational methods such as cross-validation (Everitt 2006). To my knowledge, it has not yet been applied for validating MPA-related indicators (see Pont *et al.*, 2006, for an application to fish assemblages in continental waters). Lastly, for indicators obtained from complex models, model calibration with respect to real data ensures that the model is a reasonable representation of the system modeled (see subsection 3.2).

Subsection 2.6. Increasing indicator efficiency through improved and cost-effective observation protocols

At this stage, once the way the indicator is used in the decision-support process is fully specified, it is possible to optimize or, at least, to improve the observation protocol in order to increase the indicator's efficiency. Based on the outputs of the a priori protocol already experienced, it is often possible to adjust the observation protocol. This may relate to the spatial extent, the level of detail of the information, the statistical population sampled. Besides, the scientist can suggest a distinct observation system that better matches the manager's needs, e.g. in relation with new technological developments.

In the case of quantitative metrics, a more formal optimization may be done through simulation and resampling aimed at precisely allocating sampling effort among the stages of the observation protocol.

Subsection 2.7. Synthesizing and communicating indicators

In the context of MPA, this step is still little advanced and structured. At this point, it is useful to emphasize that the indicator used to establish a diagnostic may not be the same as the one conveyed to the manager or stakeholder. To some extent, this simplifies the challenge, as it is difficult to have an indicator that is at the same time relevant, efficient and easily understandable by non-experts. But it is crucial to make explicit how to proceed from relevant and efficient indicators to simpler indicators for decision-support.

This raises several issues i) synthesis: how to present results pertaining to a set of indicators that is always deemed too large by managers?; ii) uncertainty: how to convey uncertainties about indicators without weakening the information communicated?; iii) simplification: how to communicate simply a complex result?

Synthesis is inevitable as most of the time, a single indicator cannot reflect complex, multiple linkages and feedbacks, e.g. within the ecosystem (Chapter 1). Similarly, multiple standpoints on a question cannot be easily accommodated from a single indicator. In such situations, multiple indicators can mirror inputs from several stakeholders. Brown *et al.* (2001) considered this use of indicators for trade-offs in MPA planning, but it might also be interesting to account for various, or even conflicting management objectives. The synthesis issue encompasses also several questions. Are the indicators to be presented individually, e.g. by using a dashboard approach? Or is it necessary to combine indicators into synthetic indices that are meaningful to the manager? Combining indicators implies to assign weights to individual indicators. This is never insignificant as it relates to the priorities given to indicators, and thus to underlying objectives and standpoints. Yet, there are some methods like multi-criteria analysis that evaluates the outcomes of several management actions while making explicit the priorities to a range of criteria (Brown et al. 2001). On the other hand, a dashboard nicely summarizes an assessment, particularly in the case of a single question. For instance, Koeller *et al.* (2000) presented a performance report for the assessment of a shrimp stock. But in the case of several questions, and this is definitely the case of MPA assessment, the interpretation may become more difficult as the number of entries increases. Thus, breaking the dashboard into sub-tables per management goal is a reasonable option.

Simplification is often addressed through color rating, each color corresponding to a range of values of the indicator. For instance, NMSP condition reports use six colors rating the status of a given response from “poor” to “good”, with an additional “undetermined” category (http://sanctuaries.noaa.gov/science/condition/welcome.html). Status rating is completed by an evaluation of indicator trend under the form of a symbol comprising five categories: “improving”, “not changing”, “getting worse”, “undetermined trend” and “question not applicable”. A simplified use of color rating is provided by the traffic-light approach to fisheries management (Koeller *et al*., 2000; Caddy, 2002). Color rating raises the problem of defining thresholds between distinct colors, particularly in the presence of uncertainty. Colors are also perceived differently depending on cultural settings, a well-known issue in marketing, design and psychology (see e.g. http://en.wikipedia.org/wiki/Color_symbolism_and_psychology). Alternatively to colors, one may choose to transform indicators to dimensionless values, sometimes called indices. Such values, preferably ranging between 0 (or -1) and 1, are easier to interpret, seee.g. the conservation of biological originality index in Mouillot *et al.* (2008) and Claudet *et al*., MPA book or the social acceptability indicator of Thomassin *et al.* (2009).

Section 3. Illustration of the approach.

The approach is illustrated through experiences from Liteau II-AMP (Pelletier 2007) and PAMPA (http://www.ifremer.fr/pampa), two multidisciplinary research projects involving scientists and managers of French MPAs. The objective of Liteau II-AMP (2004-2007) was to develop diagnostic and exploratory decision-support tools for assessing MPA performance. Diagnostic tools enable one to evaluate whether management objectives are reached in existing MPA. Exploratory tools yield more prospective insights about possible scenarios regarding zoning of uses in existing or projected MPAs. They also permit to assess the potential consequences of changes in anthropogenic pressure on ecosystem uses, goods and services, and the relevance of MPA management facing such changes. In this project, the issue of communicating indicators toward the public or more general stakeholders was not addressed, but the project focused on indicators that guide MPA managers toward management actions. Biodiversity conservation and fisheries management were the main themes addressed by Liteau II-AMP. The ongoing PAMPA project (2008-2011) has a larger scope as it addresses all uses linked to the existence of MPA, mostly recreational ones, as well as governance issues. Scientists belong to a panel of disciplines including law studies, geography, economy, ecology, fisheries science and biostatistics.

In the next section, I will illustrate several steps of the framework described in section 2. I will first address management objectives and actions. Second, indicators pertaining to biodiversity and resources will be discussed. The third step will relate to management of uses and governance. Interpretation of indicators will be discussed in the last subsection. I do not intend to be exhaustive, but rather to illustrate in a concrete manner the questions linked with these indicators. Validation and communication of indicators will not be dealt with here, as some previous steps need be handled first that are currently not yet advanced in the project.

Subsection 3.1. Formulation of management objectives and management actions

Workshops were organized to establish a list of goals with corresponding detailed objectives, that was suited to the MPA partners of the projects. Goals and objectives from Pomeroy *et al*. (2004) were discussed and reformulated when managers felt it was needed, some objectives were merged, and some were not considered because they were not relevant to the MPA concerned. As also underlined by Pomeroy et al. (2005), listing and, more importantly, clearly formulating goals and objectives was deemed very useful by all participants of the workshop.

MPA managers had then to list the management actions they could undertake to reach a given objective (Tables 3 and 4). Actions could be regarded as i) regulatory (e.g. restricted access, fishing controls), ii) aimed at establishing good practices through mutual agreements with user groups (e.g. divers or fishers), or iii) relating to information and education of stakeholders and the general public. The two latter favor the participation of stakeholders to management and the social acceptance of the MPA (governance objectives, Table 2). Finally, a number of monitoring actions have been listed as being in the range of manager actions. Indeed, a number of management plans listed monitoring as being an objective of the MPA.

Subsection 3.2. Indicators related to biodiversity and resources

3.2.1. Identification and estimation of relevant metrics

Biodiversity is here restricted to underwater flora and fauna, while resource is to be understood here as fishing resources. Biodiversity and resources rely on similar types of observations. UVC have been successfully used for years to estimate fish abundance or biomass in studies of population dynamics, ecology and management. Advantages and disadvantages of this method have been discussed in several papers (e.g. Harmelin-Vivien et al. 1985; Cappo and Brown 1996; Samoilys 1997; Willis et al. 2000; Watson et al. 2005). UVC are widely used for fish, benthic macrofauna, including invertebrates and fixed fauna, and for flora in tropical and subtropical coastal waters, but also in temperate waters. They are for instance recommended for monitoring by Reef Check (http://www.reefcheck.org/).

The second most frequently used data for biodiversity and resources are catch and effort data, either experimental catch carried out from scientific protocols, or sampling of fishing activities at sea or at landing sites. A third technique that has been more recently developed relies on the use of underwater video (Cappo et al. 2003; Willis et al. 2000; Tessier et al. 2005), and particularly baited underwater remote video (BRUV) (Watson et al. 2005; Langlois et al. 2006; Stobart et al. 2007), although unbaited techniques are developing. Likewise, photo-based techniques have been recently tested for monitoring benthic invertebrates and habitat in MPA (Dumas et al. 2009).

In terms of relevance for indicators of biodiversity and resources, UVC and image-based techniques provide direct observations of macrofauna and habitat, although they depend on underwater visibility. They yield presence/absence data, abundance indices for density and biomass, and coverage of sea bottom by fixed benthic fauna and flora (e.g. coral, seagrass) and by abiotic components of habitat. Catch-based observations only reflect the fraction of macrofauna that is catchable by the gear used, in general mostly carnivorous species, but catchable species may include species that are not commonly observed underwater, either because they are cryptic or night-dwelling. Catch and effort data yield Catch Per Unit Effort (CPUE) which can be considered as an abundance index under certain assumptions that have long been discussed in fisheries science (Richards and Schnute 1986; Pelletier 2003). The surface observed and thus densities can be estimated in the case of UVC, photo and unbaited video, but not for catch and nor for BRUV where bait plume is difficult to evaluate.

Willis et al. (2000) examined the relative merits of UVC, BRUV and experimental catch for detecting spatial variations of fish density. These techniques provide complementary information. For techniques requiring underwater divers, human presence must be regarded as a potential source of bias for estimating the abundance of mobile species in MPAs. Species behavior may differ in protected areas, as they become less afraid of human presence underwater and might affect observed differences in abundance between no-take area and unprotected areas. To some extent, this can be circumvented in the observation protocol, e.g. by counting the species concerned first. But techniques not requiring human presence underwater bear an advantage in this respect. With regard to resources, it might also appear logical to resort to catch data to assess an objective like sustainable exploitation of resources (Table 3). There is however a shortcoming to catch data, since they are destructive. This does not matter in the case of sampling of fishing activities, but poses a problem for conducting observations within no-take areas. More generally, tracking the achievement of progress toward conservation and restoration objectives by using extractive observation means is questionable and may in some cases be detrimental to the acceptability of the MPA, e.g. by fishers.

In a second step, collected data are combined using e.g. information on species to compute more sophisticated metrics, such as biodiversity indices and metrics per species groups. Pelletier et al. (2005) investigated the relevance of the metrics used for assessing MPA effects, on the basis of a bibliographic review of empirical studies. The relevance of the metrics was scored using the number of times the metrics had been used for assessing a given effect. Results show that some metrics are consistently more often used for MPA assessment than others (Table 5). Candidate indicators for conservation and fisheries-related effects of MPA have also been listed by Pelletier et al. (2008). In addition to empirical metrics directly computed from field data, these authors considered model-based metrics. Such metrics include abundance, catch and biomass per population and time step, and possibly per area obtained from spatially-explicit models. They can be combined into ratios or dimensionless indices that are suitable for comparisons and interpretation (see subsection 3.3.2). Depending on the model, more sophisticated metrics may be calculated such as size or biomass spectra, risk of collapse, population growth rate. By construction, model-based metrics integrate the information and knowledge that was required to build the model (see Pelletier and Mahévas (2005) for an example of model).

The existence of reference points is linked with the relevance issue (subsection 2.2). No such references exist for empirical metrics, while for model-based metrics, in most instances, reference points can be determined by exploring through simulations other domains of the dynamic modeled.

Last, a few remarks may be drawn regarding the relevance of existing metrics. Biodiversity and fisheries-related management objectives are highly integrated; they quote biodiversity conservation or sustainable exploitation of resources as a whole, not species per species. Regulatory measures are consistent with this holistic standpoint. Yet, in many assessments, effects are evaluated per species or species group. Producing overall insight on biodiversity or resource status is difficult in these conditions. A few papers handled this through multivariate statistical modeling (Amand et al. 2004; Langlois et al. 2005; Claudet et al. 2006; Ceccherelli et al. 2006), but results are not easily interpreted to guide management actions, primarily due to a lack of references for setting targets. Alternatively, integrated indices can be investigated to reflect the whole species assemblage concerned and possibly account for species function in the ecosystem (Mistri and Munari 2007). Such approaches are still rare (Mouillot et al. 2008) and need be developed. Several common biodiversity indices exhibit shortcomings limiting their relevance as an indicator for biodiversity conservation. For instance, species richness is known to depend on the surface area observed, or variations of the Shannon index may be difficult to interpret.

3.2.2. Analysis of metrics.

There has been a substantial literature about the assessment of ecological and fisheries-related effects of MPA Here I will rather focus on a few points that can give insight into the construction of indicators. Additional details may be found in Pelletier et al. (2008).

The first point deals with including context information when analyzing the spatio-temporal variations of metrics. Habitat is obviously a very important variable to account for as underlined by many authors (e.g. Garcia-Charton et al. 2004; Osenberg *et al*., MPA book). Ferraris *et al*. (2005) provided a clear-cut illustration of the interest of controlling for habitat to assess MPAs. By considering habitat at two different scales, they showed that MPA effects were more significantly detected when more precise information was included in the analysis. Alternatively, the observation design can a priori cross protection and habitat factors, particularly when habitat can be described through a single proxy and at a scale compatible with the design. Another context variable is the pressure endured by biodiversity and resources. Procedures to integrate explicitly this information in the assessment of MPA effects have not yet been developed. A first step in this direction is to consider resources depending on their interest for fishers. In an analysis of UVC data, Preuss et al. (2008) distinguished species according to i) the fishing gear that targets them, and ii) the magnitude of this interest, e.g. incidental catch, which led to more discrimination of MPA effects. Claudet et al. (2006) and Rocklin et al. (submitted) also considered groups of distinct fishing interests.

The second point relates to the usefulness of model-based metrics. These are indispensable to address some questions, notably temporal issues or scenario evaluation. Many models published in the past are theoretical contributions (Pelletier and Mahévas 2005), and sometimes simple heuristic models have been used to justify simplistic one-size-fits-all prescriptions, e.g. about the desirable size of no-take zones. Dynamic models are nevertheless indispensable to tackle certain issues raised by managers, such as evaluating the impact of current fishing activities and the consequences of alternative fishing regulations (Table 3). In order to design regulations that appropriately target the fishing activities that have the most detrimental impact on resources, it is necessary to quantify these impacts and to anticipate the outcomes of changes in regulation or other scenarios, e.g. an increase in demographic pressure. More generally, models are needed to project the consequences of scenarios at the scale of fisheries and ecosystems. A major perspective is to implement models that achieve a trade-off between parsimony and complexity, and are parameterized and calibrated against real data. In the MPA context, such models must describe the spatio-temporal dynamics of population and exploitation at the scale of MPA design, and they must account for several species and several fishing activities. These issues were discussed elsewhere in detail (Pelletier and Mahévas, 2005; Pelletier *et al*., 2008). The ISIS-Fish model provides a generic framework for applications to actual fisheries on the basis of all available knowledge (http://isis-fish.labs.libre-entreprise.org). There are to date a number of applications that have been successfully used to assess fisheries-related effects of MPAs (Drouineau et al. 2006; Kraus et al. 2009; Lehuta et al. 2009) and a number of applications in progress. Many resource indicators can be calculated from such models. Pelletier and Mahévas (2005) proposed two ratios that enable to compare the outcomes of alternative fishing regulations over a simulation: i) for a given scenario, value at the end of the simulation versus initial value; and ii) value at the end of the simulation for a scenario versus value at the end of the simulation under a statu quo scenario. These values are calculated for biomass and catch (example in Table 6). The first metric measures the consequences of the regulation scenario, while the second metric gauges this scenario with respect to the current situation. Sensitivity analysis may be used to further evaluate the relevance and efficiency of a given metric.

A real challenge for both empirical and model-based metrics is the provision of uncertainties associated with metric estimation and analysis. In the case of model-based metrics, simulation experiments enable to estimate the sensitivity of model outcomes to uncertainties (Drouineau et al. 2006). For empirical metrics, statistical models should provide confidence bounds for metrics and for resulting analyses. This issue is somehow linked with that of formal indicator validation discussed in subsection 2.5.

3.2.3. Increasing indicator efficiency through improved and cost-effective observation protocols

Beyond the relevance of a metric that depends on the observation system (see subsection 3.2.1), indicator efficiency must be increased through the design of cost-effective protocols.Costs depend on requirements in both staff capacity and time spent at sea and at the office. Observation techniques that can be implemented by the MPA staff should be preferred. Many UVC protocols require expert divers that are able to identify species, but after field work, UVC only requires data input. Photo and video transects require divers that are not necessarily experts (Francour et al. 1999; Dumas et al. 2008; Pelletier et al. (submitted)). Most video-based techniques are operated from autonomous systems and require no diver (Cappo et al. 2003; Pelletier et al. 2007), but they need the assistance of experts at the office for detailed image analysis at species level. Pelletier et al. (submitted) found out that overall time at sea and at the office was similar for UVC and video transects.

When the observation system is operated by a diver, the number of feasible observations per day and the maximum depth at which they are conducted are limited. Autonomous systems are less restricted in this respect. Baited systems take in general more time per station, while there are unbaited systems that enable a large number of observations to be conducted in a single day (Pelletier et al. 2007). It should also be noted that local habitat and macrofauna can be evaluated from the same images, whereas UVC require additional stations or longer time underwater for observing both. In general, image-based techniques reduce the time spent at sea, thus implying less field costs, which are always greater than office costs.

These considerations are important for MPA monitoring, as for a given precision/accuracy of the assessment, there is a trade-off between the number of observations that can be realized at a given time period and the spatial extent or the density of the observations, leading to different spatial coverage and replication levels.

Note that the level of expertise required does not depend only on the technique but also on the protocol. Hence, some simplified UVC monitoring programs, e.g. the protocols recommended by the Global Coral Reef Monitoring Network (Hill and Wilkinson 2004) also resort to volunteers that must observe a limited number of species and species groups. There are still very few studies evaluating the relevance of simplified protocols for deriving biodiversity and resource indicators able to track MPA effectiveness (Edgar and Stuart-Smith 2009).

Finally, image-based techniques provide information that can be archived, for other analyses, but also, and this is important in environmental assessment, for accountability of the information, thereby avoiding any doubt raised about the potential lack of reproducibility of the observation process, e.g. an observer effect.

Subsection 3.3. Indicators related to uses and governance

Although objectives linked to management of uses and to governance are clearly distinct (Table 2), both relate to human activities and behavior, and the way they can be investigated bear some similarities, particularly in contrast to highly quantitative approaches of biodiversity and resources. With regard to MPA effectiveness, there has been in the past a much larger emphasis on ecological aspects than on social and economic aspects (but see Sanchirico, MPA book; Christie and Pollnac, MPA book).

As stated in Chapter 11, socio-economic effects of MPA can be regarded as the consequences of a public investment on the society's well-being, and in a more practical way, MPA managers have to face the question of assessing how the MPA impacts the welfare of neighboring local communities, which in turn determines their acceptance of the MPA. Social and economic effects are thus linked. This subsection will focus on uses, users and governance, which are only a subset of socio-economic aspects (see Chapter 11), but represent the main questions that MPA managers can face through the range of actions they can undertake, see e.g. Table 3 for management of uses.

The term “use” is here restricted to those uses which rely on the ecosystem in which the MPA is located, mostly fishing, recreational and tourist uses. Consistently with the objectives in Tables 2 and 3, the questions addressed encompass assessing: i) the pressure of uses on the ecosystem and resources; ii) the role of MPAs in promoting or mitigating the impact resulting from this pressure; iii) the local economic benefits linked to these uses; and iv) the contribution of MPAs to local governance, including reduction of conflicts between uses and social acceptance of MPAs.

3.3.1. Identification and estimation of relevant metrics

Pelletier et al. (2005) attempted to evaluate the relevance of metrics used to assess economic and social effects of MPAs but they found few empirical studies in comparison to ecological studies. Yet, there are several types of data that can document these issues. Regarding the pressure of uses on the ecosystem, frequentation studies in and around the MPA can be conducted from direct observations, such as aerial surveys, boats or from particular observation points on the coast. Pressure is then quantified by the number of boats or users in and around the MPA, and must be estimated for each activity practiced and depending on boat characteristics when the activity requires embarking. Direct observations yield snapshot maps where frequentation is georeferenced or indicated per small area. Indirect estimates of frequentation can also be obtained from user interviews. Users’ location is then not georeferenced, but can be subjectively located on a map displaying the MPA. In reverse, interviews may provide information about the location and intensity of frequentation at other time periods than the date of the interview. Embarked frequentation studies may be carried out in collaboration with the MPA staff; collecting such information may even be done by MPA staff during the patrols (see e.g. Gamp *et al*. (2009)).

Studying the role of MPAs in promoting or mitigating the impact resulting from use pressure has rarely been investigated. It first requires to estimate the impacts of uses on the ecosystem: biodiversity (including habitat) and resources. Then it is necessary to relate pressure and impact, which has mainly been done up to now for fishing activities and resources. In the absence of established link between pressure and impact, it is difficult to guide management toward the appropriate actions to remediate impacts (see Tables 3 and 4 for possible actions), although precautionary measures can be implemented. One might also qualify activities by interviewing users about the way they practice, their motivations, and the way the MPA influences their practice (Gamp et al. 2009).

Local economic benefits linked to MPA uses are investigated through interviews of users and operators. Market data are needed to quantify benefits, but proxies can also be found, as economic data may sometimes be difficult to obtain. An illustration is provided in Chapter 11 (see also Roncin et al. 2008) in which benefits are evaluated through the numbers of visits to the MPA, and the number of persons or firms using the services provided by the MPA. Methodological caveats were also discussed in Chapter 11.

The contribution of the MPA to local governance can be studied from interviews of local populations and MPA managers, and from administration data. The latter inform about the management process (resources, procedures, etc.) and its integration in the regional coastal management. Interviews of MPA managers further document these issues, but they also provide integrated perceptions of MPA governance. Interviews of local populations are needed to appraise individual perceptions regarding conflicts between users, MPA effectiveness, MPA benefits for local populations and information and participation processes around the MPA. Interviews may be realized from different methodologies either on site or during individual appointments with users (Gamp et al. 2009; Thomassin et al. 2009). Other techniques were also described in Bunce et al. (2000) for coral reef management.

A main challenge for designing appropriate protocols for investigating uses and users in and around MPA lies in the definition and estimation of the reference population. Many uses related to MPA are informal so that this population is not a priori known. Similarly, it is necessary to define the geographical range of influence of the MPA. Information can be obtained from pilot studies, e.g. through the origin of interviewed persons, but will be conditioned on the scope of the studies. Ideally, a large-scale survey, e.g. a phone or mail survey should be undertaken for an independent estimation.

3.3.2. Analysis of metrics.

Compared to ecological aspects of MPA, there is generally a lack of knowledge and information on uses and governance. Therefore, a first question often expressed by MPA managers is that of characterizing existing uses and appraising the present governance of the MPA (Pelletier et al. 2005). Monitoring comes in a following step. This underpins the analysis of the metrics as temporal aspects are generally not developed (to the exception of commercial fishing pressure with a long history of monitoring and assessment). Depending on the protocol and on sample size, a formal statistical analysis may or may not be possible. Besides, some metrics are qualitative or semi-quantitative. Yet, their information is very valuable and should not be discarded. Most of the time, metrics are used in a descriptive way and presented in tables or figures (e.g. Chapter 11).

3.3.3. Designing cost-effective observation protocols.

As the efficiency of the metrics is not generally estimated for the reasons explained in 3.3.2, the question of cost-effective protocols amounts to choosing a relevant observation system, obtaining a representative sample from the population of interest and selecting the appropriate spatial and temporal frame for monitoring. The observation system is preferably to be operated by MPA staff. Furthermore monitoring can be coupled with patrolling in the MPA, although it might not always be desirable. It is possible to determine an appropriate sample size for frequentation studies and semi-directed interviews and to structure the protocol to avoid biased results by accounting properly for the different sources of variations in the data. A major issue in interviews lies in the formulation of questionnaires so as to minimize equivocal answers, lies, and interview refusals.

Subsection 3.3. Interpretation of indicators

Let us illustrate this issue through a brief example with two objectives relating respectively to the goals of sustainable use of marine resources and biodiversity conservation (Table 6). Under the first goal, the objective of maintaining and restoring target species is assessed through three indicators, two directly calculated from monitoring data, and one model-based. There are no reference points for none of these indicators, thus interpretation must proceed from their spatial and temporal variations. For the empirical indicators, the statistical significance and direction of the within-outside difference in abundance (D) and of the outside temporal trend in abundance (Tr) may be used to evaluate whether restoration occurs in the MPA with respect to outside. Such information results for instance from a BACI (or BACIPS) design (Chapter 8). Analyses may be more sophisticated if observations are replicated across several sites and at several dates. The aim is to be able to decide upon management actions on the basis of reliable significant changes in indicator values. These may help to discern between problems requiring action inside or outside the MPA, but they do not demonstrate whether protection is restoring or not the target species, and they do not show what might be the appropriate fishing regulation to achieve this restoration, which is a highly relevant question in the case of multiple use MPAs. The model-based indicator provides more insight into this question by investigating the consequences of several candidate fishing regulations. Population is restored when the final/initial biomass ratio (B) is larger than 1. The final/initial catch ratio (C) enables in addition to select among the regulations that restore the population, the ones that are not detrimental to catch.

Under the goal of biodiversity conservation, the objective of restoring or maintaining habitats is assessed through the seagrass cover (SC) indicator. It may evolve over time as a result of changes in water quality or detrimental effects of anchoring. A decreasing SC indicates a problem, but does not point at its cause. If estimates of the pressure due to anchoring are available, changes in seagrass cover within the MPA may be interpreted in relation with frequentation. Again, there are no reference points for these indicators. The number of boats moored in the MPA (NM), particular nearby or in the seagrass area yields additional clues as to the cause of changes in SC. In the absence of reference values, it is difficult to demonstrate that decreases in SC are due to large NM. This implies to compare seagrass areas with different boat pressure and to find a correlation that is independent of other sources of variation for SC. When trends are available, it is possible to derive management actions from the joint trends of SC and NM. Hence, even in the absence of reference points which would provide thresholds**,** the statistical significance, magnitude and direction of the variations of the indicators considered are helpful for establishing the diagnostic and targeting management actions. Determining the appropriate significance level, magnitudes and direction stems from scientific knowledge about ecological dynamics, but also from the time frame required for restoration which in turn depends on the initial ecological status. Note that as years of data accumulate, the interpretation of indicator values may become more sophisticated by accounting for values taken over successive years. Hopefully, the information collected may *in fine* provide evidence for establishing a relationship between the pressure (NM) and the impact (SC).

These illustrations show that it is often necessary to consider several indicators to decide upon actions linked to a given objective.

Conclusions

Similarly to other domains of environmental management, there is a growing demand for the provision of rigorously established indicators of MPA effectiveness that can be used to assist decision-making. A review of the literature showed a gap between on the one hand, institutional frameworks and methodologies designed at international levels, which exhibit a lack of formalization but are aimed at management issues, and on the other hand scientific contributions, which do not account for management constraints but are better formalized.

The proposed framework appears to be applicable to the three major MPA goals: biodiversity conservation, sustainable exploitation of resources, management of multiple uses and governance. The way it should be applied differs according to management objectives, asfor biodiversity and resources, data and knowledge are commonly available, including temporal series of data, whereas they are scarcer for social and economic aspects.

It favours the construction of relevant and efficient indicators. Grounding the approach in collaborations with managers guarantees that indicators satisfy manager’s needs and constraints. The framework is currently being implemented in a variety of contexts (including. Mediterranean and tropical ecosystems) by a multidisciplinary team within the PAMPA project. It might also be applied to other domains of coastal management, as long as managers are a well-identified group for collaboration. MPAs are a favorable case in this respect, as they are limited in space. In addition, many MPA managers, at least in developed countries, have a scientific background that facilitates progress during discussions. The process relies on a sustained collaboration between scientists and managers but it is not a participatory approach as all stakeholders are not associated. Note that they might be represented for discussing communication and monitoring if they are to be involved in management. For pragmatic reasons, it is nevertheless necessary that there are not too many persons for discussions. MPA managers are key to the process as they know the context, the issues, the stakeholders, and they are the ones who are going to use the indicators.

In terms of perspectives, issues of validation and communication still need to be documented and tested. Also, synthesizing and communicating results for management purpose is often quoted in the literature, but there are few concrete contributions (e.g. subsection 2.7), particularly with regard to uncertainty. But, this does not preclude the construction and validation of indicators, and can be considered separately. As explained in subsection 2.7, synthesis and aggregation, and to a lesser extent presenting indicators is never insignificant. Combining scores or color codes from different goals may exceed the scope of the scientist’s work, as it pertains to management priorities where scientists should not interfere.

Regarding evaluation of relevance and effectiveness, scientists should provide more guidance and communicate on the usefulness and relevance of candidate approaches for monitoring, indicator selection and implementation, sampling design improvement and indicator interpretation. In addition, managers often appreciate updates on scientific progress (Pelletier et al. 2007). Scientists are also expected to convey insight from systemic perspective to help managers to stand back from day-to-day problems that might distract discussions on MPA management. Last, they should also indicate and explain when some questions raised by managers cannot be addressed by simple and cheap monitoring methods and simplified indicators. In this case, managers may need scientific expertise, e.g. for prospective questions about ecosystem and resource dynamics. In contrast, part of the monitoring might be achieved by non expert (although trained) persons, such as MPA staff, but also volunteers, such as divers or fishers, which will contribute to MPA social acceptance.

The methods used at each step of the framework can be tailored to the MPA context and logistics, because collaboration with managers is central here. But it can only be applied if there are issues acknowledged by managers as requiring scientific input to MPA management, and if some scientific experts are willing and available to work with MPA managers.

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Table 1. Components of the IUCN-WCPA framework for evaluating management effectiveness. Outputs refer to the achievement of identified activities or work programme whereas outcomes reflect whether the long-term objectives are met (after Hockings 2006).

Context	Understanding the context of the protected areas, including its values, the threats that it faces, available opportunities, and stakeholders, management and political environment
Planning	Progresses to planning: establishing vision, goals, objectives and strategies to conserve values and reduce threats
Inputs	Allocating resources of staff, money and equipment to work toward the objectives
Processes	Implementing management actions according to accepted processes
Outputs	Goods and services, which should usually be outlined in management plans and work plans
Outcomes	Achieving defined goals and objectives

Table 2. Common marine protected area themes, goals and associated indicators (after Pomeroy et al. 2005).

Themes	**Goals (number of objectives)**	**Indicators**
Biophysical	Marine resources sustained or protected (6) Biological diversity protected (7) Individual species protected (4) Habitat protected (4) Degraded habitat restored (5)	• Focal species abundance • Focal species population structure • Habitat distribution and complexity • Composition and structure of the community • Recruitment success within the community • Food web integrity • Type, level and return on fishing effort • Water quality • Area showing signs of recovery • Area under no or reduced impact
Socio-economic	Food security enhanced or maintained (6) Livelihoods enhanced or maintained (4) Non-monetary benefits to society enhanced or maintained (6) Benefits from the MPA equitably distributed (3) Compatibility between management and local culture maximized (2) Environmental awareness and knowledge enhanced (4)	• Local marine resource use patterns • Local values and beliefs regarding the marine resources • Level of understanding of human impacts on resources • Perceptions of seafood availability • Perceptions of local resource harvest • Perceptions of non-market and non-use value • Material style of life • Quality of human health • Household income distribution by source • Household occupational structure • Community infrastructure and business • Number and nature of markets • Stakeholder knowledge of natural history • Distribution of formal knowledge to community • % of stakeholder group in leadership positions • Changes in conditions of ancestral and historical sites, features, and/or monuments

Table 2 (continued).

Governance	Effective management structures and strategies maintained (6) Effective legal structures and strategies for management maintained (5) Effective stakeholder participation and representation ensured (3) Management plan compliance by resource users enhanced (6) Resource use conflicts managed and reduced (1)	• Level of resource conflict • Existence of a decision-making and management body • Existence and adoption of a management plan • Local understanding of MPA rules and regulations • Existence and adequacy of enabling legislation • Availability and allocation of MPA administrative resources • Existence and application of scientific research/input • Existence and activity level of community organization(s) • Degree of interaction between managers and stakeholders • Proportion of stakeholders trained in sustainable use • Level of training provided to stakeholders in participation • Level of stakeholders participation and satisfaction in management process and activities • Level of stakeholder involvement in surveillance, monitoring, and enforcement • Clearly defined enforcement procedures • Enforcement coverage • Degree of information dissemination to encourage stakeholder compliance

Table 3. Management objectives and actions identified under the goal of sustainable uses linked to MPA.

Objectives	**Questions**	**Actions**
Sustainable exploitation of resources	Restoring and maintaining invertebrate and fish stocks	• Regulatory actions: Regulation of commercial and recreational fishing in the MPA (e.g. size limits, licenses, zoning, time closures, gear restrictions) Enforcement of regulation (both general and MPA-specific) • Artificial reefs • Establishment of agreements with users, e.g. code of conduct (fishers, divers) • Information and education, e.g. training in professional schools for sea-related jobs, leaflets
Sustainable fisheries	Viability of artisanal fisheries (both as an economic activity and because of its patrimonial value leading to indirect local benefits	• Regulatory actions: Regulation of commercial and recreational fishing in the MPA -Favor the coexistence of fishing activities through appropriate space occupation -Control of illegal activities, e.g. trawling within the 3 n.mi. zone • Installing anti-trawling devices (e.g. artificial reefs) • Establishment of agreements with users: -Contribute to added value for sea products (labels, direct sales) -Promote polyvalence (fishing and tourism-related activities) -Promote the use of repulsive devices for marine mammals • Information and education
Management of multiple uses	Reduce conflicts between uses and between users	• Regulating frequentation and nuisances • Promote adequate zoning in space and time between uses • Foster consultation between uses

Table 4. Management objectives and actions identified under the goal of conservation of biodiversity and habitats.

Objective	**Actions**
Maintaining or restoring endangered or protected species	• Enforcement and control of regulations • Monitoring species abundance • Protect essential habitat for these species (see below)
Maintaining or restoring biodiversity	• Enforcement and control of regulations • Monitoring invasive species and species indicating global trends and biogeographical changes • Interventions to reduce identified nuisances • Reintroduction of species
Maintaining or restoring habitats and associated biodiversity	• Monitoring important habitats and water quality • Identifying perturbations and evaluating impacts, e.g. for seagrass • Preventing risks of chronic and accidental pollution • Regulatory actions: – Enforcement and control of regulations – Limit the impact of fishing gears on habitats (anti-trawling devices, gear-specific closures)-Control boat anchoring, e.g. through permanent moorings – Limit frequentation of sensitive areas, e.g. number of boats or diving trips – Redirect or limit tourist frequentation via access to sea (boat ramps) or via underwater pathway – Control underwater pathway frequentation – Control and exclude illegal moorings • Establishment of agreements with users, e.g. code of conduct (fishers, divers) • Information and education, e.g. training of concerned operators and staff, leaflets, communication toward tourists and local people • Installation of devices, works: permanent moorings, maintenance or enhancement of degraded habitats (artificial reefs, wrecks)

Table 5. Relevance and effectiveness of metrics related to biodiversity and resources [after Pelletier *et al.* (2005)]. Relevance was scored from the number of times the metric has been used in the literature; effectiveness was scored from the proportion of papers where its use led to a statistically significant marine protected area effect in the reviewed studies ("*"=<33%, "**"=[33%,66%], "***"=>66%). All metrics refer to underwater visual census data, except two from catch per unit of effort.

Metric	**Maintaining or restoring biodiversity and habitat**		**Sustainable exploitation of resources**	
	Relevance	Effectiveness	Relevance	Effectiveness
Density per species or genus	***	**	***	**
Density per species per stage	*		**	***
Size distribution per species	*		**	***
Biomass per species or genus	*	ns	**	**
Mean size per species or genus	**	**	***	**
CPUE per species or genus			**	**
Density per family	**	ns	***	**
Biomass per family	*		*	***
Species richness per family	**	**	*	*
Density per trophic group			**	***
Density of fishable species			*	**
Biomass per trophic group			*	***
Overall density	*	**	***	**
Overall biomass	*	***	**	***
Overall species richness	***	**	*	*
Overall CPUE	*		**	**
Benthic cover	***	***		

Table 6. Interpretation of indicator values in relation to management objectives and actions under the goals of sustainable exploitation of resources and biodiversity conservation and restoration.

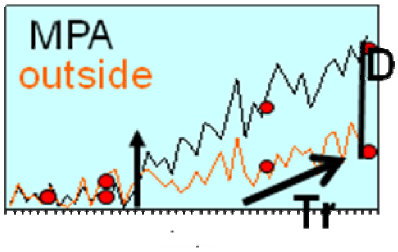
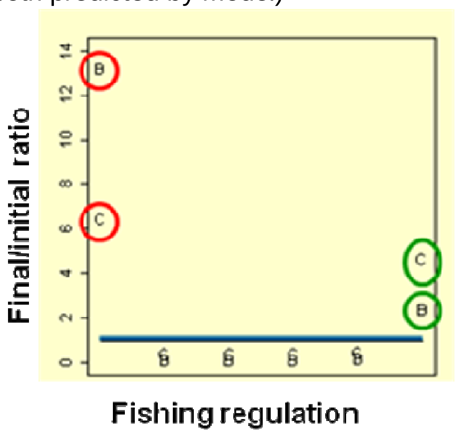
Goal	Objective	Management actions	Indicator(s)	Interpretation of indicator values
Sustainable exploitation of resources	Restoring and maintaining target species	No action Fishing regulation Fishing regulation and restricted MPA access	D = inside-outside difference Tr = outside trend over time (both density of target species calculated from UVC data) 	D ↑ and (Tr ↑ or →) no action required (D ↑ or →) and Tr ↓ action required outside D ↓ and Tr ↓ action required inside and outside
		A range of regulatory actions regarding fishing	B = final biomass / initial biomass C = final catch / initial catch (both predicted by model) 	Ratio B > 1 population is restored via measure Ratio C > 1 catch increases via measure Ratio B < 1 disregard measure where population is not restored Maximum ratio C among measures that restore population, prefer those that yield the highest catch
Biodiversity conservation	Maintaining or restoring habitats	No action Install permanent moorings in MPA Restrict boat access to MPA	SC = seagrass cover in MPA (calculated from UVC data) NM = number of boats anchored in MPA (from frequentation survey)	SC ↑ and (NM → or ↓) no action required SC → and NM ↑ anticipate further frequentation increase with permanent moorings SC ↓ and NM ↑ Restrict access to MPA

Figure 1. Overall scheme of the methodology for selecting and validating indicators of MPA effectiveness. Most steps involve collaboration with MPA managers.