20 Incorporating Ecosystem Objectives into Management of Sustainable Marine Fisheries, Including 'Best Practice' Reference Points and Use of Marine Protected Areas

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Abstract

The broadening of fisheries management to include ecosystem-related objectives raises a potentially confusing range of possible issues for consideration in management decisions, in reporting and in assessing management performance. However, there are methods available and approaches to addressing the issues that are practical, accessible to stakeholder participation and scientifically assessable. Three broad and interrelated elements are described that allow ecosystem objectives to be practically and operationally incorporated into marine fisheries management systems.

Reporting and assessment of the whole management system against sustainability objectives
Three major points are developed and emphasized:

1. Indicators and reference points – and consequently performance measures – must relate explicitly to the high-level objectives of management.
2. The structure and focus of reports on sustainability must be derived transparently from the high-level objectives. A methodology for this is described that can be used in meetings with stakeholders to elucidate the issues, indicators and reference points, management response and the justification for decisions. It can include risk-based methods to help identify the relative importance of different issues.
3. Performance assessment must be of the management system as a whole, rather than solely on the merits of particular parts in isolation. An established methodology (management strategy evaluation) is described that can be used to test quantitatively the likely performance of different management strategies in achieving ecosystem objectives. A management strategy in this context is a combination of monitoring, use of the monitoring data for assessment against reference points, identification of appropriate management measures and implementation of these measures. This methodology can be used to test any aspect of the strategy in the 'common currency' of the management objectives, and to identify the circumstances in which particular strategies are likely to perform well or fail. It has already been used in fisheries in relation to target species, important by-catch species, predator–prey dependencies and seabed habitats.

Indicators, reference points and performance measures for fisheries ecosystem objectives
There are many options available, and some recent summaries are identified. A set of target and limit reference points for fisheries ecosystem objectives are provided. These are based broadly on experience to

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date, and could be practically implemented in the short term. It is not claimed that these reference points are necessary or adequate to achieve sustainability for fisheries and marine ecosystems. Rather, they represent a practical and emerging 'best practice' means of operationally accommodating ecosystem-related objectives in fisheries management.

Use of marine protected areas to achieve ecosystem objectives in fisheries management
Fisheries have long used some forms of spatial management, such as closure of nursery areas to protect juvenile fish, but more recently there has been a focus on use of marine protected areas (MPAs) to achieve fishery objectives for the target species and for the ecosystem more generally.

MPAs hold promise as a rational and practical way of managing ocean resources to achieve fishery ecosystem objectives, although this promise should not be overstated. MPAs are best seen as part of a collection of management tools and measures, with a combination of on-reserve and off-reserve measures being used together to achieve sustainable fisheries and marine ecosystems. Several new technological developments are making their design and management more practical. These recent developments are reviewed.

Introduction

Fisheries have been important to human economies and societies since ancient times, and for much of that time fish resources were relatively little affected and even considered limitless (e.g. Smith, 1994). However, the scale of fishery impacts and perceptions about them changed during the 20th century with the development of increasingly large-scale fisheries using increasingly effective technologies. These developments first demonstrated that fish resources are finite (e.g. Beverton and Holt, 1957), then that fishing can cause the collapse of fish populations, and finally that fishing can cause significant damage to the marine ecosystem (e.g. Gislason *et al.*, 2000). Increased recognition of the potential deleterious effects of fishing resulted in significant policy and legal responses at both international and national levels. These were aimed at balancing the right to exploit fishery resources with an obligation to conserve them and the marine environment, and, increasingly, this balance has been extended to include integrated consideration of all the human uses of marine ecosystems and protection of the marine ecosystem broadly, not just the ecosystem components that directly affect fishery production.

Some important international steps in this development were:

- The UN Convention on the Law of the Sea (1982) established a right to exploit marine resources sustainably and an obligation to protect the marine environment.
- The UN Conference on the Environment and Development (1992) defined sustainable development as 'meeting the needs of the present generation without compromising the ability of future generations to meet theirs', and introduced the concept of precautionary management. Through Agenda 21, it emphasized that protection of marine ecosystems and use of marine resources were inseparable, and that protection of marine ecosystems included the maintenance of ecological relationships and dependencies.
- The Convention on Biodiversity (1992) consolidated the principles of integrated ecosystem management; called for conservation of genetic, species and ecosystem biodiversity; and recognized marine protected areas (MPAs) as a key measure for conservation of marine biodiversity.

Many national Acts of legislation and policies have been developed to give effect to these international agreements. Some recent examples are:

- The Canadian Oceans Act, which requires fisheries to be sustainable in the context of the integrated management of all human uses of marine ecosystems.
- The Australian Oceans Policy, which provides for sustainable and integrated

management of all human uses of marine ecosystems, and the Environment Protection and Biodiversity Conservation Act that requires fisheries to demonstrate ecological sustainability as a condition of export permits.

- The USA Magnuson–Stevens Act that requires fisheries to achieve sustainability of both target species and the associated marine ecosystem.

These initiatives extend the range of objectives considered to be the core business of fishery management, to include target species, by-catch, MPAs and ecosystem 'health and integrity', but the stated objectives often are very general or conceptual, and human understanding of the dynamics of marine ecosystems is fragmented and rudimentary. The challenge is to translate these conceptual objectives into practical targets and performance measures that can be used in the operational world of real fisheries. In the increasingly scrutinized world of fisheries management, it is also necessary to demonstrate that the management plans and arrangements are likely to achieve the stated management objectives. Furthermore, the management system must be able to detect and correct mistakes before unacceptable damage is done, because, given the limitations of knowledge about marine ecosystems, there will be mistakes!

Here we describe three broad and interrelated elements to incorporate ecosystem objectives operationally in marine fisheries management systems.

1. *Report and evaluate the whole management system, not its individual parts.* Fishery management is an interactive system and so the performance of the whole cannot be judged from the performance of one part alone. For example, an accurate and precise stock assessment is unlikely to result in a sustainable fishery without good implementation of management measures. Conversely, an imprecise stock assessment may be sufficient if linked to a very precautionary management response. It is only by examining the whole management system, and its robustness to uncertainties, that the likelihood of achieving objectives and the level of precaution can be determined. This has been a major lesson from single-species fishery management (e.g. de la Mare, 1998), and it is even more important in dealing with ecosystem-related objectives because of the greater uncertainties involved. Whole-system approaches to both reporting and assessment of sustainability are discussed.

2. *Operational indicators, reference points and performance measures for fisheries ecosystem objectives.* Indicators, reference points (e.g. desired targets and limits for an indicator) and performance measures are used for reporting, assessment and management decision making. 'Classical' single-species indicators and reference points are being re-evaluated to meet the needs of ecosystem-related objectives, and there is some development of practical indicators and reference points for ecosystem processes and properties. This is summarized, and a set of 'best practice' reference points for ecosystem objectives is suggested.

3. *Use of new management tools, such as MPAs.* An MPA is an area that is managed to protect and maintain biodiversity, and natural and associated cultural resources (IUCN, 1994). They may include marine reserves ('no-take' areas), and also areas in which a variety of uses are permitted and managed. Drawing on recent reviews (e.g. Guenette *et al.*, 1998; Sumaila *et al.*, 2000; Ward *et al.*, 2000), the role of MPAs in mitigating the ecosystem effects of fishing is discussed. Practical issues relating to establishment of MPAs and the use of new technologies are also addressed.

Reporting and Assessment of the Whole Management System for Ecologically Sustainable Fisheries

The range is very large of potential issues that could be reported and assessed in the context of sustainable fisheries and the marine ecosystem. There is need for a transparent and defendable way of deciding: (i) the level of importance and effort that should be put into the different issues; and (ii) the operational interpretation of high-level objectives for each issue. Progress requires explicit recognition of the hierarchy that links high-level objectives to operational indicators and performance measures. Details of nomenclature may vary between 'schools of thought', but in general terms the hierarchy is:

- *Principle* – a high-level statement of 'how things should be'.
- *Conceptual objective* – a high-level statement of what is to be attained.
- *Component* – a major issue of relevance within a conceptual objective.
- *Operational objective* – an objective that has a direct and practical interpretation, usually for a component.
- *Indicator* – something that is measured (not necessarily numerically) and used to track an operational objective. An indicator that does not relate to an operational objective is not useful in this context.
- *Reference point* – a 'benchmark' value of an indicator, usually in relation to the operational objective, such as desired targets, undesirable limits or triggers for specified management responses. A target reference point could serve as an operational objective.
- *Performance measure* – a relationship between the indicator and reference point that measures how well intended outcomes are being achieved (e.g. Fig. 20.3).

Recent examples of this hierarchy for sustainable fisheries are given by the FAO (FAO, 1995; Garcia, 2000), the Marine Stewardship Council (MSC, 1997), Canada (Jamieson *et al.*, 2001), USA (NMFS, 1998), ICES (2000) and Australia (Anon., 2000). Table 20.1 provides a general summary of common conceptual objectives and associated components. Adequate and effective governance is a core objective in all cases, and requires that the management system can reasonably achieve its objectives.

Reporting against objectives of the whole management system

A transparent and defendable approach to reporting against fishery sustainability objectives has been developed for some Australian fisheries, and adaptations of the approach are under consideration by the FAO (FAO, 2000)

Table 20.1. Conceptual objectives and components commonly identified for management of sustainable fisheries.

Conceptual objectives	Components
Natural resources conserved and environment not degraded	Fishery target species
	Fishery by-catch and incidentally impacted species
	Ecosystem structure and abundance of the components
	Habitats
	Food chain structure, productivity and flows
	Biodiversity at ecosystem, species and genetic levels
	Reversibility of impacts
	Effects of non-fishery uses on the marine environment
Human needs met now and in future	Fishery production of food and other products
	Economic production
	Social values
	Intergenerational equity
	Fishing effects on non-fishery uses of the environment
Effective management system	Legislative and policy framework
	Clear operational objectives and targets
	Management plan to achieve objectives and targets
	Management of precaution, risk and recovery
	Implementation of management measures
	Monitoring
	Evaluation against objectives and intent

and Canada (Jamieson *et al.*, 2001). Fletcher *et al.* (2001) describe the approach in detail, and elements are also described by Chesson and Clayton (1998) and Garcia *et al.* (2000). This reporting framework is very flexible and consists of four steps.

1. Selecting the components that will be reported against, based on the relevant conceptual objectives. Table 20.1 provides example components, but other components may be more appropriate in different circumstances (e.g. see Fletcher *et al.*, 2001; Jamieson *et al.*, 2001 for variations).
2. Elaborating for each component a 'tree' of relevant subcomponents, and whatever level of sub-subcomponents that are considered necessary to represent the issues considered important. Usually this is done through a participatory process involving stakeholders. Fig. 20.1 illustrates a 'component tree' for the component 'other environmental issues' in an Australian case (from Fletcher *et al.*, 2001).
3. A risk assessment to determine the relative importance and emphasis to be placed on various branches of the 'component tree,' and to guide identification of the level of risk management that is appropriate. Potentially, this could include three levels of increasingly rigorous risk assessment, each consistent with one of the many risk assessment processes that are available (e.g. Anon., 1995).

(i) A qualitative assessment to identify broad categories of risk.

Fletcher *et al.* (2001) describe a qualitative risk assessment for this based on intuitively

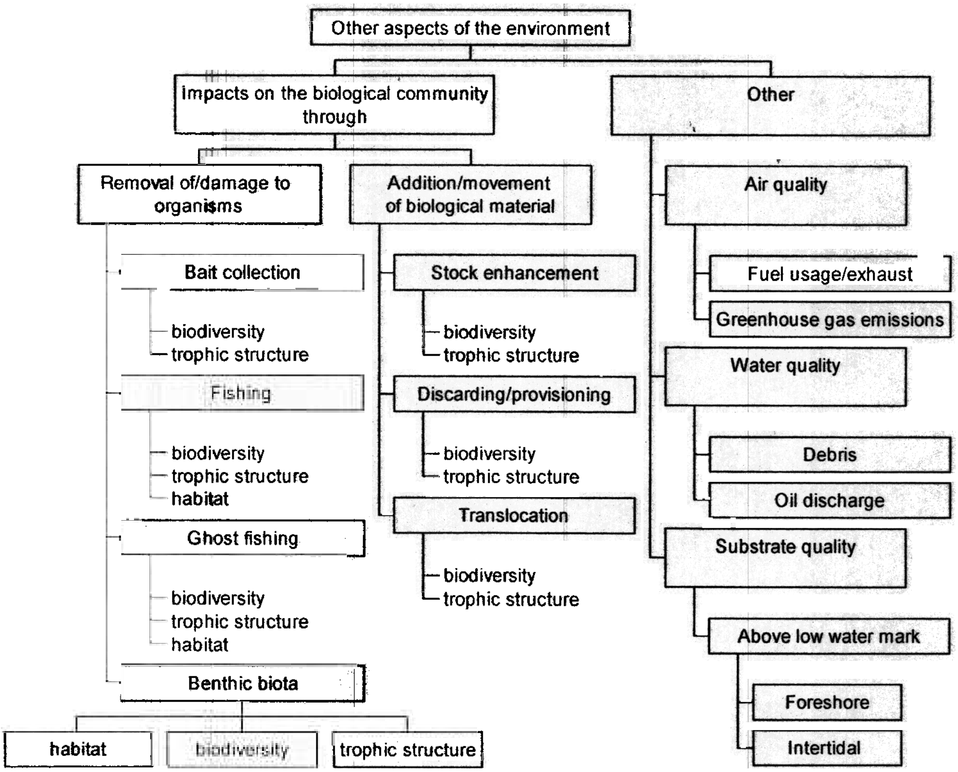

Fig. 20.1. A 'component tree' for the component 'other aspects of the environment'. showing the subcomponents considered necessary to represent the issues considered important. Usually, this is elaborated through a participatory process involving stakeholders combined with a risk assessment of subcomponents initially identified. For each branch of the tree, the sustainability report addresses operational objectives, reference points and performance measures, data requirements and availability, evaluation, robustness, fisheries management response (present and future), comments and actions, and external drivers (from Fletcher *et al.*, 2001).

scoring, first, the consequences of each issue, and then the chance that these consequences will occur. The product of these scores gives a measure of risk, and a pre-agreed range of risk is used to determine the importance given to each issue. Another qualitative methodology is the analytic hierarchy process (see Saaty, 1994) used in the marine stewardship council (MSC).

(ii) A semi-quantitative risk assessment to provide greater justification of risk categorization and the risk management response.

Typically, these assessments involve subjective and expert judgement in some major parts of the analysis and quantitative analysis in others. For example, Stobutzki *et al.* (2001) describe a semi-quantitative risk assessment for sustainability of by-catch in a tropical prawn fishery involving over 600 species. It uses a combination of expert judgement and analysis to determine both the chances of species encountering the fishing operations and the ability of each species to recover from depletion. Xi *et al.* (2001) describe a semi-quantitative method for assessing the risk of food chain-mediated interactions based on alternative hypotheses about food chain structure and diet information. The potential biological removal method (Wade, 1998) to judge the risk and set an upper limit on mortality of by-catch species illustrates another semi-quantitative assessment method. The results of such semi-quantitative assessments would be used to identify components for which the risk assessment and consequent risk management response were adequate at this level. Higher risk components require assessment at the third level of risk assessment.

(iii) Quantitative risk assessment.

A quantitative risk assessment can include formal estimates of probabilities for the hazards, and models to estimate present conditions, predict impacts, and evaluate risk management strategies. These assessments use the formal methods of quantitative risk assessment (e.g. Burgman *et al.*, 1993) and risk management evaluation (e.g. see next section and Sainsbury *et al.*, 2000).

4. Reporting for each of the branches of the component tree finally accepted, against a heading that include operational objectives and their justification, indicators, reference points and performance measures, fisheries management response (present and future) and robustness. The level of detail and quantitative rigour can be different for different branches of the component tree depending on the results of the risk assessment relating to that branch.

The final report then consists of a tree of components and subcomponents that are transparently derived from the full range of objectives of management, and a report with headings for each branch of the 'tree' addressing (at least) operational objectives, performance measures, the management response and robustness.

Quantitative risk assessment and testing of the whole management system

The framework described in the previous section can transparently guide reporting against sustainability objectives, and the risk assessment it contains can help identify the level of detail that appears reasonable for each component or subcomponent of the framework. However, the reporting framework alone is not sufficient to determine whether the treatment of any component is adequate or whether the management system as a whole is adequate to achieve the objectives of management. Performance will depend on the choices made within components – such as the reference points, assessment methods and management responses – and interaction between these choices across the different components.

There is a well-developed methodology for examining these issues quantitatively. It is based on the methods for assessing adaptive management policies (e.g. Hilborn and Walters, 1992) and operational management procedures in fisheries (e.g. Butterworth and Punt, Chapter 18 this volume). Here, this broad approach is referred to as management strategy evaluation (MSE, see Sainsbury *et al.*, 2000). In this context, a management strategy consists of the combination of monitoring, analysis of the monitoring data, use of the results of analysis in management decisions (usually through a 'decision rule') and implementation of management decisions.

The general framework for MSE evaluation is shown in Fig. 20.2. Key features are:

1. Simulation of the managed system as a whole. This means simulation of the ecological system, the fishery and the management decision system, and the connections between them made through monitoring and implementation of management decisions.
2. Each management strategy is evaluated and compared by performance measures. Figure 20.3 illustrates a simple performance measure – the difference between the present value of an indicator and its reference points in any year. Within the MSE calculations, the performance measures can be based on the true state of the simulated system.
3. The model for the biological system in Fig. 20.2 must represent the key uncertainties and reasonable alternative interpretations of 'how the world works.' A range of alternative models are often included to represent uncertainty.
4. The management decision process of Fig. 20.2 represents the management strategy being evaluated, and its simulation includes:

- The observation process, i.e. simulation of the 'information stream' (e.g. catch or survey data) that enters the analysis and decision process.
- The assessment or analysis. This model specifies how the monitoring data are analysed for performance assessment and to provide input to management decision making.
- Use of the results of analysis in decision making. MSE requires that the connection between the analysis of monitoring data and subsequent decision making be made explicit. In fisheries, this is often through a catch decision rule (e.g. Sainsbury *et al.*, 2000).

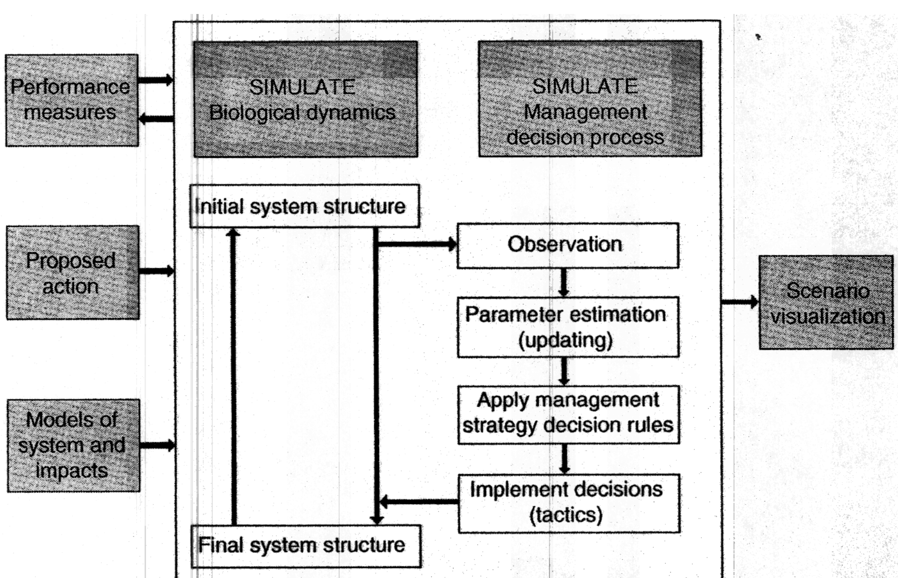

Fig. 20.2. Framework for management strategy evaluation (MSE). Performance measures are derived from management objectives and would at least include measures relating to ecological and fishery production. The biological dynamics are simulated using a model or a series of models that represent knowledge and uncertainty about the way the biological world works. Prospective management strategies are simulated as they interact with the biological model. A strategy includes the observations (monitoring) made, the analysis of those observations to update management related parameters, use of these updated parameters in management decision making and implementation of decisions. Alternative management strategies can be compared using the common currency of the chosen performance measures. From Sainsbury *et al.* (2000).

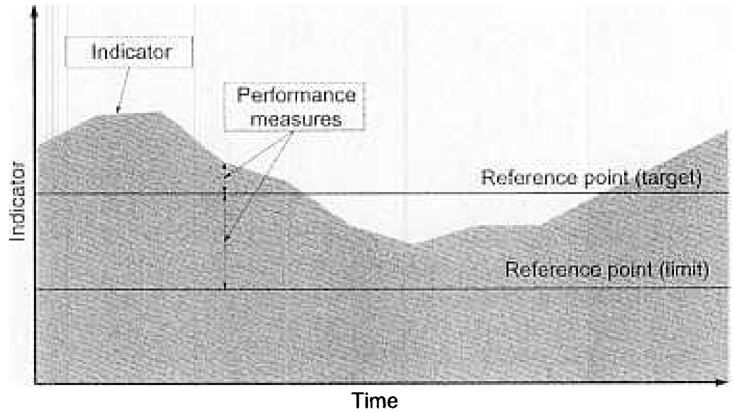

Fig. 20.3. The use of an indicator and reference points to define simple performance measures, the difference between the indicator variable and its target or limit reference point in any year.

- Implementation of management decisions. The reliability of implementation can have a major effect on the performance of management strategies, but is often overlooked.

The MSE methodology can be used to examine the overall performance of the fisheries management system, or to compare alternative options for any part of it, in the 'common currency' of the management performance measures. Specifically, it can be used to identify risks and test risk management options, to identify the indicators, reference points and management responses (including decision rules) most appropriate for particular circumstances, and to test the precaution and robustness of management strategies. The MSE methodology has proved effective in evaluating management strategies in many fishery situations (see Butterworth and Punt, Chapter 18, this volume). Sainsbury *et al.* (2000) summarize use of MSE to test strategies that address fishery ecosystem objectives – including objectives relating to by-catch species, predators dependent on harvested prey, and seabed habitats and associated fish assemblages. These methods have also been applied to the management of some 'emergent properties' of ecosystems (Duplisea and Bravington, 1999). Thus, MSE provides an established methodology to evaluate management strategies quantitatively to achieve ecosystem objectives, and to identify the management and ecological circumstances in which particular strategies are likely to perform well.

Indicators and Reference Points for Ecological Objectives in Sustainable Fisheries

Before examining possible reference points for fishery ecosystem objectives, there are two general issues to consider: (i) is there a need for explicit reference points for 'emergent properties' of the ecosystem, such as food-web dynamics, ecological community structure and biodiversity, or are species-based reference points sufficient? and (ii) should the reference points be based on properties of the undisturbed ecosystem, such as the natural range of variability?

Species or ecosystem properties

ICES (2000) suggests that there is no need for ecosystem emergent properties to be the subject of direct management objectives. They suggested that if fisheries were sustainable at the level of species and habitats, then it is unlikely that any of the emergent properties would be at risk. We argue that there remains a need to include direct consideration of emergent properties, along with consideration of the component species and habitats, because:

- Several conceptual objectives of sustainable fisheries relate to emergent properties, and so performance assessment should address them directly.
  In practice, not all species and habitats in an ecosystem can be monitored and managed individually, thereby ensuring their individual sustainability is not practical.
- Even for species and habitats that can be addressed individually, the appropriate species- and habitat-specific reference points to achieve emergent properties are not understood.
  Understanding of ecosystem dynamics is poor, and so arguments that emergent properties will be protected by protection of certain components lack robustness.

Reference points based on individual species that are sufficient to achieve emergent properties may be developed in future, but, for now, direct examination of emergent properties remains useful and necessary. This does not detract from the practical focus of the ICES (2000) suggestions, but, in the short term, most practical reference points will relate to the species level, and ecosystem considerations should not divert attention from managing individual species sustainably.

Reference points based on undisturbed natural conditions

It is intuitively attractive to define reference points in relation to undisturbed natural conditions, and this can be done in two different ways.

1. Require maintenance of some undisturbed natural conditions. For example, Jamieson *et al.* (2001) emphasize maintenance of ecosystem and species properties 'within bounds of natural variability' to 'play their historic role', while Fowler *et al.* (1999) suggest limits to fishing based on natural rates of predation. However, it seems to us possible for a fishery to meet the high-level objectives of sustainability while ecosystem and species properties are beyond their natural ranges.

2. Use the undisturbed condition as part of a measure of relative change, such as the fraction of the unfished population size or seabed habitat that remains. Such reference points are likely to be very valuable, but are difficult to establish for ecosystem properties. Often there are not reliable descriptions of the unfished ecosystem, and comparisons based on model predictions will be contentious until there is stronger scientific consensus on appropriate ecosystem models. Probably the most promising approach to measuring relative change in ecosystem properties is through comparisons with unfished reference sites, such as MPAs. There are not yet accepted methods to develop such reference points (see below), but MPAs probably provide the best means of avoiding drift in reference points as the memory of pristine conditions fades – the 'shifting baseline' effect (see Pauly, 1995).

Development of indicators and reference points for fisheries ecosystem objectives is an active area of investigation. For example, prospective indicators, some with associated reference points, are given by Garcia (2000), Gislason *et al.* (2000), Murawski (2000), Jamieson *et al.* (2001), NMFS (1998) and ICES (2000). Smith *et al.* (2001) provide a comprehensive review of ecological indicators and reference points from the fisheries and aquatic ecological literature, along with issues relating to their interpretation. There are many options available, but most have not been tested either empirically or scientifically in the context of a fisheries management strategy. There is an urgent need for this testing, especially in relation to ecosystem structure, food chain dynamics and biodiversity, but there is also need for practical guidance on indicators and reference points that can be applied while that testing is done.

Table 20.2 provides some suggested target and limit reference points for fisheries ecosystem objectives, based broadly on experience to date, that should be practically implementable in the short term. Most of these reference points relate to species, rather than ecosystem emergent properties, but take account of ecosystem processes. It is not claimed that the reference points in

Table 20.2. Suggested 'best practice' reference points for assessment against the main ecological components of the objectives of a sustainable fishery, as identified in Table 20.1.

Component	Target reference point	Limit reference point	Comments
Target species (see below for modifications of these reference points when applied to significant prey species)	Fraction of fishing mortality or spawning biomass giving maximum sustainable yield, modified according to information reliability: fraction of MSY fishing mortality or biomass levels if well estimated; otherwise fishing mortality giving 40% reduction in equilibrium spawners per recruit or fishing mortality equals 75% natural mortality. If only catch history available, then catch target is 75% of the average annual catch during period reasonably argued to be sustainable. CAY (*sensu* Francis, 1993) with < 10% probability of violating limit reference points.	Fishing mortality or spawning biomass giving maximum sustainable yield, modified according to information reliability: MSY fishing mortality or biomass levels if well estimated; otherwise fishing mortality giving 35% reduction in equilibrium spawners per recruit or fishing mortality equals natural mortality. If only catch history available then catch limit is the average annual catch during period reasonably assumed to be sustainable.	See Mace (2001) and NMFS (1998) for use of MSY points as limit points. Tiered linkage of targets and limits to information availability based on Witherell (1999) and Witherell *et al.* (2000). A reducing catch limit through time is implied for species without assessment (i.e. catch history only). Explicit decision rules needed to ensure targets achieved and limits not exceeded.
By-catch (retained, discarded, or killed but not landed)	As for target species.	As for target species.	Sustainability reference points should not depend on economic value of species.
Food chain structure, productivity and flows	Fishing mortality or biomass targets for significant prey species altered from the levels appropriate for target species (see above) to give 80% chance that spawner biomass is no less than mid-way between the unfished level and the MSY level: modifications for information reliability altered accordingly from the levels appropriate for target species. Viable and representative biodiversity undisturbed in protected areas (no specific target but viability and representativeness justified on a case-by-case basis). 'Food web in balance' (FIB) index not decreasing systematically through time.	Fishing mortality or biomass limits for significant prey species altered from the levels appropriate for target species (see above) to give 50% chance that spawner biomass is mid-way between the unfished level and the MSY level: modifications for information reliability altered accordingly.	Based on CCAMLR approach (e.g. Constable *et al.*, 2000). See Pauly *et al.* (2000) for FIB index.

Table 20.2. *Continued.*

	Target reference point	Limit reference point	Comments
	No species threatened or endangered. No loss of stocks. No reduction in number of discrete spawning areas. No local extinctions within the managed ecosystem. Fishing practices with minimal selective differential and reduction in effective spawners number (N_e). Viable and representative biodiversity undisturbed in protected areas, and protected areas encompass breeding sites (no specific target but viability and representativeness justified on a case-by-case basis).	No species extinct either globally or throughout the managed ecosystem. No populations below genetically viable level. No significant habitat type reduced to less than half unfished level. Genetically effective number of spawners (N_e) in populations not reduced below half unfished number.	Reference points above for target and by-catch species should result in larger populations and therefore N_e than many other reference points. Estimation of genetically viable population level and effective number of spawners (N_e) in Burgman *et al.* (1993). Estimation and effects of fishing practices on selective differential in Law (2000) and on N_e in Kenchington (1999). Half reduction in habitats and N_e limit by analogy with target species population size.
Endangered or protected species	Fishing mortality as close to zero as possible.	Precautionary limit on mortality that does not significantly impair recovery e.g. potential biological removal (PBR).	See Wade (1998) for description of PBR.
Reversibility of impacts	Changes potentially reversible within a human generation time (< 20 years). Recovery of overfished stocks within 10 years (or, if much longer or shorter, a fish generation time).	No irreversible change. Changes potentially reversible in a human generation (20 years). Recovery of overfished stocks in 10 years (or a fish generation time if much longer or shorter).	To meet objectives of inter-generational equity. Recovery of overfished stock from USA National Standard Guidelines (NMFS, 1998).
Effects of non-fishery uses on the marine environment	Sustainability targets for components above individually met for combined effects of all users.	Sustainability limits for components above individually met for combined effects of all users.	Management of combined effects of all users achieved through integrated management of appropriately defined local ecosystems (e.g. large marine ecosystems; Sherman and Duda, 1999).

Table 20.2 are necessary or sufficient to achieve sustainability for fisheries and marine ecosystems. Rather, they provide a starting point for an emerging 'best practice' to accommodate ecosystem considerations in fisheries management. It is expected that 'best practice' reference points will evolve substantially in the near future. It is also recognized

that the reference points suggested relate mainly to the methods of assessment and management used in commercial fisheries, rather than traditional or artisanal fisheries. Furthermore, Table 20.2 provides a set of reference points in isolation, whereas the likely outcomes of management must be evaluated in a 'whole management system' context, as discussed earlier. All these issues need and will receive further examination, but there is sufficient information available now to make a credible start on practical measures to incorporate ecosystem sustainability into fishery management.

Role and Experience of Marine Protected Areas in Fisheries Ecosystem Management

Potential roles of MPAs in fisheries management

A wide range of roles has been suggested for MPAs in fishery management (Hoagland *et al.*, 2001). A marine reserve is expected to help control fishing mortality. Where fishing technologies are non-selective, MPAs may reduce by-catch of non-target species and the impacts of trawl gear on seafloor habitat. By eliminating fishing by mobile gears, the seafloor habitat complexity and ecosystem composition are likely to change from disturbed to mature characteristics (Watling and Norse, 1998). Marine reserves can be used to implement the precautionary approach, and hedge against uncertainty and the risk of fisheries collapse (e.g. Bohnsack, 1996). Gislason *et al.* (2000) suggest that MPAs may help achieve ecosystem and biodiversity conservation objectives, provided they are selected in a way that ensures protection of a significant fraction of the major habitat types and their interdependences. MPAs have also been promoted as a way to deal with ecological impacts that are costly or impossible to reverse (Hoagland *et al.*, 2001), such as species extinctions and replacement of commercially important species by other species. MPAs can be used as reference sites for sustainability indicators and reference points (see Dayton *et al.*, 2000), but success will depend on the kind of indicators to be measured, and the period the area has been under protection. It is important to note that MPAs would not be expected to provide good reference points for sustainability if both fished and unfished areas were being degraded over time due to factors operating at larger time or space scales. Figure 20.4 summarizes the potential pathways of fisheries and ecological benefits from MPAs.

Experience with MPAs

Ecological performance within protected areas

Increased abundance or density of finfish and shellfish species, especially previously harvested species, have been documented in a great many marine reserves (see Guénette *et al.*, 1998; Sumaila *et al.*, 2000; Ward *et al.*, 2000 for comprehensive reviews). Increases in mean size, age and biomass of finfish have been found in almost all studies (e.g. Russ and Alcala, 1998). In many cases, increased fecundity and reproductive capacity are also recorded (e.g. Murawski *et al.*, 1998), which in some situations can be significant in conserving the spawning stock (Sluka *et al.*, 1996). However, such increases in MPAs have not been seen in all cases. For example, in California, red abalone populations increased in protected areas, but green and pink abalone populations did not recover until mature adults were translocated there (Tegner, 1993).

In some cases, marine reserves have been shown to reverse the decline in species richness and genetic diversity caused by fishing, often by alleviating by-catch mortality. For example, Ward *et al.* (2000) cite examples of increased species richness in reserves compared with unprotected areas, with 60% more species in the reserve in a New Zealand example.

Fisheries-related benefits from protected areas

In some cases, it has been shown convincingly that MPAs increase or maintain fishery yields in surrounding areas (e.g. Hastings

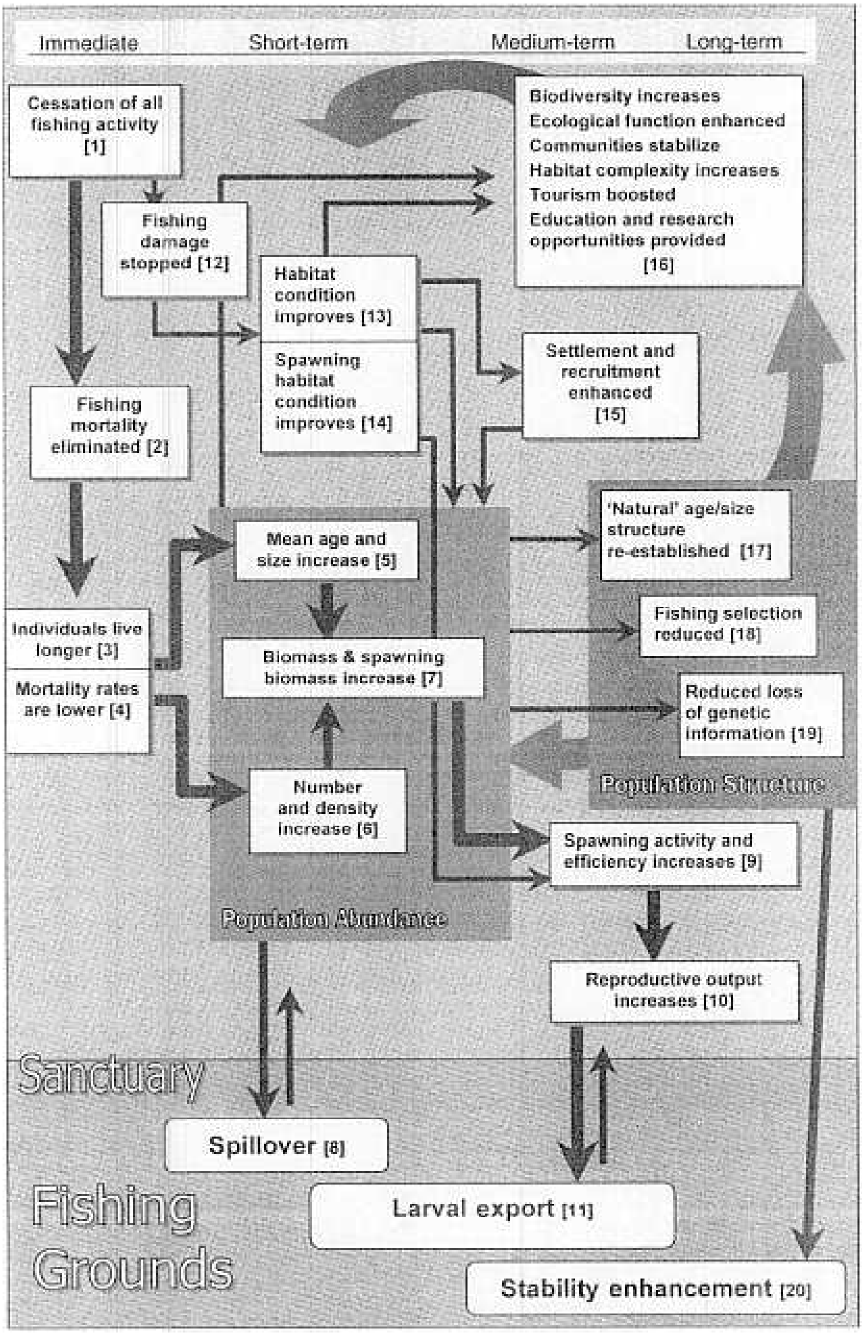

Fig. 20.4. Conceptual framework showing the pathways by which the establishment of an MPA could lead to environmental enhancement within the protected area, and biomass enhancement outside the sanctuary through the processes of spillover, larval export and stability enhancement. The size of arrows roughly indicates the hypothesized importance of that pathway to the potential for fisheries enhancement. Text boxes 5–7 are grouped together to indicate that they are the processes involved in increases in population abundance. Text boxes 17–19 are grouped because they are the processes responsible for the long-term changes to sanctuary populations expected to improve population stability and resilience. The very large arrows in the background indicate poorly defined or understood pathways. From Ward *et al.* (2000).

and Botsford, 1999), but not always (e.g. Pastoors *et al.*, 2000). It has been argued that in some species the planktonic larvae produced by adults in MPAs can significantly enhance recruitment across large fished areas (e.g. Roberts, 1997), but this is difficult to demonstrate and so far there is no direct evidence for it.

Economic benefits to fisheries have been identified through the increase of non-consumptive benefits, such as 'dolphin watch' (see Dixon and Sherman, 1990), and future benefits due to protection from the vagaries of uncertainty (e.g. Lauck *et al.*, 1998; Sumaila, 1998).

Do MPAs really achieve their objectives? In general, theory and simulation modelling support the idea that MPAs can help meet ecological, economic and social objectives, but it has been difficult to test the reality of these broader benefits in practice. A major part of this difficulty is that MPAs usually have been established without good monitoring and evaluation procedures to ensure that they are achieving their ecological, economic or social objectives. Also, many MPAs have little or no baseline data for comparison, and many are too small or too recent to demonstrate the effects of protection. A critical need is to establish monitoring and performance assessment regimes for MPAs that are capable of determining whether they are achieving their intended conservation and fishery purposes.

Establishment of MPAs to achieve fisheries ecosystem objectives

Under what conditions do MPAs work best? Various studies have shown that:

- MPAs perform best at enhancing species whose adults are relatively sedentary but whose larvae are broadcast widely (e.g. Pitcher *et al.*, 2000). The adults of such species gain maximum benefits from protection, while the larvae help 'seed' segments of the population outside the MPA.
- MPAs are likely to succeed when they are large (Walters, 2000), particularly with respect to protecting trophic flows (Pauly *et al.*, 2000) and genetic diversity (Ward *et al.*, 2000).
- Public and local community support and involvement is essential for success of MPAs (Sumaila *et al.*, 2000).
- Fishers are willing to embrace the MPA concept if it is economically neutral or does not unduly constrain the potential to increase their economic gains (Sumaila *et al.*, 2000).
- Successful MPAs require that fishing activities are monitored and controlled within and outside the MPA (Sumaila *et al.*, 2000).

MPAs fail to produce the anticipated benefits if the protected area is located in unfavourable habitat (Tegner, 1993) or does not include a sufficient portion of favourable habitats (Armstrong *et al.*, 1993). Consideration of dispersal – including home ranges, migration patterns and 'sources and sinks' for larvae and settlement – within and between habitats is needed to create an effective network of MPAs (e.g. Ballantine, 1997). The rate and scale of dispersal influence the size of the MPA necessary to rebuild or protect populations and ecosystem characteristics (e.g. Rijnsdorp and Pastoors, 1995; Watson *et al.*, 2000).

Several methods are available to design MPAs (e.g. Bennett and Attwood, 1993; Ballantine, 1997; Allison *et al.*, 1998). These methods can accommodate uncertainties about biological processes or management implementation, and MPAs can be examined using the adaptive management or MSE methods described above (e.g. Pauly *et al.*, 2000). Some of the critical information needs about the likely scale and location of major seafloor habitats can be met by new seafloor mapping technology. This uses a combination of remote-sensing techniques (such as side-scan sonar and multi-beam echo sounding), direct sampling and visual observations (such as digital photography and image processing) to characterize the seafloor (see Todd *et al.*, 1999). These techniques can provide rapid and highly detailed views of the seafloor over large areas (see Schwab *et al.*, 1997), including the effects of human activities, such as waste disposal and bottom trawling. Figure 20.5 is a

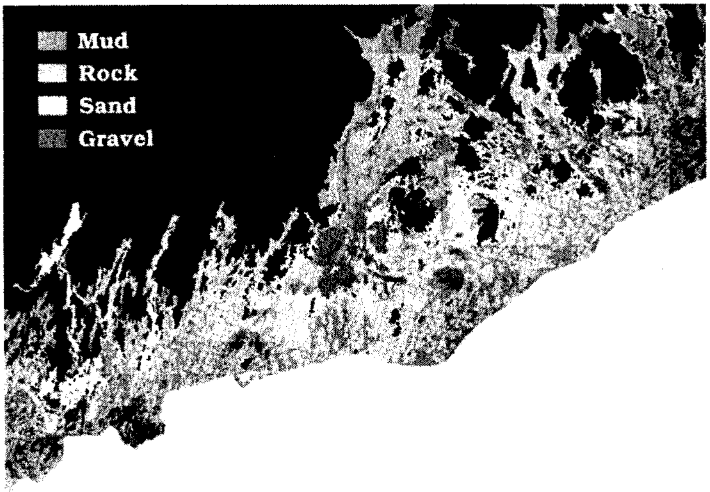

Fig. 20.5. Map of surficial geology as captured by side-scan sonar, and interpreted using GIS layers that describe the spatial distribution of rock, sand, gravel and mud on the seafloor. Source: Mapping Penobscot Bay: Surficial Geology, by Joe Kelly, University of Maine (see www.penbay.net/geology.htm).

map produced using such seafloor mapping technology.

Such maps can rapidly identify the location and scale of likely major habitat types. They can be used to design a precautionary and adaptive network of MPAs to protect the different seafloor types, even if ecological information is limited initially. They can also be used to monitor sustainability indicators, such as the spatial distribution of major seafloor habitats, as suggested by Gislason *et al.* (2000).

New technologies may also assist with monitoring and control of fishing activities within and outside the protected area. For example, advanced vessel monitoring systems are already being used in the Great Barrier Reef in Australia, in the Hawaii longline fleet and the Georges Bank off the coast of Maine (Anon., 2001).

There has been considerable debate about the optimal size of MPAs. Some have argued that they should include as much as 70% of the habitat (Lauck *et al.*, 1998) to serve as an adequate hedge against uncertainty, and Walters (1998) argues that, given our inability to provide accurate stock assessment, we should treat the seas as closed to fishing, with small exceptions (i.e. very limited fishing areas and times). To protect genetic diversity, Kenchington (1999) recommends that MPAs should include part or all of the breeding area of species of interest. A target MPA size of 20% of the world's oceans has been suggested commonly. Our view is that the optimal size of an MPA for a given habitat would depend on the objectives for setting up the MPA, and the nature of the ecosystem and species it contains.

Discussion

The broadening of fisheries management to include ecosystem-related objectives raises a large and potentially confusing range of possible issues for consideration in management decisions and in reporting or assessing management performance. However, there are existing methods and approaches to addressing the issues that are practical, accessible to stakeholder participation and scientifically assessable. In particular, there are methods and experience to allow:

- systematic and transparent selection of issues to address in reporting fishery sustainability in an ecosystem context;
- quantitative risk-based testing and identification of appropriate sustainability indicators and performance measures for key issues; and

- quantitative risk-based testing of the likely performance and level of precaution of management strategies in the context of the whole management system.

Application of these and other methods has already provided an emerging set of 'best practice' indicators and reference points that can be used practically in fishery management to address ecosystem issues. While there undoubtedly will be significant improvements in the future, these could be used in fishery management immediately.

MPAs hold promise as a rational way of managing ocean resources but, while local ecological benefits of MPAs have been demonstrated, this promise should not be overstated. In particular, MPAs should not be seen as a panacea to all the problems of fisheries management. MPAs are best seen as part of a collection of management tools and measures, with a combination of on-reserve and off-reserve measures being used together to achieve sustainable fisheries and marine ecosystems. New technologies are making the design, enforcement and monitoring of MPAs easier and more practical, but the lack of good performance assessment for most MPAs is a major impediment to conclusive evaluation of MPAs as a fisheries and ecosystem management tool. However, MPAs are the marine counterpart to terrestrial systems of national and international parks. They are conceptually easy to understand, are naturally appealing to the public and have a role in sustainable management of marine ecosystems.

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