REVIEW OF INDICATORS IN FISHERIES MANAGEMENT – A DEVELOPMENT PERSPECTIVE

P. DEGNBOL and A. JARRE†*

A review of indicators for an ecosystem approach to fisheries management is presented, focusing on multispecies fisheries and limited resources for assessments and implementation, as often is the case in developing countries. Emphasizing the need to link indicators to management objectives, indicators from the literature are grouped into four categories, relating to the immediate fisheries resource base (single-species and multispecies indicators) and the wider ecosystem (habitat structure and ecosystem functioning). The usefulness of these indicators is assessed along three dimensions of acceptability among stakeholders, observability, and relation to fisheries management using a traffic light approach. The top ranking indicators are highlighted as a generally good start for any particular fishery management case. It is, however, argued that, even with similar management objectives, indicators need to be specific to both ecosystems and the institutional set-up if they are to be effective for management, and that indicators may consequently differ considerably between individual management applications.

Key words: development, ecosystem approach, fisheries management, indicators, knowledge

THE KNOWLEDGE BASE FOR FISHERIES MANAGEMENT AND THE NEED FOR INDICATORS

The knowledge base for fisheries management

In industrialized countries, fisheries management is for the most part based on what can be called the "modern fisheries management model", in which mandated research within specialized institutions produces formalized knowledge, which is then used as a basis for management decisions and implementation by a centralized bureaucracy in interaction with representative democratic institutions. The management objectives in this model are in many cases not explicit, but the long-term sustainability of the resource base has been the overriding objective, whether explicitly stated or not. This indicates that the development of this management model has been driven largely by natural scientists.

The implementation of management within this rationality is entirely linked to an assumption of predictability, which is an understanding that specific and predictable targets can be achieved by implementing regulatory measures such as catch or effort quotas, or technical measures. This normative and regulatory context means that the production of biological knowledge of the stock dynamics and predictions of the response of stocks to fishing has been the dominating form of mandated science (Jasanoff 1990) within this model.

The specialized research organizations taking on this role were established in countries around the North Atlantic during the early 20th century, and are now an integral part of fisheries management systems in industrialized countries. In developing countries, development efforts based on the modern fisheries management model have usually emphasized the need for specialized research institutions that can produce this kind of knowledge to be set up. This has been done to the extent that this model for producing the cognitive base for management – including the encapsulation of cognitive validity within specific research institutions and the associated relevance criteria for knowledge – has been promoted by most national and international development agencies as an end in its own right, considered to be an essential component of any fisheries management system, irrespective of normative, regulatory or social context (Degnbol 2003).

This model for establishing a knowledge base for fisheries management has had limited success in both industrialized (e.g. European Commission 2001) and developing countries. In relation to the knowledge base, a decoupling of, or even contradiction between the formalized research knowledge and the users' (i.e. direct and indirect stakeholders) knowledge, has been stated as contributing to the problem, as an inherent cultural contradiction (Finlayson 1994) or as a reflection of differing discourses and interests within the man-

* Institute for Fisheries Management and Coastal Community Development, North Sea Centre, P. O. Box 104, 9850 Hirtshals, Denmark. E-mail: pd@ifm.dk
† Danish Institute for Fisheries Research, Department of Sea Fisheries, North Sea Centre, Denmark

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agement institutions (Bailey and Yeardley 1999, Wilson 2000).

Mandated fisheries research is therefore associated with two problems (Degnbol 2003):

(1) Fisheries biology is approaching the limits of cost efficiency relative to the value of fisheries – and can still not deliver the goods in terms of numerical predictions of sufficient accuracy or precision;
(2) The models and concepts of fisheries biologists are becoming increasingly alien to stakeholders. This gap is not just a question of lack of understanding or education on the side of fishers, but is rather associated with the basic scales at which the resource basis for fisheries is observed and understood.

The result is that contemporary fisheries management is facing a multifaceted crisis:

- Fisheries biology does not deliver a knowledge base for fisheries management that is considered valid by stakeholders – loss of legitimacy;
- Solutions that are direct extensions of present approaches are not feasible practically or conceptually – more of what has created the problems in the first place does not appear to be a solution;
- An extension of present approaches will be limited by rapidly escalating costs.

There is therefore a need for new approaches in fisheries management, which are cost efficient, provide knowledge considered valid by stakeholders, and which are able to deliver. However, because of the close association between the form and contents of management institutions (*sensu* Scott 1995) and their knowledge base, new approaches cannot be defined from the natural sciences alone, but need to be developed in a multidisciplinary context, including not only disciplines from the natural sciences (e.g. physical oceanographers and biologists), but also the social sciences.

This paper will investigate the options for a knowledge base for fisheries management that can inform management decisions adequately, is considered legitimate by stakeholders and can be produced within realistic costs. It will focus on the situation in developing countries, although similar considerations will be equally relevant in industrialized countries. The development context is assumed to be characterized by mixed fisheries and limited resources available for observation and management implementation. The evaluation will be different for a single-species fishery or in a situation where ample resources are available for observation and implementation, whether these conditions would apply in a developing or an industrialized country.

Widening the scope of sustainability from single target species to ecosystems: the need for indicators

Knowledge to inform management decisions must relate clearly to the objectives for management. Some concept of sustainability has been an overriding objective for fisheries management and this paper will focus on knowledge to support management for ecological sustainability. This does not imply that objectives such as social and economic benefits to society are irrelevant, but that ecological sustainability is considered an ultimate limit condition, which in the longer term defines the boundaries for fisheries.

The sustainability concept that has been pursued in fisheries management has changed over time. Following the report of the World Commission on Environment and Development (1987), sustainable exploitation is generally understood as a process balancing conservation and exploitation for long-term use, and consequently as a dynamic process evolving with changes in the way the needs of present and future generations are met. Sustainability of the target resource had for several decades been included as an objective in fisheries management, but with the Code of Conduct for Responsible Fisheries (FAO 1995), the concept of sustainability has been extended to include ecological sustainability in a wider sense, as well as social sustainability. At the same time, consensus has been growing that wild aquatic resources production is not easily and generally optimized, especially in the medium and long term. The focus of management has consequently changed from targeting production to emphasizing conservation and risk management.

Increasingly, the emphasis is on the need to consider fisheries sustainability in relation to the entire ecosystem, not only in relation to the stock (FAO 2003, Sinclair and Valdimarsson 2003). This implies a corresponding extension of the scope of the knowledge base for fisheries management, from the single stock being the unit and yield sustainability the main concern, to the ecosystem being the unit and the maintenance of system integrity the main management concern.

Even within the natural sciences, and in view of the limited resources available for developing ever more complex predictive models, a fundamentally new approach is gaining acceptance, which does not pretend to understand or measure causal relationships and all relevant processes in detail. In this approach, the "hard predictabilty" that has been the basis for the modern fisheries management model is replaced by a management system based on "soft predictability", which does not require detailed understanding of processes and capability of quantitative predictions of outcomes of specific policies (Degnbol 2002). The knowledge base for management becomes indicators and qualitative predictions, rather than quantitative predictions based on process models. A recognition of these problems has created the basis for a rapidly emerging discussion on indicators for fisheries management and of Ecological Quality Objectives in relation to fisheries.

The discussion of fisheries indicators in a wider ecosystem scope can benefit from the experiences gained from the development of single-stock indicators that has been ongoing for several decades. Single-stock indicators have been discussed in relation to reference points for fisheries management and have focused on the spawning stock and the fishing mortality, as estimated through analytical assessments, as the main indicators (e.g. the work in the International Council for the Exploration of the Sea [ICES 2002a, 2003], at NAFO [the North Atlantic Fisheries Organization] and in the National Marine Fisheries Service of the USA [NMFS 1998]). This development has revealed serious problems with the approaches, which are still unresolved. Similar problems are expected also for indicators with a wider scope beyond the single-stock perspective. One of the major problems has been the identification of reference points on the basis of historical data, because of both the large unexplained variability in time-series and the problems in distinguishing between anthropogenic impact and other causes of change. Another problem is the estimation of the uncertainty of point estimates of the indicators, which is required as a component of an implementation of the precautionary approach based on indicators.

The task of identifying the indicators, methodologies and reference points needed to implement an ecosystem approach to fisheries management has in comparison hardly begun. Important work is ongoing to develop the conceptual basis for indicators and to list and evaluate indicator candidates. In international fora, this comprises the work in the advisory committees of ICES (ICES 1999, 2000, 2001b, 2002b); the Oslo/Paris Commission's Ecological Quality Objectives process (www.ospar.org), the work in the SCOR–IOC working group on ecosystem indicators (www.ecosystemindicators.org)) and the work by FAO to develop guidelines for an ecosystem approach (FAO 2003). This work has substantiated the notion that ecosystem indicators currently cannot be based on a full understanding and monitoring of the underlying processes. It is increasingly realized that ecosystem indicators must include meta-indicators that summarize the outcome of many and complex underlying processes, which may not need to be understood in detail (Degnbol 2002).

Discussion on the knowledge base for an extended scope for fisheries management has also highlighted the close interdependence of the knowledge base and the management context. One of the first comprehensive studies was the US NMFS study that identified a number of principles, goals and policies to guide ecosystem-based fisheries management (NMFS 1999). That document presents a comprehensive discussion of the issues involved in the inclusion of ecosystem aspects in fisheries management, but it is clear that there is still a long way to go before operational indicators will have been identified. The principles refer to thresholds and limits, but this is used in a generic sense without reference to specific indicators, which are not identified.

The most mature result of this discussion emerged from the FAO-led process starting with the Reykjavik conference in 2001 (Sinclair and Valdimarsson 2003). That process resulted in a set of guidelines on the ecosystem approach to fisheries (FAO 2003), which emphasizes the linkage between indicators and objectives. The identification of indicators is seen as a step that can only be taken after a series of other steps have been made, including setting broad objectives, developing operational objectives from broad objectives, and developing operational objectives for issues. This will typically be an iterative procedure.

Indicators in the management context

It is important to keep in mind the fact that indicators for fisheries management are a means to an end, *a priori* defined system characteristics that can provide feedback on progress towards management goals and objectives (Slocombe 1999). The indicators that are relevant in a specific context will therefore depend on both the specific objectives for management, as well as the management institution that is to be informed by the indicator.

The primary consideration is the management objectives. Indicators must relate to the objectives by providing information on the state relative to the specific objectives for management and the direction to move to achieve those objectives. The set of indicators required if the objective is single-stock yield optimization will be different from that required if the objective is risk aversion relative to specific unwanted ecosystem effects of fisheries. Single stock Maximum Sustainable Yield (*MSY*) or F_{MSY} may have been considered sufficient indicators to optimize single-species yield, but they will not be sufficient to prevent unwanted ecosystem effects. Second, the institutional set-up for management has important implications for the choice of indicators. If the management institution is based on a short-term decision horizon requiring hard predictions (e.g. the Total Allowable Catch [*TAC*] system), one type of indicators will be required, whereas an adaptive management system will require indicators with different characteristics.

The participants in the management institution are also important: indicators must be accepted as valid characteristics by at least a sufficiently powerful subset of all stakeholders to be used as the basis for the management decisions taken. The importance of acceptance by stakeholders is alluded to within most of the literature dealing with environmental or fisheries indicators in relation to management. This is, however, generally stated as an important issue without further consideration of the implications. Acceptance is dealt with as if it was a trivial "add-on", without implications for other parts of the management set-up or the relevance of indicators. However, acceptance is not a trivial issue, as is known to fisheries scientists who have been confronted with fishers disagreeing strongly with their stock assessments. For the most part, such disagreements are not just a pretext to resist quota reductions, but are based on a genuine sense by fishers that they have observed a different reality from what is reflected in the assessment. Such disagreements on the actual state of the stock and the fisheries can be explained by many factors at play simultaneously, including technical (that observations are made on different scales and with different sampling pattern) and social and cultural differences between scientists and fishers and the institutions in which they operate. Data collected with high resolution from the fisheries may in specific cases demonstrate that the apparent contradictions between observations made by fishers and the overall research-based stock assessment just reflect different scales of observation of the same phenomenon, and data from fisheries can in this way be integrated directly in a research-based analysis. However, such an analysis remains within the research discourse, and such use of data from the fisheries does not necessarily facilitate better acceptance of the result by fishers.

Studies of acceptance of the knowledge base for fisheries management are now forthcoming (e.g. Neis and Felt 2000). These studies may illuminate a basic problem in achieving wide stakeholder acceptance of the validity of indicators to be used in fisheries management in a modern context: the rationality of modern fisheries management requires the knowledge base for management decisions to be firmly rooted in what is considered to be scientific objectivity as the first priority. This requirement will, in most cases, result in assessments that are incomprehensible, or which may even be counter-intuitive, to anybody beyond the small community of professional fisheries stock assessment scientists. It can be noted that this problem is not specific to fisheries, but is another variant of the basic democratic problem of the alienation of the citizen *vis a vis* the knowledge base for most decisions relating to our interaction with our physical and biological environment (Turner 2001).

A criticism that has frequently been expressed in relation to indicators describing the resource system and the biological production base is the general absence of reference points, so management needs to rely on case-to-case evaluation. However, if stakeholder involvement is to be an important component of the management system, this procedure may be suitable.

The question of scale of indicators is not trivial, especially not in relation to acceptability. The indicators should reflect the scale of the management unit, but stakeholders' observations and understanding of the resource system may reflect a very different (and often more local) scale. Integration of the spatial dimension into models and discussions is helpful for mutual understanding and increased acceptability, although it can be resource-intensive.

The cost-effectiveness of indicators must be seen in relation to the resources available to the users and to the management institutions. The evaluation of indicators in a developing-country context has also highlighted the usefulness of (and, in a situation of limited funding, need for) cooperation between the local population, through valuing local knowledge and relying on local data sampling to the maximum extent possible (e.g. monitoring of catch size and composition), and scientists to evaluate the data and correct sampling schemes if necessary, as well as overseeing the potentially complicated taxonomy of the catch and ecosystem components.

It has been demonstrated here that indicators to fisheries management cannot be developed from a technical perspective alone, but must be appropriate to the specific institutional setting within which they are to be applied. It is therefore relevant, before indicator candidates are identified and selected within the technical research-based domain, to first identify the requirement for indicators within the specific management setting.

The implication is that a general and global list of indicators will be impossible to develop, because it is based on a misconception of indicator development being a contribution to basic natural science, rather than the development of a tool to solve specific management problems. The technical options are endless, but only a small subset will be relevant in any specific situation, dependent on the management context. This paper will therefore focus on the properties of indicators from a management context perspective.

FISHERIES SUSTAINABILITY INDICATORS

Indicator concepts

OBJECTIVES AND APPROACH – INTERNATIONAL COMPARABILITY VERSUS LOCAL MANAGEMENT GUIDANCE

The development of the concept of indicators in relation to fisheries sustainability has taken place within two different agendas.

One agenda is concerned with establishing indicators that can be used to govern policies in the international domain, in relation to sustainable development and in relation to market regulations. This development is promoted by international and non-governmental organizations. It centres around the Indicators of Sustainable Development initiative of the UN Commission on Sustainable Development (CSD 2001), which is a body assigned to follow up on the United Nations Conference on Environment and Development (UNCED) Agenda 21. The Organization for Economic Cooperation and Development (OECD) has likewise developed an indicator framework for environmental performance reviews (OECD 1993). This agenda has been developed in relation to environmental sustainability in general, but is also reflected in fisheries. An account of this development in relation to fisheries has been presented by Bell and Morse (1999), FAO (1999), Garcia and Staples (2000), Dahl (2000), Garcia *et al.* (2001) and Pitcher and Preikshot (2001).

The requirements in this context of international ("horizontal") indicators are that indicators should be observable on a comparable, standardized basis across a multitude of ecological and social systems, be based on internationally accepted research and relate to the objectives set out in the relevant agreements and codes. Acceptance among international decision-makers is important, whereas local acceptance by users may have less priority.

In a development context, these requirements are currently mainly present in relation to industrialized fisheries. However, the internationalization of trade with fisheries products and the associated requirements for accountability and traceability will put increasing pressure on some coastal semi-industrial and even artisanal fisheries. This problem is highlighted by the resistance of some developing countries to proposals for green labelling, which is rooted in the fear that requirements may include formal stock assessments based on mainstream science, and associated costs.

The second agenda relates to the need to develop a basis of knowledge that can guide practical fisheries management in the local context. Practical management decisions should be guided by knowledge of the present state of the specific fisheries and resource system, and this knowledge should be sufficient to indicate directions of required regulatory measures and to evaluate the outcome of such measures. This knowledge does not necessarily need to be comparable across fisheries systems; the main issue is that it reflects the local system and can be communicated among those involved in the fisheries and in management. The emphasis is on the "vertical" use of knowledge within the fisheries systems rather than horizontal comparability across systems. The need for using indicators (and reference directions instead of reference points) in this context is rooted in the scientific community and based on a realization that mandated fisheries research may have reached its cost and complexity limits. A response to this "complexity wall" has been explorations into the identification of proxies for the standard reference points of stock assessments, and into indicators that are assumed to capture the effects of fisheries pressures on the ecosystem. This investigation of indicators has been especially pertinent in relation to the wider ecosystem effects of fisheries, which is a much more recent research area than classical fisheries biology, and where an approach involving the development of fully fledged functional models as an extension of classical approaches seems impossible from the outset (Hall 1999, Kaiser and de Groot 1999, Gislason *et al*. 2000).

The main emphasis in this case of local/regional ("vertical") indicators is acceptance by stakeholders within all levels of the local/regional management system. Dependent on the relative power and world view of stakeholders in the management system, indicators must be congruent with both local ecological knowledge and research-based knowledge. As international comparability is not the issue, indicators can be selected to satisfy local requirements in terms of knowledge and resources available for observation.

The issue of local acceptance in a fisheries development context has in some cases been equated to a need to revert to, or revitalize, what has been termed traditional management systems based on indigenous ecological knowledge. The problems involved in the concept of traditional management and revitalization of such systems are not the subject of this paper, but indigenous ecological knowledge is an important component in the identification of indicators that are locally meaningful (McGoodwin *et al.* 2000).

There is no reason to expect that indicators developed within the "horizontal" and the "vertical" contexts will coincide. As an example, the *MSY* concept, which has now largely been abandoned by fisheries biologists as a relevant and measurable reference point to guide local management decisions, is the only fisheries-related indicator on the Commission of Sustainable Development's list of indicator candidates (CSD 2001), and was mentioned as a target in the Johannesburg Implementation Plan (UN 2002). Indicators selected on the basis of their international comparability and acceptance among decision-makers or on the market should in principle be an extension of, and build on, internationally agreed results of the research agenda. However, they may be associated with low acceptance among local resource users (and *vice versa*, indicators based on a congruence between local and research-based knowledge may be specific to the local situation and may therefore carry little weight out of the local context on export markets or in international comparisons of fisheries management performance).

Such incompatibilities between different indicator systems represent a dilemma to fisheries management and especially to national governments, who must both ensure local legitimacy and practical utility of the knowledge base for management and be able to meet (future) requirements for documentation in relation to international agreements. This dilemma cannot be resolved because indicators, which are intended to inform local management in an operational sense, serve a different purpose and are therefore identified on the basis of other criteria than indicators that are useful for comparison across a wide range of fisheries systems. The problem may at best be diminished if the process of identifying and selecting indicators is prepared to consider the different institutional requirements for indicators from the outset, and as an integral part of the selection criteria.

This review focuses on the use of indicators in the local (vertical) management context rather than as a means for cross-system (horizontal) comparison. The emphasis is therefore on the ability of indicators to reflect the state of the local system and the effects of fisheries management, and on the acceptability of indicators to stakeholders in the local context in a participatory management framework.

TYPES OF INDICATORS

Smeet and Weterings (1999) distinguish four main classes of indicators. *Descriptive indicators* reflect an actual situation in a given system. In contrast, *performance indicators* compare actual conditions with a specific set of reference conditions, i.e. they measure the distances between the current and the target situation, thereby monitoring the effect of policy measures. These performance indicators may refer to different kinds of reference conditions/values, such as national or international agreed policy targets. *Efficiency indicators* relate environmental pressures to human activities and are therefore most relevant for policy-making. An example of an indicator of energy efficiency may be the volume of fuel used per ton of a particular group of fish caught. Lastly, *total welfare indicators* measure overall sustainability, e.g. using the Index of Sustainable Economic Welfare. This contribution is concerned with the classes of descriptive and performance indicators only.

In order to capture the complexity of interactions within and between society and the wider resource base in fisheries systems, and consequently to allow for the analysis of such complex systems, several conceptual frameworks have been developed (Garcia and Staples [2000] provide a review and Garcia *et al.* [2001] a summary). Frameworks provide a convenient basis for setting management objectives and organizing a set of descriptive indicators in relation to different system components, so clarifying how the various indicators relate to different purposes within the system.

The general framework for sustainable development (FAO 1999) takes a structural approach to representing the dimensions of sustainable development in the human (economic, social, institutional) and environmental subsystems. Along a different dimension, the original Pressure–State–Response (PSR) framework used by the Organization of Economic Cooperation and Development (OECD 1993) in its core set of indicators for environmental performance reviews has subsequently been amended and modified, because it is considered that driving forces reflect more accurately the economic, social and institutional dimensions of sustainable development. In this expanded framework, human *driving forces* (D, e.g. demand for food or income) exert *pressures* on the environment (P, both natural resources and their habitat) by removal or loading, which result in changes of the *state* of the environment (S, e.g. biomass and diversity levels), and may have an immediate *impact* on the functioning of the system (I, e.g. collapse of the fishery, social unrest, decline in compliance). Societies provide a *response* to these changes of state and their impact with a view to modifying the pressure (R, e.g. through technical measures). Whereas the PSR framework does not consider the response of the ecosystem to pressure as separate from its state, this DPSIR system attempts to specify some of the apparent over-aggregation and has gained wide acceptance (see Smeet and Weterings [1999] for more detail).

The distinction between indicators in frameworks of the DPSIR type may have some intuitive appeal, but this distinction only makes sense within the context of underlying assumptions of causalities. These assumptions may not be made explicit in the specific implementation, in which case lists of indicators and monitoring programmes may become pointless in the end. In the case of fisheries management in the Northern Atlantic, it is only within the past decade that a somewhat consistent set of PSR indicators has been developed, with an identification of pressure indicators (fishing mortality, with limit and precautionary reference points), closely associated state indicators (spawning stock biomass, with limit and precautionary reference points) and response indicators (action relative to harvest control rules that are based on the pressure and state indicators).

Criteria for evaluation of indicators

A range of sets of criteria for indicators have been defined, including the OECD (1993) basis for environmental performance reviews and, in relation to fisheries, criteria used by Australian authorities (Ward 2000).

The OECD criteria for environmental performance review (OECD 1993) would apply equally to fisheries and emphasize policy relevance and utility for users, analytical soundness and measurability. Ward (2000) quotes a set of criteria for sustainability indicators that relate more specifically to fisheries and have been used by the Department of Environment, Sport and Territories, Australia, in relation to marine ecosystem management. They are generally a rewording of the OECD criteria, but with the addition that indicators should "where possible and appropriate, facilitate community involvement". It is interesting that this addition includes two reservations on the use of this criterion, indicating that it is thought that there are cases where it is either not possible or appropriate to involve communities in indicator development. This may mean that these frameworks do not differentiate between the two types of indicator use discussed above, those used for more global comparisons across fisheries systems and those to be used as guides for management within a specific system.

ICES (2001b), reflecting a discussion that has primarily focused on the North Sea, gives the following list of desirable properties of indicators:

- Relatively easy to understand by non-scientists and those who will decide on their use;
- Sensitive to manageable human activity;
- Relatively tightly linked in time to that activity;
- Easily and accurately measured, with a low error rate;
- Responsive primarily to human activity, with low responsiveness to other causes of change;
- Measurable over a large proportion of the area to which the indicator is to apply;
- Based on an existing body or time-series of data to allow a realistic setting of management objectives.

In this list, the need to communicate indicators among stakeholders and managers is clearly expressed. By inference, this expresses the need for compatibility of the indicator set with management institutions. Management relevance, i.e. responsiveness to management action within a finite period of time, is in agreement with the OECD criteria, but ICES emphasizes more strongly the need for measurement accuracy and an underlying database. This is probably acceptable for the management of areas that are well known and have a long-standing history of scientific investigations, but is not generally applicable: the corresponding wording of OECD (the observability within sustainable cost) makes a potential problem more explicit. Both ICES and OECD list the relevance to the scale of management among the criteria.

The experiences from single-stock approaches over several decades have revealed that the serious problems involved in identifying reference points on the basis of time-series may not have been entirely picked up in these discussions on indicators. The requirement for reference points indicating direction and thresholds for action remain a major challenge for any candidate indicator, and has not been resolved for those indicators where the longest time-series exist and where the longest experience with their use in management has been made. Generalization across systems is an important possibility for addressing this problem initially.

In summary, fisheries sustainability indicators should be:

Related to management

- they should relate to specific management objectives;
- they should respond to management measures within a reasonable time frame;
- they should be relevant to the scale of management (local, national, regional, international);
- they need to be compatible with management institutions.

Acceptable

- by all stakeholders in fishery systems;
- by the public at large;
- they should be understandable in terms of having research-based substance and reflecting analytical soundness;
- they should be understandable in terms of reflecting

Table I: List of criteria and scoring properties

Criterion	Scoring property
1. Acceptability for stakeholders	1.1 Suitability for communication among stakeholders 1.2 Reflecting features in accordance with stakeholders' perceptions 1.3 Data-based substance 1.4 Clarity (unambiguity) of analytical results 1.5 Transparency of the observation process to stakeholders
2. Observability	2.1 Resource requirements: skilled personnel 2.2 Resource requirements: financial 2.3 Time-series of indicator required for management direction?
3. Relation to fisheries management	3.1 Indicator responding to management actions in spite of environmental fluctuations? 3.2 Management action and response closely linked in time? 3.3 Institutional requirements 3.4 Usefulness for large-scale management* 3.5 Usefulness for local management* 3.6 Reference points developed? (This is an additional item, not included in the scoring)

* Large-scale management is understood here to cover the entire distribution range of the resource base (species/group in question) or ecosystem, local management as covering only parts of it, e.g. the fisheries in a particular bay, or shelf area, that in itself is a part of a large marine ecosystem

features in accordance with stakeholders' understanding of the resource system.

Observable
- within economic resources for research on a sustained basis;
- by stakeholders, either directly or by transparency in the observation process.

CANDIDATE INDICATORS

Reflecting a discussion that is ongoing and far from converged, several compilations of indicators for fisheries management exist, including FAO (1999), ICES (2000, 2001a, b, 2002b); the work in the SCOR–IOC working group on ecosystem indicators (www.ecosystemindicators.org), Garcia and Staples (2000), Garcia *et al.* (2001), Jamieson *et al.* (2001), Sainsbury and Sumaila (2001). Indicators currently used in fisheries management refer generally to single fish stocks and focus on the sustainability of the resource base for the fisheries in this limited sense. Indicators referring to habitats, ecosystems or even integrating biological and societal issues are in the process of being identified, and have been used as a basis for actual management in a few cases. This is a reflection of the recent history of wider considerations being included in fisheries management.

Because the focus here is on situations with limited knowledge of the resource base, and limited economic resources for research, indicators selected and discussed are those that showed at least some perspective relative to the criteria of (1) acceptability to stakeholders, (2) observability and (3) relation to management discussed above. Each of these three criteria are subdivided into several scoring properties (Table I) and the relevance of each indicator for each property is evaluated with a simple numerical system similar to a traffic-light approach, where a score of 3 would be reached for high relevance to the criterion, a score of 2 for fair relevance to the criterion, a score of 1 for low relevance to the criterion, and a score of 0 indicates non-applicability relative to the criterion in question. This procedure allowed the indicators to be ranked for further analysis. The ranking is based on understanding of the properties of these indicators. Each ranking can be substantiated by research, but very little research into these institutional properties of indicators has been done. The ranking tables presented can therefore be considered a preliminary indication that represents as much a research agenda as a primary result.

The linkage to management objectives is the overriding consideration. The indicators are therefore grouped into categories according to their linkage to specific objectives, whether they relate to objectives regarding the immediate resource base or to wider ecosystem considerations. There are therefore two main categories, the first relating to the immediate resource base, i.e. the target species, and the second to the resource system, i.e. the part of the ecosystem linked to the exploited species. Within the first category, we differentiate between single population indicators (Table II) and indicators of the total resource base ("multispecies indicators", Table III). Within the second category, we divide between habitat-related, environmental indicators (Table IV) and indicators of

Table II: List of indicators describing single stock/populations targetted by the fishery

Number	Indicator	Type[1]
1.1	Consumption of local fish per person: amount and species composition	P
1.2	Number of permits issued for legal collecting and harvesting; fleet capacity	P
1.3	Descriptors of human fishing population: size, distribution, density	P
1.4	Age or length of specimens at first capture	P
1.5	Human fishing population: rate of change in density	P
1.6	Total catch (by stock and by area)	P
1.7	Exerted effort	P
1.8	Fishing intensity (effort/area)	P
1.9	Ratio of number collected to total size of reproducing population	P
1.10	Fishing mortality	P
1.11	Total catch / sustainable yield for modelled stocks	P
1.12	Average weight in catch, maximum length in catch	S
1.13	Maximum length (full geographic distribution of stock)	S
1.14	Catch per unit effort (*cpue*)	S
1.15	Disease/parasite prevalence in catch	S
1.16	Size distribution in stock (full geographic distribution)	S
1.17	Distribution area	S
1.18	Simple measures of stock size: biomass, abundance	S
1.19	Survey indices: *cpue*, length/age distribution, recruitment indices	S
1.20	Number of mature individuals in catch	S
1.21	Stock diversity of target species	S
1.22	School size of pelagic species	S
1.23	Ratio of current biomass to target biomass	S
1.24	Genetic diversity of target stocks	S
1.25	*MSY*-related estimates: *MSY*, *Y/R*, surplus production	S
1.26	Total production	S

[1]Element of a DPSIR framework; P: social pressure; S: ecosystem state

Table III: List of indicators describing the fishery production base ("multispecies indicators")

Number	Indicator	Type[1]
2.1	Fishing population	P
2.2	Total effort exerted	P
2.3	Total catch (retained + discarded), ratio bycatch/catch	P
2.4	Amount of bycatch	P
2.5	Ratio discard/catch, ratio discard/bycatch	P
2.6	Unintended mortality (e.g. through dynamite), quantity	P
2.7	Mortality (quantity) of endangered or protected species	P
2.8	Bycatch mortality rate	P
2.9	Fishing-in-balance index	P
2.10	Unintended mortality rate	P
2.11	Overall fishing mortality rate	P
2.12	Species richness in catch	S
2.13	Mean size (length or weight) of all organisms sampled	S
2.14	Total catch size frequency distribution	S
2.15	Fraction of stocks fully and/or sustainably exploited; fraction of commercial fisheries where predicted catches are observed	S
2.16	Total biomass, total abundance	S
2.17	Fraction of stocks outside safe biological limits	S
2.18	Slope of the size spectrum in the catch	S
2.19	Species diversity in the catch: k-dominance curves	S
2.20	Genetic diversity of bycatch species	S
2.21	Total production	S

[1]Element of a DPSIR framework; P: social pressure; S: ecosystem state

the biological production base (i.e. the wider ecosystem, Table V). Further, within each of these four groups, indicators are separated into "pressure" (P) and "state" (S) indicators from a DPSIR framework.

These classes (four groups each divided into two types) constituted 4–30 indicators each. It is important to note that, on the one hand, the indicators evaluated actually represented indicator concepts (e.g. the indicators directly related to the *MSY* concept for single species [1.25 in Table II] were evaluated as a single indicator), whereas on the other hand, indicators could be attributed to several of the four groups (e.g. "effort" is relevant in a single-species, multispecies and ecosystem context).

Indicators are coarsely ranked according to their scores on the criterion of acceptability, and it is in this sequence (i.e. descending acceptability) that the indicators and their scoring are listed in Tables App. 1.I –IV in Appendix 1, and discussed below. Partial and global sums of scores for the indicators are given in Appendix 2. References and remarks pertaining to the indicators are given in Appendix 3.

Indicators relating to the immediate resource base

INDICATORS DESCRIBING SINGLE POPULATIONS

These indicators relate to objectives regarding the specific target stock(s) for the fisheries.

Pressure — This group consists of 11 indicators ranging from the description of food consumed locally to effort, fishing mortality and ratios of catch to sustainable yield for modelled stocks. The highest ranking on acceptability (Table App. 2.I) was achieved by accounts of the consumption of local fish per person (quantity and species composition), as well as by descriptors of fishing capacity (number of permits issued

Table IV: List of indicators describing resource system (habitat quality and complexity)

Number	Indicator	Type[1]
3.1	Fraction of habitat lost or destroyed	P
3.2	Number of marine protected areas	P
3.3	Fraction of littoral area protected (totally, partially)	P
3.4	Relative area of each national/regional marine environment/ecosystem/habitat under protection	P
3.5	Fishing effort by method, area, year or season	P
3.6	Ratio of fished to protected (unfished) habitat	P
3.7	Fraction of habitat changed by fishing activities	P
3.8	Extent of selected marine habitat	S
3.9	Spatial integrity of habitats	S
3.10	Area of available habitat occupied (by selected species or assemblages)	S
3.11	Habitat diversity	S
3.12	Fraction of endangered/protected species/stocks where interaction with fisheries exists	S
3.13	Extent of critical habitats (spawning, nursery, migration pathways, etc.)	S
3.14	Numbers of communities identified	S
3.15	Spatial fragmentation of communities	S
3.16	Biodiversity condition of selected marine habitats and communities at selected sites	S
3.17	Sex ratio (e.g. some marine mammals, some crustaceans)	S
3.18	Indicators related to terrestrial/freshwater inputs	S
3.19	Eutrophication-related indicators	S
3.20	Climate-change-related indicators	S
3.21	Pollution-related indicators	S

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

for legal collecting or harvesting, and accounts of fleet tonnage). Among the indicators occupying medium ranks were total catch, exerted effort and fishing intensity (effort/area). Indicators related to fishing mortality and those derived from models (e.g. the ratio of total catch and sustainable yield) ranked lowest with respect to acceptability. Overall (Table App. 2.I), the highest ranking was achieved by accounts of fleet capacity and number of permits issued, total catch (by stock and area) on a large scale, exerted effort, and the age or length of specimens at first capture. Descriptions of the fishing population and accounts of consumption of local fish were regarded as comparatively weak in relation to fisheries management, in particular with respect to their responsiveness to fisheries management action (Table App. 1.I).

State — Maximum length and average weight of the target species in the catch and catch per unit of effort (*cpue*) ranked on the top of the list of state indicators according to acceptability (Table App. 2.I). More abstract concepts, like the ratio of current to target biomass, genetic diversity of target stocks, total and surplus production, ranked lowest. Overall, the highest ranks were occupied by maximum length and average weight of the target species in the catch, as well as *cpue* by stock, gear and area (assuming, in this case, that effort can be assessed adequately, Table App. 2.I). Direct fisheries-independent indicators of stock size (biomass, abundance), while fairly acceptable to stakeholders, can be too expensive to estimate. Size distributions (over the full distributional area of a stock) may be used as appropriate measures of central tendency (e.g. mean) and extremes (i.e. smallest and largest specimens observed) alone, at least in those cases where the fishery extends over the entire distributional area of the stock.

INDICATORS DESCRIBING THE FISHERIES PRODUCTION BASE ("MULTISPECIES INDICATORS")

These indicators relate to objectives regarding the composite of populations that are subject to extraction by fisheries, irrespective of whether or not they are targeted, and whether they are landed or discarded.

Pressure — Descriptors of the fishing population and total effort ranked highest in terms of acceptability (Table App. 1.II). Overall, the total effort exerted, total catch and the relative importance of bycatch in the total catch (ratio bycatch/catch), as well as the amount of bycatch, ranked as the most important indicators in a multispecies context (Table App. 2.II). Indicators building on the calculation of mortality rates were generally regarded as poorly acceptable for stakeholders.

State — Species richness in the catch, mean size (length or weight) of all organisms sampled, and the size frequency distribution of the total catch scored highest in terms of acceptability (Tables App. 1.II, 2.II). These indicators also ranked on top of the overall list (Table App. 2.II). Indicators depending on modelling (total biomass, total abundance, fraction of stocks fully or sustainably exploited, and fraction of stocks outside safe biological limits) were not only considered less acceptable, but also more severely limited by the size of research budgets (Table App. 1.II).

Indicators describing properties of the resource system

INDICATORS DESCRIBING PROPERTIES OF THE ENVIRONMENT

These indicators relate to objectives regarding the immediate productive basis for fisheries resources such

Table V: List of indicators describing the biological system (ecosystem functioning)

Number	Indicator	Type[1]
	Indicators related to single species	
4.1	Number of non-target species caught by method, area and season or year	P
4.2	Exerted effort	P
4.3	Changes in predation pressure (e.g. through removal of predators)	P
4.4	Fishing-in-balance (FIB) index	P
4.5	The number of taxa in IUCN and national threatened categories	S
4.6	Numbers of exotic species	S
4.7	Abundance of exotic species	S
4.8	Presence of indicator / charismatic / sensitive species, possibly by community	S
4.9	Biomass and/or abundance and/or breeding success of key dependent predators (e.g. seabird species)	S
4.10	Population size / abundance of charismatic species	S
4.11	Population size of sensitive / protected / endangered / threatened species	S
4.12	Average disease / parasite prevalence in ecosystem	S
4.13	Indicators of species diversity: species richness, richness of species assemblages, k-dominance curves, Multi-dimensional Scaling (MDS), species effort index	S
4.14	Number and population size of sensitive species or species at risk	S
4.15	Survey indices of non-target or non-commercial species: abundance, recruitment	S
4.16	Abundance of keystone species	S
4.17	Indicators of life history strategy: changes in reproductive parameters (age at maturity, time of breeding), lifetime reproductive success rates (early vs late maturation schedules)	S
4.18	Population trends or relative abundance of indicator species	S
4.19	Numbers of breeding individuals in Evolutionary Significant Units	S
4.20	Genetic diversity within subpopulations	S
	Trophodynamic indicators	
4.21	Abundance of alternative prey for predators	S
4.22	Fat content of selected species (as proxy for food availability and quality of food)	S
4.23	Mean and distribution in the body of contaminant burden	S
4.24	Predator-induced mortality rates on prey populations	S
4.25	Total production in ecosystem	S
4.26	Invasibility of foodwebs	S
4.27	Indicators of trophic composition, food chain structure, productivity and flows	S
4.28	Effective number of species within trophic levels, proportion of species at range of trophic levels	S
4.29	Foodweb complexity: number of trophic levels, connectivity, path length, niche width	S
4.30	Throughput, ratios of system-internal consumption to yield, flows from producer's level required to sustain the fishery	S
4.31	Return time of foodwebs after perturbation	S
4.32	Carrying capacity	S
4.33	Condition factor (average condition of a theoretical community of fixed size-structure and species composition)	S
	Size-based indicators	
4.34	Overall size distribution in ecosystem, slope of ecosystem size spectrum	S

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

as habitat or environmental factors, which are directly linked to the productivity of fisheries resources.

Pressure — Indicators related to the protection of benthic habitat, and again effort, were generally rated well suited for communication (Table App. 1.III), all estimated at low to moderate cost, and similarly suitable for large-scale and local management. Overall, the fraction of habitat lost or destroyed by fishing activities, and the ratio between fished and unfished habitat occupied the top ranks, followed by effort (Table App. 2.III). The low ranking of various versions of closed areas (3.2–3.4) in relation to response to fisheries management is based on observations that introductions of closed areas that are not associated with consistent effort reductions may result in increased pressures on habitats outside the closed areas owing to redistribution of effort. However, if such consistent measures are in place, the outcomes in terms of protecting overall habitat will be positive.

State — Similarly, habitat-related indicators describing the state of the resource system, such as the extent of selected marine habitat, the spatial integrity of habitats, and the diversity of habitats were rated well acceptable to stakeholders and observable at moderate cost (Table App. 1.III). These indicators are also responsive to management action within a reasonable time-

Table VI: Top ranking indicators in each of the categories analysed

Criterion	Pressure or state[1]	Single stock	Multispecies	Habitat	Ecosystem functioning
Acceptability	P	1.1 Local fish consumption 1.2 Number of permits	2.1 Fishing population	3.1 Fraction of habitat lost 3.2 Number of marine protected areas	4.1 Number of non-target species caught 4.2 Exerted effort
	S	1.12 Average weight in catch 1.13 Maximum size in catch	2.12 Species richness in catch 2.13 Mean size of all organisms sampled	3.10 Area of available habitat occupied 3.8 Extent of selected habitat 3.9 Spatial integrity of habitats	4.5 Number of taxa in threatened categories 4.6 Number of exotic species 4.21 Abundance of alternative prey for predators 4.22 Fat content of selected species 4.23 Contaminant burden
Observability	P	1.2 Number of permits 1.3 Fishing population 1.5 Change of fishing population	2.1 Fishing population	3.1 Fraction of habitat lost 3.2 Number of marine protected areas	4.1 Number of non-target species caught 4.2 Exerted effort 4.3 Changes in predation pressure
	S	1.12 Average weight in catch 1.13 Maximum size over distribution 1.14 Catch per unit effort 1.17 Distribution area	2.12 Species richness in catch 2.13 Mean size of all organisms sampled 2.14 Size frequency distribution of total catch	3.9 Spatial integrity of habitats 3.12 Fraction of species with fisheries interaction	4.5 Number of taxa in threatened categories 4.18 Population trends of indicator species 4.22 Fat content of selected species
Relation to fisheries management	P	1.7 Exerted effort 1.8 Fishing intensity	2.2 Effort exerted 2.3 Total catch, ratio bycatch/catch 2.4 Amount of bycatch	3.6 Ratio fished/unfished or protected habitat	4.2 Exerted effort 4.1 Number of non-target species caught
	S	1.14 Catch per unit effort	2.13 Mean size of all organisms sampled 2.14 Size frequency distribution of total catch 2.15 Fraction of stocks sutainably exploited 2.16 Total biomass or abundance	3.11 Habitat diversity 3.12 Fraction of endangered species	4.9 Abundance of key dependent predators 4.19 Number of breeding individuals in Evolutionary Significant Units 4.21 Abundance of alternative prey for predators

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

frame, and are useful for both large-scale and local fisheries management. Similarly, the fraction of endangered/protected species or stocks came out as a potentially useful indicator (Indicator 3.12 in Table App. 2.III).

Indicators related to the biological concept of "communities", while scientifically highly relevant, were rated to reflect stakeholders' perceptions less well than the concept of "habitat", and therefore occupied lower ranks in terms of acceptability.

Indicators related to general environmental conditions, such as terrestrial inputs, eutrophication, pollution and climate change, were considered to be outside the realm of fisheries management action, at least in most countries (Table App. 1.III).

INDICATORS DESCRIBING THE FULL BIOLOGICAL PRODUCTION BASE

These indicators relate to objectives regarding the aquatic ecosystem at large that ultimately is the basis for fisheries production.

Pressure — Apart from fishing effort, the number of non-target species caught (especially those unsuitable for consumption) were rated acceptable to stakeholders and observable (Criteria 1.2 and 1.5 in Table App. 1.IV). The indicator of "fishing in balance", while presenting a scientifically highly intriguing concept and certainly suitable for comparisons among different ecosystems, was considered, for any given ecosystem, to be based on rather strong model assumptions that could become expensive to test. The complexity of the modelling approach and the uncertainties around it were also considered to make the indicator less well suited for communication among stakeholders (Criterion 1.1 in Table App. 1.IV). Changes in predation pressure, as for example generated through removal of predators (culling), were scored to be particularly little responsive to management action, because of the complexity of ecosystem trophodynamics (Table App. 2.IV).

State — Ecosystem state indicators were further subdivided into species-based, trophodynamics-based, and size-based indicators (Table V). It is important to note that, whereas the first group again focuses on single species, these are not necessarily caught directly in the fishery and are therefore not necessarily covered by the indicators of the first large group, pertaining to the fisheries resource base.

Among the species-based indicators, the number of species threatened, endangered or protected (as defined through national legislation and/or recognized international agreements), the presence and abundance or population size of indicator species and sensitive species, as well as key dependent species, were rated acceptable to stakeholders (Table App. 1.IV). The latter two groups of indicators (pertaining to indicator and sensitive species, and key dependent species) obtained the highest scores with respect to relevance for fisheries management (Table App. 2.IV).

Trophodynamic indicators that depend on numerical modelling were scored to be largely unsuitable for communication among stakeholders. Trophodynamic indicators independent of numerical modelling constitute the abundance of alternative prey for predators, as well as the fat condition of selected species, as a proxy for food availability and quality of food. As discussed before in relation to parasites, although the mean and distribution of contaminant burden of selected species is a measure of general ecosystem quality and is certainly strongly discussed among stakeholders, it is generally not responsive to fisheries management action (Table App. 2.IV).

Although well suited for discussions within the scientific community, indicators relating to the overall size distribution in the ecosystem rated low in terms of acceptability for stakeholders (Table App. 2.IV), and were therefore less suitable for management in a developing-country context. In this context, it may be of particular relevance that reference points are largely not developed for trophodynamic and size-based indicators. This may, for purposes of fisheries management, be an additional point in case for focusing on indicators related to specifically relevant species groups (threatened, key dependent, indicator species) before trying to deal with trophodynamic and size-based indicators.

Without doubt, the latter two groups of indicators (trophodynamic and size-based) are highly relevant for our scientific understanding of how ecosystems function and evolve through time. Furthermore, there is no doubt that a good understanding of the functioning of the underlying ecosystem is essential to appropriate management of human interaction with that ecosystem. However, the related discussions will go through various loops in the scientific arena before the scientific discussion has converged to an extent that they can convincingly be used for management. For reasons of research budget size, this discussion is expected to take place in data-rich situations, and therefore regrettably does not take place in most developing countries. An identification of indicators that are considered relevant in a specific context should also be the basis for an identification of data requirements and should therefore contribute to focusing the scarce resources available for data collection.

SYNTHESIS AND CONCLUSIONS

The overall results of the scoring of indicators are synthesized in Table VI, which lists the top-ranking indicators in each category analysed in the present study. A further condensation of the results is given in Table VII, which lists the overall top-scoring indicators, but assuming equal weighting along the three dimensions of acceptability, observability and relation to fisheries management. The use of equal weighting may be debated, because arguments can be put forward for prioritizing any of these criteria. Basically, comparing acceptability, observability and relevance in one dimension is impossible, and it is argued above that for an indicator to be useful it must contribute to all three criteria simultaneously. Selection decisions should not be based solely on a numerical evaluation that is just a first step towards an overview. An equal weighting is a simple approach that will gain little from refinement in terms of informing selection decisions.

There is considerable concurrence between the scoring of several indicators across the three main dimensions, acceptability, observability, and relation to fisheries management (Table VI). This may not be a coincidence: some correlation between these dimensions is expected because, to some extent, they are mutually interdependent. Clear relevance and transparent observability will, for instance, contribute to acceptability.

Apart from indicators relating to fishing effort (re-

Table VII: Overall top ranking indicators for large-scale and local fisheries management, assuming equal weighting of the three dimensions acceptability, observability and relation to fisheries management

Criterion	Pressure or state[1]	Single stock	Multispecies	Habitat	Ecosystem functioning
Large-scale management	P	1.2 Number of permits 1.6 Total catch 1.7 Exerted effort	2.2 Effort exerted 2.3 Total catch, ratio by-catch/catch 2.4 Amount of bycatch	3.1 Fraction of habitat lost 3.6 Ratio fished/unfished or protected habitat	4.1 Number of non-target species caught 4.2 Exerted effort
	S	1.12 Average weight in catch 1.13 Maximum size over distribution 1.14 Catch per unit effort	2.13 Mean size of all organisms sampled 2.12 Species richness 2.14 Catch size distribution	3.9 Spatial integrity of habitats 3.8 Extent of selected habitat 3.11 Habitat diversity 3.12 Fraction of endangered species	4.5 Number of taxa in threatened categories 4.9 Abundance of key dependent predators 4.8 Presence of indicator /charismatic/sensi--tive species 4.21 Abundance of alternative prey for predators
Local management	P	1.2 Number of permits 1.4 Age or size at first capture 1.1 Local fish consumption 1.7 Exerted effort	2.2 Effort exerted	3.1 Fraction of habitat lost	4.1 Number of non-target species caught 4.2 Exerted effort
	S	1.14 Catch per unit effort 1.12 Average weight in catch 1.13 Maximum size over distribution	2.12 Species richness in catch 2.13 Mean size of all organisms sampled	3.9 Spatial integrity of habitats	4.5 Number of taxa in threatened categories 4.9 Abundance of key dependent predators 4.8 Presence of indicator /charismatic/sensitive species 4.21 Abundance of alternative prey for predators

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

flecting focus on fisheries management), indicators are different for the four categories from single stocks through ecosystem functioning, and indicative of the widening of the perspective that needs to take place for an ecosystem approach to fisheries management.

The overall result for both large-scale and local management (Table VII) is that relevant indicators relating to pressure include various variants or proxies of effort, such as direct effort measurements, fishing permits and local fish consumption, and fishing pattern, such as size at first capture. As far as ecosystem structure and functioning are concerned, useful pressure indicators are fraction of habitat lost and ratio of fished to protected or unfished habitat, and catches of non-target species. Relevant indicators of state include indicators relating to size, such as average weight in catch, size of organisms sampled and maximum size over the distribution range, whereas *cpue* is a relevant indicator of abundance. For ecosystem structure and functioning, the most relevant indicators are spatial integrity of habitats, number of species under threat, and estimates pertaining to indicator species. The differences between the set of indicators useful for large-scale and local management mainly relate to the impossibility to observe parameters relevant to the total population (total catch, overall size measures) on a local scale.

The scoring applied assumed mixed fisheries and limited resources available for observation or implementation as is typically the case in a development context. A scoring assuming single-species fisheries (i.e. fisheries exploiting one stock only, and without bycatch) or ample resources available for observation and implementation would have resulted in very different scorings and thus different overall results, and would more likely have included indicators referring to single-species biological characteristics and indicators requiring extensive data collection and modelling.

The scoring was also based on the use of indicators in the "vertical" context, as direct guidance for ongoing management decision processes. This means that "acceptability" refers to the acceptability of indicators among local stakeholders, which includes considerations of what can be observed by local resource users.

As an outlook, and based on increased experience with application of an ecosystem approach to fisheries, the sets of "vertical" indicators resulting from concrete management applications, should be analysed with respect to the management situation in which they performed well. They will subsequently be applied "horizontally", understood as constituting a set of "defaults" for any new case. Fisheries certified by the Marine Stewardship Council (www.msc.org) and their respective management systems may represent such an initial set of cases.

An *a priori* scoring of indicators to be used in the "horizontal" context, for comparisons between fisheries systems in relation to international agreements or the market, would have emphasized acceptability on the basis of general requirements in agreements or by consumers without insight in the specific resource system and with only very limited knowledge about fisheries.

The present study has emphasized the need to discuss indicators in relation to objectives and to evaluate the utility of indicators in a specific fisheries system in the three dimensions of acceptability, observability, and relation to fisheries management. An evaluation of indicators relating to four different aspects of sustainability (single stock, multispecies stock complex, habitat, ecosystem functioning) as presented in the literature has been presented. However, a selection of indicators for use in a specific context will require that a specific evaluation be made for that context, based on studies of the utility of indicators along the three dimensions in the specific context and management set-up.

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APPENDIX 1

Scoring of four categories of indicators according to the criteria of acceptabililty for stakeholders, observability and relation to fisheries management

Table App. 1.I: Scoring of indicators describing single stock/populations targetted by the fishery according to criteria of acceptabililty for stakeholders, observability and relation to fisheries management (see Table I for list of scoring properties for the criteria)

Criterion/ indicator	1.1[1]	1.2[1]	1.3[1,2]	1.4[1]	1.5[3]	2.1[3]	2.2[5]	2.3	3.1[1]	3.2[1]	3.3[6]	3.4[3,7]	3.5[3,7]	3.6[8]
1.1	3	3	3	3	3	2	3	Yes	1	2	2	1	3	2
1.2*	3	3	3	3	3	3	3	Yes	2	2	3	3	3	1
1.3	3	3	3	2	3	3	3	Yes	0	0	3	1	2	0
1.4	2	3	3	2	3	2	2	Yes	3	2	2	3	2	3
1.5	2	3	3	2	3	3	3	Yes	0	0	3	2	2	1
1.6*	3	3	3	2	2	3	2	Yes	1	3	3	3	1	2
1.7*	2	3	3	2	2	2	2	Yes	3	3	3	3	3	2
1.8	2	3	3	2	1	2	2	Yes	3	3	3	3	2	2
1.9	2	1	2	2	2	1	2	No	1	2	1	2	0	2
1.10	1	1	2	2	2	1	2	No	1	2	1	2	0	3
1.11	2	1	2	1	1	1	1	Yes	1	3	1	3	0	2
1.12	3	3	3	3	2	2	2	Yes	2	2	2	3	1	1
1.13	2	3	3	3	3	2	2	Yes	2	2	2	3	1	2
1.14*	3	3	3	2	2	2	2	Yes	2	2	3	3	2	1
1.15	3	3	2	2	3	1	2	Yes	0	0	1	0	0	0
1.16	3	2	3	2	2	1	1	Yes	1	2	1	3	1	2
1.17	3	3	2	2	2	1	1	Yes	1	1	1	2	1	0
1.18	2	3	2	2	2	2	2	Yes	2	2	1	3	1	2
1.19*	1	1	3	2	3	1	1	Yes	2	2	1	3	1	2
1.20	2	3	2	1	2	1	1	Yes	2	1	1	3	1	1
1.21	2	2	2	2	1	1	1	Yes	3	1	1	2	1	2
1.22	1	2	2	2	2	2	1	Yes	0	1	1	2	0	0
1.23	2	2	1	2	1	1	1	No	2	1	1	2	1	2
1.24	1	1	3	2	1	1	2	Yes	2	1	1	2	0	1
1.25	2	1	2	1	1	1	2	Yes	1	2	1	2	0	2
1.26	2	1	1	1	1	1	1	No	2	2	1	2	1	1

[1] Rating scale: 0: non-existent; 1: poor; 2 fair, 3: good
[2] Can be based on raw data in principle, but under the assumption that adequate resources for data collection are available
[3] Rating scale 0: non existent; 1: low; 2: moderate; 3: high
[4] Rating scale: 1: highly specialized personnel; 2: locally trained, specialized personnel; 1: locally trained, unspecialized personnel
[5] Rating scale: 1: high (e.g. research vessel time); 2: moderate; 3: low
[6] Rating scale: 1: research institute collecting and processing data (possibly on board vessel); 2: data collection according to scientific principles, scientific processing of data; 3: reliable public statistics (population, fisheries, precipitation, land use)
[7] Large-scale understood as covering the total distribution area of the species/stock(s) in question; locally understood as covering only a fraction of the total distribution area
[8] Rating scale: 0: n.a.; 1: not yet; 2: in a few cases; 3: broadly
* Catch-and-effort data are often unavailable and therefore represent estimates rather than hard data including, e.g., extrapolations and assumptions on gear standardizations

Table App. 1.II: Scoring of pressure indicators describing the fishery production base ("multispecies indicators") according to criteria of acceptability for stakeholders

Citerion/ Indicator	1.1[1]	1.2[1]	1.3[1,2]	1.4[1]	1.5[3]	2.1[3]	2.2[5]	2.3	3.1[1]	3.2[1]	3.3[6]	3.4[3,7]	3.5[3,7]	3.6[8]
2.1	3	3	3	2	3	3	3	Yes	0	0	2	1	2	0
2.2	2	3	3	2	2	2	2	Yes	3	3	2	3	3	2
2.3**	3	3	2	2	1	3	2	Yes	3	3	2	3	1	2
2.4**	3	3	2	2	1	2	2	(Yes)	3	3	2	3	1	2
2.5**	3	3	2	2	1	2	2	(Yes)	2	2	2	2	2	1
2.6	3	3	1	2	1	2	2	No	2	3	1	3	3	1
2.7	2	3	2	2	1	2	2	No	2	2	1	3	3	2
2.8	1	1	2	2	2	2	2	(Yes)	3	3	1	3	1	2
2.9	1	1	1	1	2	1	2	(Yes)	2	3	1	2	1	1
2.10	1	1	0	1	2	1	1	(Yes)	3	3	1	2	3	1
2.11	1	1	0	1	2	1	1	(Yes)	3	3	1	0	0	1
2.12	3	1	3	3	3	2	2	Yes	2	2	1	2	2	1
2.13	2	2	3	3	3	2	2	Yes	2	2	2	2	1	1
2.14	2	1	3	3	3	2	2	Yes	2	2	2	2	1	1
2.15	3	3	2	1	2	1	1	No	2		1	3	2	2
2.16	2	3	2	2	2	1	2	Yes	2	2	1	3	2	2
2.17	2	1	2	2	2	1	1	No	2	2	1	2	1	2
2.18	2	0	2	2	3	1	2	Yes	2	2	1	2	1	1
2.19	1	1	2	2	3	1	2	Yes	1	1	1	2	1	1
2.20	1	1	3	2	2	1	1	Yes	1	1	1	2	2	1
2.21	1	1	1	1	2	1	2	Yes	1	2	1	3	1	1

(See Appendix Table App. 1.I for annotations)
** Bycatch understood as non-targetted catch taken aboard at least once (retained or discarded), but excluding unretained catch, here referred to as unintended mortality

Table App. 1.III: Scoring of pressure indicators describing the resource system (habitat quality and complexity)

Criterion/ indicator	1.1[1]	1.2[1]	1.3[1,2]	1.4[1]	1.5[3]	2.1[3]	2.2[5]	2.3	3.1[1]	3.2[1]	3.3[6]	3.4[3,7]	3.5[3,7]	3.6[8]
3.1	3	3	3	3	3	2	2	No	2	3	2	2	2	2
3.2	3	3	3	3	3	3	2	(Yes)	0	0	3	2	2	2
3.3	3	3	3	2	3	2	2	(Yes)	0	0	3	2	2	2
3.4	3	3	2	2	3	2	2	(Yes)	0	0	2	2	2	1
3.5	2	3	3	2	2	2	2	Yes	2	3	2	3	3	2
3.6	3	3	2	2	2	2	2	Yes	3	3	2	3	3	2
3.7	3	3	2	1	2	2	2	Yes	2	1	2	3	2	1
3.8	3	3	3	3	3	2	2	Yes	2	2	1	3	3	1
3.9	3	3	3	3	3	2	2	No	2	2	1	3	3	1
3.10	3	3	3	3	3	1	1	Yes	2	2	1	3	3	1
3.11	3	2	3	3	3	2	2	Yes	2	2	2	3	3	1
3.12	3	3	3	2	3	2	2	No	2	2	1	3	3	2
3.13	3	2	3	2	3	2	1	No	2	2	1	3	3	1
3.14	3	1	3	3	3	1	1	Yes	1	2	1	2	2	1
3.15	3	1	3	3	3	1	1	No	1	2	1	2	2	1
3.16	3	1	3	2	3	1	1	Yes	1	2	1	2	2	1
3.17	3	2	2	2	3	2	1	Yes	1	2	2	2	2	1
3.18	3	2	2	2	2	2	2	Yes	0	0	3	1	1	1
3.19	3	2	3	2	3	1	2	Yes	0	0	2	1	1	1
3.20	3	2	2	2	3	1	2	Yes	0	0	2	1	1	1
3.21	3	2	2	2	2	1	2	Yes	0	0	2	1	1	1

(See Appendix Table App. 1.I for annotations)

Table App. 1.IV: Scoring of pressure indicators describing the biological system (ecosystem functioning)

Criterion/ indicator	1.1[1]	1.2[1]	1.3[1,2]	1.4[1]	1.5[3]	2.1[3]	2.2[5]	2.3	3.1[1]	3.2[1]	3.3[6]	3.4[3,7]	3.5[3,7]	3.6[8]
4.1	3	3	3	3	2	1	2	No	3	3	1	3	3	1
4.2	2	3	3	2	2	2	2	Yes	3	3	2	3	3	3
4.3	1	2	2	1	3	1	3	(Yes)	2	1	1	3	3	1
4.4	1	1	1	1	2	1	1	(Yes)	3	2	1	2	1	1
4.5	3	3	3	3	3	1	2	No	2	1	1	3	3	3
4.6	3	3	3	3	3	1	2	Yes	1	1	1	2	2	1
4.7	3	3	3	2	3	1	2	Yes	1	1	1	2	2	1
4.8	3	3	3	3	2	1	2	Yes	2	2	1	3	3	2
4.9	3	2	3	2	3	1	2	Yes	3	2	1	3	3	2
4.10	3	2	2	2	3	1	2	Yes	2	1	1	3	3	1
4.11	2	2	3	2	3	1	1	(No)	2	1	1	3	3	1
4.12	3	2	2	2	3	2	2	(No)	0	0	1	2	1	1
4.13	1	2	3	2	3	1	1	Yes	2	2	1	2	2	2
4.14	2	2	3	2	2	1	1	Yes	2	2	1	3	3	2
4.15	1	1	3	2	3	1	1	Yes	2	2	1	3	1	2
4.16	2	1	2	2	3	1	2	Yes	2	2	1	3	3	2
4.17	2	1	2	2	3	1	2	Yes	2	2	1	3	3	2
4.18	1	1	2	2	3	2	2	Yes	2	2	1	3	3	2
4.19	1	1	2	2	2	1	2	Yes	2	3	1	3	2	3
4.20	1	1	2	2	1	1	1	Yes	2	1	1	3	2	1
4.21	2	2	2	2	3	1	1	No	2	3	1	3	3	1
4.22	2	2	2	2	3	2	2	Yes	1	2	1	2	2	1
4.34	2	2	2	2	3	1	1	No	0	0	1	2	3	1
4.24	1	1	2	2	3	1	1	Yes	2	2	1	3	3	1
4.25	1	1	2	2	3	1	1	Yes	0	0	1	1	0	0
4.26	1	2	1	1	3	1	1	(Yes)	2	1	1	2	1	1
4.27	1	1	2	1	3	1	1	No	2	1	1	2	1	1
4.28	1	1	2	1	3	1	1	Yes	1	1	1	2	1	1
4.29	1	1	2	1	3	1	1	Yes	1	1	1	1	1	1
4.30	1	1	2	1	3	1	1	Yes	2	1	1	1	1	1
4.31	1	1	2	1	3	1	1	Yes	2	2	1	2	1	1
4.32	1	1	2	1	3	1	1	Yes	1	1	1	2	2	1
4.33	1	1	1	2	3	1	1	Yes	1	2	1	2	2	1
4.34	1	1	1	2	3	2	1	Yes	2	1	1	2	2	1

(See Appendix Table App. 1.I for annotations)

APPENDIX 2

Partial and global sum of scores for indicators

Table App. 2.I: Partial and global sum of scores for indicators describing single stock/populations targeted by the fishery

Number	Type[1]	Acceptability	Observability	Relevance, large scale	Relevance, local	Sum of scores, large scale	Sum of scores, local
1.1	P	15	5	6	8	26	28
1.2	P	15	6	10	10	31	31
1.3	P	14	6	4	5	24	25
1.4	P	13	4	10	9	27	29
1.5	P	13	6	5	5	24	24
1.6	P	13	5	10	8	28	26
1.7	P	12	4	12	12	28	28
1.8	P	11	4	12	11	27	26
1.9	P	9	4	6	4	19	17
1.10	P	8	4	6	4	18	16
1.11	P	7	2	8	5	17	14
1.12	S	14	4	9	7	27	25
1.13	S	14	4	9	7	27	25
1.14	S	13	4	10	9	27	26
1.15	S	13	3	1	1	17	17
1.16	S	12	2	7	5	21	19
1.17	S	12	4	5	4	21	20
1.18	S	11	2	8	6	21	19
1.19	S	10	2	8	6	20	18
1.20	S	10	2	7	5	19	17
1.21	S	9	2	7	6	18	17
1.22	S	9	3	4	2	16	14
1.23	S	8	3	6	5	17	16
1.24	S	8	3	6	4	17	15
1.25	S	7	3	6	4	17	14
1.26	S	6	3	7	6	16	15

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

Table App. 2.II: Partial and global sum of scores for indicators describing the fishery production base ("multispecies indicators")

Number	Type[1]	Acceptability	Observability	Relevance, large-scale	Relevance, local	Sum of scores, large scale	Sum of scores, local
2.1	P	14	6	3	4	23	24
2.2	P	12	4	11	11	27	27
2.3	P	11	5	11	9	27	25
2.4	P	11	4	11	9	26	24
2.5	P	11	4	8	8	23	23
2.6	P	10	5	9	9	24	24
2.7	P	10	5	8	8	23	23
2.8	P	8	4	10	8	22	20
2.9	P	6	4	8	7	18	17
2.10	P	5	2	9	10	16	17
2.11	P	5	2	7	7	14	14
2.12	S	13	4	7	7	24	24
2.13	S	13	4	7	7	25	24
2.14	S	12	4	8	7	24	23
2.15	S	11	3	8	7	22	21
2.16	S	11	3	8	7	22	21
2.17	S	9	3	7	6	19	18
2.18	S	9	3	7	6	19	18
2.19	S	9	3	5	4	17	16
2.20	S	9	2	5	5	16	16
2.21	S	6	3	7	5	16	14

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

Table App. 2.III: Partial and global sum of scores for indicators describing the resource system (habitat quality and complexity)

Number	Type[1]	Acceptability	Observability	Relevance, large scale	Relevance, local	Sum of scores, large scale	Sum of scores, local
3.1	P	15	5	9	9	29	29
3.2	P	15	5	5	5	25	25
3.3	P	14	4	5	5	23	23
3.4	P	13	4	4	4	21	21
3.5	P	12	4	10	10	26	26
3.6	P	12	4	11	11	27	27
3.7	P	11	4	8	7	23	22
3.8	S	15	4	8	8	27	27
3.9	S	15	5	8	8	28	28
3.10	S	15	2	8	8	25	25
3.11	S	14	4	9	9	27	27
3.12	S	14	5	8	8	27	27
3.13	S	13	4	8	8	25	25
3.14	S	13	2	6	6	21	21
3.15	S	13	3	6	6	22	22
3.16	S	12	2	6	6	20	20
3.17	S	12	3	7	7	22	22
3.18	S	12	4	4	4	20	20
3.19	S	12	3	3	3	18	18
3.20	S	12	3	3	3	18	18
3.21	S	11	3	3	3	17	17

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

Table App. 2.IV: Partial and global sum of scores for indicators describing the biological system (ecosystem functioning)

Number	Type[1]	Acceptability	Observability	Relevance, large scale	Relevance, local	Sum of scores, large scale	Sum of scores, local
4.1	P	14	4	10	10	28	28
4.2	P	12	4	11	11	27	27
4.3	P	9	4	7	7	20	20
4.4	P	6	2	8	7	16	15
4.5	S	15	4	7	7	26	26
4.6	S	15	3	5	5	23	23
4.7	S	14	3	5	5	22	22
4.8	S	13	3	8	8	24	24
4.9	S	13	3	9	9	25	25
4.10	S	12	3	7	7	22	22
4.11	S	12	3	7	7	22	22
4.12	S	12	5	3	2	20	19
4.13	S	11	2	7	7	20	20
4.14	S	11	2	8	8	21	21
4.15	S	10	2	8	6	20	18
4.16	S	10	3	8	8	21	21
4.17	S	10	3	8	8	21	21
4.18	S	9	4	8	8	21	21
4.19	S	8	3	9	8	20	19
4.20	S	7	2	7	6	16	15
4.21	S	11	3	9	9	23	23
4.22	S	11	4	6	6	21	21
4.23	S	11	3	3	4	17	18
4.24	S	9	2	8	8	19	19
4.25	S	9	2	2	1	13	12
4.26	S	8	3	6	5	17	16
4.27	S	8	3	6	5	17	16
4.28	S	8	2	5	4	15	14
4.29	S	8	2	4	4	14	14
4.30	S	8	2	5	5	15	15
4.31	S	8	2	7	6	17	16
4.32	S	8	2	5	5	15	15
4.33	S	8	2	6	6	16	16
4.34	S	8	3	6	6	17	17

[1] Element of a DPSIR framework; P: social pressure; S: ecosystem state

APPENDIX 3

Remarks and references for indicators

Table App. 3.I: Remarks and references for indicators describing single stocks/populations targeted by the fishery

Number	Reference	Remarks
1.1	Ahmed *et al*. (1998)	Overall production has been estimated on the basis of consumption surveys, applied for instance in the Mekong River Basin
1.2	Saunders *et al*. (1998), cited in Ward (2000)	
1.3	Adapted from Saunders *et al*. (1998), cited in Ward (2000)	
1.4	Hardy (1958), cited in Pitcher and Hart (1982)	
1.5	Ward (2000)	
1.6	Gilbert *et al*. (2000)	In use in New Zealand as ME22, difficult in highly multispecies situations – stock to be replaced by groups of species; these groups need to be defined very carefully
1.7	Pitcher and Hart (1982), Gilbert *et al*. (2000)	In use in New Zealand as ME33. Standardization over fleets and through time is a major problem
1.8	Garcia and Staples (2000)	
1.9	Garcia and Staples (2000)	Can be complicated by sex inversions, frequent for fish and shellfish
1.10	Pitcher and Hart (1982)	Widely used. Not well suited in hightly multispecies fisheries.Data collection (catch at age) costly. Weakness in decoupling of exploitation and recruitment – management responses
1.11	Gilbert *et al*. (2000)	In use in New Zealand as ME24
1.12	Pitcher and Hart (1982)	Catches give a biased estimate of population structure due to gear selectivity
1.13	Pitcher and Hart (1982), ICES (2001a)	
1.14	Pitcher and Hart (1982)	Relatively easily observable, but not necessarily a proxy for stock size. Requires reliable information from the fisheries. Problems: standardization, discarding, misreporting
1.15	Pitcher and Hart (1982)	Indicator mainly from pollution effects on single stocks/populations. Habitat and/or seafood quality index rather than fisheries management index
1.16	Pitcher and Hart (1982)	Estimation as an add-on to catch and effort sampling can be costly
1.17	Garcia and Staples (2000)	Possible proxy for biomass under stable environmental conditions. Suggested for small pelagics, but could also be relevant for demersal species, e.g. Baltic cod
1.18	Pitcher and Hart (1982)	Widely used. Powerful if observable. Not well suited in highly multispecies situations. Related: *B*, *SSB*, *B/MSY*, *B/B*50%*R*, *B/B*90%*R* (Garcia and Staples 2000)
1.19	Pitcher and Hart (1982)	Fishery-independent estimate of *cpue*, often only estimate of recruitment, problem: large surveys are costly, beyond economic reach of most countries
1.20	Pitcher and Hart (1982), Garcia and Staples (2000)	Another measure of spawning stock size, costly to obtain. Not necessarily linked to recruitment. Can be complicated by sex reversals, as frequently found in in fish and shellfish
1.21	Sinclair and Iles (1988), Jamieson *et al*. (2001)	Link in time only over several generations. For conservation purposes rather than remedial action
1.22	Garcia and Staples (2000)	Possible proxy for biomass only under stable environmental conditions remedial
1.23	Gilbert *et al*. (2000)	In use in New Zealand as ME16
1.24	Stephenson and Kenchington (2000), Jamieson *et al*. (2001)	Link in time only over several generations. For conservation purposes rather than remediate action
1.25	Pitcher and Hart (1982); Garcia and Staples (2000), UN (2002)	Classical sustainability indicator in fisheries biology, scientifically largely abandoned because of problems in estimation and conceptual weakness in decoupling exploitation and recruitment
1.26	Pitcher and Hart (1982)	As for fishing mortality and surplus production. Problem: decoupling of fishing and natural mortalities, fishing and recruitment. Useful assessment requires ecosystem models with estimate of natural mortality for the period in question

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Table App. 3.II: Remarks and references for indicators describing the fisheries production base

Number	Reference	Remarks
2.1	Ward (2000)	
2.2	Pitcher and Hart (1982)	In use in New Zealand as ME33; Standardization over fleets and through time is a major problem
2.3	Ward (2000)	Suggested as biodiversity indicator (Saunders *et al*. 1998, cited in Ward 2000)
2.4	Sainsbury and Sumaila (2001)	
2.5	Garcia and Staples (2000)	
2.6	NMFS (1999)	Including, e.g., mortalities through use of dynamite
2.7	Sainsbury and Sumaila (2001)	
2.8	Pitcher and Hart (1982)	
2.9	Pauly *et al*. (2000)	
2.10	Sainsbury and Sumaila (2001)	
2.11		Older multispecies literature, especially analysis of aggregate models
2.12	Hill (1973), Rosenzweig (1995), ICES (2001a)	
2.13	ICES (2001b)	Metric of size distribution in catch
2.14	ICES (2001b)	Metric of size distribution in catch
2.15	Fisheries Western Australia (2001)	Used by Fisheries Western Australia as performance indicator for biological sustainability
2.16	ICES (2001b)	
2.17	Fisheries Western Australia (2001)	Used by Fisheries Western Australia as performance indicator for biological sustainability
2.18	Sheldon *et al*. (1972), Pope and Knights (1982), Rice and Gislason (1996), ICES (2001b)	Metric of size distribution in catch
2.19	ICES (2001b)	
2.20	Garcia and Staples (2000), Jamieson *et al*. (2001)	
2.21	ICES (2001a)	

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Table App. 3.III: Remarks and references for indicators describing the resource system structure (habitat quality and complexity)

Number	Reference	Remarks
3.1	Garcia and Staples (2000)	
3.2	Garcia and Staples (2000)	
3.3	Garcia and Staples (2000)	
3.4	Gilbert *et al*. (2000)	In use in New Zealand as ME7
3.5	Gilbert *et al*. (2000)	In use in New Zealand as ME33
3.6	Jamieson *et al*. (2001)	
3.7	Ward (2000), Jamieson *et al*. (2001)	Ratio of residual area and "pristine" or reference area – Garcia and Staples (2000)
3.8	Gilbert *et al*. (2000), Ward (2000)	In use in New Zealand as ME6
3.9	ICES (2001a)	
3.10	Jamieson *et al*. (2001)	
3.11	Standard ecology textbooks	
3.12	CSD (2001), WWF Australia (2002)	
3.13	Staples (1997), NMFS (1999), Ward (2000), Jamieson *et al*. (2001)	
3.14	Jamieson *et al*. (2001)	
3.15	Jamieson *et al*. (2001)	
3.16	Gilbert *et al.* (2000)	In use in New Zealand as ME6a
3.17	Garcia and Staples (2000), Jamieson *et al*. (2001)	Only where relevant, e.g. some marine mammals, some crustaceans
3.18	Jamieson *et al*. (2001)	
3.19	Garcia and Staples (2000), Jamieson *et al*. (2001)	Relevant in an ecosystem approach to fisheries, i.e. management across sectors
3.20	Garcia and Staples (2000), Jamieson *et al*. (2001)	Relevant in an ecosystem approach to fisheries, i.e. management across sectors
3.21	Garcia and Staples (2000), Jamieson *et al*. (2001)	Relevant in an ecosystem approach to fisheries, i.e. management across sectors

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Table App. 3.IV: Remarks and references for indicators describing the biological production base (ecosystem functioning)

Number	Reference	Remarks
4.1	Gilbert *et al*. (2000)	In use in New Zealand as ME32
4.2	Standard textbook	In use in New Zealand as ME33
4.3	Volterra (1928), several contributions in Daan and Sissenwine (1991)	
4.4	Pauly *et al*. (2000)	
4.5	Gilbert *et al*. (2000)	In use in New Zealand as ME7
4.6	Jamieson *et al*. (2001)	
4.7	Jamieson *et al*. (2001), ICES (2001b)	Anthropogenic introduction: failure to mainain natural levels of biodiversity
4.8	ICES (2001b)	
4.9	ICES (1999)	ICES advice on sandeels
4.10	ICES (2001a)	
4.11	Jamieson *et al*. (2001)	
4.12	ICES (2001a)	
4.13	ICES (2001a)	
4.14	Jamieson *et al*. (2001)	
4.15	ICES (2001), Jamieson *et al*. (2001a)	Fishery-independent estimate problem: large surveys are costly, beyond economic reach of most countries
4.16	Jamieson *et al*. (2001)	
4.17	Jamieson *et al*. (2001), ICES (2001a)	
4.18	ICES (2001b)	
4.19	Jamieson *et al*. (2001)	
4.20	Jamieson *et al*. (2001)	Allele frequencies (genetic variance), inbreeding coefficient
4.21	Crawford (1998), Jamieson *et al*. (2001)	
4.22	Garcia and Staples 2000	Example, index for goodness of the trophic status of small pelagics used for reduction
4.23	ICES (2001a)	Index of body well-being
4.24	Standard ecology textbooks	Example, ongoing discussion on cod–seal interactions off Canada
4.25	ICES (2001a)	Measured through biomass of species in surveys: total weight assumed to be a proxy for biomass, and in turn, a proxy for production
4.26	ICES (2001a)	
4.27	Odum (1969), Ulanowicz (1986), Pauly *et al*. (1998) ICES (2001a)	
4.28	Jamieson *et al*. (2001), ICES (2001a),	
4.29	Finn (1976), Odum (1971)	
4.30	Ulanowicz (1986), Pauly and Christensen (1995)	
4.31	ICES (2001a)	
4.32	Odum (1971)	
4.33	ICES (2001b)	
4.34	ICES (2001b), Jamieson *et al*.(2001)	

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