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A framework for selecting a suite of indicators for fisheries management

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Abstract:

We develop a framework for the objective selection of a suite of indicators for use in fisheries management. The framework encompasses eight steps, and provides guidance on pitfalls to be avoided at each step. Step 1 identifies user groups and their needs, featuring the setting of operational objectives, and Step 2 identifies a corresponding list of candidate indicators. Step 3 assigns weights to nine screening criteria for the candidate indicators: concreteness, theoretical basis, public awareness, cost, measurement, historic data, sensitivity, responsiveness, and specificity. Step 4 scores the indicators against the criteria, and Step 5 summarizes the results. Steps 3–5 offer technical aspects on which guidance is provided, including scoring standards for criteria and a generalized method for applying the standards when scoring individual indicators. Multi-criterion summarization methods are recommended for most applications. Steps 6 and 7 are concerned with deciding how many indicators are needed, and making the final selection of complementary suites of indicators. Ordinarily, these steps are done interactively with the users of the indicators, thus providing guidance on process rather than technical approach. Step 8 is the clear presentation to all users of the information contained. The discussion also includes the special case in which indicators are used in formal decision rules.

Keywords: criteria; ecosystem; framework; guidelines; indicators; objectives; scoring

Introduction

Many policy and management bodies with an interest in aquatic or marine systems have endorsed indicator-based approaches to management (OECD, 1998; World Bank, 2002; FAO, 2002; EEA, 2003). In all cases, these agencies note that ecosystems are so complex and unpredictable that suites of indicators are needed to give an adequate picture of their state. In fact, often it is noted that suites of indicators are needed for each of the major dimensions of sustainability: ecological, social, economic, and institutional (Charles, 2001; FAO, 2003). Indicators now have a prominent and legitimate role in monitoring, assessing, and understanding ecosystem status, impacts of human activities, and effectiveness of management measures in achieving objectives; and have a growing role in rule-based decision-making. Given all these roles, the suites of indicators intended to fulfil them must be chosen wisely.

For evaluations of ecosystem effects of fishing, marine ecosystems have so many properties of concern and so few proven general state measures that generally there is no shortage of proposals for indicators (e.g. ICES, 2001; CSAS, 2001; Link et al., 2001). The task we undertake here is outlining the steps necessary to choose wisely from the long lists of diverse potential indicators.

Because each indicator implies monitoring, evaluation, and reporting costs, at least redundant indicators should be avoided. Both the capacity for meaningful dialogue, and the processing ability of rule-based decision-making systems become saturated when overloaded with information from too many indicators (FAO, 2002, 2003). Most seriously, with even modest numbers of indicators, "current values" of different indicators are likely to support arguments for incompatible management actions. Thus, indicators may simply become a new battleground for partisan arguments, with adversaries selecting the indicators whose values happen to support the decision they desire. For example, for single-species fisheries management the International Council for the Exploration of the Seas (ICES) advises largely within the comparatively simple context of annual estimates of spawning stock biomass (SSB) and fishing mortality (F). Fisheries commissions commonly have argued against implementing ICES advice to reduce exploitation when F is above its precautionary reference point, if SSB happens to also be larger than its reference point. They argue that under these circumstances the excessive F imposes no immediate conservation issue, and that they will have time to reduce F when SSB really requires so (ICES, 2003).

Clearly, to be cost effective and provide clear management guidance, suites of indicators should be kept as small as possible while still fulfilling the needs of all users. The challenge is to identify the suite that best meets the needs in each particular application. Marine ecosystems differ in historic data available, monitoring capacity, fisheries being prosecuted, other human uses, and governance system, as well as in their ecological properties. All these factors may affect the utility of a specific indicator (Belfiore, 2003; Olsen, 2003), making it obvious that no single suite of indicators will be universally the best to use.

The framework presented is designed to be a guide for practice, and therefore comprises a series of steps and specific tasks to be performed at each step. In practice, governance processes often make their selection of indicators in dynamic, interactive exercises, and rigid, stepwise algorithms are unlikely to be followed. Hence, the framework has to be flexible in its application. However, whatever process is followed, the issues described in each step *must* be addressed to select the final suite, and for some of these steps the order matters (e.g. criteria must be weighted before indicators are scored).

STEP 1: Determine user needs

To determine the needs of the users involved in management or governance, it is, of course, necessary to identify who they are. Needs of both managers and stakeholders will be affected by the types of decisions to be made and the objectives pursued. Both legislated and cultural governance considerations influence which aspects of the fishery (catch or effort quota; gear, spatial, or seasonal restrictions) are amenable to regulation, and this may influence the practicality of different indicators (FAO, 2002, 2003).

Whether the indicators are intended to just inform discussion or directly support decision-making, the management objectives need be clearly specified. Some jurisdictions are attempting to do this explicitly (Bergen Declaration, 2002; EC, 2003), in which case the operational objectives can be taken directly from the policy documents. However, often objectives either do not exist, or are so general and vague that they provide little guidance for selecting appropriate indicators. In those cases, management bodies first must formulate operational objectives. This is efficient to involve those participating in the indicator selection in the process of formulating the operational objectives , to ensure that the final suite of indicators matches the concerns behind the Objectives, even when their wording reflects compromises among differing points of view.

At this stage, the major threats to achievement of the objectives should be identified – the pressures in a Driver-Pressure-State-Impact-Response framework (OECD, 1993; UNEP, 2000; IIED, 2002; Bowen and Riley, 2003). When fishing is placed in an integrated management framework with other human activities (Belfiore, 2003; FAO, 2003), it is even more important to specify the major avenues by which each of these activities may threaten achievement of objectives, because the indicators must inform managers about the effects of multiple uses. Indicators of effects of fishing either need to be robust to other anthropogenic effects or the effects of other human activities need to be understood well, if they are to provide a sound basis for managing fisheries. Information on threats will be important when evaluating the sensitivity, specificity, and responsiveness of candidate indicators.

Universally applicable algorithms for identifying participants, objectives, and threats do not exist. However, general approaches for identifying stakeholders and developing consensus-based objectives provide useful guidance (Smith *et al*., 1999; Walker *et al*., 2002; FAO, 2003).

STEP 2 –Develop a list of candidate indicators

The next key consideration is that candidate indicators truly measure ecosystem status relative to the objectives. Knowledge of the ecosystem, characteristics of the fisheries, and societal values must all be considered. Where clear, system-specific operational management objectives have been set, this step can be as straightforward as listing reasonable ways to measure the property reflected in each of these objectives. Even in this simple case substantial technical knowledge may be required to develop a comprehensive initial list of candidate indicators. When objectives are only defined conceptually or developed without adequate technical expertise and full stakeholder representation, this process requires care and patience, because the whole array of potential ecosystem effects of fishing must be considered. Examples include status of non-target species (Bellail *et al*., 2003), size structure of the fish community (Bellail *et al*., 2003; Jennings *et al*., 1999), the central node of a wasp-waisted food web (Rice, 1995; Cury *et al*., 2003), top predators (Scott, in press; Trites, in press; Karpozi, in press), habitat features (NRC, 1994; ME-NZ, 1999), and others. Likewise, candidate fishery indicators should be considered such as target species, gears, spatial and temporal distribution, amounts and kinds of discards, and even levels of participation (Garcia, 1996; Garcia and Staples, 2000). Candidate social and economic indicators may be no more straightforward to list comprehensively, particularly when policy goals in these respects are not well articulated, or in conflict (Bowen and Riley, 2003; Rice, 2003). Where other uses may affect the opportunities available to fisheries, or yields expected from them, the list might have to include indicators of the status of these activities (Gottret and White, 2001; Belfiore, 2003; Talaue-McManus *et al*., 2003). Social scientists, economists and community leaders may be required, if the inventory is to be complete enough to select a final suite that provide a basis for informed discussion and management support.

Step 3 – Determine screening criteria

Published lists of criteria on which indicators should be evaluated (EC/Eurostat, 1999; ThemaNord, 1999; UNCSD, 2001; ICES, 2002; EEA, 2003) are generally quite similar. Table 1 lists a selection of nine that cover the concepts behind those proposed by all expert groups, although some agencies may list subsidiary considerations as full criteria reflecting their particular priorities.

All nine criteria should always be considered, but they are not equally important in every case. Moreover, even in individual applications, different participants in the governance process are likely to value their importance differently. However, to keep the screening process objective, the relative importance of the nine criteria should be established *before* the screening is done.

Although complex weighting and scoring algorithms have been developed for specific situations (MSC, 2004), weighting the criteria on a refined scale would usually give a false sense of precision to an exercise generally lacking a quantitative basis. Moreover, the final steps in the framework are sufficiently consultative to diffuse any great precision of inputs early in the process anyway.

Experience as well as the results of some comparative experiments (Rochet and Rice, this volume) suggest that ranking their importance according to three classifications – high ≈ essential, moderate ≈ useful, minor ≈ inconsequential – generally should suffice. Sorting and ranking should be done interactively and systematically with the client groups involved.

We make a distinction between three major user groups, who may be expected to attach differential importance to the nine criteria (Table 1). Technical experts and science advisors would use indicators to measure progress towards achievement of explicit objectives, often supported by the use of reference points (OECD, 1998; ICES, 2002; FAO, 2002, 2003). The criteria of major and moderate importance to this group would presumably be Measurement, Historic Data, Theoretical Basis, Sensitivity, and Responsiveness/Specificity. When indicators are used in formal decision rules, science advisors are likely to reject those performing poorly on any of these criteria.

Table 1. Relative importance (Minor, Moderate, High) that three different user groups are expected to attach to the nine criteria used in screening candidate indicators. Numbers in brackets are tentative rankings within each group, although these will deviate on a case by case basis (there is no basis for ranking criteria of Minor importance).

Criterion	Technical Experts & Advisors	Decision-Makers & Managers	General Audience
Concreteness	*Minor*	*Moderate* / *High*. Decisions would be easy to explain to public, and to relate to other management activities. (5/6)	*High*. Low score means that it would be difficult to relate personal experience to indicator. (2)
Theoretical Basis	*High*. Inconsistency with established theory means low confidence, however solid the empirical basis (3/4)	*Minor*. Management generally based on values and performance, not ecological theory.	*Minor*.
Public Awareness	*Minor*.	*Moderate*. Valuable for getting compliance with management plans. (5/6)	*High*. If general knowledge is lacking, a major education programme would be required (1)
Cost	*Minor*. In general, not their concern	*High*. Governance systems are budget-conscious. (3)	*Minor* to *High*. Value for money. (4)
Measurement	*High*. Low or unknown accuracy and precision often sufficient grounds for rejection. (1/2)	*Minor*. As long as technical advisors and public have confidence.	*Minor*. Unless sampling design is not considered representative of personal experience (scientific survey debate [ref]). (5)
Historic Data	*High*. For estimating reference points, and to have confidence in interpretation. (2/3)	*Minor*. As long as technical advisors and public have confidence. May become *Moderate* to *High* when management has to function without technical support.	*Minor* to *High*. Depends on how much context is needed to interpret changes in value.
Sensitivity	*High*. Poor sensitivity may be reason for rejection. (1)	*Moderate*. To interpret biological and economic importance of changes in value.(4)	*Moderate*. To attach meaning to changes in value. (3)
Responsiveness	*Moderate*(5/6)	*High*. For those wanting feedback on effectiveness of management plans. (1)	*Minor*.
Specificity	*Moderate* . To disentangle fishing effects from other impacts. (5/6)	*High*. For those wanting to take proper actions to remedy problems in fishery (or other managed activities). (2)	*Minor* to *Moderate*. To understand how fishery relates to the “big picture”

Decision-makers and Managers use indicators to support decision rules, or less formally to guide management actions in addressing discrepancies of indicator status relative to an objective. If indicators are to be used in a structured decision-support context, their selection needs to be guided even more closely by suitable criteria. However, outside a decision-support context, application of the more stringent criteria might exclude more cost-effective ones. Criteria valued in both rule-based and consultative decision-making include Responsiveness, Specificity, Cost, and Concreteness/Public Awareness, Sensitivity and Responsiveness. For rule-based decision-making, the indicators have to perform well also on Historic Data, so that meaningful reference points and decision rules can be set.

When indicators are used to inform General Audiences about ecosystem status or effects of management, they are mainly concerned with Public Awareness, Concreteness, Sensitivity and Cost, and sometimes Measurement. However, a differentiation may be needed between situations where the role of the indicator is to inform an aware and engaged public, or to motivate an uninterested public. In the latter case, an explanation of the underlying theory in accessible language may become more important, as well as recent deviations from historic values. For specific users such as fishers it is also important that personal experience can be linked to changes in indicator values.

Step 4. Score indicators against criteria

The scoring process has two components: the evaluation of the information content or quality of each indicator relative to each criterion, and the strength of the evidence by which information content or quality is judged. These ’properties’ will not necessarily co-vary. Hence, there may be different scores on different properties of a single criterion that will have to be reconciled subsequently.

With regard to scoring of the information itself, a quantitative evaluation may be made available for a few properties of a few criteria only. For example, programme audits provide estimates of the cost of obtaining periodic indicator values. In general, however, attempts to provide fully quantitative estimates of the value of all indicators on each criterion are likely to fail.

Moreover, some criteria are multi-dimensional (e.g., bias, variance, accuracy, precision). Calibrating a criterion value for effects in different dimensions is almost certainly impractical, if not impossible. Hence, candidate indicators often have to be scored in the face of complex dimensionality of the criterion and in the absence of sound quantitative measures of the properties of interest. Under such circumstances, detailed quantitative scores would give a misleading sense of discrimination power among indicators. In practice, an ordinal scoring on a scale of three to five ranks for each candidate indicator on each criterion would seem sufficient (e.g. low, fair, moderate, high). If a multi-dimensional criterion is of major importance, , one practical option may be to retain the ordinal scores of the candidate indicators on the key dimensions of the criterion, and deal with the added complexity in Step 5. The strength of the evidence supporting each evaluation of information quality is likewise rarely amenable to a fully quantitative scoring. Table 2 proposes a ranking of the inherent reliability of different information sources. Such rankings are straightforward to apply and generally adequate for the task. As long as the relative position of candidate indicators is carried forward with regard to their strength of evidence, subsequent steps can be performed with objectivity and rigour.

Existing experimental and analytical approaches enable direct testing of the effectiveness of indicators in supporting decision-making. Tools like signal detection theory (Helstrom, 1968) have been explored as a means for testing the performance of indicators of fishing effects on the basis of Responsiveness, Sensitivity, and Specificity (Piet and Rice, 2003). However, the interpretation of the performance error rates obtained required external information about costs that users would assign to different types of management errors (e.g., unnecessary TAC reductions vs. permitting overfishing). This suggests that even quantified error rates might not be comparable across criteria, and hence only useful for ranking within criteria (e.g., high 'miss' rates for one indicator may arise from a lack of Sensitivity; high 'false alarm' rates for another from a lack of Specificity; which type of error is more serious depends on many factors, including the uses and the objectives being supported by the indicators). Nonetheless, to ensure that sound indicators are chosen from among the candidates, retrospective analysis of their performance in supporting decision-making (Piet and Rice, 2003; ICES, 2003) should be fed directly into the evaluation process.

Table 2. For each of the screening criteria, the constituent considerations in conducting the evaluation and the methods by which the evaluation could be conducted. Stars on cells labelled high mean that IF that consideration (or Method of Evaluation) is relevant, scoring high here is really important, and the indicator should get serious attention. Stars on items labelled Low mean that IF the consideration is relevant, scoring low is nearly a fatal flaw**.** Methods of Evaluation include **SI** [Conclusive published experimental research using Strong Inference]; **MP** [Multiple Independent Publications providing consistent findings**]; FS** [Formal Designed Surveys]; **MM** [Multiple Independent Models Producing Consistent Results]; **IC** [Interdisciplinary Consensus of weight of evidence], **TJ** [Research Team Professional Judgement]. Most relevant Methods of Evaluation are presented in decreasing order of confidence in results.

Criteria	Components	Type of Evidence likely to be used in evaluations
Concreteness	Concrete property of physical/biological world (High), or abstract concept (Low)?	FS; IC; TJ
	Units measurable in the real world (High), or arbitrary scaling factor (Low)?	IC; TJ
	Direct observations (High), or interpretation through model (Low)?	IC; TJ
Theoretical basis	Theoretical basis is not contested among professionals (High); ii) basis credible, but debated; Can account for patterns in many data sets (High to Fair, depending on how other models fit the same data) ;iii) credible, but competing theories have adherents and empirical support is mixed (Moderate) ;iv) adherents, but key components untested or not generally accepted (Moderate to Low)	MP**, SI*, MM, IC; TJ (number of competing theories to allow contrast is important)
	If indicator derived from empirical observations: i) concepts readily reconciled with established theory (High) ii) concepts not inconsistent with – but not accounted for by - ecological theory (Moderate);iii) concepts difficult to reconcile with ecological theory (Low)	SI**; MP; MM; IC, TJ
	Theory allows calculation of reference point associated with serious harm* .	MP; MM; IC, TJ
Public awareness	Is it a property with a high (High) or low (Low) public awareness outside the use as an indicator?	FS*; IC; TJ
	Does public understanding correspond well (High) or poorly (Low) with the technical meaning of indicator?	FS; IC; TJ
	If public awareness is high, is the public likely to demand action that is: i) proportional to the value of the indicator as determined by experts (High) ii) disproportionately severe proportional to the value of the indicator (Moderate) iii) largely indifferent to the indicator (Low)	FS; IC; TJ
	Does the nature of what constitutes "serious harm" (used to define a reference point) depend on values that are widely shared (High) or vary widely across interest groups (Low)?	FS; IC; TJ
	International binding agreements, national or regional legislation require that a specific indicator be reported on at regular intervals (High), to agreements/legislation require environmental status reporting but Indicator not specified (Mod) to no such requirements (Low)	IC; TJ. (when Indicator not specified in legislation)
Cost	Uses measurement tools that are widely available and inexpensive to use (High), to needs new, costly, dedicated, and complex instrumentation (Low)	IC; TJ
Measurement	Can the variance and bias of the indicator be estimated? Yes (High) No (Low)	MP; MM; IC; TJ

	If it can be estimated, is the variance of the indicator low (High) to high (Low)	MP, IC; TJ
	If it can be estimated, is the bias in the indicator low (High) to high (Low)?	MP, IC; TJ
	If the indicator is biased, is the direction of the bias usually in the direction of over-estimating risk (High) or towards underestimating the risk (Low)	MP; MM; IC; TJ
	If they can be estimated, have the variance and bias been consistent over time (High), or varied substantially over time (Low)	MP; MM; IC; TJ
	Probability that indicator value exceeds reference point can be estimated with accuracy and precision (High) to very coarsely or not at all (Low)**	MM; IC; TJ (type of risk quantification is important)
	Indicator measured using tools whose accuracy and precision are known and consistent (High), to unknown or known to be poor/inconsistent	MP;MM; IC;TJ
	Value obtained for indicator unaffected by sampling gear (High) to sampling methods can be calibrated (Moderate) to calibration difficult or not done (Low)	SI; MP; IC;TJ
	Seasonal representativeness: Season variation: unlikely or highly systematic (High) to irregular (Low)	SI; MP; MM IC; TJ
	Geographic representativeness: geographic variation: irrelevant or stable and well quantified (High) through random (Moderate) to systematic on scales inconsistent with feasible sampling (Low)**	SI; MP; IC;TJ
	Taxonomic representativeness: Indicator reflects the status of: from all taxa sampled/modelled (High), through ecologically predictable subset of species (Moderate), to only specific species with no identifiable pattern of representativeness (Low)	SI; MP; IC;TJ
Availability of historic data	Necessary data are available for: periods of several decades (High), to only relatively recent period (moderate), to opportunistic or none available (Low)	MP, IC; TJ
	Necessary data are: from the full area of interest (High), to restricted but consistent sampling sites (Moderate) to opportunistic and inconsistent sources or none (Low)**	MP, IC; TJ
	Necessary data have high contrast, including periods of harm & recovery (High), to high ocntrast but without known periods of harm and recovery, (Moderate) to uninformative about range of variation expected (Low)	MP, IC; TJ
	The quality of the data and archiving is known and good (High) to data scattered with reliability not systematically certified, and archives not maintained (Low)	MP, (e.g. environmental indicators)IC; TJ
	Data sets are freely available to research community (High) to in private or commercial holdings (Low)	IC;
Sensitivity	Value of indicator responds to fishing in ways that are i) smooth, monotonic and high slope of response (High)** ii) smooth, monotonic and low slope (Moderate) iii) smooth, monotonic over a restricted range of fishing effort characteristics (Mod. to Fair) iv)unreliable (Mod. to Fair, depending on when it fails to inform about fishing effects)v) insensitive or irregular: magnitude of response does not depend on magnitude of signal in effort (Low)	SI; MP; MM; MC; TJ (length of time series for testing is important)
Responsivenes s	Indicator changes value within1-3 years of implementation of measures (High) to indicator will only reflect system responses to management on decadal scales or longer (Low)	SI; MP; MM; MC; TJ (length of time series for testing is important)

Specificity	Is the impact of environmental forcing on the indicator known and small (High) or strong (Low)?	SI; MP; MM; MC; TJ (contrast in data series used in testing is important)
	If environmental forcing affects indicator, is effect systematic and known (High) to irregular or poorly understood (Low)**	SI; MP; MM; MC; TJ (contrast in data series used in testing is important)
	Relative to other factors the indicator: i) is known to be unresponsive (High) ii) responds to specific known factors in known ways (Moderate) iii) is thought to be unresponsive (Fair) iv) responds to many factors in only partly understood ways (Low)**	SI; MP; MM; MC; TJ (contrast in data series used in testing is important)

Step 5 – Summarise scoring results

For the final evaluation two matrices will be available: one with the weights assigned to the nine criteria for each user group, and one with scores of each candidate indicator on each criterion. Entries of the second matrix, should contain both the score for information quality and some designation of the weight of evidence for that score, and sometimes may have multiple pairs of these for different dimensions of a criterion. This step describes how these two matrices are converted into information that can be used in the final selection process.

Of course, it would be possible to compute a final score of each indicator as the sum of the matrix products of weights by scores. Although this procedure provides unique scores that would facilitate subsequent crossing off the lower ranks, there are several reasons for advising against such a simple procedure. (1) Weighted averages could give moderate scores to candidate indicators that were strong on some criteria, but fatally flawed on others, and it is by no means certain that a few attractive properties balance other severe shortcomings. (2) The approach would tend to give similar scores to indicators with similar properties, fostering selection of redundant rather than complementary indicators. (3) It would be tempting to make the scoring on individual criteria more finely differentiated, without sufficient information to justify such scores and neglecting that scorings are comparable within criteria only. (4) Information on the strength of evidence, which we stressed as an important part of the evaluation process, would be disregarded.

Graphic methods such as radar plots ("AMOEBA") have been proposed for display of the status of an ecosystem using semi-quantitative information on a selection of ecosystem indicators (e,g, Collie *et al*., 2001). Conceptually, displaying the status of a candidate indicator on multiple criteria would be similar: the relative performance on each criterion would be reflected in the lengths and orientations on the different axes and define the polygon. Hence, if the screening process were seeking indicators that could serve several different uses, different regions of the plotting space could be taken as reflecting the ability of an indicator to meet the criteria associated most closely with each use. The differential weight of evidence could be reflected in the density of the filled space of the plot. Such a graphic approach would allow a visual assessment of the degree to which an indicator corresponded to the properties desired by different user groups, and indicators falling short on important criteria would be readily apparent. However only a small number of competing indicators could be superimposed on a single set of axes, comparative evaluations among many indicators would be problematic. Although really superior indicators would clearly stand out , the graphic displays become too complex to interpret when a large number of indicators has to be evaluated, or if their performance is good and poor on different criteria.

Other methods of data reduction proposed include clustering algorithms for grouping sets of indicators with similar performance on the criteria (CSAS, 2001), and ordination methods for a spatial display of the relative positions of the indicators in spaces of lower dimensionality than the number of criteria (Pitcher and Preikhost, 2001; Link *et al*., 2001). Either approach has potential flaws. Ordinal scores are likely to be poorly calibrated across criteria and possibly even across different types of indicators. Information on strengths of evidence is hard (but not impossible) to preserve in such analyses. When ordination methods reduce dimensionality among criteria, they seek overall patterns of covariation. Hence, they relegate the subtle distinctions among criteria such as Sensitivity, Specificity, and Responsiveness to later axes, often considered noise or “stress”, thus disguising features important for decision-making.

The type of data used in the selection of candidate indicators have much in common with those used in Psychometrics: multiple criteria which overlap in information content but vary in importance for different uses; at best ordinal scores of cases on the criteria; and varying strength of evidence. Psychometrics addresses these analytical problems, particularly in the field of personality and aptitude testing by developing multi-dimensional response “profiles” using the test scores directly (Dorfman and Hersen, 2001; Murphy and Davidshofer, 2001). The response profiles are interpreted relative to normative samples – scores of hundreds to thousands of subjects whose performance traits are known accurately on exactly the properties that the test is intended to measure. For many tests different norms must be provided for applications in different contexts. Two important messages come from this work. First, the information in inherently multi-dimensional traits (like indicator “value”) should not be collapsed into misleadingly simple aggregate scores. Second, it will be necessary to build up “normative scores” of indicators suites for ecosystems perturbed in various known ways before it will be legitimate to interpret the values of indicators with various properties in management contexts. There is much to learn about how to approach this complex task.

Step 6 – Decide how many indicators are needed

This step requires strong interaction among the ultimate users. For reasons discussed in Steps 1 and 2, it is simultaneously desirable to have the fewest possible number of indicators to serve all uses, while having all key system components featuring in the objectives covered by trustworthy indicators. This is where the information on other threats must be taken into consideration, together with the knowledge of how they may affect different candidate indicators.

Decisions on the number of indicators to keep are aided by effective profiling of how the candidate indicators score on the evaluation criteria. Effective profiling (graphical or otherwise) should show whether there are a few clusters of indicators with similar attributes, or a diverse array of indicators, each with a distinctive set of performance characteristics. In the former case, the number to keep would be a small multiple of the number of clusters. The actual multiple would increase with the number of operational objectives decided upon, and the number of different system components addressed by the objectives. In the latter case, it would probably be inappropriate to set a fixed number of indicators separately from a discussion of the number and types of threats. Identification of multiple threats should result in selecting yet larger numbers of indicators. Although this has not been studied formally, we expect the multiplier effect to depend on how the ecosystem effects of other threats resembled the ecosystem effects of fishing. The more similar the effects of the multiple forcers, the greater the number of indicators needed to differentiate between the contributions of each forcer to the status and trends in the indicators. Without such differentiation, it will be less likely to meaningfully use the indicators in selecting effective management actions. This is also where the need for normative profiles becomes clear, as is routine in Psychometrics. Indicator-based "decisions" have to be tested retrospectively for different conditions (governance systems and combinations of threats), so objective information can be accumulated about what combinations of properties of indicators are the best guides for decision-making.

Step 7 – Make Final Selection

When working directly with the matrices of scores by criteria and criteria by stakeholder weights, selection should strive to find suites of indicators that perform well on all criteria important to each expected use, as well as to cover the entire spectrum of ecological, social and economic objectives. If no candidate indicators perform well on all the important criteria for a given use, then the suite should try to balance strengths and weaknesses. That is, some indicators in the suite should perform well on each important criterion, and members of a suite should not all perform poorly on the same criteria. When the suite is intended to serve multiple uses, it should be more effective to have select indicators matched well to each intended use, rather than to derive a compromise among uses, not performing particularly well for any of them.

In this step, the reasons for selection should be well documented and retained. When indicators with known shortcomings are retained because they have unique strengths as well, users need to keep these in mind when interpreting their values and take decisions. Also, tolerances for weaknesses or strengths might change over time for different reasons. Time series data expand continuously and knowledge of an ecosystem and effects of fishing are likely to increase, new forcers – natural or anthropogenic - might become important, and societal values could change. All these events would be cause to reconsider which indicators should be used, or how they are interpreted in practice. Retaining the evaluation matrices and the reasons for the selection of indicators allows choices or uses to be adapted without repeating the entire exercise, enhancing consistency.

Step 8 – Report on the suite of indicators

Given the final suite of indicators, it is necessary to present the annual (or other periodic) values effectively. We found many different presentation methods, each with advantages and drawbacks (Table 3). Many integrating methods require some standardisation and some kind of weighting , and have the potential to reintroduce all problems in selecting the indicators (Step 3-6) to begin with.

Table 3 Review of presentation methods from the literature on indicators (*IND*). Three categories of methods are included, corresponding to the three steps in combining indicators: 1) methods for standardising indicators and bringing them on comparable scales. 2) Methods to weight indicators. 3) Methods to combine the weighted standardised indicators.

Method (reference)	**How it works**	**Pros (+) and cons (-)**
Methods for standardising indicators		
Scoring	Convert the IND values into scores (a discrete variable with limited (ltd) number of classes)	+ Easy for qualitative var. with ltd number of classes - usually arbitrary for quantitative var. -: No explicit scoring meth. available -Huge scope for subjectivity (see Rochet and Rice, 2005)
Fuzzy scoring	1. Conversion to qualitative var. with ltd number of classes 2. Score each observation from 'no affinity' (0) to 'high affinity' (5) with each modality	+: Allows uncertainty and ltd knowledge; -: Not much experience available. -Complex to explain
Linear interpolation between extreme observed values	Scale all indicators on a common range (*e.g.*, [0, 1]) by assuming linear variation between each IND's minimum and maximum observed values.	+: Simple; -: IND may not show linear variation -:Sensitive to history of data series
Linear interpolation between reference values	Similar but using pre-defined reference values instead of min and max	+Simple - Linear variation might not be relevant for all *IND* - Often difficult to define the limits for the interpolation (reference values)
Multivariate methods	Usually performed on normalised variables, hence standardisation by their standard deviation	+Takes account of uncertainty and variability - Sample dependent
Weighting methods		
Multivariate methods	Projections on maximum inertia axes, hence give lower weights to correlated *IND*	+Objective way of reducing redundancy without eliminating *IND* that might be useful in a particular situation - No account taken of management objectives.
Analytic Hierarchy Process (AHP) (in Tran *et al.*, 2002)	1. Breakdown of problem into smaller constituent parts at different levels 2. A series of pair-wise comparison judgements at the various levels	+ User-defined weighting -If many *IND* and potential values, the number of pair-wise

	in the hierarchy are asked to users	comparisons increases exponentially.

Method	How it works	Pros (+) and cons (-)
Graphic displays		
Kites (Garcia and Staples, 2000)	One standardised *IND* per edge Outer rim = "good" scores, centre = "bad" scores. *IND* scores linked and resulting area possibly shaded	+Quick and easy Not too many data manipulations +Good at communicating - Polygon surfaces and shapes influenced by the order of the IND around the kites -Misleading (equal weight suggested for all *IND*) -Redundancy possible
Pie slices (Andreasen et al. 2001)	One standardised *IND* per slice Circumference = "degraded" reference condition, *IND* value shaded	<u>Idem</u> Slices better than kites (shaded area equal whatever the order)
Amoeba (Collie et al. 2001)	Circle = reference level Length of arrows = *IND* values Directions of arrows = correlations between *IND* Polygon shape influenced by the relative *IND* variances	+Takes account of *IND* redundancy, since based upon their correlation - (NB ordering based on correlations) hard to display multiple IND
Indices		
Weighted average (Andreasen *et al*. 2001)	1. Standardise indicators 2. Define weights 3. Average	+Simple - Outcome determined by standardisation and weighting methods, and hard to test weighting validity - prone to eclipsing (some good traits obscure some bad ones)
Weighted geometric average	Multiply weighted *IND* rather than summing them to increase the influence of 'bad' scores	<u>Idem</u> - Eclipsing not removed

Method	How it works	Pros (+) and cons (-)
Indices of Biotic Integrity (IBI) (Hughes et al. 1998; McCormick et al. 2001)	1. Define reference condition, based on minimally disturbed sites, historical data, or models 2. "Score" IND continuously by linear interpolation between reference values 3. IBI = sum of scores / number of *IND* 4. Eliminate redundant and inconsistent IND based on correlations 5. Measure variability in *IND* and IBI using multiple sampling at each site and estimate power of IBI	+ Scoring methods may be improved and weights might be introduced. Rules for combining IND scores are specified. - Eclipsing and redundancy still present and can distort scores, but can be reduced by additional rules to eliminate some IND
Fuzzy numbers (Tran et al. 2002)	1. Normalise *IND* with 0 ideal and 1 undesirable by linear interpolation 2. Each normalised *IND* with its observed min and max in a given site make a fuzzy number 3. Compute fuzzy distance of each *IND* to 0 and 1 4. Weight and aggregate the distances	+Appealing because seems a way to transfer uncertainty towards aggregated levels - Fuzzy numbers are NOT fuzzy; must specify some distribution , - Generally no *a priori* basis for specifying the sampling distributions which must be assumed, and very sensitive to the distribution assumed
Framework for ecologically sustainable development (Chesson & Clayton 1998)	1. Define hierarchical structure of the assessment 2. Standardise *IND e.g.* by linear interpolation 3. Weight and sum at desired level, using beforehand chosen weights 4. Examine trends at various levels	+ Hierarchical structure allows to examine situation at various levels +Method recognises that process is subjective +Dynamic approach - Method does not account of uncertainty in the data + Possible to explore use in Pressure and Impact..

Method	How it works	Pros (+) and cons (-)
Multivariate Ordination Methods		
MDS of scored *IND* (Pitcher & Preikhost 2001)	1. Choose attributes that are "easily and objectively scored" with obvious 'good' and 'bad' extremes 2. Ordinate a set of fisheries or the trajectory in time of a fishery 3. MDS. The first axis is supposed to represent sustainability 4. Construct fixed reference points (extreme scores for each attribute) and a randomisation test	+ The general advantages of multivariate methods. - No scoring method: scores are arbitrary - Reference points are misleading because no fishery can exhibit together all indicators at extreme values
PCA and canonical correlation analysis of *IND*\(Link et al. 2001)	1. Gather metrics of community and abiotic and human factors 2. PCA 3. Interpret the axes in terms of exploitation 4. Canonical correlation analysis of community versus factors	+ The general advantages of multivariate methods. - Interpretation not always obvious (but possibly improved by can. corr. analysis). - Not easy to understand for customers.
Multivariate analysis of IND (Charvet et al. 2000)	1. Measure IND in a set of communities 2. Fuzzy scoring 3. Fuzzy correspondence analysis 4. Hierarchical clustering 5. For each group, profiles of IND (frequency distributions of mean scores) 6. Reference Point (RP) possibly given by extreme situations	+ The general advantages of multivariate methods. - Interpretation not always obvious (but possibly improved by can. corr. analysis). - Not easy to understand for customers.

Several reporting aspects are often entangled. Indicators may be used to report: (1)the current state; (2)the dynamics of the state; (3)value judgements about the state (well or poor); (4)value judgements about the dynamics (improving or worsening). To avoid confusion over what is being reported, each aspect should be taken in a separate step. For example, under certain conditions a set of state indicators may be aggregated, and the aggregated index compared relative to an objective for the aggregate value. Likewise, some methods advocate scoring the dynamics of a set of state indicators, and then aggregating or presenting the set of these scores (Bellail *et al*., 2002; EEA, 2003), because it makes it easy to track temporal changes in the aggregate value, and, by inference, in the ecosystem. However, aggregation methods have a risk of concealing the nature of what is being perturbed. Moreover, even if the suite of indicators being aggregated covers the properties of the ecosystem well, perturbations like fishing may affect some state indicators in one direction and others in the opposite direction (the "eclipse" effect, see Andreasen, 2001). Users usually are aware of obvious conflicts in the directional response of different indicators to fishing, but the expected patterns are not always founded on good theory (e.g., state indicators of diversity). Hence, aggregated trends should always be used with great caution.

Many methods in Table 3 apply weightings, where again there is ample opportunity for presenting misleading information because they do not differentiate between weighting for methodological reasons (redundancy and unequal uncertainty among indicators) and weighting for policy reasons. This again makes changes in the weighted value of the aggregate score difficult to interpret without returning to the patterns observed in the individual indicators.

Thus, we are again faced with the trade-off between the complexity of trying to interpret large amounts of information, and the risks inherent in collapsing information in apparently simple ways. The solution must lie in developing reference profiles for interpreting each indicator individually. Unfortunately, this solution is a long-term one for marine application.

Use of Indicators in Decision Support

If a large suite of indicators is going to be used in a formal decision-support system, the number of inputs to the system will be correspondingly large. Formal guidance as to how they should be treated is largely lacking. For example, Annex III-B of the Bergen Declaration includes five indicators of eutrophication, accompanied by a footnote that the ecological quality objectives for each of these represent "an integrated set and cannot be considered in isolation", but provides no guidance on how that is to be achieved. The Precautionary Approach (FAO, 1996a, b) could be interpreted as requiring management action to be matched to the indicator with highest risk of being at or outside its conservation reference point. However, analytical risk management approaches indicate that an overall risk profile should be built up across all indicators, and it is that risk, not each component, which should be managed. This would present a major challenge in practice, but is the intent implied by agencies adopting both indicator-based and risk-based management principles.

In either case, when a suite of indicators was retained because each member complemented some deficiency of the other ones, the question remains how to carry that information into the overall decision-making process. Consider the comparatively simple case of management using single decision rules for each indicator, with each rule individually tailored to the strengths and weaknesses of the indicator as reflected in the evaluation matrices. Unless the decision rules associated with each indicator all require exactly the same management response, a family of "meta-rules" would have to be developed to determine which management response is appropriate.

The full management problem is even more difficult. Not only are there multiple indicators supporting dialogue or decision-making in relation to a given objective, keeping the ecosystem effects of fishing within sustainable bounds requires multiple operational objectives as well (ICES, 2001, 2003; FAO, 2002). Many management actions may affect the probability of achieving several of them at once. At the same time, they may cause new problems. For example, closed areas cause redistribution of effort. What may be gained for some species, but be all wrong for others (Dinmore et al., 2003; Hilborn et al, 2004).

Conclusions

Indicator-based decision-making can give managers structured insight into the likely effects of alternative actions, which is essential in integrated management approaches. However, this is only true if the performance characteristics of the indicators are understood, and their trends and current values relative to reference points can be interpreted correctly. This is a particularly compelling reason to attempt a formal screening of the performances of candidate ecosystem indicators, as outlined in our framework, even if the actual choices are to be made by partisan political processes rather than scientific ones.

After the tests we have tried to design and implement for the framework outlined (Rochet and Rice, this symposium), much remains to be done to establish its validity. Even when the complete framework is tested in interactive settings with managers, stakeholders, and scientists each fulfilling their normal roles, and improved as needed, we expect that selection usually will continue to be done by consensus and dialogue. Nevertheless, the important function lies in its potential to structure the dialogue. If all steps are included in the dialogue leading to the selection of the final suite of indicators for use, the most important stumbling blocks should have been addressed. This would be an improvement over an haphazard or manipulative approach, and a step towards the rigour and transparency required and justified, given their importance in subsequent management.

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