Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems.

1. The IndiSeas project

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One of the challenges faced by the scientific community grappling with the ecosystem approach to fisheries is to propose a generic set of synthetic ecological indicators, which would accurately reflect the effects of fisheries on marine ecosystems, and could support sound communication and management practices. The IndiSeas Working Group was established in 2005 under the auspices of the Eur-Oceans Network of Excellence to develop methods to provide indicators-based assessments of the status of exploited marine ecosystems in a comparative framework. Here, we present the two main outputs of the first phase of the project: a suite of papers documenting a combination of indicator-based methods and results comparing the ecological status of the world’s exploited marine ecosystems, and a website aiming to communicate these results beyond scientific audiences.

Keywords: comparative approach, fishing impacts, indicator, IndiSeas, marine ecosystem status.

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Introduction

It has been long recognized that single-species-based fisheries management approaches should be informed by multispecies and/or ecosystem-based approaches that place the species being managed in the broader context of the ecosystem (environmental, ecological, and socio-economic). This line of thinking has become evident in several international conventions and agreements, notably the 1992 Convention on Biological Diversity, the 1995 Jakarta Mandate on Marine and Coastal Biological Diversity, and the 1995 Kyoto Declaration on Sustainable Contribution of Fisheries to Food Security, culminating in the Reykjavik Declaration of 2001 and the 2002 World Summit on Sustainable Development. During the past decade, there has been a strong move towards the ecosystem approach to fisheries (EAF) worldwide. To make progress towards implementing the EAF, integration of single-species assessments and holistic ecosystem assessments are needed to guide management advice. One approach to integrating ecosystem-level information is the use of carefully selected and appropriate indicators to translate ecosystem impacts and changes into management measures that can be assessed for their effectiveness. To take forward the work that was completed in 2004 by the SCOR/IOC Working Group on Quantitative Ecosystem Indicators (http://www.scor-int.org/Working_Groups/wg119front.html; Cury and Christensen, 2005), the IndiSeas working group was established, under the auspices of the Eur-Oceans European Network of Excellence (NoE) to look at “EAF Indicators: a comparative approach across ecosystems”. Ecological indicators from a number of fished ecosystems were assembled, examined, and reviewed with respect to several selection criteria, before agreement was reached on an initial suite of what were considered then to be the most suitable ecological indicators to evaluate ecosystem effects of fishing across different types of ecosystems (Shin et al., 2010a). The aim of the working group was to use a comparative approach to build a dashboard of these indicators to evaluate the status of marine ecosystems in a comparative framework.

During the first phase of the project (2005–2008), the IndiSeas WG agreed on a suite of eight ecological indicators to assess the recent state of 19 fished marine ecosystems and to compare changes in ecosystems over the past few decades (Shin et al., 2010a). The indicators were selected in particular to measure fishing-induced impacts on exploited marine ecosystems, representing tropical, temperate, high latitude, and upwelling systems. The goals of IndiSeas were to gather and share indicator expertise across marine ecosystems and member institutions to (i) develop a set of synthetic ecological indicators, (ii) build a generic dashboard using a common set of interpretation and visualisation methods, and (iii) evaluate the exploitation status of marine ecosystems in a comparative framework. The suite of papers here reports the results of comparative analyses, and a dedicated website synthesizes the scientific analyses to inform the public and fisheries managers of relative states and recent trends in the world’s fished marine ecosystems.

What has been learned?

The initial results of comparative analyses of 19 fished marine ecosystems are presented in this suite in terms of eight indicators of recent ecosystem state and trends over the past three decades.
The suite includes interpretations of combined sets of indicators representing ecosystem states (Shin et al., 2010b), interpretations of trends in indicators (Blanchard et al., 2010), and develops methods (e.g. ranking, decision tree) for assessing the status of exploited marine ecosystems (Bundy et al., 2010; Coll et al., 2010). Practical concerns underlying the estimation of IndiSeas indicators from trawler-based data are addressed by Jouffre et al. (2010). Capturing signals from environmental variability and how they combine with fishing effects are the subjects covered by Link et al. (2010). The overexploited state (Shin et al., 2010b) and declining trends (Blanchard et al., 2010; Bundy et al., 2010) in most of the 19 exploited marine ecosystems should be a point of major concern for scientists and fisheries managers alike.

Experience gained from the various analyses employed in the papers published here highlights the need to standardize methodologies of data collection and processing to facilitate comparable methods of estimating indicators across ecosystems (Jouffre et al., 2010; Shannon et al., 2010; Shin et al., 2010b). Our data-based indicators are estimated from multiple survey types that measure different parts of the ecosystem and which are often difficult to combine (Jouffre et al., 2010). Further work on standardizing how information from these different kinds of surveys can be merged is clearly necessary.

The originality of the work presented here relies on a cross-system comparison of marine ecosystems. In addition to providing a first attempt at categorizing ecosystems according to the extent of fishery impact, the comparative approach was found to be useful for different reasons. First, it provided a constraining framework within which to select a limited list of indicators that could be applied in different ecosystems with various means and histories of monitoring (Shin et al., 2010a). Interestingly, ecosystems from developing countries were not always those for which we encountered the greatest difficulties in estimating the indicators. Moreover, given the difficulty in establishing baseline levels and reference points for most ecosystem indicators (Shin et al., 2010b), the comparative approach across ecosystems facilitated the provision of an extended range of indicator values against which each ecosystem could be assessed. The more ecosystems included in the comparative analyses covering wide ranges of indicator values, the more significant the comparative analysis would be. However, because multiple indicators were considered and because they are not redundant (Blanchard et al., 2010), the comparison of the status and trends of exploited ecosystems was not straightforward. Theoretically, the indicators we selected are all expected to decrease with increasing fishing pressure, but they do not vary exclusively in response to fishing. Several of the papers here emphasize the need to consider multiple drivers of ecosystem change (Bundy et al., 2010; Coll et al., 2010; Link et al., 2010), especially in upwelling systems under strong environmental control (Shannon et al., 2010). The IndiSeas indicators were selected to reflect fishery impacts, but these require contextualization with respect to other human (e.g. pollution, economic) and environmental (e.g. regime shifts, climate change) drivers that may act concomitantly with fishing. Bundy et al. (2010) tabulate various factors that may be expected to cause our various fishery-selective indicators to increase or decrease. Further, Link et al. (2010) and Coll et al. (2010) show that different statistical methods need to be used to detect the relative roles of the different drivers in marine ecosystems. Comparative modelling provides an additional means of exploring these differential and combined drivers of ecosystem dynamics (Shannon et al., 2008).

The need for extensive further work on thresholds and reference points for the indicators is recognized as a priority for the future. In the absence of well-established and consensual ecosystem models that allow precise definition of reference levels, the experimental study of Shin et al. (2010b) explored whether interim reference levels can emerge from international scientific expertise on ecosystem indicators. The work confirmed that expert-defined thresholds for our indicators were not significantly different across ecosystem types and confirmed that the IndiSeas study was comparative in nature. Modelling studies in addition to empirical methods are recognized for their strong potential in further work on thresholds and reference points for the indicators (Link et al., 2010). In addition, the need to assess the responsiveness of indicators to specific management actions has been identified as a future priority (Blanchard et al., 2010).

A main lesson learned during the IndiSeas comparative study across ecosystems is that a suite of ecological indicators is needed to resolve inconsistencies in information communicated by various indicators that measure different ecosystem attributes (Bundy et al., 2010; Coll et al., 2010; Shin et al., 2010b). Discrepancies between indicators of state, or improving/deteriorating trends of indicators over time, exist and underscore the need for methods that combine multiple indicators of trends (e.g. decision tree analysis; Bundy et al., 2010), states (Shin et al., 2010b), and particularly important, combinations of state and trends (Coll et al., 2010). Blanchard et al. (2010) found that no single indicator was redundant across all ecosystems, providing support for retaining all within the suite. Each indicator seemingly provides complementary information that is useful for summarizing ecosystem dynamics in response to fishing.

**Reaching the public at large: the IndiSeas website**

In conjunction with this suite of papers based on the selection and estimation of eight ecological indicators across ecosystems, the development of images for data presentation and synthesis, and indicator-based analyses of ecosystem status, the website www.indiseas.org has been developed as a platform to disseminate the results of the analyses beyond a scientific audience. The IndiSeas website was launched in September 2009, following a multi-institutional effort in providing indicators and ecosystem descriptions. Its aim is to inform fishery scientists, managers, policy-makers, and the public at large of the status of the world’s marine ecosystems as a consequence of fishing. A common protocol for representing and communicating a carefully selected suite of indicators needed to be established for a wide range of ecosystems. Information is provided at increasing levels of detail, starting with an overview of each ecosystem in a synthetic and understandable form, and progressively providing more detailed and technical information. An option is also provided to compare the states and trends of ecosystems graphically and directly (Figure 1).

For each ecosystem, a synthetic overview is displayed (Figure 2), using the same template for all ecosystems. The way the ecosystem template is designed reflects the various technical and scientific choices which were made by the IndiSeas WG from the beginning of the project, in order eventually to communicate the results of the comparative approach to the general public. For example, to facilitate their interpretation, all indicators are represented so that larger values or increasing trends signal a less degraded or improving ecosystem, respectively. Hence, some indicators are represented as inverses, such as the coefficient of variation of the
biomass. Further, it was necessary to adopt simple graphic representations to render their interpretation more straightforward. The results of the state indicators averaged over the most recent period (2003–2005) are summarized in the form of polar area pie charts, representing state indicators as a fraction of the maximum value observed across the 19 ecosystems for the same period (Shin et al., 2010b). Trends in indicators are depicted by bar graphs of the short-term slopes of fitted linear trends (1996–2005), where an increase represents an improvement, and vice versa (Blanchard et al., 2010). Details on the graphic representations, justifications, choices of time frames, and standardization procedures are provided by Blanchard et al. (2010) and Shin et al. (2010a). To complement the visual diagnosis suggested by pie and trends graphs, a summary textual diagnosis of the status of each ecosystem is provided by an expert on each. This short text is crucial in reinforcing the graphic information to report potential limits of the comparative approach for some specific ecosystems or potential biases in the calculation of some indicators or to provide information on other drivers that could interact with fishing. Supplementary information on each ecosystem includes plots of time-series (1980–2000) for each indicator, a detailed description of the ecosystem, and short descriptions of the key species. In order to select the key species and functional groups to be documented on the website, generic categories were defined by the Working Group to be applied potentially in every ecosystem (Table 1). The set of species to be documented needed to contribute significantly to the trophic fluxes and to track the direct and indirect effects of fishing.

**Directions for future research**

The experience gained during the first phase of the IndiSeas WG and the results presented in the suite here constitute no more than a start and a basis for further work. The effort has demonstrated the potential for a small set of ecological indicators, easily measured and readily available across most ecosystems, to reflect how fishing is impacting the ecosystems and how the management approaches adopted may be helping to alleviate the effects. It has also highlighted potential pitfalls in viewing indicators at face value, emphasizing the need for careful interpretation from within the context of each specific ecosystem. Having a common but small suite of indicators is useful to compare ecosystems, but at the same time, a limit of the approach is that it provides insufficient local information. This was especially the case for Peru, for example, where the eight indicators selected were not felt to reflect the status of the ecosystem satisfactorily. The northern Humboldt ecosystem ranked as relatively degraded when compared with others (Coll et al., 2010), and even within the set of upwelling ecosystems alone (Shannon et al., 2010). However, it may be argued that indicators other than ecological ones exclusively, e.g. those measuring the potential for implementation of the EAF (Alder and Pauly, 2008) paint Peru in a much rosier light. Diagnosis depends on the objective behind the choice of a particular indicator suite. In our case, only ecological indicators believed to reflect fishery impacts have been used, and biodiversity and socio-economic indicators were not considered. The importance also of considering environmental indicators as synergistic...
or antagonistic drivers of ecosystem dynamics, together with anthropogenic factors such as fishing, is highlighted in particular by Link et al. (2010).

Future research initiatives building on the current IndiSeas results are encouraged to add other fished marine ecosystems to the comparison and to explore additional ecological indicators. The set of indicators examined by the Working Group is viewed in the context of several other indicators of interest, which are not necessarily available in every ecosystem, e.g. discards, as well as model-derived indicators for groups of ecosystems, e.g. indicators generated using Ecopath with Ecosim (EwE) models of upwelling systems (Coll et al., 2006; Shannon et al., 2009) and model-estimated indicators of fishing pressure.

Building bridges with other scientific fields

Additional indicators, and especially non-ecological ones, from other scientific fields also need to be considered in parallel to strengthen the ecosystem diagnosis and to provide a more integrated evaluation of ecosystem state in support of ecosystem-based fishery management. Three specific tasks have been identified for the future, and they are described in the subsections below.

Studies of the joint effects of climate and fishing changes on the indicators selected

Studies of the joint effects of changes in climate and fishing on the selected indicators will be a priority in future because it is recognized that ecosystems need to be managed in the context of environmental variability, decade-scale change, and longer-term environmental and climate change. Time-series analyses of fishing effort and regional climate indices are clearly needed. Ecosystem models can also be used to assess the specificity of ecosystem indicators to fishing effects against climate effects (e.g. EwE, Osmose, and Atlantis models). Identification of environmental indicators of ecosystem change should be encouraged, although they will likely need to be relatively system- or region-specific.

Integration of conservation and biodiversity issues in diagnosing ecosystem states

Although two of our ecological indicators (proportion of predatory fish and proportion of underexploited stocks) belonging to the suite of eight that were selected specifically to measure the impacts of fishing corresponded to the ecological attribute “Conservation of functional biodiversity” (Shin et al., 2010a), full integration of conservation and biodiversity issues in our diagnosis of ecosystem states was not the focus nor was it achieved in the first phase of the IndiSeas project. A set of indicators that can quantify the broader biodiversity and conservation risks in ecosystems needs to be considered in future, e.g. integrated indicators that reflect the status of various vulnerable species of conservation concern, various traditional indicators of species diversity, indicators of habitat quality, and indicators of biological traits.

Integration of socio-economic issues

Recent worldwide evaluation of ecosystem status has been undertaken using socio-economic indicators, with emphasis on the vulnerability of ecosystems to the impact of climate change on fisheries (Allison et al., 2009), on the performance of nations in managing their fisheries (Alder and Pauly, 2008), or on their...
compliance with the FAO Code of Conduct for responsible fishing (Pitcher et al., 2009). Developing a collaboration with social scientists and economists working on fisheries would be beneficial and of particular importance in order for an EAF to be based on ecological as well as socio-economic indicators.

Testing the performance of ecosystem indicators in fisheries management

How do we know how well an indicator indicates and guides management decisions? This is a crucial question in developing indicators and is often ignored. Performance testing is a formal procedure for assessing whether an indicator and an accompanying decision rule actually guides decision-makers to make the correct decision, in hindsight. Performance testing scores the ratio of “right” to “wrong” decisions. The suite of indicators collected under the IndiSeas initiative provides a unique opportunity to test these indicators across a range of ecosystem types. This would help to validate the choice of indicators and to guide future selections.

Developing reference points for indicators

Establishing reference points for ecosystem indicators has proven to be a major challenge to implementing an EAF (Sainsbury and Sumaila, 2003; Jennings and Dulvy, 2005), owing to the complexity of ecosystems and their response to fishing in a changing environment. A key benefit of the comparative approach is that it provides empirical data on ecosystem-indicator behaviour across a range of ecosystem types and states. As mentioned earlier, Shin et al. (2010b) explored a pragmatic way of identifying thresholds based on expert opinion. That preliminary study provides much food for thought for future work, which should be focused on defining and quantifying ecosystem overexploitation (Murawski, 2000). Ecosystem and end-to-end models (Travers et al., 2007) should also be used to identify baseline levels (Jennings and Blanchard, 2004; Greenstreet and Rogers, 2006), as well as threshold reference levels in the broader context of climate change.

Conclusions

The work so far undertaken by the IndiSeas Working Group in its first phase is presented as merely a start from which ecological indicators might be synthesized into forms that are usable and meaningful for the public. In providing the bridge between scientific analyses and their relevance and implications for decision-makers, IndiSeas has proposed a way for communicating ecological information on fisheries impacts. Methods for comparing ecosystems using ecological indicators have been proposed and the results are analysed and discussed here in the form of a suite of scientific papers and in the broader context of a website for informing the general public and decision-makers at large. It is our hope that these two products of IndiSeas Phase One can serve as a useful and practical framework for communicating and incorporating ecosystem advice into fisheries management for an EAF.

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References


Table 1. Key species categories selected in each ecosystem for documenting on the IndiSeas website.

<table>
<thead>
<tr>
<th>Species Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target species</td>
<td>are those fished for commercial gain or subsistence (food), and fishers, managers, and consumers are concerned by their state and dynamics. The species are those that may reflect direct effects of fishing, and those that are generally most heavily impacted in the foodweb.</td>
</tr>
<tr>
<td>Habitat-linked species</td>
<td>are restricted to certain habitat types and therefore indicators of habitat quality. They participate in the functioning of identified subparts of the ecosystem (e.g. mangroves, rocky areas, pelagic layers) that can usually be located spatially.</td>
</tr>
<tr>
<td>Charismatic species</td>
<td>evoke public emotion, are used to communicate to the public about the severity of the state of an ecosystem or environmental impacts, and are the species for which it is easier to obtain funding for conservation purposes. Marine examples often include turtles, whales, and dolphins, and certain species of seabird. There is strong pressure from the general public to monitor such species.</td>
</tr>
<tr>
<td>Vulnerable species</td>
<td>are recognized as such with respect to their conservation status. They may be formally classified as vulnerable by a conservation body and would ideally appear on the IUCN red list. They provide early warning signals of perturbations within an ecosystem.</td>
</tr>
<tr>
<td>Forage species</td>
<td>have clear bottom-up effects on predatory fish and top predators and are usually present at high biomass. They have fast turnover rates and, as a result, their dynamics may be closely linked to environmental variability. In addition, they may be very responsive to changes in fishing mortality.</td>
</tr>
</tbody>
</table>

Charismatic species:
- Turtles
- Whales
- Dolphins

Vulnerable species:
- Turtles
- Whales
- Dolphins

Forage species:
- Pelagic fish
- Squid
- Demersal fish

Habitat-linked species:
- Mangroves
- Rocky areas
- Pelagic layers

Target species:
- Those fished for commercial gain or subsistence
- Those concerned by their state and dynamics
- Those generally most heavily impacted in the foodweb

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