POINT-OF-VIEW

Global in scope and regionally rich: an IndiSeas workshop helps shape the future of marine ecosystem indicators

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Abstract This report summarizes the outcomes of an IndiSeas workshop aimed at using ecosystem indicators to evaluate the status of the world's exploited marine ecosystems in support of an ecosystem approach to fisheries, and global policy drivers such as the 2020 targets of the Convention on Biological Diversity. Key issues covered relate to the selection and integration of multi-disciplinary indicators, including climate, biodiversity and human dimension indicators, and to the development of data- and model-based methods to test the performance of ecosystem indicators in providing support for fisheries management. To enhance the robustness of our cross-system comparison, unprecedented effort was put in gathering regional experts from developed and developing countries, working together on multi-institutional survey datasets, and using the most up-to-date ecosystem models.

Keywords Indicator · Ecosystem approach to fisheries · Ecosystem model · Fisheries management · Global comparison

Please refer the "Appendix" section for the "IndiSeas Working Group" authors.

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Background

Growing global demand for fish increasingly alters marine biodiversity and ecosystem structure, compromising ecosystem services and human-well being (Worm et al. 2006; Allison et al. 2009; Butchart et al. 2010; Perry et al. 2011). Over the past two decades, there has been significant progress towards sustainable development of fisheries and integration of effects of exploitation on the ecosystem, emphasizing the need for implementing the ecosystem approach to fisheries (EAF) worldwide (Garcia et al. 2003; Link 2011; Christensen and Maclean 2011). However, despite the increasing number of frameworks and multilateral agreements (e.g. 1999 Reykjavik Declaration, 2002 World Summit on Sustainable Development), practical implementation of an EAF is still in its early stages and patchy. Progress on the EAF relies heavily on the ability of scientists to provide and communicate an assessment of past and current ecosystem effects of fishing and an evaluation of the effectiveness of management measures to promote resource sustainability.

In response, IndiSeas was established in 2005 as an international collaborative program under the auspices of the EUROCEANS European Network of Excellence and endorsed by IOC/UNESCO. IndiSeas performs comparative analyses of ecosystem indicators from many of the world's marine ecosystems to quantify the impact of fishing and to provide decision support for fisheries management. A comparative framework enables the selection of a robust suite of indicators that are meaningful and measurable over diverse and contrasting conditions. It provides the basis for developing a range of reference values, under different environmental, fishery, and human dimension conditions, against which ecosystems can be assessed. Ultimately, it enables a broader ecosystem perspective and allows generalizations to be drawn about ecosystem response to multiple drivers.

The first phase of IndiSeas (IndiSeas I: 2005–2009) culminated in the publication of nine papers (Shin and Shannon 2010; Shin et al. 2010a) and a website of comparative analyses (http://www.indiseas.org). Nearly 80% of the 19 ecosystems assessed using a suite of 8 ecological indicators were classified as deteriorating over the past several decades (Bundy et al. 2010). Results of IndiSeas I highlighted two major challenges that form the basis of IndiSeas II: (1) the need to consider multiple drivers including the human dimension and climate forcing (Coll et al. 2010; Link et al. 2010; Shannon et al. 2010) that interact with ecological processes in complex ways; and (2) the need to determine how indicators can be effectively used for improving management and conservation. These issues must be addressed urgently in light of policy drivers such as the European Commission Marine Strategy Framework Directive (MSFD) and the convention on biological diversity (CBD) Aichi Targets which call for effective ecosystem-based fisheries management to be in place by 2020.

To address these two challenges, IndiSeas II (2010–2013) is developing a combination of data-driven and ecosystem modelling approaches to evaluate the status of the world's exploited marine ecosystems subject to multiple drivers in support of EAF. By contrast with other indicator initiatives aimed at a global comparison, IndiSeas relies on research survey data rather than commercial catch data. This has the benefit of data being less biased and more robust, but faces the challenge that these are national data, generated and owned by institutions. However, IndiSeas has engaged partner countries from the developed and developing world, their institutions and collaborators in a collective effort to leverage their expertise of individual systems (Fig. 1). IndiSeas thus strengthens linkages between global and national indicator development and reporting, in line with the CBD Nagoya Strategic Plan for Biodiversity 2011–2020.

Here, we present outcomes of the second IndiSeas II workshop held at UNESCO, Paris, from 15 to 18 November 2011, and attended by 41 participants from 34 research institutes. We summarize the main themes and discussions, and highlight the way forward. We conclude with how IndiSeas II will generate the science that will support international stewardship

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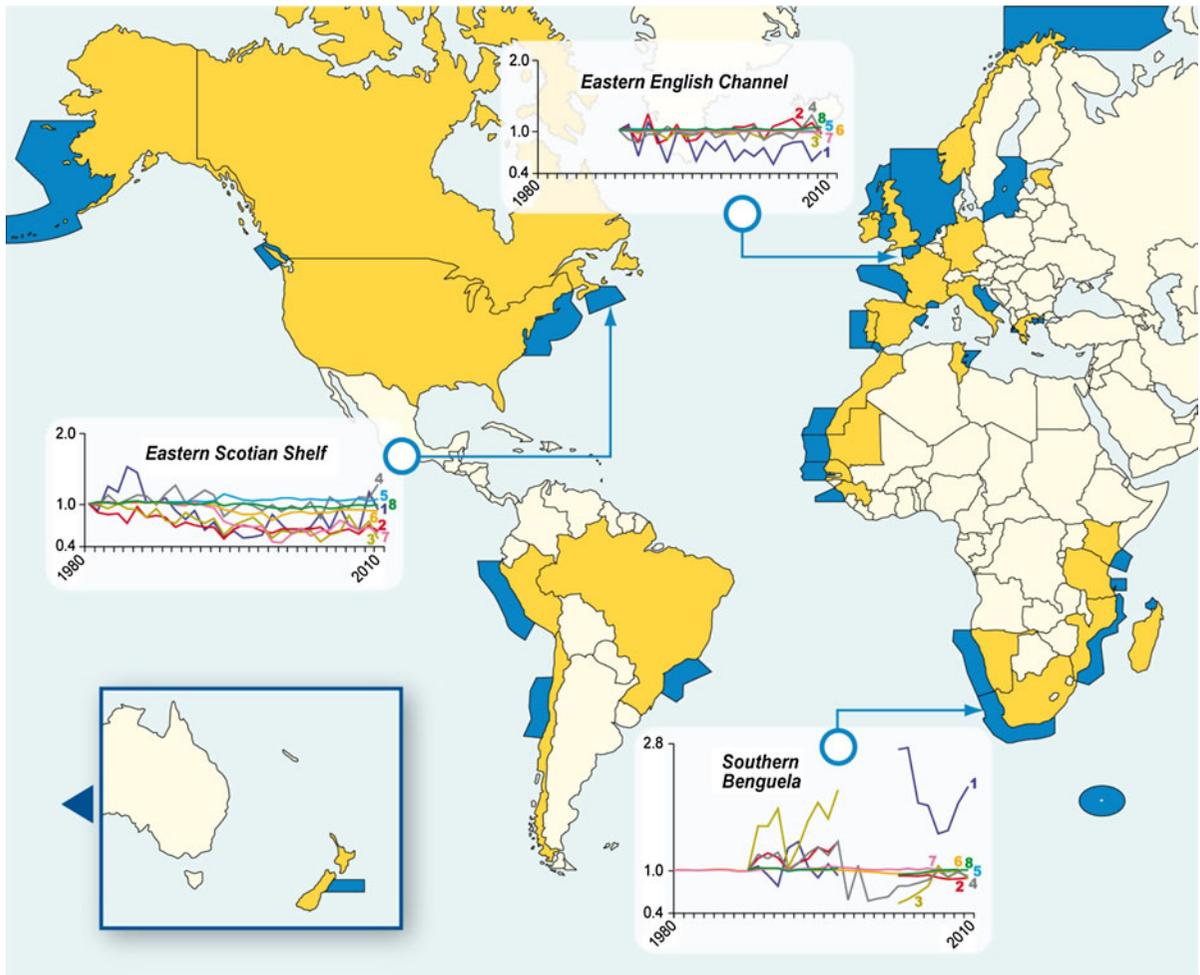
Fig. 1 Marine ecosystems considered by the IndiSeas program. *Blue*, the marine ecosystem; *yellow*, the countries participating in the analyses. Examples of time series of standardized ecological indicators collated by the program. *1* total biomass surveyed, *2* mean length of fish in the community, *3* proportion of predatory fish, *4* mean lifespan, *5* intrinsic vulnerability index of the catch, *6* trophic level of the landings, *7* Marine Trophic Index, *8* trophic level of the surveys. *Data source*: EEC—IFREMER, France; ESS— Maritimes Region, Fisheries and Oceans Canada; SB—Department of Agriculture, Forestry and Fisheries, South Africa

efforts to manage our oceans, and how experts and institutes can be a part of IndiSeas.

The workshop

During the workshop, four major questions were explored:

1. *Indicators.* Which complementary indicators (climate, biodiversity, social and economic) should be used to diagnose ecosystem status and to inform fisheries decision-makers?
2. *Method development.* What methods are most effective for analysis of a broad suite of multidisciplinary indicators?
3. *Performance testing.* How well do indicators reflect change in fishing pressure and provide support for decision making for sustainable fisheries?
4. *Synthesis.* How best can the status of exploited marine ecosystems be assessed under multiple drivers and objectives?

To answer these questions, workshop discussions were structured around six Task Groups (TGs), linking experts in the general fields with those working on specific ecosystems.

Climate and environmental indicators

A major gap identified in IndiSeas I was that fishing may not always be the only or even the main driver of some ecosystem indicators of fishing. Climate variability in terms of inter- and intra-annual variations in temperature, primary productivity and influence by large-scale meteorological indices (e.g. El Niño Southern Oscillation and the North Atlantic Oscillation) can affect survival of fish larvae and recruitment (Platt et al. 2003; Beaugrand et al. 2003; Bakun 1996), and the catchability of adult fish (Agenbag et al. 2003). Climate change will also affect the carrying capacity and distribution of fish species (Cheung et al. 2010). To determine whether, when, where and how ecosystem indicators can be used to measure effects of fishing in a fluctuating environment, specific aims of the TG1 are to: (1) assess the relative importance of fishing and environment for different ecological indicators; (2) identify years where the environment was more important than fishing; and (3) compare relative effects of fishing and climate across ecosystems.

Discussions centred on determining methods for detecting and quantifying environmental signals on ecological indicators. Preliminary analyses using redundancy analysis and generalized linear modelling helped us develop analytical approaches (see e.g. Blanchard et al. 2005). To quantify the relative response of ecological indicators to fishing and the environment and to propose a concrete framework for ecosystem-based fisheries management, we will use a three-step approach. The first is a detailed system analysis, where the principle is to customize regional analyses using a suite of system-specific climate and environmental indicators. In particular, recent remote-sensing techniques will help refine regional production indicators and their link to fisheries (Demarcq et al. 2012). The second approach is a global analysis to enable comparisons between fishing and environmental pressures across ecosystems, where the challenge would be to derive a single fishing pressure index and a composite environmental index common to all ecosystems. The third approach identifies potential regime shifts in ecological indicators to determine possible causes of change and whether the sensitivity of ecological indicators to fishing and climate drivers differ between regimes. Building on these three approaches will provide strong support for the practical use of ecosystem indicators in fisheries management, by helping to select ecological indicators which would respond primarily to fishing impact, and by specifying the environmental conditions and the type of ecosystems for which they are most informative.

Biodiversity and conservation-based indicators

The initial IndiSeas I list of ecological indicators is being reanalyzed by TG2 to emphasize biodiversity and conservation-based issues in the diagnosis of ecosystem state and trends in response to fishing. The selection of indicators is based on a set of criteria, adapted from Rice and Rochet (2005) to address the specific objectives of IndiSeas.

Indicators must first satisfy three scientific criteria: (1) *theory*—indicators should have a firm theoretical basis reflecting well-defined ecological processes underlying fishing pressure; (2) *sensitivity*—trends in indicators should be sensitive and responsive to fishing pressure; and (3) *measurability*—indicators need to be routinely measurable and have historical time-series available. Indicators must also satisfy three strategic criteria: (4) *tractability*—indicators should be small in number, tractable for a range of ecosystems, and updated annually by regional experts; (5) *public awareness*—the meaning of the indicators and their link to fishing should be intuitively understood by the general public; and (6) *coordination*—the selection of indicators must be linked to international frameworks and projects (e.g. the CBD, European MSFD, Sea Around Us Project) to create synergies (e.g. documenting common databases, exchanging expertise).

These criteria were used to select the following biodiversity and conservation-based indicators: proportion of exploited species with declining biomass; intrinsic vulnerability index of the catch (Cheung et al. 2007); marine trophic index (Pauly and Watson 2005); trophic level (TL) of surveyed and modelled community; abundance of flagship species; and discard rate. This list complements the IndiSeas I ecological indicators (Shin et al. 2010a) which we continue to

estimate: mean length of fish in the community; TL of landings; proportion of under- and moderately exploited stocks; proportion of predatory fish biomass; mean lifespan; 1/CV of the total biomass surveyed; and 1/(landings/biomass).

Consensus in the selection process was not always easily reached. In particular, the group debated the necessity to add a habitat indicator to be in line with the European MSFD and other management frameworks but agreed that the "area not impacted by bottom trawling" indicator and other habitat indicators were not sensitive enough to fishing over time and, in addition, they could be capturing management responses rather than reflecting biodiversity changes due to fishing.

Once indicators have been calculated in all ecosystems, the usefulness of the indicators for fisheries management will be evaluated by testing systematically indicator sensitivity, level of redundancy, and specificity to fishing pressure vs environmental forcing. In particular we will focus on the widely used TL-derived indicators to retain the most useful for comparison of ecosystems' status under multiple drivers. Using a combination of survey and catch data, and model output, we expect to make significant progress on the recent debate concerning the appropriateness of indicators based on trophic level to track fishing impact (Pauly et al. 1998; Pauly and Watson 2005; Branch et al. 2010).

Human dimension indicators

Although the human dimension is part of EAF (Ward et al. 2002; FAO 2003; Garcia and Cochrane 2005), in practice it has been a poor cousin to ecological and biological considerations (Bundy et al. 2008). In many respects the development of indicators of human dimensions of exploited ecosystems is challenging due to the breadth of the area, complexity, scale issues and data availability. For example, we have much better access to demographics of fish populations in many ecosystems than we do to information about human populations that exploit them. Further, unlike ecological indicators, some indicators of the human dimension are not normative (i.e. there are no necessarily "good" or "bad" values), so they may simply describe the human context of an exploited ecosystem (e.g. value of fish export as a % of total export value) rather

than be used for scoring and ranking ecosystem performance.

TG3 has developed a conceptual framework with clear objectives and indicators to evaluate human dimensions of governance, fisheries contributions to society and human wellbeing of exploited ecosystems. As an ultimate goal of the EAF is to achieve lasting benefits for fisheries to society, we will evaluate the: (1) effectiveness, efficiency and fairness of fisheries management; (2) contribution of fisheries to the broader society; and (3) wellbeing and resilience of fishing communities.

We have selected a suite of indicators to evaluate these goals. Indicators for the first goal are based on data from an ecosystem expert survey designed to assess the effectiveness of fisheries management. This approach draws on the work of Pitcher et al. (2009), but is enhanced by directly involving recognised experts for each ecosystem. Outputs will be assessment of how well a fishery is managed, and whether ineffective management contributes to a diagnosis of poor ecological health of a fishery.

For the second and third goals, due to data availability challenges, we have used data available at the macro level to estimate indicators, such as "total landed value of marine fisheries as a % of GDP". Next steps include refining indicators on a more local scale; evaluating the information from all indicators using comparative multivariate analyses; and comparing macro and local scale indicators so we can evaluate whether local data change our perception. Outputs will be the assessment of the degree of economic and food dependency of fishing communities and society on their fisheries, and whether fishing communities are doing well and have the capacity to cope with or adapt to negative changes in the fishery. These results will be integrated with the ecological status of ecosystems to provide a holistic ecosystem evaluation.

Reference levels for indicators

Few reference levels for characterising unfished situations, limits to be avoided, or optimal management targets have been defined for ecosystem indicators (Jennings and Dulvy 2005; Link 2005; Shin et al. 2010b). The objective of TG4 is to explore and determine reference levels for ecosystem indicators so

as to: (1) standardise indicators to compare the status of exploited marine ecosystems; and (2) propose a control rule framework for EAF. Although these two applications are complementary, the fundamental requirement for each type of reference level is different. The first application of reference levels is related to intrinsic ecosystem properties such as productivity at pristine or any reference state. The second use directly serves management purposes, with reference levels acting as predetermined benchmarks that when reached, should trigger particular management actions (Hall and Mainprize 2004).

These objectives will be addressed using modelling and time series analyses. Using published ecosystem models that have been fitted to time-series, we will standardise indicators across ecosystems by reconstructing the multispecies yield to fishing mortality curve for each ecosystem. We will identify multispecies maximal sustainable yield (MMSY—Worm et al. 2009; Smith et al. 2011) and corresponding reference values for ecosystem indicators under current climate and fishing patterns. Then, the relative difference of the current indicator value from its reference level can be considered a measure of the distance of the ecosystem from its potential-MMSY, given current climate conditions and structure of the fishing fleet. Indicators can thus be scaled relative to their potential level and can be directly compared across ecosystems. Outcomes from the modelling approach could also be useful to management if a range of MMSY values and corresponding ecosystem indicators values could be derived by testing different fishing strategies. It was noted that to make comparisons consistent, it was necessary to agree on how we should define the "current period" for projecting catch curves, and we decided that structural change time-series analysis was appropriate here (Zeileis et al. 2003; Andersen et al. 2008). The use of time series analyses was also discussed as an alternative approach for setting indicator reference levels. Where there are significant regression relationships between ecosystem indicators and fishing pressure indicators, the intersection between the regression line and some selected pressure reference levels (e.g. F_{MMSY}, F_{PA} for a flagship species) can be used to provide estimates of corresponding reference levels for ecosystem indicators. This approach requires long time-series that span contrasting periods in the magnitude of exploitation.

Performance of indicators and links to management

The suite of indicators in IndiSeas I has been useful for assessing trends and states over relatively short time scales (10–20 years) and for cross-system comparisons (Shin et al. 2010b; Blanchard et al. 2010). However, whether these indicators are sufficiently robust to track changes resulting from specific pressures and how they might be employed in management are open questions.

Goals of TG5 are to advance understanding of how ecosystem indicators can be used in management by: (1) empirically testing how particular indicators might signal deteriorations and thresholds in ecosystem state through time, (2) developing decision rules that account for different environmental conditions; and (3) simulation-testing of the performance of a range of indicator and decision rules. At the workshop, several presentations described recent progress and future ideas for addressing these aims.

Decision rules—or harvest control rules—are management decision systems that use indicators to signal the status of a resource (e.g. spawning stock biomass or catch per unit effort) and to specify what management action is to be taken (e.g. change in fishing mortality or total allowable catch) when deviations from operational targets are observed. Decision rules can be empirical and trend-based or rely on reference levels and models (Rademeyer et al. 2007). Although there are many different approaches for designing decision rules, they are normally based on single-species indicators in traditional fisheries management. An empirical trend-based decision rule method called the CUSUM method (Scandol 2003; Mesnil and Petitgas 2009) was discussed as a potential way to investigate whether using ecosystem indicators would result in different retrospective signals and decisions in comparison to single species indicators. The development of environment-based decision rules similar to the environmental harvest control rules (eHCRs) developed for single-species by Brunel et al. (2010) was deemed important as the productivity of fish and whole ecosystems vary across different environmental regimes, and hence appropriate reference levels and management targets should be conditional on the environment.

Simulation modelling provides a means for testing the performance of indicators in signalling change and

supporting decision rules (Fulton et al. 2004). IndiSeas indicators respond differentially to fishing pressure (Blanchard et al. 2010), suggesting that some indicators, if used to detect a change in status, could have a higher incidence of triggering false alarms. The application of a suite of ecosystem models in IndiSeas II is seen as a valuable approach for exploring trade-offs in conflicting management objectives across a range of ecosystems, management scenarios, and decision rules. This will help to assess how well ecosystem indicators perform in management, in the face of multiple sources of uncertainty and environmental change.

Integration of indicators

To compare and evaluate ecosystem status for an EAF, we must integrate information across multiple and multi-disciplinary indicators. We reviewed existing methods to combine multiple indicators, discussed their pros and cons, and identified three categories of approaches: (1) a scoring approach aggregating indicators into a single composite indicator, (2) a multi-dimensional approach, and (3) multi-criteria decision analysis. The scoring approach is the most common and relies on a simple combination of indicators such as the sum, arithmetic mean, hierarchical mean, weighted mean, median, product (Halpern et al. 2008; Allison et al. 2009; Alder et al. 2010; Butchart et al. 2010; Ojaveer and Eero 2011; Coll et al. 2010). Although the method is simple, it is sensitive to the aggregation formula chosen (Allison et al. 2009; Ojaveer and Eero 2011), indicator weights (Alder et al. 2010), and initial indicator selection. The second approach encompasses multi-dimensional methods. In their evaluation of the level of compliance of 53 countries with the UN Code of Conduct for Responsible Fisheries, Pitcher et al. (2009) ranked nations' performances using a non-parametric multidimensional scaling of standardized indicators scores with fixed anchors representing "good" and "bad" situations. Compared to the simple scoring approach, the method is less sensitive to correlation between indicators and seems robust to the definition of anchors, but interpretation is less intuitive as information on individual indicators in each ecosystem is lost. The last approach is multicriteria decision analysis, which has a wide application in fisheries for integration of multiple indicators (Jarre et al. 2008). We particularly discussed a type of multicriteria decision analysis known as decision tree analysis, which has been used in recent studies for categorizing the status of fisheries and marine ecosystems (Rochet et al. 2005; Paterson et al. 2007; Bundy et al. 2010). The method is transparent and intuitive, but is sensitive to decision rules. It raises a variety of general issues, from definitions of ecosystem health and ecological and human well-being to more specific issues about the way decisions are computed (boolean rule-based or fuzzy logic) and the hierarchical structure of the decision tree.

We will produce three types of outputs to compare exploited marine ecosystems, which will involve increasing levels of complexity in the analyses and interpretation of results: (1) general trends in ecosystem effects of fishing; (2) the ranking of the relative status of marine ecosystems; and (3) categorising or diagnosing their exploitation status. To provide levels of confidence and robustness of our results, systematic sensitivity analyses will be conducted on the different steps involved in the process of integrating indicators: selection of indicators, standardisation, combination, evaluation, and representation.

Priorities and future opportunities

The workshop has highlighted the way forward for the IndiSeas program and more generally, the steps that the scientific community as a whole need to take to make EAF a reality:

1. *Combining and integrating multi-disciplinary indicators*. These include indicators of climate, ecological and human dimensions that represent different facets of the EAF. Integration should be quantitative to compare, classify and rank the status of exploited marine ecosystems. It should also be graphical so we can communicate ecosystem status to a broad spectrum of stakeholders including managers, decision-makers and the public.

2. *Developing a synergy between model- and data-based approaches*. This will allow the testing of the sensitivity and specificity of ecological indicators to fishing versus climate, the performance of indicators for decision support, and the

identification of reference levels and tipping points of ecosystems submitted to different drivers. Owing to the expertise gathered in IndiSeas II, we will use state-of-the-art ecosystem models including EwE (Christensen and Walters 2004), OSMOSE (Shin and Cury 2004; Travers et al. 2009), Atlantis (Fulton et al. 2004, 2011) and simpler size-based and multispecies models (Blanchard et al. 2009, 2011; Hartvig et al. 2011) as test laboratories. Some ecosystems of IndiSeas II will also benefit from ongoing development of "end-to-end modelling" (Travers et al. 2007; Rose et al. 2010; Shin et al. 2010c; Barange et al. 2011), involving coupling ecosystem models that focus on higher trophic levels with hydrodynamic, biogeochemical and economic models. This important step allows models to handle explicitly multiple drivers, their impacts, and expected feedbacks in marine ecosystems. It will therefore enable ecosystem indicators to be tested in a fully integrated way under various scenarios of global change and fisheries management.

3. *Using research survey data.* Global comparisons of states of marine exploited ecosystems have previously relied almost exclusively on commercial catch data. Catch data have advantages of easy access through FAO and Sea Around Us Project (http://www.seaaroundus.org) databases, extensive geographical coverage, and existence of long time series, but have biases associated with sampling by commercial vessels. It is striking that the CBD Strategic Plan for Biodiversity 2011–2020 only lists indicators based on commercial catch data for monitoring marine ecosystem status (Strategic goal B, Target 6; Butchart et al. 2010). Again, this reflects the lack of accessibility to scientific observations. The structure of IndiSeas II, based on a multi-institutional effort to contribute datasets from scientific surveys fills this gap.

4. *Being global in scope and regionally rich.* Our aim is to be truly global in scope, with a rich and extensive mix of ecosystems from tropical to polar and from upwelling to oligotrophic. The full participation of regional experts in every step of the project will ensure robust and meaningful global comparisons of marine ecosystems. This long but rewarding process has meant that by the end of 2011, IndiSeas II includes 35 marine ecosystems and researchers from 32 countries and 44 research institutes. We have also put considerable effort into the inclusion of scientists from developing countries, women, and early career researchers, leading to local capacity building for effective national action towards EAF, cooperation and technology transfer among institutes and nations.

We continue to look for partners interested in our approach and who have time series of survey data from ecosystems not currently included in IndiSeas II. We invite expressions of interest to join; please contact the corresponding author. We believe that only through an inclusive approach can we fill gaps in geographical coverage, enhance the rigour of the comparative approach, and ensure that our results are meaningful and applicable.

Appendix

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