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Ecological indicators to capture the effects of fishing on biodiversity and conservation status of marine ecosystems

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ABSTRACT

IndiSeas ("Indicators for the Seas") is a collaborative international working group that was established in 2005 to evaluate the status of exploited marine ecosystems using a suite of indicators in a comparative framework. An initial shortlist of seven ecological indicators was selected to quantify the effects of fishing on the broader ecosystem using several criteria (i.e., ecological meaning, sensitivity to fishing, data availability, management objectives and public awareness). The suite comprised: (i) the inverse coefficient of variation of total biomass of surveyed species, (ii) mean fish length in the surveyed community, (iii) mean maximum life span of surveyed fish species, (iv) proportion of predatory fish in the surveyed community, (v) proportion of under and moderately exploited stocks, (vi) total biomass of surveyed species, and (vii) mean trophic level of the landed catch. In line with the Nagoya Strategic Plan of the Convention on Biological Diversity (2011–2020), we extended this suite to emphasize the broader biodiversity and conservation risks in exploited marine ecosystems. We selected a subset of indicators from a list of empirically based candidate biodiversity indicators initially established based on ecological significance to complement the original *IndiSeas* indicators. The additional selected indicators were: (viii) mean intrinsic vulnerability index of the fish landed catch, (ix) proportion of non-declining exploited species in the surveyed community, (x) catch-based marine trophic index, and (xi) mean trophic level of the surveyed community. Despite the lack of data in some ecosystems, we also selected (xii) mean trophic level of the modelled community, and (xiii) proportion of discards in the fishery as extra indicators. These additional indicators were examined, along with the initial set of *IndiSeas* ecological indicators, to evaluate whether adding new biodiversity indicators provided useful additional information to refine our understanding of the status evaluation of 29 exploited marine ecosystems. We used state and trend analyses, and we performed correlation, redundancy and multivariate tests. Existing developments in ecosystem-based fisheries management have largely focused on exploited species. Our study, using mostly fisheries independent survey-based indicators, highlights that biodiversity and conservation-based indicators are complementary to ecological indicators of fishing pressure. Thus, they should be used to provide additional information to evaluate the overall impact of fishing on exploited marine ecosystems.

1. Introduction

Changes in marine resources and ecosystems have been documented worldwide (Butchart et al., 2010; Lotze et al., 2006) and multiple anthropogenic and climate-related drivers of change have been identified (Halpern et al., 2008). These drivers can alter ecosystem structure and functioning (Christensen et al., 2003; Frank et al., 2005) and can affect the ecosystem services that humans obtain from healthy oceans (Worm et al., 2006). Consequently there is growing concern about the status of marine ecosystems and a need to define, test and prioritize robust indicators to track ecosystem status to inform management decisions.

In the marine science research field, there has been considerable discussion about how to define, calculate, prioritize, test and evaluate indicators to monitor the pressures on, and status of exploited marine ecosystems (e.g., Rombouts et al., 2013; Shin et al., 2010a). Initially, indicators were developed to include ecological considerations with the goal of capturing the impact of dominant pressures, such as fishing or eutrophication (Cury et al., 2005; de Leiva Moreno et al., 2000). However, recently the scope of ecosystem indicators has expanded to include socio-economic and governance issues and the cumulative impacts of multiple human activities (e.g., Boldt et al., 2014; Halpern et al., 2012; Large et al., 2015; Levin et al., 2009; Tittensor et al., 2014).

Fishing represents one of the greatest pressures on marine ecosystems (Costello et al., 2010), and ecological indicators have been used to quantify its impacts on the status of ecosystems and to provide the rationale for scientific advice. Progress has included the establishment of criteria and frameworks to: (i) guide the selection of indicators (e.g., Rice and Rochet, 2005) that are used to assess the effects of fishing via trend (e.g., Blanchard et al., 2010; Coll et al., 2010b) and threshold (Large et al., 2013) analyses, (ii) define preliminary reference levels and reference directions for selected indicators (e.g., Link et al., 2002; Shin et al., 2010a), and (iii) develop and test evaluation frameworks (e.g., Bundy et al., 2010; Kleisner et al., 2013).

In 2005, the *IndiSeas* ("Indicators for the Seas") Working Group was initiated under the auspices of the European Network of Excellence, Eur-Oceans. *IndiSeas* followed from the Scientific Committee on Oceanic Research of the Intergovernmental Oceanographic Commission (SCOR/IOC) Working Group on "Quantitative Ecosystem Indicators" (Shin and Shannon, 2010; Shin et al., 2010b, www.indiseas.org). During the first phase of *IndiSeas* (2005–2010, hereafter *IndiSeas*-phase I), the goals were to perform analyses of ecological indicators to quantify the impact of fishing on the status of exploited marine ecosystems in a comparative framework and to provide decision support criteria for an Ecosystem Approach to Fisheries (EAF) by means of a common suite of interpretation and visualization methods. The rationale was that, although the current primary objective of fisheries management is to ensure sustainable levels of harvest for commercial stocks, the incorporation of broader ecosystem considerations into managing fisheries has become an increasingly important obligation in many countries and regions throughout the world (e.g., Link, 2002; Murawski, 2000; Pikitch et al., 2004; Walters et al., 2005).

Thus, in *IndiSeas*-phase I, a suite of empirical ecological indicators was selected using several criteria (ecological meaning, sensitivity to fishing, data availability, management objectives and public awareness), to create a shortlist of indicators that were easy to calculate from landings and surveys data and that were meaningful and comparable across many marine ecosystems worldwide (Shin et al., 2012). These indicators were: (i) the inverse coefficient of variation of total biomass in the surveyed community (also referred to "Biomass Stability", or BS), (ii) mean fish length in the surveyed community ("Fish Size", LG), (iii) mean maximum life span of surveyed fish species ("Life Span", LS), (iv) proportion of predatory fish in the surveyed community ("Predators", PF), (v) proportion of under and moderately exploited stocks ("Sustainable Stocks", SS), (vi) total biomass of surveyed species ("Biomass", TB), and (vii) mean trophic level of the landed catch ("Trophic Level", TLc) (Table 1). All the indicators are survey-based with the exception of SS and TLc. In previous studies these indicators were