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Evaluating the specificity of ecosystem indicators to fishing in a changing environment: A model comparison study for the southern Benguela ecosystem

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ABSTRACT

Ecological indicators used to monitor fishing effects in the context of climate change and variability need to be informative to enable effective ecosystem-based fisheries management. We evaluated the specificity of the response of ecosystem indicators to different fishing and environmental pressure levels using Ecosim and Atlantis ecosystem models for the southern Benguela ecosystem. Three fishing strategies were modelled to represent a variety of ways of targeting fishing within an ecosystem: one focused on low trophic levels (i.e. forage species), another on higher trophic levels (i.e. predatory fish) and a third tested fishing pressure across the full range of potentially exploitable species. Two types of environmental change were simulated for each fishing mortality scenario – random environmental variability and directional climate change. The specificity of selected ecological indicators (mean trophic level of the community, proportion of predatory fish, biomass/landings, mean intrinsic vulnerability and marine trophic index) was evaluated for different combinations of fishing strategy, fishing mortality and both types of environmental change. While there were mostly large differences in indicator values computed from the Atlantis and Ecosim models, the specificity of the ecological indicators considered under changing climate generally corresponded between the two models. Certain indicators (i.e. mean trophic level of the community) were less specific in detecting effects of fishing in the southern Benguela for some of the three fishing strategies modelled (i.e. high trophic level fishing strategy) under climate change. This helped refine the most appropriate indicator set for our system, reflecting the focus of a particular fishing strategy, and improved confidence in the suitability of these indicators for monitoring fishing effects in the Southern Benguela.

1. Introduction

Ecosystem indicators are useful tools to provide insights on marine ecosystems, and have been used for assessment and management purposes to support an ecosystem approach to fisheries management (Garcia et al., 2003; Garcia and Cochrane, 2005). Some of their applications include evaluation of ecosystem effects of fishing (Shin et al., 2012, 2010b), ecosystem status (Gascuel et al., 2016) and impacts of climate change on fisheries and fishing dependent communities (Cheung et al., 2010; Colburn et al., 2016). The performance of candidate indicators must be assessed against screening criteria, of which sensitivity and specificity are essential properties (Rice and Rochet, 2005; Rochet and Trenkel, 2003). Sensitivity refers to the capacity of an indicator to detect change in an ecosystem, while specificity to fishing refers to the confidence with which a variation in an indicator can be attributed to changes in fishing pressure or altered management arrangements (Houle et al., 2012). For an indicator to be of use in achieving effective ecosystem based management, there must be a clear association between the changes observed in the indicator and the changes in a given stressor (e.g. fishing, pollution) and the indicator must be informative and attributable even in the presence of environmental variability or other anthropogenic stressors.

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Climate change is a ubiquitous anthropogenic factor affecting marine ecosystems. Its effects are evident as changes in temperature, wind and circulation patterns, precipitation, and sea level rise (among others). All have potentially profound consequences for marine ecosystems and their services to societies (Barange et al., 2014; Hoegh-Guldberg et al., 2010; Pörtner et al., 2014). An increase in the frequency and intensity of extreme events (e.g. temperature, precipitation) has also been associated with climate change, and is likely to continue (Schlegel et al., 2017; Seneviratne et al., 2012; Ummenhofer and Meehl, 2017). In upwelling systems, characterized by high natural variability, the climate change-driven trend in environmental drivers is not clearly distinguishable from decadal variability, making predictions of the effects of climate change challenging (Lluch-Cota et al., 2014). Nevertheless, Henson et al. (2017) found that under a business as usual scenario, the climate-change trend in environmental drivers will be identifiable from the background of natural variability in more than 50% of the ocean in the next 15 years. Likely increases in climate variability associated with climate change will result in the need to find a suite of sensitive and specific indicators able to disentangle fishing effects from environmental variability. Simulation experiments can assist the selection of candidate indicators by providing a control environment to test different fishing and environmental variability scenarios within controlled conditions (Houle et al., 2012).

Environmental variability and fisheries exploitation are considered the main drivers of the southern Benguela system (Blamey et al., 2012; Kirkman et al., 2015; Shannon et al., 2004; Smith and Jarre, 2011). For the southern Benguela, ecosystem indicators have been used to evaluate, compare and communicate its ecological status, determine ecosystem trends and the influence of both fishing and environmental variability (Lockerbie et al., 2016; Shannon et al., 2014, 2010; Shin et al., 2010a,b). Moreover, the sensitivity of ecosystem indicators to fishing have been evaluated for the southern Benguela using different ecosystem models (Smith et al., 2015; Travers et al., 2006). However, no studies have evaluated in detail the specificity of ecosystem indicators for this system. Although Shin et al. (2018) undertook a comparative specificity analysis across ecosystems, including an assessment based on a single model of the Southern Benguela, the lack of comparison between different model outputs has been highlighted. The use of comparative approaches across different ecosystem models to estimate the sensitivity and specificity of ecosystem indicators should be valuable, since it can address the uncertainty in model structure and assumptions underlying different ecosystem models. Moreover, if model-derived indicators show a good agreement between ecosystem models, this increases the confidence in model predictions and can assist the selection of a robust set of indicators that can be reliably applied in the system. In this study, we evaluated the specificity of the response of ecosystem indicators to fishing in the context of environmental change. The indicators were systematically tested against different fishing and environmental pressure levels using the Ecopath with Ecosim (EwE) and Atlantis ecosystem models for the southern Benguela system.

2. Materials and methods

2.1. Ecosystem models

The Atlantis (Fulton et al., 2011) and the Ecopath with Ecosim (EwE, Christensen and Walters, 2004) modelling frameworks were used in this study. The southern Benguela system, our study area, extends from the Orange River mouth (29°S, South African – Namibian border) to the city of East London (28°E), to a maximum depth of 500 m offshore and has a total area of ~220 000 km^2 (Shannon et al., 2003). In the Atlantis model of the Benguela and Agulhas Currents (ABACuS v2), the southern Benguela is divided into 18 boxes, with one to four depth layers; the EwE model is not spatially explicit. In ABACuS v2, vertebrates are represented as age-structured groups consisting of 10 age classes, while invertebrates are modelled as biomass pools. In the EwE model, groups such as horse mackerel, shallow- and deep-water hake are modelled as juvenile and adults while other groups such as anchovy and sardine are not age-structured (Shannon et al., 2008). The initial biomass, distribution and diets used in both models represent the conditions in the southern Benguela system during 1990–1999. Further details on the Atlantis and EwE models for the southern Benguela can be found in Ortega-Cisneros et al. (2017) and Shannon et al. (2004, 2008) respectively.

Fisheries in ABACuS v2 were originally forced using catch time series from 1990 to 2013. For this study, fisheries were represented using fishing mortality rates instead of catch time series to more easily allow for the construction of the various scenarios and to facilitate comparison with the EwE model, which uses fishing mortalities to determine the modelled catches. Detailed information on the time series of observed and modelled catch and biomass from ABACuS v2 using fishing mortalities can be found in Appendix 1. Most target species were fished in both ecosystem models, with the exception of mesopelagic fish and chub mackerel (included in the other small pelagic fish group in ABACuS), the catches of which are modelled in the EwE model but not in ABACuS v2.

2.2. Ecosystem indicators

Five ecosystem indicators were assessed, based on the set of indicators recommended by IndiSeas (Coll et al., 2016; Shin et al., 2010b). Specifically, the indicators were: the total biomass over catch ratio, the marine trophic index (MTI), mean intrinsic vulnerability (IVI), mean trophic level (TL) of the community and proportion of predatory fish (Table 1). The Intrinsic Vulnerability Index ranges from 1 to 100, with higher values indicating higher vulnerability (Cheung et al., 2007). Indicators such as mean lifespan and mean length were not evaluated, since EwE is not an age or size-structured model. The ecosystem indicators were calculated using information on those species in the model that are surveyed or retained by fishing in the southern Benguela. For the trophic level calculations, a fixed TL was used for each species in both models. IVI was calculated using information on retained finfish groups only since no IVI scores are available for invertebrates. Similarly, MTI was calculated for all retained species, with the exception of sardine, which has a TL < 3.25. Cephalopods were the only invertebrate group included in our indicator calculations.

The performance of the indicators was evaluated under a range of scenarios, including combinations of fishing strategy (i.e. which part of the food web is targeted), fishing mortality (i.e. differing levels of fishing pressure) and two types of environmental change - random environmental variability and directional climate change.

Table 1
List of indicators used in this study. Indicators were calculated from model outputs. B = biomass (tons), Y = catch (tons), IVI = intrinsic vulnerability index and TL = trophic level.

Indicator	Calculation	Data requirements[1]	References
Biomass/Landings	B/Y	All retained species	Shin et al., 2010b
Marine Trophic Index	$\frac{\sum_s TL_s Y_s}{\sum_s Y_s} TL_s > 3.25$	All retained species	Pauly and Watson, 2005
Mean Intrinsic Vulnerability	$\frac{\sum_s IVI_s Y_s}{\sum_s Y_s}$	All retained species	Cheung et al., 2007
Proportion of predatory fish	$B_{predatoryfish}/B_{surveyed}$	All pelagic and demersal surveyed species	Shin et al., 2010b
Trophic level of the community	$\frac{\sum_s TL_s B_s}{\sum_s B_s}$	All pelagic and demersal surveyed species	Cury et al., 2005

[1] Definition of retained and surveyed species follows Shin et al. (2010b).