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Evaluating changes in marine communities that provide ecosystem services through comparative assessments of community indicators

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A B S T R A C T

Fisheries provide critical provisioning services, especially given increasing human population. Understanding where marine communities are declining provides an indication of ecosystems of concern and highlights potential conflicts between seafood provisioning from wild fisheries and other ecosystem services. Here we use the nonparametric statistic, Kendall's tau, to assess trends in biomass of exploited marine species across a range of ecosystems. The proportion of 'Non-Declining Exploited Species' (NDES) is compared among ecosystems and to three community-level indicators that provide a gauge of the ability of a marine ecosystem to function both in provisioning and as a regulating service: survey-based mean trophic level, proportion of predatory fish, and mean life span. In some ecosystems, NDES

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Comparative approach
Community metric
IndiSeas
Fishing impacts

corresponds to states and temporal trajectories of the community indicators, indicating deteriorating conditions in both the exploited community and in the overall community. However differences illustrate the necessity of using multiple ecological indicators to reflect the state of the ecosystem. For each ecosystem, we discuss patterns in NDES with respect to the community-level indicators and present results in the context of ecosystem-specific drivers. We conclude that using NDES requires context-specific supporting information in order to provide guidance within a management framework.

1. Introduction

Oceans provide important ecosystem services for human well-being, including provisioning services (e.g., procurement of seafood and medicinal products), regulating services (e.g., moderation of climate fluctuations and protection against flooding and erosion), cultural services (e.g., esthetic and spiritual benefits, and recreation), and supporting services (e.g., nutrient cycling, carbon storage, and trophic stability) (Worm et al., 2006; Daniel et al., 2012). The provision of seafood from wild capture fisheries is one of the most critical benefits that humans derive from the ocean and as such, the regulation of commercial harvests of fish stocks has become a priority. Additionally, there has been a concerted effort to measure and regulate other ecosystem services that may have negative impacts on fisheries (e.g., balancing conservation objectives underlying ecotourism) through marine spatial planning (Foley et al., 2010), better valuation (Börger et al., 2014) and analyses of the synergies and trade-offs (Halpern et al., 2012) of marine ecosystem services. However, while declines in some fisheries have been halted or some fish stocks have recovered due to precautionary fisheries management or reduced exploitation rates (Worm et al., 2009), many exploited stocks around the world are in decline due to a combination of stressors such as overfishing, pollution, habitat degradation, and climate change. These stock declines result in fisheries yields, which are less than optimal and ultimately can lead to stock collapse. This is of growing concern due to the direct impacts on food security for over three billion people who rely on fisheries to supply a significant portion of their animal protein (FAO, 2014). Fishing represents one of the most significant human impacts on marine ecosystems and has led to many changes including alterations of the trophic structure, declines in the abundance of top predators, biodiversity, and overall resilience and biomass of some ecosystems (Pauly et al., 1998; Jackson et al., 2001; Christensen et al., 2003; Perry et al., 2010; Jackson et al., 2011). Additionally, the spatial footprint of fishing has continued to increase as fisheries have expanded offshore (Coll et al., 2008a, Swartz et al., 2010) and into deeper waters (Morato et al., 2006). These expansions have often been facilitated by the use of increasingly sophisticated fishing technology (Pauly et al., 2002). These remarkable technological improvements have resulted in fleets that are more efficient (Pauly and Palomares, 2010) and more powerful (Anticamara et al., 2011) than at any time in the past. However, this has not led to increased catches but rather a stagnation or even slow decline in the overall global catch (FAO, 2014), threatening the delivery of this critical ecosystem service.

Traditionally, fish stocks have been assessed and managed as single units, with little consideration for the linkages with other components of the ecosystem. However, there is a growing push to manage fish stocks cohesively as one aspect of an ecosystem-based approach to marine management (Link et al., 2002; Garcia, 2009). This is in line with the objectives of several international conventions such as the Convention on Biological Diversity (CBD, 2010) and regional legislations such as the European Marine Strategy Framework Directive (EU Directive, 2008/56/EC) or the EU Common Fisheries Policy (European Commission, 2013). An ecosystem approach to management requires the development of indicators and robust methods to gauge changes in marine ecosystems. This requires indicators of ecosystem change that are easy to interpret in order to measure the impacts of fishing, climate change, and other factors across ecosystems and to provide management guidance at an ecosystem level.

However, the development of robust and reliable marine indicators is still in its infancy, and multiple indicators may be necessary to capture changes in different components of the community and to provide a more complete understanding of ecosystem status (Shin et al., 2010b; Bundy et al., 2012). For example, trophic level indicators calculated for different portions of the ecosystem (e.g., surveyed biomass vs. landings) can provide differing views of the status of the ecosystem (Shannon et al., 2014) and highlight places where trophic instability may be affecting the delivery of provisioning and/or regulating ecosystem services. The need to interpret multiple ecosystem indicators to obtain a more complete understanding of the status of the system is particularly important in an ecosystem services framework since the majority of ecosystem indicators currently available are not comprehensive and are often inadequate to characterize ecosystem services when used alone (Liquete et al., 2013).

Here we test an indicator, which has been proposed as a 'simple community analysis' (Lynam et al., 2010), and which can be interpreted in terms of trends and correlations of multiple species at the community-level, for use as a gauge of the ability of an ecosystem to deliver provisioning services. This measure was originally developed and demonstrated using fish survey and phytoplankton count data from waters off the west coast of Ireland (Lynam et al., 2010). The indicator is based on a nonparametric test statistic, Kendall's tau (Kendall and Gibbons, 1990), which is used to determine the strength of declining or non-declining trends in a set of time series of species biomass from the comparison of theoretical and observed distributions of the statistic. We also assess the proportion of non-declining species across several ecosystems.

Similar to Lynam et al. (2010), we use this statistic in a simple community analysis approach to explore biomass trends for exploited species within ecosystems and to estimate the proportion of non-declining exploited species biomass, the 'Non-Declining Exploited Species' (NDES) indicator. The rationale for exploring non-declining trends, rather than the proportion of declining trends, is to have an indicator that should have a lower value at higher levels of fishing pressure (i.e., more declining biomass trends with higher exploitation rates), in line with other ecological indicator formulations selected for comparing the effects of fishing across ecosystems (Shin et al., 2010b). Cross-ecosystem comparisons of the NDES indicator are possible because it accounts for the distinct number of species and differing length of the time series data available in each ecosystem. First, we illustrate, based on the full set of single exploited species trends for each ecosystem, the proportion of non-declining species and compare the indicator values between ecosystems. Second, in order to understand the patterns in NDES, which provides information specific to the exploited portion of the community, we compare NDES to three community-level indicators that provide a gauge of the ability of a marine ecosystem to function both in a provisioning role and as a regulating service (i.e., through maintenance of biodiversity, tro-