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Exploring methods for predicting multiple pressures on ecosystem recovery: A case study on marine eutrophication and fisheries

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ABSTRACT

Efforts to attain good environmental status in the marine realm require decisions which cannot be done without knowledge of effects of different management measures. Given the wide diversity of marine ecosystems, multitude of pressures affecting it and the still poor understanding on linkages between those, there are likely no models available to give all the required answers. Hence, several separate approaches can be used in parallel to give support for management measures. We tested three completely different methods – a spatial impact index, a food web model and a Bayesian expert method. We found that a large uncertainty existed regarding the ecosystem response to the management scenarios, and that the three different modelling approaches complemented each other. The models indicated that in order to reach an improved overall state of the ecosystem nutrient reductions are the more effective of the two management variables explored, and that cumulative effects of the management of nutrient inputs and fishing mortality are likely to exist.

1. Introduction

Making informed decisions to achieve cost-effective improvements in environmental status requires knowledge about the ecosystem responses to the changes in managed pressures caused by human activity (Borja et al., 2010; Borja, 2014; Duarte et al., 2015). Marine science has collated a large body of evidence of impacts of various human activities to the marine ecosystems; however this information will by its very nature always be considered incomplete (Knowlton and Jackson, 2008; Borja, 2014). Moreover, the vast majority of this knowledge comes from marine environments where human pressures have increased; and if we wish to assess the recovery rate of the ecosystem as the pressures are relieved, the possibility of hysteresis in the recovery process should be recognised (Duarte et al., 2015). The issue is further complicated by "shifting baselines", i.e. the gradual change in variables such as climate, atmospheric pollution, patterns of human use, etc. (Duarte et al., 2009). The challenge in designing the optimal management strategy is two-fold: we need to assess the likely recovery paths of the ecosystem considering likely reductions in pressures, and we must understand the cumulative, or synergistic, effects of these processes during recovery (Borja, 2014).

When acting simultaneously, pressures may have effects that are additive, i.e., the combined effect can be evaluated by simply adding up the individual effects of the pressures; but often they have cumulative, i.e. synergistic or antagonistic effects, either strengthening or weakening each other (Griffith et al., 2011, 2012). Understanding these effects is needed in order to help the manager select and implement an effective set of measures to protect the ecosystem, and to predict ecosystem recovery when these pressures are relaxed. There are many cases where the deterioration of the ecosystems has been experienced and documented (Myers et al., 1997; Möllmann et al., 2009), but less cases where there are evidence of pressure relief and subsequent improvement of the environmental status (however see Carstensen et al., 2006; Andersen et al., 2015b; Riemann et al., 2015). Therefore, the current understanding in modelling and prediction of ecosystem recovery is not sufficient to provide operational management tools for quantitative decision-making in situations where multiple pressures are impacting the environment (Francis et al., 2011; Planque, 2015). Managers facing this fundamental uncertainty in

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knowledge and modelling tools have to make decisions and proceed in managing human activities, using the best available scientific information. Therefore the understanding of the trade-offs and potential synergies between various actions and their effects on the marine environment is crucial (Lester et al., 2013). Managers need advice on how the effects of the management measures propagate beyond their primary target (Samhouri et al., 2011), an example being how the nutrient loading reductions in a eutrophied system have consequences beyond phytoplankton biomass to food web structure, the benthos, etc. Further, they need the best available estimates about the interactions of various management measures; whether they are likely to give boost to each other (i.e. be synergistic) or dampen each other's effects (antagonistic), or whether one of them only works if the other is implemented at the same time (Judd et al., 2015).

The need to manage human activities and predict the outcome in the environment has increased with the environmental legislation (e.g. Marine Strategy Framework Directive (MSFD), European Union, 2008), emerging maritime spatial planning (European Union, 2014) and the increased awareness of impacts of multiple human activities on marine ecosystems (Korpinen et al., 2012; Halpern and Fujita, 2013; Korpinen et al., 2013). The MSFD requires EU Member States to create and regionally coordinate programmes of management measures to reach good environmental status (GES) of Europe's seas. The challenge of this requirement is underlined by the fact that only part of the pressures are measured quantitatively. Likewise, the impacts of some pressures are not very well understood, and building quantitative models is a challenge (as compared to, e.g., the impact of a fisheries on a well monitored fish stock). Further, for example marine biodiversity has been divided into categories, which are often too broad to be used directly in models that aim to estimate potential effects of management measures. For example, marine ecosystem complexity is often divided into three broad categories: (1) species abundance and condition, (2) quality of habitats and their communities, and (3) food web structure (European Union, 2008, 2010; HELCOM, 2010). Ecosystem assessments in the Baltic Sea and NE Atlantic are recent examples of this approach (HELCOM, 2010; OSPAR, 2010). Due to the difficulty in capturing the processes of an entire ecosystem and pressures affecting them, ecosystem models and assessments have used indicator species (e.g. keystone species, predominant food web elements) which simplify the multitude of interactions and reflect broad-scale phenomena in the system (Heslenfeld and Enserink, 2008; HELCOM, 2010; OSPAR, 2010; ICES, 2015a).

The aim of this study is to explore different approaches to estimate the potential outcome of pressure reductions by including two well-known, and in the study area, central, anthropogenic pressures – nutrient inputs and fishing – with different reduction scenarios (alone and together). We approached this challenge using three types of approaches: (1) a spatial model for cumulative impacts (additive approach), (2) a food web model, and (3) a Bayesian model harnessing expert knowledge. We present the approaches and results and discuss their pros and cons in a challenging management situation.

Fig. 1. The Baltic Sea.