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Projections of change in key ecosystem indicators for planning and management of marine protected areas: An example study for European seas

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A B S T R A C T

Marine Protected Areas (MPAs) are widely used as tools to maintain biodiversity, protect habitats and ensure that development is sustainable. If MPAs are to maintain their role into the future it is important for managers to understand how conditions at these sites may change as a result of climate change and other drivers, and this understanding needs to extend beyond temperature to a range of key ecosystem indicators. This case study demonstrates how spatially-aggregated model results for multiple variables can provide useful projections for MPA planners and managers. Conditions in European MPAs have been projected for the 2040s using unmitigated and globally managed scenarios of climate change and river management, and hence high and low emissions of greenhouse gases and riverborne nutrients. The results highlight the vulnerability of potential refuge sites in the north-west Mediterranean and the need for careful monitoring at MPAs to the north and west of the British Isles, which may be affected by changes in Atlantic circulation patterns. The projections also support the need for more MPAs in the eastern Mediterranean and Adriatic Sea, and can inform the selection of sites.

1. Introduction

Marine protected areas (MPAs) are a key element of strategies to protect coastal and shelf sea ecosystems in many parts of the world. They have been set up to maintain biodiversity, restore damaged ecosystems, ensure sustainable development and to protect a representative range of species and habitats (OSPAR Commission, 2013). Creation of MPAs was spurred by the 1992 Convention on Biological Diversity (CBD) and the current CBD target is for 10% of coastal and marine areas to be conserved by well-managed, ecologically-representative and well-connected protected areas by 2020 (Gabrié et al., 2012). As well as protecting biodiversity, MPAs can help to ensure the long-term sustainability of fisheries (Weigel et al., 2014) and preserve coastal and marine sites of socio-cultural value (Börger et al., 2014; Gabrié et al., 2012).

Marine areas worldwide, and particularly coastal areas, face many anthropogenic threats, arising from both local and non-local sources (Halpern et al., 2008). Marine Protected Areas can reduce threats from local sources such as fishing and recreation, but they remain vulnerable to impacts from riverborne nutrients sourced from the wider area and from global climate change. These exogenous, unmanaged drivers (Elliott et al., 2015) will affect MPAs regardless of their protected status, and effective planning and management requires an understanding of the change in local environmental conditions that they are likely to produce. Environmental change may make an MPA unsuited to the purpose for which it was set up, for example if conditions are no longer appropriate for a target species. Management regulations which are framed in terms of current conditions may no longer be appropriate if climate change affects what can be considered 'normal' for a given system – the shifting baseline effect (Elliott et al., 2015).

A number of studies have looked at the potential impact of climate change on MPAs and suggested ways in which MPAs can be designed and managed so as to limit the risk of ecosystem damage. Results include guidance produced for North American MPAs (Brock et al., 2012; ICES, 2011), for coral reefs and other tropical seas (Green et al., 2014) and for the Mediterranean (Otero et al., 2013). These studies are based on the expected response of organisms and ecosystems to rising temperatures (e.g. O'Connor et al., 2007; Marras et al., 2015; Hoegh-Guldberg and Bruno, 2010). Studies

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are beginning to show how the effect of other variables can interact with temperature changes, making assessments based only on temperature changes inadequate e.g. (Deutsch et al., 2015; Muir et al., 2015).

There has been little use of model projections of future conditions for the planning of marine protected areas (Levy and Ban, 2013; Makino et al., 2014) and those that do tend to use projections of surface temperature only. They also rely on global climate models (GCMs) with resolutions typically 50 km or more. Satellite data provides higher resolution, but does not by itself give information about future conditions (Chollett et al., 2014). As future projections downscaled to the regional level become more common, their potential for MPA planning and management can be developed.

Other studies have used a species-based approach to investigate the threat to biodiversity from climate change. Jones et al. (2013) used species distribution models to project changes in the range of 17 fish species in the North Sea. The species distribution models made use of a number of variables taken from GCMs, and so they go beyond projections based only on temperature. Jones et al. considered the use of their model results to judge the change in habitat suitability of protected areas, but they suggest that this would need to be done on a species by species and area by area approach: there is no simple pattern of change across areas.

Another anthropogenic threat to marine ecosystems comes from riverborne influxes of nitrates and phosphates. Eutrophication associated with high river nutrient loadings has long been a problem in parts of the North Sea and the Mediterranean (Coll et al., 2010; Langmead et al., 2007). Reduction of this threat requires changes in land use and water treatment upstream, perhaps in a different jurisdiction. Model projections have been more widely used to investigate this issue and the consequences of possible mitigation actions (e.g. Lenhart et al., 2010; Skogen et al., 2014). In practice, MPAs are experiencing the combined effects of climate change and river nutrient loadings and models can be used to investigate the interaction between these stressors.

Here we show how a regional model, downscaled from global data, can be used to make projections of change in a number of key ecosystem indicators resulting from changes in climate and river nutrient loadings. We present spatially-aggregated results that give an overview of projected change in conditions in a selected area under two different scenarios: these provide a starting point from which managers and planners can go on to investigate possible actions, such as increased protection through changes in local management (Micheli et al., 2012), an extension of the MPA area, creation of other MPAs nearby to give a more robust network or perhaps future relocation of the MPA to an area where future conditions are more appropriate for its purpose. The model projections include both physical and biogeochemical indicators – temperature, salinity and mixed layer depth, nutrient concentrations, dissolved oxygen, surface chlorophyll, primary production and zooplankton biomass. They thus give a richer view of conditions in an area of interest than is possible with use of a single indicator, and they demonstrate how resilient a given area is to climate change, i.e. whether the changes occurring in this area are significantly altering habitat conditions. They also illustrate how susceptible an area is to policy change by showing how much the projected changes differ between the contrasting scenarios. The examples given are for European seas, but the methods used are general and could be applied anywhere in the world – and to any spatial area of interest, not just to MPAs.

Our study areas are the Mediterranean Sea and the North-East Atlantic (Fig. 2). These seas encompass a wide range of temperate marine conditions and include coastal, shelf sea and deep water areas. The Mediterranean is largely enclosed, being connected to the Atlantic only via a narrow strait at the western edge. The sea has a long northern coastline which limits the poleward movement of species in a warming climate. Surface temperatures are typically 16–28 °C (Butenschön and Kay, 2013). The North-East Atlantic comprises the shallow North Sea and English Channel, to the east and south of the British Isles respectively, as well as the deeper waters to the west. Unlike the Mediterranean, it is open to influence from the wider Atlantic Ocean and has no land mass to the north. Surface temperatures are cooler and more variable than in the Mediterranean, from near-freezing up to 20 °C (Butenschön and Kay, 2013).

Networks of protected areas have been set up in both seas. In 2012 Mediterranean MPAs covered an area of about 115,000 km^2, about 4.6% of the Sea's area. However, three quarters of this was in a single MPA, the Pelagos Sanctuary for Mediterranean Marine Mammals (Gabrié et al., 2012). The network is largely restricted to small coastal sites and there are relatively few sites on the southern and eastern shores. The North-East Atlantic has a better-developed MPA network: in December 2012 there were 333 MPAs, covering an area of 700,000 km^2, 5% of the entire OSPAR area and 22% of coastal waters (OSPAR Commission, 2013). These range from coastal zones to larger shelf sea areas and deep sea areas around seamounts. Fig. 2 shows the sample of MPAs which are included in the current study and their main features are listed in Table 1.

The scenarios presented here have been produced using projections of marine physics and biogeochemistry and the lower trophic level ecosystem. These projections were developed under the EU project VECTORS (Austen et al., this issue) and have delivered the baseline for the socioeconomic scenarios used in this project (Groenveld et al., 2015). They have been run for two contrasting future scenarios of climate change and river nutrient levels for the period 2040–2049, as well as a reference run for 2000–2009. The two scenarios were chosen to represent more and less sustainable situations of economic development – lower/higher greenhouse gas emissions and river nutrient levels. The projections thus give an envelope of potential conditions in the 2040s.

2. Methods

2.1. The numerical model

Modelling was carried out using the biogeochemical and lower trophic level model ERSEM (Blackford et al., 2004; Butenschön et al., 2016) coupled to the hydrodynamic shelf sea model POLCOMS (Holt and James, 2001). Both have a long history of use in modelling the North-East Atlantic system e.g. (Allen et al., 2007; Siddorn et al., 2007) and global shelf seas (Barange et al., 2014; Blanchard et al., 2012; Holt et al., 2009). For the current study the model system was designed to be consistent across all marine areas included: the same model resolution (0.1°, about 6–11 km) and the same sources of forcing data. Separate domains were used for the Mediterranean and the North-East Atlantic. A full description of the model set-up is given in Butenschön and Kay (2013); a brief summary is given here.

ERSEM includes three size-class based functional types of phytoplankton plus diatoms, three functional types for zooplankton, bacteria, three size classes of particulate organic matter, dissolved and semi-labile organic matter and the inorganic components nitrate, phosphate, silicate, dissolved oxygen and DIC (Fig. 1). The cycles of the main chemical constituents of the system, i.e. carbon, nitrogen, phosphate and silicate, are resolved explicitly, with variable stoichiometry in the organic components, and the model also includes microbial dynamics. For the North-East Atlantic the ERSEM benthic model was used to model the seabed