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Using a multi-model ensemble forecasting approach to identify key marine protected areas for seabirds in the Portuguese coast

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ABSTRACT

Marine Protected Areas (MPAs) have been established across all marine environments, though their coherence and effectiveness in protecting umbrella species remains unclear. We used a multi-model ensemble forecasting approach, on 8 years of at-sea censuses of 30 seabird species to identify candidate MPAs in the Portuguese coast, prioritizing important areas for their conservation based on their occurrence and distribution. We overlapped the outputs generated by the Ensemble Ecological Niche Models (EENMs) with layers representing important environmental stressors (fishing intensity, ship density and oil pollution risk), and calculated loss in conservation value using them as cost layers. Three key marine areas were identified along the Portuguese coast: For breeders, there was a key marine area encompassing the Tagus and Sado estuaries and Berlengas archipelago; for non-breeders and migratory species two important areas were identified in the Northern and Southern coast. The key marine area identified in the Northern coast is characterized by high productivity and biodiversity, and can be affected by oil pollution from the refineries and the intensive ship traffic in this area. Also, the area identified in the Southern coast of Portugal for migratory seabirds overlaps extensively with areas of high fishing activity. Our results show that the Important Bird and Biodiversity Areas (IBAs) established along the Portuguese coast protect more than a third of the areas that we prioritized for breeding species and the official MPAs near 65% of the same areas. In contrast, current IBAs and national legislation protect less than 4% of the coastal areas that we prioritize for non-breeding species in this study. Our study, combining multi-species distribution with environmental constraints induced by human activities, allowed us to assess the coherence of the Portuguese marine planning and identify candidate areas to join the Portuguese network of marine protected areas. Our results, employing data from annual at-sea surveys together with the human stressors known to affect the Portuguese coast, proved to be an extremely useful strategy to identify spatial conservation areas along the Portuguese coast as well as to access the adequacy and consistency of those areas. Despite the constraints of this demanding approach, we are confident that our study provides a reliable strategy to inform marine conservation efforts and management planning in similar coastal environments elsewhere, characterized by strong coastal upwelling movements.

1. Introduction

Marine Protected Areas (MPAs) are recognized as key tools to provide a network-framework for integrated area-based biodiversity (Lovejoy, 2006). MPAs were firstly established in coastal areas but are now being established across all marine environments. The suitable design and management of MPAs rely mostly on the quality of the ecological information used to identify key marine areas (Abecasis et al., 2014; Fulton et al., 2015). These data will help decision-makers allocate the initial position and boundaries of priority areas for conservation based on the species' habitat fidelity and will also provide important information for the management of already established MPAs (Maxwell et al., 2014, 2015). Marine predators, such as seabirds, may be used as biological indicators to identify and prioritize areas for marine conservation because they are wide ranging, long-lived marine predators and their distribution often overlaps with that of other

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List of abbreviations

BATG	Gradient of bathymetry
CHL	Chlorophyll-*a* concentration
CHLG	Gradient of Chl-*a* concentration
CR	Critically Endangered
DCOAST	Distance to Coastline
EN	Endangered
KEYs	Proposed Key Areas
LN	Least Concern
SSTG	Gradient of Sea Surface Temperature
VU	Vulnerable

marine predators and with important anthropogenic stressors, such as commercial fisheries (Breen et al., 2016; Maxwell and Morgan, 2013; Paiva et al., 2015).

Coastal ecosystems are heavily impacted by human activities, which can be difficult to take into account during MPA identification and design (Maxwell et al., 2013). To truly protect the biodiversity of marine ecosystems, MPA implementation must take into account the relation between the distribution of marine organisms, oceanographic processes and the impact of environmental stressors (e.g. ocean acidification, oil pollution, vessels traffic density, fisheries density, etc.) on marine biodiversity (Fulton et al., 2015; Halpern et al., 2008). Besides climate change effects, fisheries are considered the environmental stressor with a major impact on marine biodiversity, responsible for modifying worldwide ecosystems and for reducing populations of marine top predators (Brown et al., 2015; Rolland et al., 2010). Because fisheries' distribution often overlaps with biodiversity hotspots (Queiroz et al., 2016), and bycatch is one of the main causes for seabirds' high mortality levels (Croxall et al., 2012), already established protected areas may not be enough for the conservation of all seabird species (Krüger et al., 2017). Therefore, it is important to assess which species are truly protected by the currently established MPAs (Lascelles et al., 2012; Ramirez et al., 2017).

Multi-species approaches based on the overall species' occurrence and diversity are usually desirable and have been used to identify biodiversity hotspots across large spatial scales (Briscoe et al., 2016; Maslo et al., 2016; Nur et al., 2011; Raymond et al., 2015). Several studies used shipboard surveys, following the European Seabirds at Sea (ESAS) procedures (Camphuysen and Garthe, 2004; Tasker et al., 1984) to identify seabird hotspots and use that information to develop potential MPAs scenarios in offshore waters (Arcos et al., 2012; Nur et al., 2011). Several important marine areas were prioritized and identified based on the occurrence and distribution of seabird species, and proposed to integrate the current worldwide network of MPAs (Lascelles et al., 2016). The marine Important Bird and Biodiversity Areas (IBAs) represent one of the most recent wide-ranging European efforts to identify key marine areas and the first step for MPA establishment (Lascelles et al., 2012). However, the effectiveness of coastal MPAs for the conservation of highly mobile marine predators and targeted species is not usually assessed by combining oceanographic data with environmental stressors.

Most seabird species are closely distributed within a range of dynamic oceanographic processes which enhance oceanic productivity and prey availability, and so require more complex analyses such as dynamic modelling approaches (Louzao et al., 2011) or a combination of multiple modelling techniques (Araújo and New, 2007; Oppel et al., 2012; Scales et al., 2016; Zhang et al., 2015). However, most studies used a single-algorithm approach, such as the widely used Maximum Entropy (MaxEnt) modelling technique, despite their frequent overfitting on habitat suitability predictions which limit their predictive performance and extrapolative ability (Torres et al., 2015). An alternative to reduce potential bias and increase the robustness in predictions is to adopt a multi-model ensemble forecast by combining the best predictive outputs of each modelling technique into one unique weighted average surface (Araújo and New, 2007; Thuiller et al., 2009; Zhang et al., 2015). Ensemble Ecological Niche Modelling (EENM) has been used successfully for identifying at-sea areas for marine predators, including sea turtles (Pikesley et al., 2013) and seabirds (Fox et al., 2017; Legrand et al., 2016; Oppel et al., 2012; Scales et al., 2016).

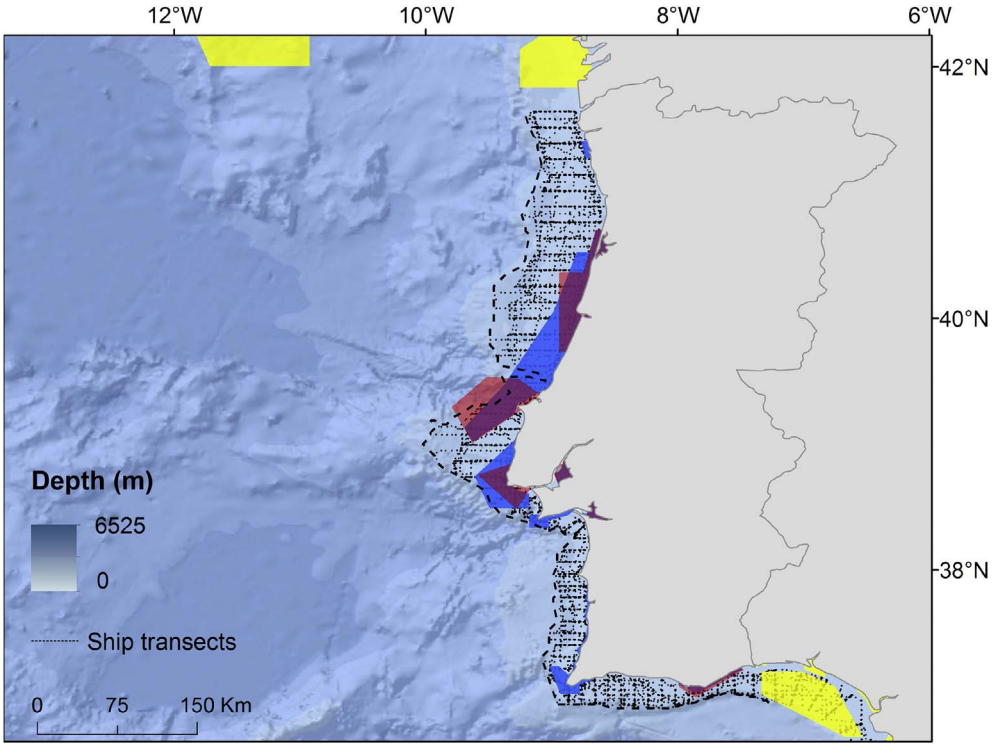

Fig. 1. Map showing the overall effort during the 8-years of the surveying period (2004–2012) within the Continental Portuguese Economic Exclusive Zone. At-sea shipboard surveys (represented by small black dots) used in this study for the Ensemble Ecological Niche Modelling of individual species within the Continental EEZ. The 200 m isobath is also shown (black dashed line) and is overlaid on the bathymetry of the region. Portuguese Marine Protected Areas (blue), Portuguese marine Important Bird Areas (mIBAs; red) and Spanish Marine Protected Areas (MPAs; yellow). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)