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Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: Implications for the use of broad-scale models in fisheries management

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ABSTRACT

Management of human activities which impact the seafloor in the deep ocean is becoming increasingly important as bottom trawling and exploration for minerals, oil, and gas continue to extend into regions where fragile ecosystems containing habitat-forming deep-sea corals and sponges may be found. Spatial management of these vulnerable marine ecosystems requires accurate knowledge of their distribution. Predictive habitat suitability modelling, using species presence data and a suite of environmental predictor variables, has emerged as a useful tool for inferring distributions outside of known areas. However, validation of model predictions is typically performed with non-independent data. In this study, we describe the results of habitat suitability models constructed for four deep-sea reef-forming coral species across a large region of the South Pacific Ocean using MaxEnt and Boosted Regression Tree modelling approaches. In order to validate model predictions we conducted a photographic survey on a set of seamounts in an un-sampled area east of New Zealand. The likelihood of habitat suitable for reef-forming corals on these seamounts was predicted to be variable, but very high in some regions, particularly where levels of aragonite saturation, dissolved oxygen, and particulate organic carbon were optimal. However, the observed frequency of coral occurrence in analyses of survey photographic data was much lower than expected, and patterns of observed versus predicted coral distribution were not highly correlated. The poor performance of these broad-scale models is attributed to lack of recorded species absences to inform the models, low precision of global bathymetry models, and lack of data on the geomorphology and substrate of the seamounts at scales appropriate to the modelled taxa. This demonstrates the need to use caution when interpreting and applying broad-scale, presence-only model results for fisheries management and conservation planning in data poor areas of the deep sea. Future improvements in the predictive performance of broad-scale models will rely on the continued advancement in modelling of environmental predictor variables, refinements in modelling approaches to deal with missing or biased inputs, and incorporation of true absence data.

1. Introduction

The concept of vulnerable marine ecosystems (VMEs) is one that has become important in recent years for the management of impacts of bottom trawling on benthic habitats in the deep sea (e.g., Ardron et al., 2014). VMEs are found in areas that may be subjected to negative impacts from human activities such as bottom trawling, offshore oil/gas development, and deep sea mining. Potential VMEs are identified by biological characteristics that express the vulnerability of their species, communities, and/or habitats to damage or disturbance (FAO, 2009; CCAMLR, 2009). The United Nations General Assembly (UNGA) Resolutions 61/105 and 64/72 state the urgent need to identify and map VMEs in order to effectively implement cohesive networks of Marine Protected Areas (MPAs) and the need for Regional Fisheries Management Organisations to

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implement a precautionary approach to fishing on the high seas.

The South Pacific Regional Fisheries Management Organisation (SPRFMO) was formed to manage high-sea fisheries across a large area of the South Pacific Ocean, to ensure the sustainable use of fishery resources, and to safeguard the marine ecosystems in which they occur. This non-governmental organisation aims to implement management strategies to protect VMEs and thereby conserve biodiversity and ecosystem function in the deep sea. The SPRFMO convention area comprises the region of the South Pacific beyond areas of national jurisdiction, an area of about 59 million km^2. Currently, SRFMO has some interim measures in place to protect VMEs (Penney et al., 2009) but the efficacy of these measures has been questioned (Penney and Guinotte, 2013). A general need for improved protection of VMEs in areas of the High Seas based on more robust spatial management planning has been recognised (Ardron et al., 2014).

Very little information exists on the spatial distribution of VMEs within the SPRFMO area, which is an impediment to the design of management strategies. The SPRFMO area is too large for cost-effective and comprehensive survey programmes to directly determine the location of all VMEs so predictive methods have been explored to help fill this management need (Rowden et al., 2013). Many studies have used habitat suitability models to predict the potential distribution of benthic fauna that may be indicators of VMEs in other areas (e.g., Davies and Guinotte, 2011; Yesson et al., 2012; Rengstorf et al., 2013, 2014). The use of such models has been recommended as part of a process for designing effective management plans for protecting VMEs from the adverse effects of fishing on the high seas (Ardron et al., 2014; Vierod et al., 2014), and for benthic ecosystem management in general (Reiss et al., 2014), even though the practical application of model outputs into conservation management can be difficult to achieve (Marshall et al., 2014).

While there are many recognised VME indicator taxa (Parker et al., 2009; Parker and Bowden, 2010), it is the reef-forming deep-sea scleractinian corals which have attracted the most attention because of their role in providing habitat which is associated with diverse fish and invertebrate communities (McCloskey, 1970; Jensen and Frederiksen, 1992; Husebø et al., 2002; Jonsson et al., 2004; Buhl-Mortensen and Mortensen, 2005; Costello et al., 2005; Stone, 2006; Henry and Roberts, 2007; Moore et al., 2008; Mortensen et al., 2008; D'Onghia et al., 2010; Mastrototaro et al., 2010). Coral reefs throughout the deep sea, including in the South Pacific, have suffered damage over the last 30 years from bottom trawling (Koslow et al., 2001; Fossa et al., 2002; Hall-Spencer et al., 2002; Rogers, 2005; Reed et al., 2007; Waller et al., 2007; Clark and Rowden, 2009; Althaus et al., 2009; Williams et al., 2010) and continue to be threatened by this activity. In addition, deep-sea coral reef VMEs are also threatened by changes in the physical environment including the shoaling of the aragonite saturation horizon and increasing ocean temperatures (Guinotte et al., 2006; Maier et al., 2009; Tittensor et al., 2010; Thresher et al., 2015).

In the northern hemisphere, *Lophelia pertusa* is the species primarily responsible for deep-sea coral reef formation. These reefs can grow to be tens of kilometres in length and tens of metres in height (e.g. Huehnerbach et al., 2007). This species is uncommon in the southern hemisphere where other reef-forming scleractinian species dominate including *Solenosmilia variabilis, Goniocorella dumosa*, *Enallopsammia rostrata*, and *Madrepora oculata* (Tracey et al., 2011). The distributions of these coral species are well described for the New Zealand EEZ and environs from compilations of data records and from regional habitat suitability models (Tracey et al., 2011). These four species are widely distributed throughout the region, have well defined depth zonation ranges, and are strongly associated with seamounts around New Zealand (Tracey et al., 2011). Prior habitat suitability modelling studies conducted in the New Zealand region indicated depth, slope, surface water primary productivity, and tidal currents were all strong predictors of their distribution (Tracey et al., 2011).

Few studies have attempted to verify modelled predictions of deep-sea corals by direct comparison with independent field data, despite many stressing the need for such surveys (e.g. Tittensor et al., 2009; Davies and Guinotte, 2011; Guinotte and Davies, 2014). One example, highlighted by Dullo et al. (2008), characterized known *Lophelia pertusa* reef locations by the ambient water density (sigma-theta), temperature, salinity, oxygen levels, bottom relief, and current regimes. A manned submersible was used to "ground-truth" coral locations on the Norwegian continental shelf predicted from CTD casts and bathymetric analysis, but correspondence between predictions and observations was not quantified. Field validation of model results is often not carried out due to the expense of such surveys, which leads to uncertainty surrounding the accuracy of the modelled results and by extension, reluctance of managers and stakeholders to use the model results for management decisions. There is a clear and urgent need to test the ability of habitat suitability models to correctly predict suitable habitat for VME indicator taxa by conducting field surveys that sample the seafloor directly in areas with gradients of predicted habitat suitability. Such validation is particularly important in data-poor areas that are of high commercial interest. A prime example of this within the SPRFMO area is the Louisville Seamount Chain. The Louisville Seamount Chain lies in international waters and is an important area for New Zealand's commercial fishing interests, primarily for orange roughy (*Hoplostethus atlanticus*) (Clark, 1999). The seafloor habitats of the Louisville Seamount Chain have only rarely been sampled by independent research studies and only a limited number of records of reef-forming scleractinian corals and other VME indicator taxa exist from these seamounts.

In this study we produced broad-scale habitat suitability models for four species of reef-forming corals in the SPRFMO area using two statistical modelling approaches that are commonly used in deep-sea applications. We then tested these models using data from a systematic independent visual survey of a sub-region of the area to enable assessment of the correspondence between habitat suitability as predicted by the models, and actual presence or absence of corals. In order to assess which factors may drive differences between observed and predicted values, we compared the measured characteristics of the study region against the broad-scale environmental data used in the models. We discuss shortcomings of the modelling approaches and the implications of these results for fisheries management and conservation planning.

2. Methods

2.1. Study area

The Louisville Seamount Chain lies near the southern centre of the SPRFMO area, the region of the South Pacific beyond areas of national jurisdiction from 10° N to 60° S, and 120° E to about 67° W (Fig. 1). It is made up of over 80 seamounts and extends over 4000 km from the junction of the Pacific and Indo-Australian Plates (latitude ~27° S) south eastwards into the central southwest Pacific (latitude ~47° S) (Fig. 1). Many of the seamounts in the chain are large guyots (flat-topped seamounts, formed by erosion and subsequent submersion of islands). The region is known from New Zealand fisheries observer records to host VME indicator taxa including Porifera (sponges), Actiniaria (anemones), Alcyonacea (soft corals and gorgonians), Pennatulacea (sea pens), Scleractinia (stony corals), Antipatharia (black corals), Stylasterida (hydrocorals); and VME-associated taxa such as Crinoidea (sea lilies and