Building a Tool for Management: A Species Distribution Model of Invasive Lionfish (*Pterois* spp.) Around Bermuda

La Construcción de Una Herramienta de Gestión: Modelo de la Distribución de las Poblaciones de las Especies Invasoras de Peces León (*Pterois* spp.) en de las Bermudas

Construire un Outil de Gestion: Un Modèle de Ditribution de L'espèce de la Population de Poissons-lions (*Pterois* spp.) Invasive aux Bermudes

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EXTENDED ABSTRACT

Introduction

The invasion of the Indo-Pacific lionfish (*Pterois miles* and *P. volitans*) has the potential to become one of the most ecologically and economically harmful marine invasions to date (Albins and Hixon 2013). Since their introduction off the coast of Florida in the mid-1980s their numbers and range have expanded rapidly, with the first sighting in Bermuda in 1999 (Whitfield et al. 2007, Schofield 2009). Despite this, the true distribution of the lionfish population across Bermuda's reef systems, and much of their invaded range, is still unknown. Such information is vital for effective management programs. This piece of research attempts to address this lack of knowledge through the generation of a species distribution model (SDM) based on known lionfish presence locations and various environmental predictors.

SDMs quantify the correlation between environmental factors and the distribution of species (Miller 2010). This is used to describe and measure the importance of specific factors and to predict species' distribution across unsampled areas (Guisan and Zimmermann 2000, Elith and Leathwick 2009). R and MaxEnt software (Phillips et al. 2006) were the main tools used to create the SDM here. MaxEnt is one of the most popular tools used for species distribution modelling; it typically outperforms other methods of creating SDMs based on its predicative accuracy (Merow et al. 2013).

The major aim of this study was to create a functioning and robust species distribution *model*. It must be stressed that the goal of this work was to create a working model that can be built upon as more environmental data is collected. However, it is also hoped that the initial output from this SDM will still give an insight into the lionfish's spatial ecology around Bermuda.

Methods

The modelling process relied on presence-only data for *Pterois* spp. and environmental data in the form of raster layers. 160 presence-only lionfish observations were collected using Baited Remote Underwater Video Stations (BRUVS) and data from Bermuda's Ocean Support Foundation lionfish reporting website (www.oceansupport.org). Environmental predictor raster layers (depth, temperature, benthic habitat and slope) were generated using ESRI ArcGIS 10.3.1. R was then the main interface and was used to carry out the initial stages of the modelling process. A package within R called 'dismo', which works in conjunction with the probability algorithms in MaxEnt, was used to create the probability model that formed the SDM map.

Results

Figure 1 shows the final output from the modelling process and represents a SDM for the presence of lionfish around Bermuda. The final model returns a mean AUC (Area Under Curve) score of 0.756. Despite this being an early model output it does make ecological sense.

The main areas of high lionfish presence probability are associated with mesophotic coral ecosystems (MCEs); depths ranging from 30 - 150 m.

Conclusions

The present study represents the first species distribution model of invasive lionfish around Bermuda and could be an important tool for assisting existing management programs. As well as lionfish management, the model has the potential for a wide array of important applications in the management of marine systems.

The main aim of this study was to develop a protocol for a SDM for lionfish that can be built upon over time, however the environmental data used was far from obsolete, and in fact, the model consistently returns an AUC score > 0.7 with the output (Figure 1) making ecological sense. With this in mind mesophotic coral ecosystems (MCEs) have been highlighted as habitats with high suitability for lionfish presence in Bermuda. Given the potential importance of MCEs (Brokovich et al. 2007; Hinderstein et al. 2010) Bermuda's lionfish management efforts should be focusing a large part of their resources into gaining a greater understanding of the role MCEs have in the health of Bermuda's reef system, what the abundance of invasive lionfish is in these ecosystems and also to what extent lionfish are influencing MCEs. This should be alongside developing methods for controlling the lionfish population at depth. It has been suggested that modified lobster pots could be used as they are known to successfully trap large numbers of lionfish (personal communication).

Eradication of the invasive lionfish is highly unlikely (Barbour et al. 2011). The only way to minimise the impacts of this invasion is through concentrated and sustained efforts to reduce lionfish numbers at key locations (Hare and Whitfield 2003). What has been achieved in the work presented here, a fully functioning SDM with the potential for the easy addition of additional presence and environmental data, could become a vital tool in the identification of such locations; and therefore a vital tool in the battle to mitigate the ecological impacts of the invasive lionfish.

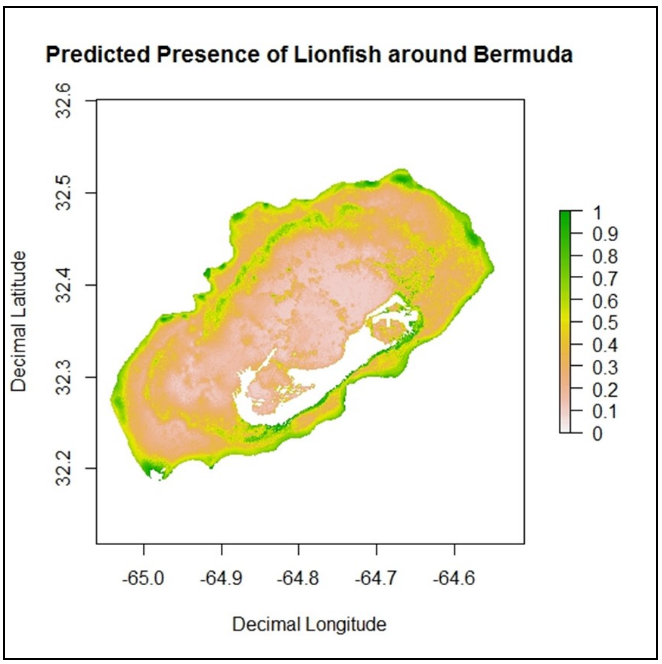

Figure 1. MaxEnt prediction of lionfish presence around Bermuda, constrained to the 150 m isobaths. The coloured scale bar represents the predicted suitability of lionfish presence - with 0 (white) being 0% likelihood and 1 (dark green) representing a 100% likelihood of occurrence.

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