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Improving essential fish habitat designation to support sustainable ecosystem-based fisheries management

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ABSTRACT

A major limitation to fully integrated ecosystem based fishery management approaches is a lack of information on the spatial distribution of marine species and the environmental conditions shaping these distributions. This is particularly problematic for deep-water species that are hard to sample and are data poor. The past decade has seen the rapid development of a suite of advanced species distribution, or ecological niche, modelling approaches developed specifically to support efficient and targeted management. However, model performance can vary significantly and the appropriateness of which methods are best for a given application remains questionable. Species distribution models were developed for three commercially valuable Hawaiian deep-water eteline snappers: *Etelis coruscans* (Onaga), *Etelis carbunculus* (Ehu) and *Pristipomoides filamentosus* (Opakapaka). Distributional data for these species was relatively sparse. To identify the best method, model performance and distributional accuracy was assessed and compared using three approaches: Generalised Additive Models (GAM), Boosted Regression Trees (BRT) and Maximum Entropy (MaxEnt). Independent spatial validation data found MaxEnt consistently provided better model performance with 'good' model predictions (AUC = > 0.8). Each species was influenced by a unique combination of environmental conditions, with depth, terrain (slope) and substrate (low lying unconsolidated sediments), being the three most important in shaping their distributions. Sustainable fisheries management, marine spatial planning and environmental decision support systems rely on an understanding species distribution patterns and habitat linkages. This study demonstrates that predictive species distribution modelling approaches can be used to accurately model and map sparse species distribution data across marine landscapes. The approach used herein was found to be an accurate tool to delineate species distributions and associated habitat linkages, account for species-specific differences and support sustainable ecosystem-based management.

1. Introduction

Management of marine resources has evolved from single species approaches to more holistic ecosystem based management approaches in order to integrate ecosystem, bioregional and societal facets based on ecosystem boundaries rather than sectoral or jurisdictional boundaries [1–3]. The National Oceanic and Atmospheric Administration (NOAA) defines an ecosystem approach as "management that is adaptive, specified geographically, takes account of ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives". The approach recognises the full suite of interactions within an ecosystem as well as human influences [2,4]. This shift in focus involves the implementation of a range of marine management strategies, including improved marine spatial planning, to balance conservation objectives with sustainable resource use [3,5]. As ecosystem-based management encompasses a vast array of interactions, it can be seen as a complex process that

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is difficult to implement [4,6]. Therefore, defining clear objectives has been one of the most important steps. This often involves identifying focal species or groups of species, such as threatened, indicator, commercially valuable, predator or prey species, to provide a thorough understanding of critical ecosystem components [7–11]. These species are useful for monitoring an ecosystem's status, to provide feedback on management progress and to feed into integrated ecosystem modelling approaches and marine spatial planning [6, 10, 12, 13].

Commercial scale deep-water fishing in the tropical and subtropical region of the Pacific Ocean began in the 1970 s [14–17]. This so called "bottomfish" fishery targets a group of deep-water species including snappers (Lutjanidae), groupers (Epinephelidae), and jacks (Carangidae). Most of these species have a relatively high age at maturity, long life span and slow growth rate, making them particularly susceptible to overfishing and therefore in need of careful management [16, 18–21]. Historically, these species have been targeted using deep handlines from canoes. While the modern fishery employs similar handline gear, the use of powered vessels and advances in technology, such as powered reels to haul gear and global positioning systems (GPS) to find fishing grounds, have meaningfully increased fishing efficiency (e.g. [22–24]). As a result, it has only been in a few places, with extensive and productive fishing grounds (e.g. Hawaii, Fiji and Tonga), that larger commercial ventures have persisted [16, 25].

Recently, with limited potential to further develop commercial shallow water reef and lagoon fisheries, many Pacific Island countries have expressed renewed interest in developing their deep-water fisheries [14, 16, 26]. However, many deep-water fisheries in the Pacific have proved unviable as catch rates have quickly dropped from virgin to sustainable levels, and in some areas, localised depletions have been reported [14, 27]. For example, the two most commercially valuable deep-water species in the Main Hawaiian Islands (MHI), *Etelis coruscans* and *Etelis carbunculus*, were identified as being in a state of overfishing from as early as 1989 [27, 28]. In response to steady declines and unfavourable biological indicators the State of Hawaii implemented several measures in an effort to restore the fishery [23, 29]. This included bottomfish restricted fishing areas (BRFAs), a bottomfish boat registry and the introduction of a non-commercial bag limit. Further management actions, including temporal closures, have subsequently been implemented [29]. The BRFAs were designed to protect 20% of the deeper portion (100–400 m) of the 0–400 m bottomfish essential fish habitat (EFH) across all islands and banks. EFH is defined as 'the water and substrate necessary for fish spawning, feeding or growth to maturity' [30, 31], and closing 20% of the portion occupied by *E. coruscans* and *E. carbunculus* was expected to help replenish their stocks across the Main Hawaiian Islands. Since their implementation, responses in the size and abundance of bottomfish within the BRFAs has been variable but in most cases the most commercially important species increased in size [32, 33].

When the Hawaiian BRFAs were originally created, the identification of suitable geographic areas was difficult as there was a lack of adequate species distribution and essential fish habitat data. This problem is not uncommon for many marine species, particularly deep-water species, as preferred habitat and species distribution data is often sparse. A subsequent review and revision of the BRFAs in 2005 successfully incorporated more extensive distribution and habitat data (i.e. fishing records, submersible and ROV transects, multibeam mapping and commercial catch records) enabling a more rigorous assessment of how well the BRFAs were sited. However, more recent developments in the field of species distribution modelling has seen advances in the accuracy and power of modelling individual species-environment relationships providing detailed information on the geographical extent of species and the environmental drivers shaping their distributions. These spatially explicit and quantitative assessments of individual and combined species distributions can contribute to the advice provided to fishery managers.

Species distribution modelling has developed as a powerful tool for understanding species-environment relationships and predicting species distributions across unsampled locations [34, 35]. While initially more commonly used for the terrestrial environment, research has demonstrated that species distributions can also be reliably predicted across marine landscapes using bathymetry and derived terrain variables [8, 36, 37]. Species distribution modelling approaches have been demonstrated to provide important and cost-effective tools to reliably model and map EFH [8, 36]. As sustainable fisheries management shifted towards ecosystem-based approaches, a restructuring of the management framework in many areas has moved from species-based Fishery Management Plans to a place-based Fishery Ecosystem Plans [38]. Developing an accurate understanding of the type and distribution of EFH supporting these commercially valuable deep-water species is a critical need. This requires accurate species distribution data, as well as accurate environmental and habitat data. Novel flexible modelling approaches being developed in the species-environment modelling domain can be explored to fill this data gap. These approaches not only can be used to inform spatial management of bottomfish species in Hawaii, but also to potentially provide key inputs for ecosystem-based management of deep-water stocks across the Indo-Pacific. Indeed, a recent study has used an ensemble predictive modelling framework to predict deep-water genera (*Etelis*, *Pristipomoides*, and *Aphareus*) across the Western Central Pacific Ocean [39]. While the study provides much needed broadscale information on the spatial distribution (a resolution of 0.016° or ~1 nmi) of these genera across the region it acknowledges a need for this information at both a higher taxonomic and spatial resolution.

The aim of this study was to identify a robust modelling method to further improve the accuracy of EFH designations. Three species distribution modelling approaches were tested to see which provided the most accurate and ecologically interpretable predictive model; the modelling approaches were: Generalised Additive Models (GAM), Boosted Regression Trees (BRT) and Maximum Entropy (MaxEnt). These methods were chosen as they are widely used and have been demonstrated to provide strong predictive performance but differ substantially in their statistical approach [40–42]. The model providing the best predictive performance was chosen to define the species-environment relationships and to predict and describe accurate spatial maps of preferred bottomfish habitat across the area under consideration. Developing an effective modelling approach provides additional decision support tools for the sustainable management of the Hawaiian bottomfish fishery and, even more importantly, for the data sparse deep-water fisheries across the Indo Pacific.

2. Materials and methods

2.1. Study area

The location of this study was in BRFA "F" on the south side of Penguin Bank off the coast of Molokai, Hawaii (Fig. 1). Historically, Penguin Bank is one of the most important bottomfish fishing grounds in the MHI, as it is an extensive relatively shallow shelf area within easy reach of major population centres and is a site known to support significant populations of bottomfish [18].