Fisheries Research 195 (2017) 19–27

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Full length article

Habitat-based species distribution modelling of the Hawaiian deepwater snapper-grouper complex

Zack. S. Oyafuso[a,*], Jeffrey C. Drazen[b], Cordelia H. Moore[c,d], Erik C. Franklin[a]

[a] Hawaii Institute of Marine Biology, School of Ocean and Earth Science and Technology, University of Hawaii, Kaneohe, HI 96744, USA
[b] Department of Oceanography, University of Hawaii, Manoa, 1000 Pope Road, Honolulu, HI 96822, USA
[c] Department of Environment and Agriculture, Curtin University, Bentley Campus, Perth, WA 6102, Australia
[d] Australian Institute of Marine Science, UWA Oceans Institute (M096), 35 Stirling Highway, Crawley, Perth, WA 6009, Australia

ARTICLE INFO

Handled by B Arara

Keywords:
Species distribution models
Snapper-grouper complex
Boosted regression trees
Fish habitat
Baited remote underwater video (BRUV)

ABSTRACT

Deepwater snappers and groupers are valuable components of many subtropical and tropical fisheries globally and understanding the habitat associations of these species is important for spatial fisheries management. Habitat-based species distribution models were developed for the deepwater snapper-grouper complex in the main Hawaiian Islands (MHI). Six eteline snappers (*Pristipomoides* spp., *Aphareus rutilans*, and *Etelis* spp.) and one endemic grouper (*Hyporthodus quernus*) comprise the species complex known as the Hawaiian Deep Seven Bottomfishes. Species occurrence was recorded using baited remote underwater video stations deployed between 30 and 365 m (n = 2381) and was modeled with 12 geomorphological covariates using GLMs, GAMs, and BRTs. Depth was the most important predictor across species, along with ridge-like features, rugosity, and slope. In particular, ridge-like features were important habitat predictors for *E. coruscans* and *P. filamentosus*. Bottom hardness was an important predictor especially for the two *Etelis* species. Along with depth, rugosity and slope were the most important habitat predictors for *A. rutilans* and *P. zonatus*, respectively. Models built using GAMs and BRTs generally had the highest predictive performance. Finally, using the BRT model output, we created species-specific distribution maps and demonstrated that areas with high predicted probabilities of occurrence were positively related to fishery catch rates.

1. Introduction

Snappers (Family Lutjanidae) and groupers (Family Serranidae) are commercially important marine species in many tropical-subtropical fisheries. These fishes are often characterized as large, long-living species with high site fidelity and thus are vulnerable to fishing pressure (Jennings et al., 1999; Coleman et al., 2000; Morris et al., 2000; Newman et al., 2016). For many countries in the Indo-Pacific region, there has been limited fisheries management of deepwater snappers and groupers and assessments of stock status (Newman et al., 2016). Improvements to increase and standardize fisheries, habitat, and life history data for this species complex are ongoing and top priorities for the Indo-Pacific region (Newman et al., 2015).

In the main Hawaiian Islands (MHI), the deepwater snapper-grouper or “bottomfish” complex is a commercially and culturally valuable fishery (Pooley, 1993; Hospital and Pan, 2009; Hospital and Beavers, 2012). The Hawaiian Deep Seven Bottomfishes is a state and US federally managed species complex consisting of six eteline snappers and one endemic grouper: *Etelis coruscans, E. carbunculus, Pristipomoides filamentosus, P. sieboldii, P. zonatus, Aphareus rutilans*, and *Hyporthodus quernus*. Two species, *E. coruscans* and *P. filamentosus*, comprise the majority of the Deep Seven bottomfish catch (Brodziak et al., 2014). The major component of fisheries data is a 60+ year time series of catch and effort data, with ongoing efforts to establish a fisheries-independent surveying program using invasive and non-invasive techniques (Richards et al., 2016). Regulations for this fishery include: annual catch limits, size and gear restrictions, bag limits, fisher and boat registrations, and permanent restricted fishing areas.

Habitat information is an important piece of knowledge that informs the spatial management of fisheries. Depth is a consistent habitat feature found to delineate bottomfish species distributions (Sundberg and Richards, 1984; Ralston and Williams, 1998; Martinez-Andrade, 2003; Gomez et al., 2015). Misa et al. (2013) and Moore et al. (2016) established preliminary habitat associations for the top four commercially important species in the MHI (*E. carbunculus, E. coruscans, P. filamentosus*, and *P. sieboldii*). They noted depth segregations among the species complex, and high-relief, hard-bottom areas as important habitat features. Raised physical features like promontories and pinnacles

* Corresponding author.
E-mail addresses: oyafusoz@hawaii.edu (Z.S. Oyafuso), jdrazen@hawaii.edu (J.C. Drazen), C.Moore@aims.gov.au (C.H. Moore), erik.franklin@hawaii.edu (E.C. Franklin).

http://dx.doi.org/10.1016/j.fishres.2017.06.011
Received 20 October 2016; Received in revised form 5 June 2017; Accepted 18 June 2017
Available online 03 July 2017
0165-7836/

allow for an upward advection and retention of deeper-dwelling zooplankton to shallower waters that may attract fish predators, and is concurrent with submersible observations of bottomfishes (e.g., *P. filamentosus*) near underwater headlands, especially in upcurrent localities (Ralston et al., 1986; Kelley et al., 2006). Macrohabitat features like substrate rugosity and natural cavities also serve as important predator rufugia (Kelley and Ikehara, 2006).

Our main research objective was to develop habitat-based species distribution models for each of the Hawaiian Deep Seven Bottomfishes throughout the MHI. Species occurrence was collected using Baited Remote Underwater Videos (BRUVs) deployed between 30 and 365 m across the MHI. Probability of occurrence was modelled with various benthic habitat landscape variables using Generalized Linear Models (GLMs), Generalized Additive Models (GAMs), and Boosted Regression Trees (BRTs). To account for possible spatial autocorrelation (SAC) in the model residuals, a residual autocovariate (RAC) model (Crase et al., 2012, 2014) was included as an additional model to the GLMs, GAMs, and BRTs. The model output was then interpolated to the entire MHI between 50 and 400 m depth, resulting in a predictive map of probability of occurrence for each of the seven species. Finally, as an application of the species distribution models, we related model output with fishery catch rates within statistical fishery reporting areas to examine whether model predictions of species hotspots were positively related to fishery yields.

2. Material and methods

2.1. Data sources

Presence-absence data for each of the seven species were collected at 2381 sites from 2007 to 2015 across the MHI (Fig. 1) ranging 30–365 m via Bottom Baited Camera Stations (BotCam; Merritt et al., 2011). The main goal of the BotCam surveys was to monitor bottomfish populations inside and adjacent to bottomfish restricted fishing areas (BRFAs). BotCam locations were selected using a stratified-random design with protection (inside or outside of BRFAs) and coarse habitat features (soft-bottom/low slope, hard-bottom/low slope, soft-bottom/high slope, hard-bottom/high slope (Misa et al., 2013)) as the sampling strata. The BotCam system used two ultralow-light video cameras that recorded under ambient light conditions and was propped 3 m above the sea floor to optimize the field of view for observations. At each site, species presence was recorded over a 30–40 min soak period, a soak period found to be adequate for stereo-video surveys for these species (Misa et al., 2016). Full details on the BotCam protocol are provided in Misa et al. (2013), Moore et al. (2013) and Sackett et al. (2014). Species occurrence as a percentage of the total dataset ranged from 5.45% for *H. quernus* to 28.3% for *P. filamentosus*. Bathymetry layers at 5-m resolution were provided by the Hawaii Mapping Research Group (HMRG). A backscatter synthesis at 60-m resolution was accessed from the HMRG website (http://www.soest.hawaii.edu/HMRG/multibeam/index.php). Fisheries logbook data from 2003 to 2014 were provided by the State of Hawaii Division of Aquatic Resources. For each commercial bottomfish trip, fishers reported the date caught and fishery reporting area (Fig. 1) and the total number of pieces, weight, and number of hours and lines used for each species caught.

2.2. Habitat variables

Bathymetry-derived variables—slope, aspect, and curvature—were calculated in ArcGIS (V.10.3) with an eight-cell neighborhood (Burrough and McDonnell, 1998). Terrain ruggedness, referred to as rugosity hereafter, was calculated with an eight-cell neighborhood using ArcGIS Benthic Terrain Modeler (Wright et al., 2005) and ranged from 0 (no variation) to 1 (complete variation). Rugosity was log-transformed to normalize the positively skewed distribution. Bathymetry-derived variables were calculated at two resolutions of bathymetry (5-m and 60-m) to provide different scales of habitat features.

Bathymetric position index (BPI; Lundblad et al., 2006) describes a particular point in relation to the overall landscape similar to the topographic position index (Weiss, 2001; Iampietro and Kvitek, 2002). BPI was calculated using ArcGIS Benthic Terrain Modeler using scale factors of 125 (fine-scale BPI) and 1250 (broad-scale BPI), and then standardized similar to the protocol of Lundblad et al. (2006). Under standardized bpi units, values > 100 indicate scale-specific ridge-like structures, values < −100 indicate scale-specific depressions, and values between −100 and 100 indicate either slopes or flat plains. Maps of each of the 12 habitat covariates can be viewed in the supplementary material (Figs. S8–S19).

2.3. Model parameterization

Due to the differences in observed depth ranges for the seven species, creating a model that included sites outside of the depth range would have produced overly confident model predictions. Thus, for

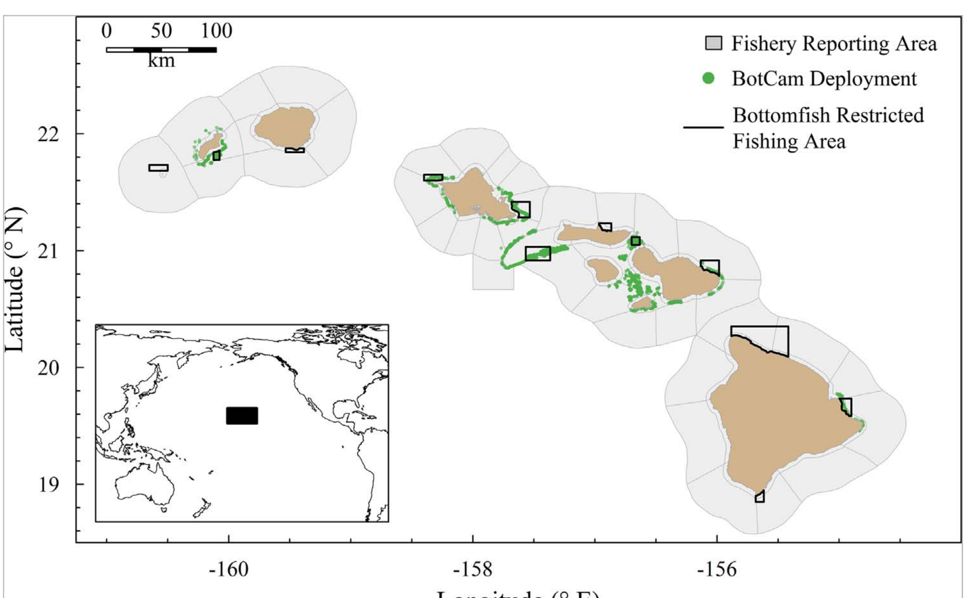

Fig. 1. Location of Bottom Camera Bait Station (BotCam) sites (green dots) within the main Hawaiian Islands (located within the solid black box in insert) deployed during 2007–2015. The State of Hawaii statistical fishery reporting areas (gray areas) and current bottomfish restricted fishing areas (bold outlines) are also shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)