Estuarine, Coastal and Shelf Science 208 (2018) 191–204

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Evaluating Rockfish Conservation Areas in southern British Columbia, Canada using a Random Forest model of rocky reef habitat

Dana Haggarty*, Lynne Yamanaka

Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd, Nanaimo, BC V9T 1K6, Canada

ARTICLE INFO

Keywords:
Sebastes
Conservation planning
Marine protected areas
Fisheries management
Seafloor models
Multibeam bathymetry
Supervised classification

ABSTRACT

We developed a rockfish habitat model to evaluate a network of Rockfish Conservation Areas (RCAs) implemented by Fisheries and Oceans Canada to reverse population declines of inshore Pacific rockfishes (*Sebastes* spp.). We modeled rocky reef habitat in all nearshore waters of southern British Columbia (BC) using a supervised classification of variables derived from a bathymetry model with 20 m^2 resolution. We compared the results from models at intermediate (20 m^2) and fine (5 m^2) resolutions in five test areas where acoustic multibeam echosounder and backscatter data were available. The inclusion of backscatter variables did not substantially improve model accuracy. The intermediate-resolution model performed well with an accuracy of 75%, except in very steep habitats such as coastal inlets; it was used to estimate the total habitat area and the percent of rocky habitat in 144 RCAs in southern BC. We also compared the amount of habitat estimated by our 20 m^2 model to the 100 m^2management model used to designate the RCAs and found that a slightly lower proportion of habitat (18% vs 20%) but a considerably smaller area (400 km^2 vs 1370 km^2) is protected in the RCAs, likely as a result of the poor resolution of the original model. Empirically derived maps of important habitats, such as rocky reefs, are necessary to support effective marine spatial planning and to design and evaluate the efficacy of management and conservation actions.

1. Introduction

Networks of Marine Protected Areas (MPAs), or reserves that exclude fisheries, are being implemented worldwide to conserve exploited species and sustain fisheries (Gaines et al., 2010). MPAs have been shown to be a successful strategy to increase the size, abundance and diversity of species protected within them (Allison et al., 1998; Mosqueira et al., 2000; Halpern and Warner, 2002; Alcala et al., 2005; Claudet et al., 2008; Babcock et al., 2010; Gaines et al., 2010; Edgar et al., 2014). In response to conservation concerns driven by a sharp decline of rockfish catches throughout the 1990s in British Columbia (BC), Canada, Fisheries and Oceans Canada (DFO) implemented a system of 164 Rockfish Conservation Areas (RCAs) in BC as part of a Rockfish Conservation Strategy (Yamanaka and Logan, 2010). Although the RCAs are often not considered to be MPAs because they are managed as fishery closures under the Fisheries Act as opposed to being permanently protected as MPAs by Canada's Oceans Act (Robb et al., 2011), they are spatially defined areas where fisheries that target or lead to substantial bycatch of rockfishes are prohibited. RCAs for inshore rockfishes were established between 2004 and 2007 and prohibit both commercial and recreational hook and line and bottom trawl fisheries. Inshore rockfishes include six species of the genus *Sebastes* (Copper Rockfish *S. caurinus*, Quillback Rockfish *S. maliger*, Black Rockfish *S. melanops*, China Rockfish *S. nebulosus*, Tiger Rockfish *S. nigrocinctus*, and Yelloweye Rockfish *S. ruberrimus*) that are found on shallow (< 200 m) rocky reefs. Spatial fisheries closures, such as the RCAs, may be effective for promoting rockfish population recovery because they are long-lived (some > 100 years) and have small home ranges (Yoklavich, 1998; Parker et al., 2000). MPAs and RCAs have been effective for conserving rockfish in California (Paddack and Estes, 2000; Hamilton et al., 2010; Keller et al., 2014), rockfish were found to be more abundant in an RCA on the West Coast of Vancouver Island (Haggarty et al., 2017) and larger Yelloweye Rockfish have been observed in RCAs in BC's Central Coast (Frid et al., 2016).

Habitat structure is one of the most important criteria in the design and assessment of MPAs (Parnell et al., 2006; Claudet and Guidetti, 2010; Miller and Russ, 2014). Inshore rockfishes are associated with complex nearshore rocky habitats (Richards, 1987; Matthews, 1990; Love et al., 2002; Haggarty et al., 2016). Although individual rockfish species select and partition habitat based on characteristics such as complexity, biogenic structure and depth (Haggarty et al., 2016), rockfish habitat used here refers to the genus' general use of rocky reef

---

* Corresponding author.
E-mail addresses: dana.haggarty@dfo-mpo.gc.ca (D. Haggarty), lynne.yamanaka@dfo-mpo.gc.ca (L. Yamanaka).

https://doi.org/10.1016/j.ecss.2018.05.011
Received 5 April 2018; Received in revised form 10 May 2018; Accepted 14 May 2018

habitat (Love et al., 2002). A rockfish habitat model based on topographic complexity using low-resolution (100 m^2) bathymetry data combined with spatial Catch per Unit of Effort (CPUE) data was used to identify rockfish habitat in the designation of RCAs and to ensure even distribution of the closed areas by management area (Pacific Fishery Management Area, PFMA) (Yamanaka and Logan, 2010). DFO also used this model to evaluate if the closed area targets of 30% of identified rockfish habitats in "inside waters" between Vancouver Island and the mainland, and 20% of habitats on the outer coast had been reached. Using this model, Yamanaka and Logan determined that the management targets were nearly met as 28% and 13% of modeled habitat in inside waters and on the outer coast, respectively, was protected in the RCAs.

The quality of the habitat inside the RCAs has been questioned, with some studies concluding that the RCAs did not include fine-scale habitat features with the highest rockfish abundance such as a boulder piles (Marliave and Challenger, 2009; Cloutier, 2011). Haggarty et al. (2016) conducted Remotely Operated Vehicle (ROV) surveys of 35 RCAs and found that although some RCAs contained an abundance of rockfish habitat, rocky reef habitat was sparse in others. They also found that the density of Quillback and Yelloweye Rockfishes observed was dependent on the percent of rock substrates observed on ROV transects, but not protection status. SCUBA surveys of rockfish in Barkley Sound, BC, also showed that Black Rockfish density was related to the habitat complexity and the proportion of rocky substrates (Haggarty et al., 2017). Collectively, these results suggest that lack of suitable habitat might impede rockfish population recovery in some RCAs. Revised habitat models are therefore necessary for evaluating the effectiveness of RCAs.

Seafloor habitat maps are produced by interpreting a continuous digital bathymetry using biological or geological ground-truthing observations of the seabed. The ground-truthing process samples only a small portion of the seafloor; therefore, a complete seafloor map is inferred from the association between the remotely sensed environmental data, such as bathymetry and bathymetry derivatives (e.g. slope, rugosity) and the available substrate data (Brown et al., 2012). High resolution (2–5 m^2) multibeam echosounder (MBES) data are often used to model substrates and habitats (Brown et al., 2011; Lucieer et al., 2013; Diesing et al., 2014; Hill et al., 2014), including rockfish habitats (Yoklavich et al., 2000; Iampietro et al. 2005, 2008; Young et al., 2010; Yamanaka et al., 2012; Yamanaka and Flemming, 2013). Iampietro et al. (2008) combined rugosity (a measure of benthic roughness), slope, aspect, depth, and the bathymetric positioning index (BPI) (Wright et al., 2012) using a General Linear Model (GLM) to effectively predict Yellowtail Rockfish (*S. flavidus)* habitat in one MPA in California. Acoustic backscatter data are produced by the reflectance of the MBES acoustic signal as it is scattered by the seabed. The strength of the signal and the textural information it contains relates to the hardness of the seabed (Che Hasan et al., 2014); however, the capacity to interpret standardized backscatter data to provide useful information about seafloor characteristics is just being developed (Lucieer et al., 2013) and was formerly only interpreted through "expert interpretation" (Brown et al., 2012). MBES models with and without backscatter data have not, to date, been applied at a broader regional scale.

Although the Canadian Hydrographic Service (CHS) has collected MBES and backscatter data along some of BC's extensive coastline, many areas have yet to be surveyed, particularly in water shallower than 50 m (an area termed the "white strip") (Gregr et al., 2013) and are therefore not useful for regional scale analyses. Low-resolution (90–100 m^2) data have been used to model hard-bottom substrates (Dunn and Halpin, 2009) and rockfish habitat (Yamanaka and Logan, 2010) at regional scales, but these models have not been compared to finer-resolution models. We used a new intermediate-resolution (20 m^2) digital bathymetric model (unpublished data, E. Gregr, Scitech Consulting and S. Davies, Fisheries and Oceans Canada) to identify rockfish habitat, defined as rocky substrate above 200 m in depth (Love et al., 2002; Haggarty et al., 2016). We used Random Forest (RF) classification (Breiman, 2001) to model the relationship between observed substrates and topographic derivatives of the bathymetry. RF has been used to classify terrestrial (Prasad et al., 2006; Cutler et al., 2007; Freeman et al., 2012) and marine benthic habitat (Che Hasan et al., 2012; Lucieer et al., 2013; Diesing et al., 2014). A comparison of different supervised algorithms for classifying benthic substrates found that RF achieved the highest accuracy and the best predictive capability when results were tested using an independent validation dataset (Diesing et al., 2014). Next, we test the validity of our intermediate-resolution model by comparing it to similar models that included MBES and backscatter data in five test areas. We then use our rocky reef model to assess habitat in 144 RCAs, evaluate the conservation targets of the RCAs, and compare overall rockfish habitat estimates to the 100 m^2 resolution model (Yamanaka and Logan, 2010).

2. Methods

2.1. Data sources

Regional 20 m^2 digital bathymetry models were built from point sounding data from the CHS, as well as data from CHS's electronic nautical charts. Natural neighbour interpolation between depth points was then used in ArcMap 10.2.2 to create the 20 m^2 continuous depth raster (unpublished data, E. Gregr, Scitech Consulting and S. Davies, Fisheries and Oceans Canada). Separate digital bathymetry models were created for the West Coast of Vancouver Island (WCVI), the Queen Charlotte Strait-Johnstone Strait region (QCS), and the Strait of Georgia (SoG) (Fig. 1).

The MBES bathymetry and backscatter data (Fig. 1) were provided for this study under a data-sharing agreement with CHS. The MBES bathymetry data were resolved to 5 m^2 and output as an XYZ grid from Caris (Geospatial Software Solutions www.caris.com) and converted to a raster in ArcGIS 10.2.2 (ESRI, 2011). Seven variables were derived from each bathymetry (5 and 20 m^2 resolution): bathymetric positioning index (BPI) at three scales; slope; standard deviation of the slope; curvature and rugosity. BPI is a measure that compares the elevation of a cell to the mean elevation of surrounding cells. Locations higher than surrounding cells are positive and depressions are negative (Wright et al., 2012). BPI is scale-dependent and was calculated at 3 scales (broad, medium and fine) (Table 1).

Backscatter data needs to be processed to remove noise before it is useful in substrate classification (Che Hasan et al., 2014). Processed backscatter data were not available for the whole extent of the MBES bathymetry data, so we chose five regions with processed backscatter data as study areas (Fig. 1). Prior to analysis, we used ArcGIS to filter and perform focal statistics on the backscatter raster to remove any remaining noise in the dataset and saved the backscatter raster as a TIFF file. We then used the package GLCM (Zvoleff, 2015) in R (R Development Core Team, 2008) to calculate a grey-level co-occurrence matrix (GLCM) from the TIFF files and to derive mean, variance, homogeneity, entropy, correlation and dissimilarity measures (Table 1) (Lucieer et al., 2013; Che Hasan et al., 2014). The Gini Index, a measure of variable importance calculated by RF (Breiman, 2001) showed that only the mean and variance of the backscatter GLCM contributed to our classifications, so the other GLCM variables were dropped from the analysis.

Our dependent variable was seafloor substrate observations from a historical dataset of substrate grab samples from the CHS supplemented (CHS unpublished data) with ROV substrate observations. ROV observations of fish and habitat which included primary substrate observations were mapped as polygons (Haggarty et al., 2016). We used the "polygon to point" tool in ArcGIS 10.2.2. to convert the polygons to points every 20 or 5 m^2 (for the intermediate and high resolution, respectively) along the transect. We reclassified all substrate points into a binary classification of Rock (bedrock and boulder) and not rock (all