**Evaluating Rockfish Conservation Areas in Southern British Columbia,
Canada using a Random Forest Model of Rocky Reef Habitat.**

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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 m² resolution. We compared the results from models at intermediate (20 m²) and fine (5 m²) 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 m² model to the 100 m² management model used to designate the RCAs and found that a slightly lower proportion of habitat (18% vs 20%) but a considerably smaller area (400 km² vs 1370 km²) 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.

Keywords

Sebastes; conservation planning; Marine Protected Areas; fisheries management; seafloor models; multibeam bathymetry; supervised classification.

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 habitat (Love et al. 2002). A rockfish habitat model based on topographic complexity using low-resolution (100 m²) 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 m²) 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, Iampietro et al. 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”) (Gegr et al. 2013) and are therefore not useful for regional scale analyses. Low-resolution (90 - 100 m²) 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 m²) digital bathymetric model (unpublished data, E. Gegr, 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 m² resolution model (Yamanaka and Logan 2010).

2. Methods

2.1 Data Sources

Regional 20 m² 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 m² 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 m² 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 m² 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 (Zvleff 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 m² (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 other substrates, including cobble and gravel). This work does not consider differences in the complexity of rocky substrates.

2.2 Random Forest Habitat Model

Random Forest Classification is a supervised classification algorithm that has been used in machine learning, data-mining and large-scale predictions (Prasad et al. 2006) to produce accurate predictions without overfitting the data (Breiman 2001, Cutler et al. 2007). It is related to classification and regression tree (CART) analysis that uses predictor variables to construct a number of decision trees by recursively partitioning the data into smaller homogeneous groups

based on a single predictor (Prasad et al. 2006). Unlike CART, RF combines the results of many classification trees that are created by resampling with replacement (bootstrapping). The number of predictors used to find the best split at each node of the tree is also randomly chosen (hence “random”) and a large number of trees (500-2,000) are generated (hence “forest”). Not all of the observations are used to create the bootstrapped sample used to generate the classification. These randomly selected withheld or “out of bag” samples can be used to assess the accuracy of predictions and to compare the relative importance of each variable (Prasad et al. 2006). We used RF to model rocky substrates at a resolution of 20 m² in each of the three regions (WCVI, QCS, and SOG). Next, we used RF to model rocky substrates using MBES bathymetry derivatives and backscatter data in five test areas (Fig.1). To explore the value of backscatter data, we also modeled the test areas using only MBES bathymetry derivatives without any backscatter variables. Finally, we used any available MBES bathymetry data mosaicked for the SOG, QCS, and WCVI and modeled the three regions using only bathymetry data (no backscatter) (Fig.1). We also used RF to model the entire extent of the available MBES (Fig. 1) without the inclusion of the backscatter variables because processed backscatter data were not available for the full extent.

The first step in our modeling process was to align the substrate observations (points) with the rasters (gridded data) for each predictor variable. We exported data from ArcGIS and used the R packages “Maptools” (Bivand and Lewin-Koh 2015) and “Raster” (Hijmans 2015) to create a data frame of our dependent and independent variables. Next, we used the Marine Geospatial Ecology Tools (MGET) within ArcGIS 10.2.2 to randomly split our data frame into a training and test set, reserving a third of the data as test data (Roberts et al. 2010). MGET provides tools that link ArcGIS to R (R Development Core Team 2008) in order to perform

statistical analysis from within the ArcGIS platform (Roberts et al. 2010). Using the training dataset, MGET and the R package “randomForest” (Liaw and Wiener 2002) we fit the RF classification model and tested the model predictions with the reserved test data. We looked at the model performance statistics as well as the importance of each predictor variable using the Gini Index (Breiman 2001). We dropped any variables with low importance and re-fit the RF model. Finally, we mapped the predicted classification as a probability surface (i.e., the value in each raster cell is the probability of the presence of rock) using MGET and “randomForests” (Liaw and Wiener 2002, Roberts et al. 2010).

To translate the probability surface into a binary habitat classification indicating habitat presence and absence, a probability cut-off threshold is needed. The common default is a probability threshold of 0.5, but this does not necessarily result in the highest prediction accuracy (Freeman and Moisen 2008). The selection of a cut-off threshold has implications for the prediction accuracy of the classification and for the amount of area classified (i.e., a lower cut-off will classify a larger area with lower accuracy while a high cut-off will classify a small area with higher accuracy). Cohen’s Kappa is a frequently used statistic to compare the performance of classifiers that measure the proportion of correctly classified locations after accounting for the expected agreement by random chance (Freeman and Moisen 2008, Stephens and Diesing 2014). Kappa ranges from 0 (fully distinct) to 1 (fully identical) and is a measure of similarity between two maps that is based on the percent agreement with a correction for the fraction of agreement that can be expected by pure chance. Freeman et al. (2008) found that the least biased results were obtained when threshold cut-offs were chosen to maximize Kappa. For each model, we calculated model performance statistics with the test data set for the following threshold range: 0.6, 0.7, 0.8 and 0.9.

Once cut-offs were determined, we reclassified each predicted probability surface to show the presence and absence of rock (1, 0). We overlaid the resulting classifications in ArcGIS and tested the agreement of the models. We also compared the predicted classifications from the three models in each test area using the Map Comparison Kit (MCK). The MCK compares each map on a pixel-by-pixel basis and produces a contingency table that can be used to calculate Kappa and the percent agreement between maps (Visser and de Nijs 2006).

Next, we used the 20 m² models to calculate the area of rocky habitat in each RCA. However, we found that the 20 m² models underestimated habitat in areas such as inlets with very steep sides (see Results). This meant that the 45 RCAs found in inlets had unrealistically low habitat estimates. To correct this problem we combined the 20 m² resolution rocky reef models and the fine resolution models (mosaicked 5 m² MBES bathymetry data) to create a final model termed 20 + 5 rocky reef model. To do so, we converted both rasters to polygon shapefiles and then used the union tool to combine the two modeled rock substrate extents. MBES bathymetry data were only available for 24 of the 45 RCAs in inlets; therefore, we compared the habitat area estimates from the models with and without MBES in the 24 RCAs in inlets and found that the habitat estimates with MBES were an average of 4 times higher. We multiplied the modeled area of habitat in the 21 RCAs without MBES data by 4 in our estimates of habitat by RCA (indicated in bold print in Appendix Table 1). We calculated the area of predicted rocky habitat using the 20 + 5 m² model in every RCA and by management area (PFMA) and compared them to the amounts estimated in the original 100 m² model used to designate the RCAs (Yamanaka and Logan 2010).

Table 1. Bathymetric and Backscatter (BS) variable descriptions for the MBES and 20 m² DEM models.

Variable	Description	Parameters		Software
		MBES 5 m ²	DEM 20 m ²	
Fine BPI	Inner and outer neighbourhoods are specified in map-units and meters in brackets.	3 x 25 (15 x 125 m)	3 x 25 (60 x 500m)	BTM Toolbox ¹
Medium BPI		10 x 100 (50m x 500m)	10 x 100 (200 x 2000m)	BTM Toolbox ¹
Broad BPI		25 x 250 (250 x 1250m)	25 x 250 (500 x 5000m)	BTM Toolbox ¹
Slope	The maximum change in depth between the cell and the cells in a neighbourhood. Output is in degrees from horizontal.	3 x 3	3 x 3	Spatial Analyst ArcGIS 10.2.2 ²
SD of Slope	Standard deviation of slope in a neighbourhood.	3 x 3	3 x 3	Focal Stats, Spatial Analyst ArcGIS 10.2.2 ²
Curvature	The slope of slope (the rate of change of the slope).	3 x 3	3 x 3	Spatial Analyst, ArcGIS 10.2.2 ²
Rugosity	An index of surface roughness using the arc-chord ratio defined as the contoured area of the surface divided by the area of the surface orthogonally projected onto a plane of best fit (Du Preez 2015).			Arc-chord ratio ³
BS GLCM Mean	Mean backscatter from grey-level co-occurrence matrix (GLCM) in a neighbourhood.	3 x 3	NA	GLCM ⁴
BS GLCM Variance	Variance of backscatter from GLCM in a neighbourhood.	3 x 3	NA	GLCM ⁴

¹Wright et al. 2012, ²ESRI 2011, ³Du Preez 2015, ⁴Zvoleff 2015

Figure 1. Location of RCAs in southern British Columbia and the extent of the 20 m² bathymetry for the Strait of Georgia (SoG), the Queen Charlotte-Johnstone Straits (QCS) and the West Coast of Vancouver Island (WCVI) as well as the extent of the MBES bathymetry data used. The five test areas used for comparisons among the 20 m² models and 5 m² MBES models with and without backscatter are outlined in orange and indicated by letters: A) Goletas Channel, B) Barkley Sound, C) Georgia Strait, D) Gulf Islands, E) Captain Passage.

3. Results

3.1 Random Forest Habitat Model

Random Forest classification allowed us to predict rocky substrates with high accuracy even when using bathymetry data with an intermediate resolution of 20 m². Receiver operator characteristic (ROC) plots graph the false positive rate versus the true positive rate as one way of visualizing the performance of a classifier (Fawcett 2006). The area under the ROC curve (AUC) is a common measure of overall model performance, with good models having an AUC close to 1 (Freeman and Moisen 2008). While not without its critics (Lobo et al. 2008), the AUC is independent of the threshold value used and provides an accepted measure of model performance. In this study, the AUC was high for all models (minimum 0.84, maximum 0.98) indicating good overall performance (Table 2). Our 20 m² models had AUC values between 0.84 and 0.89, which places them in the “excellent discrimination” category, while most of the 5 m² models had AUC values between 0.91-0.98, giving them “outstanding discrimination” ability (Dunn and Halpin 2009). The “out-of-bag” (OOB) error rate calculated within the RF models ranged from 13-26 percent and was similar to the error rate calculated with the test data set (Table 2). Model accuracy was higher for the 5 m² resolution models than for the 20 m² models, but even the 20 m² models had accuracies higher than 70%. Model performance of the 5 m² models in the test areas with and without backscatter was very similar (Table 2). Performance of the 5 m² MBES models with mosaicked data in each of the three regions was also very high (Table 2).

We selected a cut-off of 0.6 for the 5 m² resolution models, because it produced the highest kappa values for all the 5 m² models (Table A1). A cut-off of 0.5 produced the highest kappa for the mosaicked 5 m² models. When we compared the area classified as rock in the 5 m²

models in our test areas using this cut-off with the area classified as rock from the 20 m² models using the same cut-off, we found the estimates of rock were greater with the 20 m² models when classified with the same cut-off in the Barkley Sound, Captain Pass and Georgia Strait test areas. The amount of rock found in the Barkley Sound test area was vastly greater in the 20 m² model. To produce more realistic estimates of habitat area using the broader resolution data, we classified the probability surface for the 20 m² models using higher thresholds. We used 0.7 as our cut-off for the QCS and the SOG and 0.8 for the WCVI (Table 3). The area classified as rock in the 20 m² models in Goletas Channel and the Gulf Islands was, however, lower than predicted by the 5 m² models (Table 3).

The maps of the model predictions using MBES with and without backscatter showed very good agreement with each other in all regions with kappa values ranging between 0.65 and 0.92 (Table 4). The best agreement between 20 m² and 5 m² models was in rocky reef areas around islands in the Barkley Sound and Captain Pass test areas, while the poorest agreement was in very steeply sloping rocky bottoms (i.e., Goletas Channel, Gulf Islands (Fig. 2; Table 4). The Georgia Strait test area is dominated by soft substrates with less than 1% of the area classified as rock, therefore the % agreement was very high in this test area (Table 4).

3.2 Rocky Reef Habitat in RCAs

We combined the 20 m² models with the 5 m² mosaicked MBES models in each region to assess the amount of rockfish habitat in the RCAs and in each management area (Fig. 3). Our habitat model predicts that a lower area of rocky habitat is protected in the RCAs than the original 100 m² model used to designate them but also predicts a lower overall area of rocky habitat (Yamanaka and Logan 2010). Our estimate of the total area of potential rockfish habitat (2180 km²) is roughly a third of the amount estimated by the low-resolution (100 m²) model used

to designate the RCAs (6820 km²) (Table 5) (Yamanaka and Logan 2010). It is likely that the spatial resolution of the 100 m² model over-estimated habitat (Fig. 3). When the proportion of habitat inside to outside the RCAs was considered, the overall percent habitat protected is similar with 18% protected vs 20% (Table 5). Management targets were, however, different for the “inside” and “outside” waters. Our model estimates for the overall amount of habitat protected in RCAs inside waters (between Vancouver Island and the mainland) was lower than the original estimate (22% vs. 28%), although it was equal or higher in two management areas (PFMA 18 and 19). Our model estimated that slightly more habitat is protected in RCAs on the WCVI (14% vs 13%) in outside waters (Table 5).

We estimated a mean of 20% of the area of the RCAs is rocky habitat; however, there was large variation among RCAs (SD 17.7%). The mean area of habitat per RCA is 3 km²; however, the RCAs vary greatly by size as well as amount of habitat (SD 5.1 km²) (Table A2). The RCA with the lowest percent rocky habitat was in an inlet without any MBES data (0.05%) and the RCA with the highest percent habitat is Race Rocks (97.9%), in the Southern Strait of Georgia (Table A2). Twenty-eight (19.4%) of the 144 RCAs studied contain less than 5% modeled rocky habitat and almost 50% if these RCAs are in coastal inlets (Table A2).

Table 2. Model Performance Statistics for the 20 m² models by region and the 5 m² full models (with Backscatter (BS) and 5 m² models without BS at the selected cut-offs. SoG=Strait of Georgia, QCS=Queen Charlotte Strait, WCVI=West Coast of Vancouver Island.

Area	Res. m	Cut-off	OOB Error Rate	AUC	Accuracy	Error rate	True positive rate	True negative rate	Kappa
QCS	20	0.7	0.26	0.84	0.73	0.27	0.50	0.94	0.45
QCS	5	0.5	0.16	0.91	0.84	0.16	0.77	0.89	0.66
Goletas BS	5	0.6	0.15	0.97	0.90	0.10	0.86	0.93	0.79
Goletas No BS	5	0.6	0.13	0.98	0.93	0.07	0.96	0.91	0.86
WCVI	20	0.8	0.18	0.89	0.75	0.25	0.61	0.94	0.51
WCVI	5	0.5	0.14	0.92	0.86	0.14	0.84	0.87	0.71
Barkley Sound BS	5	0.6	0.12	0.95	0.91	0.09	0.77	0.96	0.76
Barkley Sound No BS	5	0.6	0.13	0.95	0.91	0.10	0.76	0.97	0.76
SoG	20	0.7	0.21	0.86	0.75	0.25	0.50	0.93	0.46
SoG	5	0.5	0.20	0.85	0.80	0.20	0.62	0.89	0.53
Georgia Strait BS	5	0.6	0.07	0.87	0.92	0.08	0.43	0.99	0.53
Georgia Strait No BS	5	0.6	0.07	0.86	0.91	0.09	0.29	1.00	0.41
Gulf Islands BS	5	0.6	0.18	0.92	0.83	0.17	0.81	0.86	0.63
Gulf Islands No BS	5	0.6	0.20	0.92	0.81	0.19	0.79	0.86	0.61
Captain Passage BS	5	0.6	0.14	0.92	0.84	0.16	0.81	0.88	0.67
Captain Passage No BS	5	0.6	0.15	0.91	0.82	0.18	0.81	0.83	0.63

Table 3. Comparison of area of habitat modeled at two resolutions in five test areas by model cut-off. 5 m² models were made with and without backscatter (BS) data. The cut-off selected for the 20 m² models is shown in bold.

Model Test Area	Resolution	Cut-off	Habitat Area km ²	% of Total Area
Captain Passage	5 (BS)	0.6	0.2	3.4
	5 (no BS)	0.6	0.4	6.0
	20	0.6	0.8	11.8
	20	0.7	0.5	7.3
	20	0.8	0.2	3.3
	20	0.9	0.1	0.9
Barkley Sound	5 (BS)	0.6	6.7	4.6
	5 (no BS)	0.6	6.9	4.8
	20	0.6	32.1	22.2
	20	0.7	22.6	15.7
	20	0.8	13.7	9.5
	20	0.9	5.2	3.6
Goletas Channel	5 (BS)	0.6	4.1	4.3
	5 (no BS)	0.6	6.2	6.5
	20	0.6	5.7	6.0
	20	0.7	2.3	2.4
	20	0.8	0.8	0.9
	20	0.9	0.2	0.2
Gulf Islands	5 (BS)	0.6	23.4	43.3
	5 (No BS)	0.6	22.4	41.6
	20	0.6	19.1	35.4
	20	0.7	12.3	22.8
	20	0.8	6.3	11.7
	20	0.9	1.6	3.0
Georgia Strait	5 (BS)	0.6	4.1	0.8
	5 (No BS)	0.6	4.0	0.8
	20	0.6	11.3	2.3
	20	0.7	4.2	0.9
	20	0.8	1.7	0.3
	20	0.9	0.5	0.1

Table 4. Model agreement between maps in the test areas.

Model	Kappa	% Agreement
Captain Pass		
5 BS vs 5 No BS	0.72	0.99
20 vs 5 BS	0.35	0.95
20 vs 5 no BS	0.45	0.95
Barkley Sound		
5 BS vs 5 No BS	0.66	0.97
20 vs 5 BS	0.24	0.91
20 vs 5 no BS	0.30	0.91
Goletas Channel		
5 BS vs 5 No BS	0.84	0.98
20 vs 5 BS	0.13	0.94
20 vs 5 no BS	0.14	0.93
Gulf Islands		
5 BS vs 5 No BS	0.65	0.99
20 vs 5 BS	0.25	0.67
20 vs 5 no BS	0.25	0.66
Georgia Strait		
5 BS vs 5 No BS	0.92	1.00
20 vs 5 BS	0.19	0.99
20 vs 5 no BS	0.19	0.99

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Figure 2. Comparison of the probability of rocky substrate in 20 m² and 5 m² habitat models without backscatter (BS) showing four test areas. The black outline indicates the limit of the MBES extent. The 20 m² models were classified using a cut-off of 0.7 except Barkley Sound, which was classified using 0.8. Kappa and % agreement statistics between the 20 m² models and the 5 m² models without and with backscatter are shown.

Figure 3. Modeled rocky reef habitat on top of the 100 m² model used to designate the RCAs (Yamanaka and Logan 2010). Boundaries of the RCA and Pacific Fishery Management Areas (PFMAs) are also shown.

Table 5. Total modeled area (km²) and % rocky habitat in RCAs by Pacific Fishery Management Areas (PFMA).

Area and % estimates from the 100 m² habitat model (Yamanaka and Logan 2010) are shown for comparison. Area estimates by sub-area on the WCVI were not given in Yamanaka and Logan (2010).

Area (PFMA)	20+5 m ² Model			100 m ² Model		
	Total Habitat Area	Habitat in RCAs	% of Habitat in RCAs	Total Habitat Area	Habitat in RCAs	% in RCA
Inside	1223.9	267.4	22	3159.2	897.4	28
12	456.5	105.7	23	1154.0	314.1	27
13	123.1	22.6	18	454.4	133.2	29
14	65.1	10.4	16	144.3	40.6	28
15	106.0	20.6	19	242.6	72.5	30
16	128.8	29.0	22	262.6	77.6	30
17	73.2	18.7	26	282.8	82.2	29
18	65.8	19.6	30	217.2	58.6	27
19	74.4	22.1	30	186.0	55.4	30
20	50.6	2.8	6	0.0		
28	37.8	9.7	26	132.3	38.2	29
29	42.7	6.2	14	83.0	25.1	30
Outside (WCVI)	953.8	132.4	14	3660.5	471.7	13
11	161.7	25.2	16			
21	12.8	0.7	6			
23	204.8	27.8	14			
24	88.6	4.6	5			
25	123.1	8.7	7			
26	158.0	20.8	13			
27	204.7	44.6	22			
Total	2177.8	399.8	18	6819.7	1369.1	20

4. Discussion

Re-evaluating management targets based on new and improved data and models is necessary to managing marine resources in RCAs or MPAs. Marine Spatial Planning should be an iterative process as new data are made available (Pressey et al. 2013, Mills et al. 2015). Although high resolution MBES data are the gold standard for modeling marine benthic habitats, they are often not available at regional or provincial scales required for marine spatial planning and fisheries management (Dunn and Halpin 2009, Le Pape et al. 2014, Rinne et al. 2014). This is the case in BC that has a coastline almost 27,300 km long made up of a complex network of inlets, straits, passes, sounds, narrows and islands (Thomson 1981). Our model of rocky reef habitats uses a comprehensive intermediate resolution (20 m²) bathymetry model that was not available when the RCAs were designated. DFO scientists have been working to improve rockfish habitat models (Yamanaka et al. 2012, Yamanaka and Flemming 2013), but these models were limited to the extent of existing high resolution MBES bathymetry and backscatter data. Spatial planning and fisheries management must often occur at a regional scale, which often lacks comprehensive high-resolution data. Our analysis advances spatial planning in two ways: 1. we used a supervised classification to modeled habitat at a regional scale and with a finer resolution (20 m²) than was previously available; 2. our model comparisons showed that MBES bathymetry models perform similarly enough to models using MBES bathymetry and backscatter so we were able to also use all available MBES bathymetry data without backscatter in our final model. This is significant because resources are often not available for the expert interpretation involved in cleaning and interpreting backscatter data for the use in habitat modeling and spatial planning.

Model comparison at different resolutions (20 and 5 m²) also helped to explore the strengths and weaknesses of using different resolutions in different landscapes. The intermediate resolution models performed well in areas such as Barkley Sound and Captain Pass that have small islands surrounded by rocky reefs. Rinne *et al.* (2014) used bathymetry data with a similar resolution (25 m²) to model rocky reefs in an island archipelago and found that their model also performed well and successfully predicted 81% of the ground-truthed reefs. Our 20 m² model performed worse in steeply sloping habitats such as Goletas Channel and the eastern side of the Southern Gulf Islands. This bias was likely a result of the coarser resolution and scale as well as the truncation of the dataset imposed by the high water line (i.e. an edge-effect). Bathymetry derivatives are affected by the resolution of the bathymetry data because derivatives such as slope and BPI will be calculated over a broader scale which will have a smoothing effect on the output (Calvert et al. 2015). This presented a problem for estimating habitat within other steeply sloping areas such as the RCAs in coastal fjords and narrow straits such as Johnstone Strait. Combining the 20 m² resolution predictions with predictions from MBES data with a 5 m² resolution improved our habitat estimates in areas with steeply sloping bottoms such as in coastal fjords. Future work could also explore joining bathymetry data to terrestrial elevation data to determine if this improves the nearshore classification abilities by avoiding edge-effects. Area estimates in these steeply sloping habitats are also limited because they are a two-dimensional representation of a habitat with three dimensions. Although this is an issue for all of our area estimates, it is exaggerated in inlets with steep vertical walls. 3-D habitat mapping methods should be explored, particularly to obtain better estimates of the value of RCAs in the inlets (Yamanaka and Flemming 2013).

RF model performance is constrained by the number and distribution of substrate observations used to train the classification (Breiman 2001). The MBES test area in the central Strait of Georgia had relatively sparse substrate data ($n_{\text{train}}=229$) and a low proportion of observations of rock (9%). The low proportion of observed rock is probably a true characteristic and not a sampling bias because the test area contains the Fraser River, BC's largest river that deposits fine sediments over a large area (Thomson 1981). The MBES models in this test area with and without backscatter data had the lowest AUC values (0.87 and 0.86, respectively) of the MBES model, although their discriminatory ability is still considered "excellent" (Dunn and Halpin 2009). We were surprised by the similarity in the model performance statistics as well as the area estimates produced by the MBES models with and without backscatter, particularly in this test area. We expected that the acoustic backscatter data which relates to the hardness of benthic substrates (Lucieer et al. 2013, Che Hasan et al. 2014) would be useful in discriminating between soft mounds and rocky outcrops (Yamanaka and Flemming 2013). If this had been the case, we would have expected the RF model with backscatter in the central Strait of Georgia to find a lower area of rocky habitat than the model without backscatter. Conversely, the two models found almost the same area of rock (Table 3, 4.1 km² vs. 4.0 km²), indicating that MBES bathymetry data without backscatter can be used to adequately model substrate using RF. Other authors have also found that bathymetry derivatives could successfully predict rocky substrata without backscatter data (Calvert et al. 2015). The 20 m² model in this test area did predict rocky substrates along these areas of soft sediment, but often with a probability less than our cut-off of 0.7. Future work could include adding water energy data (tides, current and exposure) (GREGG et al. 2013) into the 20 m² RF model to improve the classification of rock versus soft mounds. We

are encouraged by the ability of RF to model substrates without the use of backscatter because little processed backscatter data are available for substrate analysis in BC.

Comparing models using the same input variables but at different spatial resolution was an important step in our estimates of the amount of habitat. In most of our test areas, the amount of habitat predicted was greater with the intermediate resolution model when using the same cut-off values on the fine resolution models. Coarser resolution data may overestimate the area of habitat since they do not have the spatial resolution to capture the relevant habitat heterogeneity present in the grid cell (Rinne et al. 2014). Selecting an appropriate threshold to turn the probability surface into a binary habitat classification is difficult but has major implications for the accuracy of the predictions as well as the total area of predicted habitat (Freeman and Moisen 2008). Comparing our models to finer resolution models and choosing a higher threshold to classify the 20 m² data (0.7 in inside waters and 0.8 on the WCVI) allowed us to realistically estimate the amount of potential Rockfish habitat. This has significant implications not just for the RCAs, but for marine spatial planning exercises that consider habitats at broad regional scales.

Previous estimates of total area of available rockfish habitat area in southern BC were more than three times greater than our estimates. The broader spatial resolution of the 100 m² model overestimated patchy habitats of key importance. A re-evaluation of the RCA targets with our model found that only 22%, rather than the previously estimated 28% of habitats were protected in the RCAs. However, at the subarea level, some areas (18 and 19) achieved the targeted 30% protection. On the WCVI, we found a slightly higher proportion of habitat was protected. We also calculated the amount of habitat protected in each RCA (see Table A2) and found although a mean of 20% of the area of the RCAs is rocky habitat, this ranged widely (from

less than 1% to 98%). Although some of the RCAs with low habitat estimates are in inlets, and are therefore probably biased; other RCAs with low habitat estimates should be re-evaluated for their effectiveness. Finer resolution habitat models could also be used to refine the shape or boundaries of RCAs so that reef habitats are contained within the protected area rather than crossing the boundaries because the isolation of habitats within protected areas is thought to reduce the spillover of fishes and increase protected area effectiveness (Edgar et al. 2014). If fine-scale mapping or *in-situ* investigations of RCAs that we identified with little habitat reveal that habitat is indeed limited, management should consider replacing them with areas with better habitat.

Our model of rocky reefs identified potential rockfish habitat. The realized habitat corresponds to the portion of the potential habitat that is occupied at a given time (Le Pape et al. 2014). Further work should be done to explore rockfish habitat as well as the habitat of the various inshore rockfish species. Observations of inshore rockfishes from ROV or long line surveys could be used with the RF model results of rocky substrates and combined with depth, complexity, exposure and currents to build habitat suitability models for the inshore rockfish community (Le Pape et al. 2014) using methods such as generalized linear or non-linear regression analysis (Young et al. 2010), boosted regression trees (Hill et al. 2014), or gradient forests (Ellis et al. 2012). We are also not able to draw any conclusions about the quality of rocky habitat from our model in terms of its complexity or the presence of features such as boulders, which have both been identified as important habitat characteristics for rockfishes (Marliave and Challenger 2009, Haggarty et al. 2016) because the 20 m resolution of the model is still too coarse to find high rugosity areas important for fish habitat use. In addition, boulder and bedrock were both grouped as “rock” in our RF model so we did not specifically model if

boulder habitat is found in RCAs. The RF model could, however, be expanded to predict other substrate types. Habitat evaluations of the RCAs could also be extended to include data on kelp forests, eelgrass beds, and sponge reefs (Cook et al. 2008, Marliave et al. 2009). Estimate of the amount of rockfish habitat in some RCAs would likely change with the incorporation of these biogenic habitats.

5. Conclusion

Until recently, our ability to model habitat at a broad scale in BC has been limited by the poor resolution of available data. The representation of suitable habitat in a marine reserve is one of the most important criteria of reserve effectiveness (Roberts et al. 2003, Gaines et al. 2010); however, models and data upon which to base conservation decisions are often not available at broad regional extents (Dunn and Halpin 2009). Our modeling results showed that the original 100 m² bathymetry data used to plan the RCAs overestimated the amount of available habitat and that in inside waters, a smaller proportion and much lower total area of rockfish habitat is protected in the RCAs. It also showed that some RCAs do not contain much habitat and/or have a low percent rocky habitat. These RCAs should be targeted for MBES surveys to refine habitat models and to determine the value of these RCAs. As additional 20 m² bathymetry data become available for the rest of BC, this habitat model could be used evaluate the remaining 20 RCAs in BCs north coast. Our model could also feed into conservation planning as Canada works to achieve its Aichi biodiversity target of protecting 10% of the oceans by 2020 (Secretariat of the Convention on Biological Diversity 2011) as well as species distribution modeling and environmental impact assessments. This information should be incorporated into re-evaluations of RCAs to ensure that they are achieving their fishery management objectives of rebuilding rockfish populations.

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495 **6. Acknowledgements**

496 This work was funded by an NSERC Strategic grant (STPSC 357012-2007) and SPERA
497 (Strategic Program for Ecosystem-based Research and Advice, PAC-2014-040) funding to KLY
498 and an NSERC PGSB and UBC Star Fellowship to DRH. Mesha Sagram provided invaluable
499 GIS assistance. This work would not have been possible without the work of E. Gregr, Scitech
500 Environmental Consulting, and S. Davies, DFO. Helpful reviews were provided by J. Shurin,
501 E.Gregr and A. Frid.

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Appendix for Haggarty et al. Evaluating Rockfish Conservation Areas in Southern British Columbia using a Random Forest Model of Rockfish Habitat.

Table A1. Model performance statistics using a range of probability cut-offs. Statistics for the chosen cut off are shown in bold. The OOB error rate, area under the curve (AUC) and root mean squared error (RMSE) statistics are not sensitive to the cutoff.

Area	Cut-off	OOB Error Rate %	AUC	RMSE	Accuracy	Error rate	Sensitivity (True positive rate)	Specificity (True negative rate)	Cohen's kappa (K)
QCSt 20 x 20	0.6	25.8	0.84	0.40	0.76	0.24	0.63	0.88	0.52
	0.7				0.73	0.27	0.50	0.94	0.45
	0.8				0.69	0.31	0.38	0.97	0.36
	0.9				0.62	0.38	0.22	0.99	0.22
Goletas 5 x 5	0.6	14.7	0.97	0.27	0.90	0.10	0.86	0.93	0.79
	0.7				0.90	0.10	0.79	0.98	0.79
	0.8				0.90	0.10	0.79	0.98	0.79
	0.9				0.82	0.18	0.54	1.00	0.59
No BS	0.6	12.6	0.98	0.25	0.93	0.07	0.96	0.91	0.86
	0.7				0.89	0.11	0.82	0.93	0.76
	0.8				0.90	0.10	0.79	0.98	0.79
	0.9				0.83	0.17	0.57	1.00	0.62
WCVI 20 x 20	0.6	18.0	0.89	0.36	0.81	0.19	0.80	0.83	0.62
	0.7				0.80	0.21	0.73	0.89	0.59
	0.8				0.75	0.25	0.61	0.94	0.51
	0.9				0.66	0.35	0.43	0.97	0.36
Barkley Sound 5 x 5	0.6	12.3	0.95	0.28	0.91	0.09	0.77	0.96	0.76
	0.7				0.89	0.11	0.67	0.98	0.71
	0.8				0.87	0.13	0.56	1.00	0.64
	0.9				0.80	0.20	0.33	1.00	0.41
No BS	0.6	13.4	0.95	0.29	0.91	0.10	0.76	0.97	0.76
	0.7				0.89	0.12	0.66	0.98	0.70
	0.8				0.85	0.15	0.51	0.99	0.58
	0.9				0.79	0.21	0.29	1.00	0.36
Strait of Georgia 20 x 20	0.6	20.9	0.86	0.39	0.78	0.22	0.62	0.89	0.53
	0.7				0.75	0.25	0.50	0.93	0.46
	0.8				0.70	0.30	0.35	0.97	0.34
	0.9				0.63	0.37	0.15	0.99	0.16
Captain Passage	0.6	13.6	0.92	0.34	0.84	0.16	0.81	0.88	0.67

Area	Cut-off	OOB Error Rate %	AUC	RMSE	Accuracy	Error rate	Sensitivity (True positive rate)	Specificity (True negative rate)	Cohen's kappa (K)
5 x 5	0.7				0.82	0.18	0.77	0.88	0.64
	0.8				0.78	0.22	0.71	0.88	0.57
	0.9				0.78	0.22	0.65	0.96	0.58
	0.6	14.6	0.91	0.34	0.82	0.18	0.81	0.83	0.63
	0.7				0.82	0.18	0.77	0.88	0.64
	0.8				0.78	0.22	0.68	0.92	0.57
	0.9				0.71	0.29	0.55	0.92	0.44
Georgia Strait	0.6	7.4	0.87	0.28	0.92	0.08	0.43	0.99	0.53
5 x 5	0.7				0.90	0.11	0.14	1.00	0.23
	0.8				0.89	0.11	0.07	1.00	0.12
	0.9				0.88	0.12	0.00	1.00	0.00
	0.6	7.4	0.86	0.27	0.91	0.09	0.29	1.00	0.41
	0.7				0.89	0.11	0.07	1.00	0.12
	0.8				0.88	0.12	0.00	1.00	0.00
	0.9				0.88	0.12	0.00	1.00	0.00
Gulf Islands	0.6	18.2	0.92	0.33	0.83	0.17	0.81	0.86	0.63
5 x 5	0.7				0.80	0.20	0.73	0.93	0.60
	0.8				0.75	0.26	0.63	0.96	0.51
	0.9				0.64	0.36	0.46	0.98	0.36
	0.6	20.0	0.92	0.33	0.81	0.19	0.79	0.86	0.61
	0.7				0.78	0.22	0.71	0.92	0.56
	0.8				0.73	0.27	0.61	0.96	0.48
	0.9				0.60	0.40	0.40	0.98	0.30

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Table A2. Total modeled rockfish habitat per RCA, the total size of the RCA and the percent habitat. Comments indicated if the RCA is found in an inlet or not and if there was any MBES data used in the model. Habitat is likely underestimated in inlets with no MBES data.

RCA	Region	Total Area (km ²)	Habitat Area (km ²)	Percent Habitat	Comments
Teakerne Arm	NSOG	8.4	1.50	17.81	Inlet, MBES
Bute Inlet North	NWVI-JS	46.2	4.78	10.34	Inlet, MBES
Goletas Channel	NWVI-JS	36.7	7.24	19.74	Inlet, MBES
Havannah Channel	NWVI-JS	32.0	5.94	18.50	Inlet, MBES
Hotham Sound	NWVI-JS	22.4	5.95	26.55	Inlet, MBES
Lower Clio Channel	NWVI-JS	13.9	2.36	16.96	Inlet, MBES
Port Elizabeth	NWVI-JS	6.0	0.28	4.70	Inlet, MBES
Queen's Reach East	NWVI-JS	4.5	0.83	18.25	Inlet, MBES
Queen's Reach West	NWVI-JS	3.5	0.60	17.08	Inlet, MBES
Viscount Island	NWVI-JS	21.9	2.23	10.12	Inlet, MBES
Burgoyne Bay	SSOG	2.6	0.28	11.04	Inlet, MBES
Eastern Burrard Inlet	SSOG	2.7	0.10	3.54	Inlet, MBES
Indian Arm - Crocker Island	SSOG	8.9	1.24	13.86	Inlet, MBES
Mariners Rest	SSOG	1.9	0.17	9.05	Inlet, MBES
Mid Finlayson Arm	SSOG	1.9	0.34	17.94	Inlet, MBES
Navy Channel	SSOG	8.3	0.80	9.63	Inlet, MBES
Indian Arm - Twin Islands	SSOG	2.9	0.48	16.83	Inlet, MBES
Upper Centre Bay	SSOG	1.1	0.24	21.23	Inlet, MBES
West Bay	SSOG	1.1	0.25	23.91	Inlet, MBES
Salmon Inlet	NSOG	17.5	2.67	15.20	Inlet, no MBES
Skookumchuck Narrows	NSOG	13.1	5.98	45.26	Inlet, no MBES
Chancellor Inlet East	NWVI-JS	3.5	0.02	0.64	Inlet, no MBES
Chancellor Inlet West	NWVI-JS	13.9	2.43	17.53	Inlet, no MBES
Forward Harbour	NWVI-JS	3.3	0.002	0.05	Inlet, no MBES
Loughborough Inlet	NWVI-JS	37.1	0.48	1.29	Inlet, no MBES
Princess Louisa Inlet	NWVI-JS	6.2	0.53	8.43	Inlet, no MBES
Thompson Sound	NWVI-JS	13.9	0.36	2.61	Inlet, no MBES
Upper Call Inlet	NWVI-JS	21.0	0.23	1.07	Inlet, no MBES
Wellborne	NWVI-JS	22.9	3.91	17.03	Inlet, no MBES
Belleisle Sound	NWVI-Q	5.1	0.07	1.40	Inlet, no MBES
Bond Sound	NWVI-Q	3.8	0.03	0.69	Inlet, no MBES
Burley Bay - Nepah Lagoon	NWVI-Q	10.7	0.19	1.79	Inlet, no MBES
Drury Inlet - Muirhead Islands	NWVI-Q	11.6	2.21	18.99	Inlet, no MBES
Greenway Sound	NWVI-Q	15.1	5.70	31.83	Inlet, no MBES

RCA	Region	Total Area (km ²)	Habitat Area (km ²)	Percent Habitat	Comments
Holberg Inlet	NWVI-Q	22.5	11.94	53.10	Inlet, no MBES
Kwatsi Bay	NWVI-Q	3.4	0.05	1.58	Inlet, no MBES
Mackenzie - Nimmo	NWVI-Q	4.0	0.01	0.35	Inlet, no MBES
Susquash	NWVI-Q	8.1	1.07	13.19	Inlet, no MBES
Wakeman Sound	NWVI-Q	12.3	0.24	1.91	Inlet, no MBES
Bedwell Sound	WCVI	15.3	1.09	7.09	Inlet, no MBES
Ajax / Achilles Bank	NSOG	73.9	2.55	3.45	MBES
Copeland Islands	NSOG	15.3	4.37	25.83	MBES
Davie Bay	NSOG	10.2	1.60	15.65	MBES
Deepwater Bay	NSOG	1.8	0.02	1.14	MBES
Desolation Sound	NSOG	60.0	11.27	18.78	MBES
Dinner Rock	NSOG	6.6	0.23	3.38	MBES
Hardy Island	NSOG	16.0	3.51	21.96	MBES
Heriot Bay	NSOG	5.1	1.07	20.92	MBES
Kanish Bay	NSOG	8.0	0.45	5.37	MBES
Lasqueti Island South	NSOG	18.5	4.75	25.65	MBES
Lasqueti South - Young Point	NSOG	9.3	0.40	4.32	MBES
Malaspina Strait	NSOG	28.3	3.33	11.75	MBES
Maud Island	NSOG	3.1	0.29	9.52	MBES
McNaughton Point	NSOG	2.2	0.94	42.66	MBES
Mitlenatch Island	NSOG	24.9	2.34	9.40	MBES
Octopus Islands to Hoskyn Channel	NSOG	35.8	4.49	12.53	MBES
Oyster Bay	NSOG	9.1	0.22	2.46	MBES
Read - Cortes Islands	NSOG	30.3	5.77	19.05	MBES
Sabine Channel-Jervis-Jedediah I.	NSOG	22.3	6.14	27.39	MBES
Sinclair Bank	NSOG	19.2	2.30	11.95	MBES
Sisters Islets	NSOG	10.7	2.08	19.50	MBES
Thormanby Island	NSOG	3.2	0.95	29.21	MBES
Thurston Bay	NSOG	6.6	1.04	15.79	MBES
Walken Island to Hemming Bay	NSOG	13.6	3.76	27.69	MBES
Topknot	NWVI	96.1	6.61	6.88	MBES
Bate - Shadwell Passage	NWVI-JS	17.8	2.20	12.36	MBES
Bolivar Passage	NWVI-JS	16.7	11.26	67.22	MBES
Browning Passage - Hunt Rock	NWVI-JS	10.0	3.89	38.97	MBES
Cracroft Point South - Sophia Islands	NWVI-JS	2.7	0.81	30.10	MBES
Eden-Bonwick-Midsummer-Swanson	NWVI-JS	68.7	30.20	43.97	MBES
Hardy Bay - Five Fathom Rock	NWVI-JS	0.1	0.02	13.01	MBES
Pendrell Sound	NWVI-JS	15.2	2.93	19.23	MBES
Shelter Bay	NWVI-JS	15.5	4.77	30.69	MBES

RCA	Region	Total Area (km ²)	Habitat Area (km ²)	Percent Habitat	Comments
West Cracroft Island - Boat Bay	NWVI-JS	3.6	1.98	54.50	MBES
Brooks Bay	NWVI-Q	72.3	9.55	12.96	MBES
Checleset Bay	NWVI-Q	147.4	21.03	14.08	MBES
Weynton Passage	NWVI-Q	17.6	8.42	47.84	MBES
Ballenas Island	SSOG	5.8	1.71	29.42	MBES
Baynes Sound - Ship Point	SSOG	2.5	0.03	1.03	MBES
Bedwell Harbour	SSOG	2.5	0.76	30.37	MBES
Bell Chain Islets	SSOG	13.0	5.18	39.80	MBES
Bowyer Island	SSOG	3.1	0.58	18.44	MBES
Brentwood Bay	SSOG	3.4	0.65	19.01	MBES
Brethour,Domville,Forrest,Gooch I.	SSOG	18.7	6.66	35.44	MBES
Coal Island	SSOG	3.1	0.81	25.94	MBES
D'Arcy Island to Beaumont Shoal	SSOG	53.8	11.20	20.77	MBES
Departure Bay	SSOG	2.7	0.32	11.71	MBES
Discovery - Chatham Islands	SSOG	3.2	2.23	59.44	MBES
Domett Point	SSOG	2.1	0.17	8.32	MBES
Duntze Head(Royal Roads)	SSOG	0.9	0.28	30.65	MBES
Gabriola Passage	SSOG	2.6	0.54	20.09	MBES
Galiano Island North	SSOG	9.7	0.45	4.61	MBES
Halibut Bank	SSOG	33.0	1.63	4.94	MBES
Lions Bay	SSOG	4.8	0.59	12.26	MBES
Maple Bay	SSOG	3.2	0.41	12.54	MBES
Mayne Island North	SSOG	7.0	4.04	57.26	MBES
McCall Bank	SSOG	13.4	0.83	6.19	MBES
Nanoose - Schooner Cove	SSOG	12.0	2.15	17.88	MBES
Northumberland Channel	SSOG	14.8	1.43	9.67	MBES
Pam Rock	SSOG	5.7	1.19	20.97	MBES
Pasley Island	SSOG	12.0	3.63	30.17	MBES
Passage Island	SSOG	0.8	0.18	23.65	MBES
Patey Rock	SSOG	0.9	0.38	41.82	MBES
Portland Island	SSOG	3.0	1.51	49.66	MBES
Prevost Island North	SSOG	9.0	1.91	20.95	MBES
Race Rocks	SSOG	2.7	2.69	97.85	MBES
Russell Island	SSOG	2.4	0.20	8.44	MBES
South Saturna	SSOG	30.8	4.38	14.15	MBES
Thetis-Kuper Islands	SSOG	25.5	5.73	22.32	MBES
Trial Island	SSOG	0.8	0.38	46.05	MBES
Trincomali Channel	SSOG	21.6	1.80	8.27	MBES
Valdes Island East	SSOG	10.0	1.66	16.45	MBES

RCA	Region	Total Area (km ²)	Habitat Area (km ²)	Percent Habitat	Comments
West Vancouver	SSOG	2.8	0.51	18.15	MBES
Woolridge Island	SSOG	3.8	0.73	19.15	MBES
Broken Islands Group	WCVI	39.7	23.93	51.71	MBES
Folger Passage	WCVI	17.0	4.52	26.62	MBES
Scott Islands	WCVI	338.4	33.28	9.81	MBES
Chrome Island	NSOG	3.9	0.11	2.87	No MBES
Menzies Bay	NSOG	3.9	0.14	3.65	No MBES
Nelson Island	NSOG	8.7	1.46	16.37	No MBES
Savoie Rocks - Maude Reef	NSOG	1.7	0.06	3.65	No MBES
Browning Island to Raynor Group	NWVI-JS	16.6	4.07	23.34	No MBES
Haddington Passage	NWVI-JS	2.5	0.17	6.90	No MBES
Numas Islands	NWVI-JS	28.9	5.69	19.71	No MBES
Storm Islands	NWVI-JS	37.2	18.30	49.03	No MBES
Dickson - Polkinghorne Islands	NWVI-Q	15.9	8.45	53.05	No MBES
Nowell Channel	NWVI-Q	12.4	4.85	38.98	No MBES
Salmon Channel	NWVI-Q	14.1	4.63	31.98	No MBES
Becher Bay East	SSOG	1.0	0.56	55.94	No MBES
Bentinck Island	SSOG	0.5	0.49	89.06	No MBES
Coffin Point	SSOG	4.3	0.22	5.17	No MBES
Danger Reefs	SSOG	1.5	0.99	66.91	No MBES
De Courcy Island North	SSOG	4.0	0.63	15.78	No MBES
Reynolds Point - Link Island	SSOG	4.3	0.30	7.01	No MBES
Ruxton - Pylades Island	SSOG	6.8	1.71	25.05	No MBES
Saltspring Island North	SSOG	8.4	1.41	16.65	No MBES
Sooke Bay	SSOG	3.4	0.23	6.75	No MBES
Carmanah	WCVI	8.2	0.31	3.75	No MBES
Dare Point	WCVI	3.5	0.08	2.30	No MBES
Estevan Point	WCVI	186.0	11.28	6.06	No MBES
Pachena Point	WCVI	19.1	0.52	2.69	No MBES
Saranac Island	WCVI	10.9	0.88	8.03	No MBES
Vargus Island to Dunlap Island	WCVI	2.8	0.54	18.88	No MBES
West of Bajo Reef	WCVI	41.8	0.52	1.24	No MBES
Mean		18.08	3.07	20.06	
SD		36.04	5.14	17.72	
Minimum		0.13	0.00	0.05	
Maximum		338.41	33.28	97.85	

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