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A Regional Assessment of Ecological Attributes in Rockfish Conservation Areas in British Columbia

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

We conducted a regional assessment of four ecological attributes (size, rockfish habitat, depth, and connectivity) in 164 Rockfish Conservation Areas (RCAs) in British Columbia. The purpose of this research was to evaluate how effective RCAs are at achieving their conservation objective, which is to protect portions of inshore rockfish populations and their habitat from fishing pressure. Analyses were conducted using GIS information and existing habitat models. Attribute thresholds were derived from the literature. We took three approaches to our analyses. RCAs were scored based on:

1. individual attributes,
2. attributes summed together to form a single index of overall status, and
3. ideal attribute criteria to assess how the current network compares to a best case scenario.

Generally RCAs were ranked by lowest score/poorest performer to help prioritize RCAs for further evaluation to determine whether a strategic change (boundary adjustment, relocation) might improve their conservation value to rockfish.

Although inshore rockfish have small home ranges, some RCAs might be too small resulting in excessive spillover of mature fish. Available model-based data indicate some RCAs contain very little rockfish habitat and, therefore, may not support high abundances of fish which would limit population rebuilding efforts. RCAs generally protect more shallow (<50 m) areas preferred by Black, Copper, and China Rockfishes and not deeper areas (>100 m) utilized by other species like Quillback and Yelloweye Rockfishes. The network is well connected at distances of 100 km; at distances of 50 km several gaps exist in Haida Gwaii, the central coast, along the west coast of Vancouver Island, and in three inlets (Bute, Holberg, Jervis). RCAs in the Northern Shelf Bioregion (NSB) generally scored higher suggesting these RCAs might be providing greater protection to rockfish. Eight point five percent (14) of RCAs currently meet the ideal criteria for attributes, and an additional 43% (70) meet at least five of seven criteria and, therefore, may be good candidates for improvement. Considerable rockfish habitat exists in other types of protected areas outside the RCA network, especially in federal protected areas such as Marine Protected Areas, National Marine Conservation Areas, and Marine National Wildlife Areas where there is some protection afforded to rockfish and their habitat. Rockfish habitat is also prevalent in provincial conservancies, although no long-term protection for rockfish currently exists in provincial protected areas.

RCAs with the lowest attribute scores should be evaluated further to determine how to improve their conservation benefit to rockfish. First, existing surveys and data can be used to test the efficacy of our ranking system. Second, ecological monitoring and improved compliance should be considered before implementing boundary changes or relocating RCAs. Third, conservation benefits to rockfish might be increased in RCAs if their boundaries are adjusted and configurations changed to increase their sizes, incorporate more habitat over a broader range of depths, and encompass entire habitat areas to limit spillover of mature fish. Those RCAs where there is very little habitat inside and nearby could be moved to better locations.

Recommendations and knowledge gaps are listed. A long-term recommendation is most RCAs should be ground-truthed using non-destructive sampling methods to verify conclusions in this report and the presence of essential habitat and rockfish. Results from this research will help inform consultations with First Nations and stakeholders regarding potential changes to existing RCAs.

CHAPTER 1: ATTRIBUTES

1.1 OVERVIEW

The Inshore Rockfish Conservation Strategy was developed by Fisheries and Oceans Canada (DFO) in 2001 to help address the precipitous decline of inshore rockfish species. The Strategy focused on improving four areas of rockfish fisheries management:

1. account for all inshore rockfish catch,
2. decrease fishing mortality on inshore rockfish,
3. establish areas closed to fishing, and
4. improve inshore rockfish stock assessment and monitoring.

Using the Fisheries Act, DFO designated Rockfish Conservation Areas (RCAs) as harvest refuges (fishery closures or marine refuges) where commercial and recreational fisheries with direct and incidental catch of inshore rockfish were restricted. This intention was to decrease fishing mortality of exploited inshore rockfish populations within RCA boundaries and provide opportunities for these species to rebuild. In addition, RCAs protect rockfish habitat from impacts of fishing activities caused by certain types of bottom contact fishing gear. Inshore rockfish include Quillback (*Sebastes maliger*), Yelloweye (*S. rubberimus*), Copper (*S. caurinus*), Tiger (*S. nigrocinctus*), China (*S. nebulosus*), Black (*S. melanops*), Brown (*S. auriculatus*), and Deacon (*S. diaconus*; often mistakenly considered to be Blue [*S. mystinus*]; Frable et al. 2015). These eight rockfish species aggregate over rocky areas in nearshore waters generally shallower than 200 m. Although this review of RCAs focuses on eight species of rockfish, it should be noted there are 37 species of rockfish in BC, some whose life-history characteristics are beyond the scope of this review. Consequently, 29 rockfish species may have limited or no protection compared to the few inshore species for which RCAs were created to protect.

When RCAs were established, rockfish habitat was identified in multiple phases between 2002 and 2006. In 2002, marine charts were used during consultations with stakeholders where participants identified habitat for Quillback and Yelloweye Rockfishes. Areas of socioeconomic importance to fishers (other groundfish, salmon, herring, and shellfish) were also identified using this method so these areas would remain open. Other factors considered included ease of description in fishery regulations, clear recognition by the public, and ease of monitoring and enforcement. In 2003, DFO conducted an internal review of the proposed area closures identified from consultations and compared them to catch data to determine areas of high or medium rockfish value. In 2004, a rockfish habitat model (100×100 m resolution) was developed in GIS using commercial and recreational Quillback and Yelloweye Rockfish catch data from logbooks, and bathymetry data. The model combined fishery catch-per-unit-effort density analysis to highlight areas of high rockfish catch, and a complexity analysis to identify high slope. These two metrics combined were used as a surrogate for rockfish habitat coast-wide. Proposed RCA locations and boundaries were made available for comment during public consultations between 2003 and 2006. All 164 RCAs were established by 2007 and they protected 28% and 15% of modelled rockfish habitats in the Inside and Outside Management Areas (Figure 1), respectively (Yamanaka and Logan 2010). The design was considered to be a ‘network’; it was believed many smaller areas located close together would facilitate movements of larvae and adults between protected areas, and provide spillover to adjacent areas open to fishing.

As of 2018, a coast-wide monitoring program has not yet been formally established for the RCA network. Various researchers from governments (federal and First Nations), academia, and

NGOs have collected monitoring data related to rockfish and RCAs using ROV, scuba, and hook-and-line surveys, and also conducted genetic analyses (see Haggarty 2014 for a review of these research initiatives). In general, these studies compared data collected inside RCAs to nearby sites that are open to fishing because no data were collected before RCAs were established, and this, unfortunately, makes it impossible to track whether there are more fish in RCAs since these areas were closed. An important baseline dataset is the first study published on RCAs by Marliave and Challenger (2009) in Howe Sound in 2006 using scuba surveys. More recently there has been some research to study the effectiveness of RCAs in rebuilding inshore rockfish populations (Frid et al. 2016, Haggarty 2015). Recreational (non) compliance in RCAs has been studied in the south coast using aerial surveys (Haggarty et al. 2016a), dock-side interviews (Lancaster et al. 2015), and shore-based remote cameras (Lancaster et al. 2017). Having no cohesive monitoring program and very little baseline data, combined with the unique life histories of inshore rockfish (e.g. long-lived), creates challenges when trying to determine the effectiveness of the RCA network. Collecting future data that can be compared to earlier studies will be valuable to assess RCAs over time.

It has been at least 11 years since RCAs were first established and resource managers are currently interested in knowing how the network is performing and whether any improvements might be necessary. Furthermore, there is a Ministerial mandate to establish ten percent of Canada's marine and coastal area through marine protected areas by 2020, and RCAs are under review as potential contributions to the Marine Conservation Targets if they can meet Other Effective Area Based Conservation Measure (OEABCM) criteria outlined in DFO's Operational Guidance for Identifying 'Other Effective Area-Based Conservation Measures' in Canada's Marine Environment. A review of the RCA network is therefore timely.

1.1.1 Ecological Attributes

We conducted a regional assessment of four ecological attributes of RCAs (size, rockfish habitat, depth, and connectivity) and their associated metrics to provide some indication as to how effective RCAs are as a spatial protection measure for inshore rockfish. The ecological attributes of RCAs include:

1. Size:
    a. Minimum size criteria - minimum size recommended for marine protected areas (MPAs); minimum size in relation to the range of movements of adult rockfish.
    b. Distance to nearest boundary - measured from the center of the RCA to the nearest water boundary (not against the shore).
2. Rockfish habitat (rocky reef, kelp forest, eelgrass bed, glass sponge reef):
    a. Proportion (%) of RCA that contains rockfish habitat.
    b. Area (km^2) of rockfish habitat in RCA.
    c. Isolation
        - Boundary to area ratio
        - Boundary intersecting habitat ratio.
3. Depth: area in RCAs which encompasses the depth range of inshore rockfish (0 to 200 m), in 50 m depth categories.
4. Connectivity: water distances between RCAs compared to distances larvae disperse.

Prioritizing attributes in terms of their ecological importance to RCAs and their relationship to rockfish conservation is under the discretion of resource managers. We provide scores for

RCAs based on individual attributes and rank them accordingly. RCAs are also ranked according to a single index of overall status that is an additive (unweighted) score based on most attributes. For both individual attributes and the single index, RCAs are usually ranked from lowest to highest score to help prioritize those that may not be optimally conserving rockfish or their habitats and might benefit from further investigation. Lastly, RCAs are ranked according to ideal attribute criteria to evaluate how the current network compares to a best case scenario. General results, conclusions, recommendations, and knowledge/research gaps are provided in the text. Habitat type map examples of low scoring RCAs with respect to particular attributes are in Appendix 1.

1.1.2 GIS Methods

Spatial analyses were conducted using a GIS with ESRI ArcGIS Desktop software (minimum version 10.4.1). An Albers Equal Area Conic projection (NAD_1983_BC_Environment_Albers) was used. Datasets used for this research are listed in Table 1.

A polygon shapefile of RCA boundaries was provided by DFO Science and used for these analyses. DFO Science had reviewed the official boundaries of RCAs (dated 2007) and discovered some RCA polygons included areas representing islands and lakes which would inflate RCA sizes. These portions of RCA polygons were removed and the areas of these RCAs recalculated. Adjusted RCAs include Broken Group Islands, Copeland Islands, Discovery – Chatham Islands, Duntze Head (Royal Roads), Kanish Bay, Nelson Island, Salmon Channel, Smith Sound, and Viscount Island. We used the ArcGIS ‘dissolve’ tool on the shapefile to convert multipart polygons into single polygons (one polygon per RCA) so proper area estimates could be made.

Rockfish habitat was calculated from a GIS layer created using a combination of rocky reef (substrate [20×20m resolution] and multi-beam [5×5m resolution] habitat models), kelp canopy, eelgrass bed, and sponge reef layers.

1.1.3 Other Considerations

Coastlines used when creating the official version of RCAs sometimes did not align well with coastlines used in other datasets that were derived from various sources compiled at different scales. Due to time constraints, we were unable to resolve this issue.

When performing analyses using habitat data there are issues regarding spatial shape and location. When rockfish habitat files were originally created they were digitized at a different scale, projection, and used a different coastline file for reference; consequently, habitat files do not always line up with RCA coastline boundaries. Efforts were made to better align habitats with RCA boundaries in order to obtain the most accurate results; however, there are still discrepancies. In addition, some habitat data sets do not encompass the entire BC coast; therefore, analysis of RCAs where data are missing could not be completed and, as a result, habitat statistics for these areas were noted as not available. For these reasons, all calculations are considered to be approximate.

Two RCAs are divided between bioregions and management areas. Walken Island to Hemming Bay RCA exists in both the Strait of Georgia and Northern Shelf Bioregions, and Carmanah RCA exists in both the Inside and Outside Management Areas. For this assessment, Walken Island to Hemming Bay RCA is included in the Strait of Georgia Bioregion because 67% of its area exists there. Carmanah RCA is included in the Outside Management Area because 62% of its area exists there. The Inside Management Area includes Pacific Fishery Management Areas (PFMAs) 12 (except Subarea 12-14) to 20, 28, and 29 (Figure 1). The Outside Management Area includes PFMAs 1-11, 21-27, 101-111, 121-127, 130, 142 and Subarea12-14.

Table 1. Datasets used for the regional assessment of RCAs.

Dataset	Source and Date Last Modified
RCAs	DFO 2018[1]
Rocky Reef Habitat Models (5×5m and 20×20m)	DFO 2018 Haggarty and Yamanaka 2018
Eelgrass Bed	BCMCA 2006-2013[2] CRIMS (Province of BC) 2017[3] Harper and Morris 2014
Kelp Canopy	BCMCA 2006-2013 CRIMS (Province of BC) 2017 Harper and Morris 2014
Sponge Reef	DFO 2018 NRCan 2018[4]
Marine Bioregions	DFO 2016[5]
Pacific Fishery Management Areas	DFO 2007[6]
Conservation Areas Reporting and Tracking System (CARTS)	CCEA 2017
Derived 20 m DEM Bathymetry	Davies et al. in prep[7]
80 m DEM Bathymetry	NOAA 2013

BCMCA = BC Marine Conservation Analysis
CCEA = Canadian Council on Ecological Areas
CRIMS = BC's Coastal Resource Information Management System
DFO = Fisheries and Oceans Canada
NOAA = National Oceanic and Atmospheric Administration
NRCan = Natural Resources Canada

[1] DFO 2018. Rockfish Conservation Areas

[2] British Columbia Marine Conservation Analysis. 2006-2013. The British Columbia Marine Conservation Analysis

[3] Ministry of Forests, Lands and Natural Resource Operations. GeoBC. 2017. Eelgrasses – Coastal Resource Information Management System (CRIMS)

[4] Natural Resources Canada (NRCan). 2018. West Coast Sponge Reefs. Provided by Kung, R (Geological Survey of Canada, NRCan, 2018).

[5] DFO 2016. Federal Marine Bioregions

[6] DFO 2007. Pacific Fishery Management Area Regulations

[7] Davies, S.C., Gregr, E.J., Lessard, J., Bartier, P., and Wills, P. In prep. Development of bathymetric elevation models for ecological analyses in Pacific Canadian coastal waters. Can. Tech. Rep. Fish. Aquat. Sci.

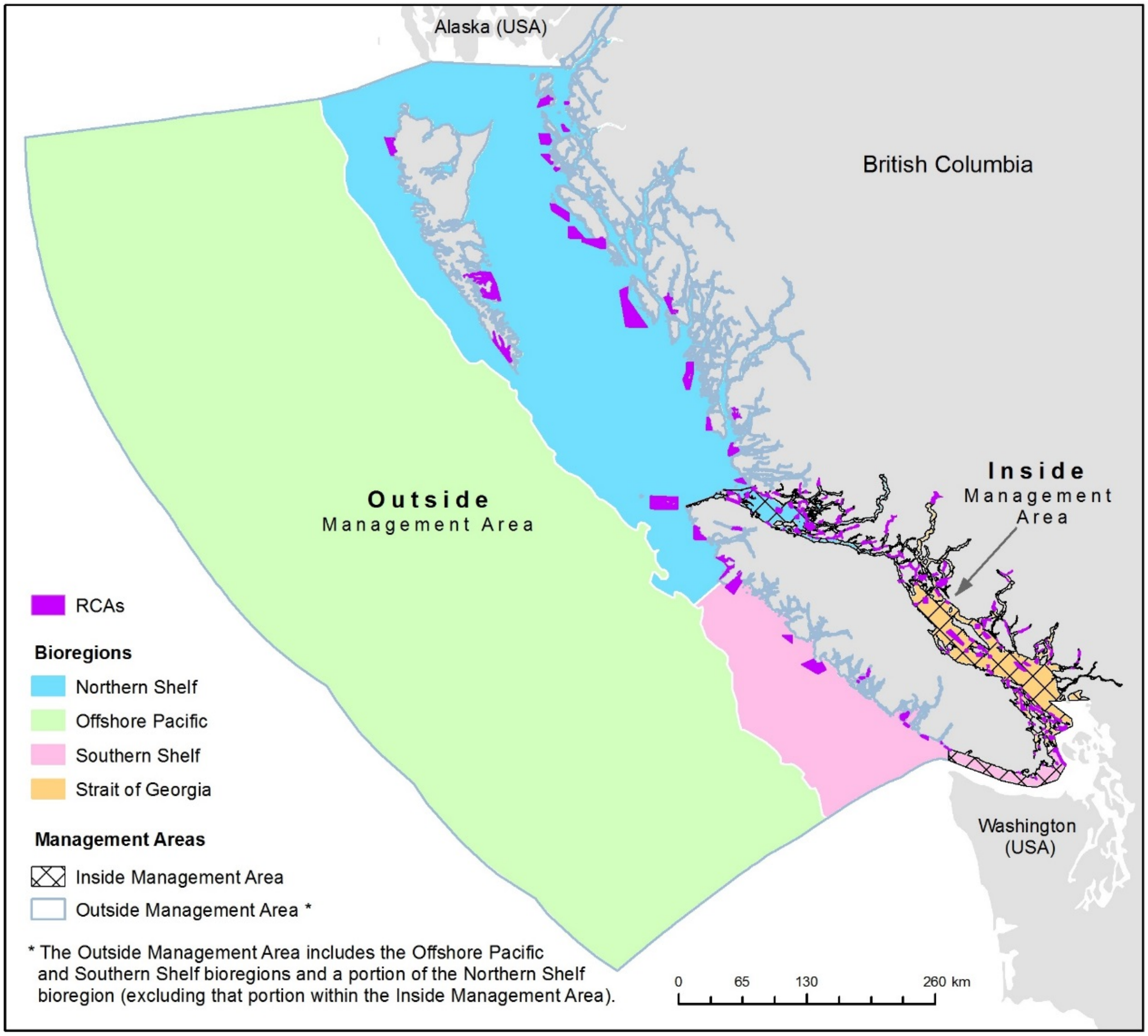

Figure 1. RCAs in relation to bioregions and Inside and Outside Management Areas.

1.2 RCA SIZE

There is a considerable range in RCA size (0.13 to 493 km^2); however, the majority of RCAs (125 RCAs or 76%) are smaller than 25 km^2 (Figure 2). The median size of RCAs is 10.8 km^2 (Table 2).

RCAs are generally smaller in the Strait of Georgia Bioregion and considerably larger in the Northern Shelf Bioregion. RCAs are considerably smaller in the Inside Management Area compared to the Outside Management Area.

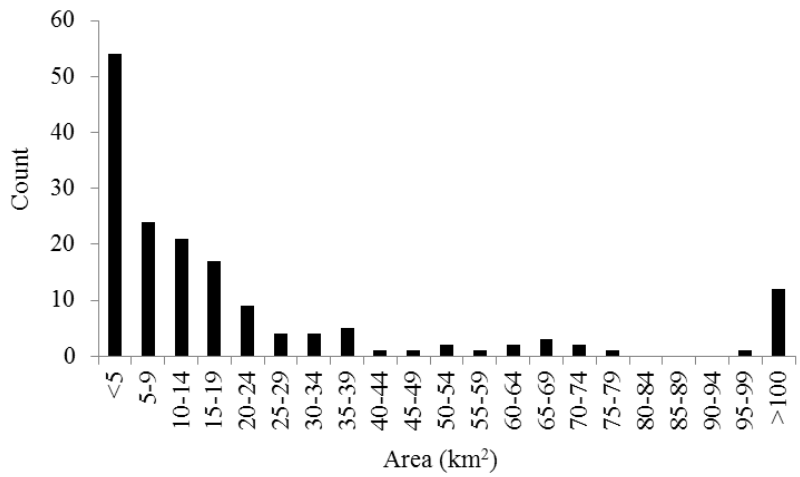

Figure 2. Frequency distribution of RCA size.

Table 2. RCA size (km²) by bioregion and management area.

Bioregion / Management Area	Area (km²)		Range (km²)	n
	Median	Mean ± SE		
Strait of Georgia	6.7	11.1 ± 1.4	0.75 – 73.9	84
Southern Shelf	8.2	29.5 ± 11.8	0.55 – 186.3	19
Northern Shelf	17.8	53.7 ± 11.1	0.13 - 493.1	61
Inside	8.1	12.1 ± 1.2	0.13 – 73.9	128
Outside	61.0	90.7 ± 17.8	2.80 – 493.1	36
All RCAs	10.8	29.4 ± 4.7	0.13 – 493.1	164

1.2.1 RCA size compared to recommended minimum MPA size

The California MLPA Advisory Team (2006) determined that 5 km^2 of habitat within any MPA was a sufficient amount based on adult fish movement patterns. Fifty-four RCAs (33%) are smaller than 5 km^2 (Figure 2).

The adult stage of many nearshore coastal species, particularly reef-associated species with limited mobility, can be protected in MPAs with a minimum size of 10 km^2 (Burt et al. 2014, Mora et al. 2006). MPAs of this size would have to be placed directly in the appropriate species habitat, and would not necessarily be large enough to ensure population level protection (Burt et al. 2014). Seventy-eight RCAs (47.6%) are smaller than 10 km^2. A minimum size for protected areas suggested for sessile organisms is 12.6 km^2 (DFO 2019). Eighty-nine RCAs (54.3%) are smaller than 12.6 km^2.

Guidelines supported by academic literature and implemented in California recommend a minimum MPA size range of 23 to 80 km^2 (Burt et al. 2014, Palumbi 2004). One hundred and twenty-four RCAs (75.6%) are smaller than 23 km^2. Twenty-eight RCAs (17.1%) fall within this minimum size range.

In a global review by Edgar et al. (2014), large MPA size (>100 km^2) was found to be one of five key features that contributed directly to conservation effectiveness. Most RCAs (152; 92.7%) are smaller than 100 km^2.

There is considerable evidence that MPA size is important when conservation objectives are a priority. For example, size and age of MPAs in Palau's marine protected areas network explained most of the variation in fish assemblage structure, particularly for piscivores, which are a major target of the local fisheries (Friedlander et al. 2017). A meta-analysis of 19 European no-take MPAs found that for every one-fold increase in no-take MPA size, there was a 35% increase in the density of commercial fishes (Claudet et al. 2008). Edgar and Barrett (1999) compared four no-take MPAs in Tasmania with unprotected reference regions and found the largest MPA had higher fish species richness, higher density of large fish, and larger-sized exploitable fishes when compared with fished reference sites. A study of MPAs in eastern Australia showed that many of the targeted taxa examined were more abundant in large no-take MPAs within a few years of establishment compared with small no-take MPAs and fished sites (Malcolm et al. 2016). Larger MPAs have been shown to possess more and larger resource fishes compared with smaller MPAs (Lester et al. 2009, Claudet et al. 2008).

Larger MPAs may be more effective because they protect a greater amount and diversity of habitats, and encompass and protect critical habitats or processes that maintain populations and ecosystem stability, which provide protection for a wider range of species and buffers against losses associated with environmental fluctuations and large-scale disturbances (Toonen et al. 2013, Allison et al. 2003, Dayton et al. 2000). Large MPAs are more likely to contain fully functional ecosystems and suffer less from outside effects since they have a smaller perimeter-to-area ratio (McLeod et al. 2009, Bartholomew et al 2008).

1.2.2 RCA size in relation to movements of adult rockfish

To ensure the persistence of populations within a reserve, reserve size should encompass the adult home range or neighbourhood size (Burt et al. 2014). Home range is defined as the area an animal uses on a regular basis for its routine activities (Moffit et al. 2009). Species with adult home ranges larger than the size of the reserve will only be partially protected (Palumbi 2004, Botsford et al. 2003). Neighbourhood size refers to the area that is large enough to encompass species movements during the adult life stage, as well as offspring of those adults (Palumbi 2004).

Tagging studies of Blue (Freiwald 2012, Miller and Geibel 1973), Copper (Buonaccorsi et al. 2002), Black (Freiwald 2012, Starr and Green 2007, Lea et al. 1999, Culver 1986, Love 1980, Gotshall et al. 1965), and Quillback (Matthews 1990) Rockfishes all reported most fish moved less than 5 km. A circle-shaped protected area with a radius of 5 km that would encompass most of the movements of these rockfish species would be 78.5 km^2, near the upper end of the minimum MPA size range mentioned above.

RCAs smaller than the minimum sizes suggested for MPAs might still be effective at protecting fish within their boundaries because inshore rockfish generally have small home ranges. Home ranges for five rockfish species are up to 2.8 km, and potentially larger for Blue and Black Rockfishes (Burt et al. 2014). A circle with a diameter of 2.8 km (radius = 1.4 km) has an area equal to 6.2 km^2. Sixty RCAs (36.6%) are smaller than 6.2 km^2.

Hannah and Rankin (2011) suggest small (3.4–15 km^2) no-take MPAs located on high-relief rocky reefs would provide some protection for Black, Copper, and Yelloweye Rockfishes, and greater protection for Quillback and Tiger Rockfishes. Thirty-eight RCAs (23.2%) are smaller than 3.4 km^2 and therefore may not provide sufficient protection for all rockfish species within their boundaries.

1.2.3 Distance from the center to fished boundaries

Another metric related to protected area size is the distance to fished boundaries, and not simply area (Dunham 2018). A RCA could be relatively large, but be long and narrow which could facilitate fish moving across boundaries.

Methods

Distance was determined from the center to the nearest (potentially fished, not against the shore) boundary for each RCA using ArcGIS software. The centroid for a particular RCA polygon was determined using the 'feature to point' tool (default settings with 'inside' option unchecked). This option of the tool uses a proprietary center of gravity-based algorithm to determine the center of mass which may fall inside or outside the polygon. For 11 RCAs, results yielded centroids placed on land or outside RCA boundaries. These RCAs included Bond Sound, Brooks Bay, Fish Egg Inlet, Greenway Sound, Havannah Channel, Loughborough Inlet, Mackenzie-Nimmo, Nowell Channel, Sooke Bay, Thurston Bay and Walken Island to Hemming Bay. For these RCAs, centroids were forced inside by re-running the analysis and specifying the 'inside' option in the tool (Figure 3).

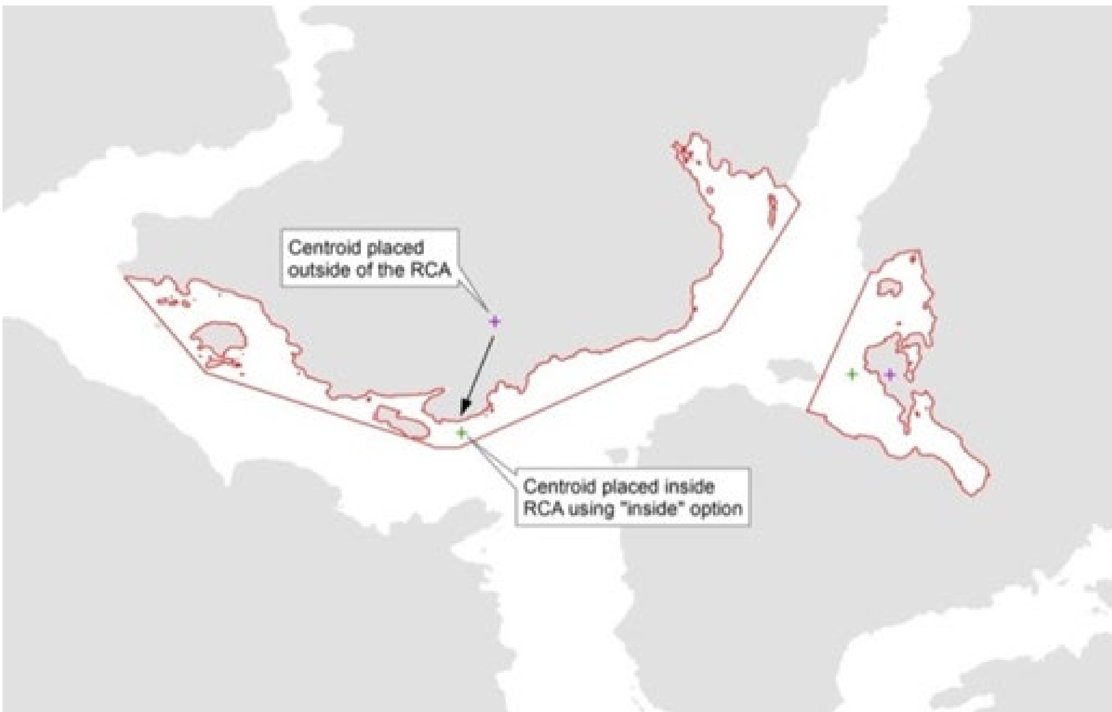

Figure 3. An example of an RCA (Walken Island to Hemming Bay) where the centroid determined to be outside the RCA was 'forced' inside the RCA.

This option uses an algorithm to adjust a centroid that falls outside the polygon to a position based on what is considered to be the center of gravity within its boundaries. This option could have been used initially to create centroids for all RCAs; however, we found that results varied for some RCAs between both options and the default option provided more centered positions. As many RCA polygons are irregularly shaped, we acknowledge a single centroid might not be the best approach and there may be other methods for estimating centroids.

To calculate the distance from the centroid to the nearest potentially fished boundary, we removed those portions of RCA boundaries located against the shore. RCA polygons were converted to linear features and split at the vertices using the 'feature to line' and 'split line at vertices' tools. All line segments representing the shoreline portion of each RCA were selected and then deleted so only the water portion of each RCA boundary remained. Finally, the 'near' tool was used to determine the approximate nearest distance from the centroid to the water boundary segments of each RCA.

Results

Mean home range values for six inshore rockfish species are less than 0.5 km (the highest value being for Black Rockfish). Some Quillback, Blue, and Black Rockfishes likely move further than this (Burt et al. 2014). There are 19 RCAs (11.6%) that are either small or narrow and the distance from the center to the nearest boundary is less than 0.5 km (Table 3). Most inshore rockfish species have movements less than 1 km (Burt et al. 2014). A circle with a radius of 0.5 km has an area of 0.8 km^2 and we suggest this could be a minimum size for RCAs. Three RCAs are smaller than 0.8 km^2: Hardy Bay – Five Fathom Rock, Bentinck Island, and Passage Island (Table 3). These small RCAs might not be sufficiently large to effectively protect rockfish because too many fish will move across boundaries into fished areas.

Although inshore rockfish generally have small home ranges, we caution against making RCAs too small. We used mean home range values to determine the threshold minimum distance from the center of RCAs to the nearest fished boundary. However, some proportion of movements/home ranges will exceed the mean and, therefore, it would be more precautionary to use the 75th percentile of values, which are, for example, 16 km for Black Rockfish and 1.6 km for Blue Rockfish (Freiwald 2012). It is possible the 0.5 km minimum threshold may not be precautionary enough for a subset of inshore rockfish. RCAs in Outside waters are larger and therefore protect species with greater ranges of movement, such as Black Rockfish. Most Black Rockfish are found in Outside waters as they have been fished down in Inside waters (except Queen Charlotte Strait). Smaller RCAs in the Strait of Georgia Bioregion were designed to protect those inshore species with small movements, like Copper, Quillback, and Yelloweye Rockfishes.

Table 3. Small RCAs that fail to meet several size criteria: 1 = less than 0.8 km^2; 2 = less than 1 km^2; 3 = the center to the nearest boundary is less than 0.5 km; 4 = less than 3.4 km^2.

RCA	Bioregion	RCA Area (km^2)	Size Criteria
Hardy Bay - Five Fathom Rock	Northern Shelf	0.13	1, 2, 3, 4
Bentinck Island	Southern Shelf	0.55	1, 2, 3, 4
Passage Island	Strait of Georgia	0.75	1, 2, 3, 4
Trial Island	Southern Shelf	0.83	2, 3, 4
Duntze Head (Royal Roads)	Southern Shelf	0.90	2, 3, 4
Patey Rock	Strait of Georgia	0.91	2, 3, 4
Becher Bay East	Southern Shelf	1.01	3, 4
West Bay	Strait of Georgia	1.06	4
Upper Centre Bay	Strait of Georgia	1.13	4
Danger Reefs	Strait of Georgia	1.48	3, 4
Savoie Rocks - Maude Reef	Strait of Georgia	1.74	3, 4
Deepwater Bay	Strait of Georgia	1.82	4
Mariners Rest	Strait of Georgia	1.86	3, 4
Mid Finlayson Arm	Strait of Georgia	1.92	3, 4
Domett Point	Strait of Georgia	2.06	4
McNaughton Point	Strait of Georgia	2.20	3, 4
Russell Island	Strait of Georgia	2.43	4
Haddington Passage	Northern Shelf	2.47	4
Bedwell Harbour	Strait of Georgia	2.50	4
Baynes Sound - Ship Point	Strait of Georgia	2.53	3, 4
Burgoyne Bay	Strait of Georgia	2.57	4
Gabriola Passage	Strait of Georgia	2.68	4
Cracroft Point South - Sophia Islands	Northern Shelf	2.70	3, 4
Departure Bay	Strait of Georgia	2.70	4
Eastern Burrard Inlet	Strait of Georgia	2.75	4
Race Rocks	Southern Shelf	2.75	4
West Vancouver	Strait of Georgia	2.82	4
Vargas Island to Dunlap Island	Southern Shelf	2.84	4
Indian Arm - Twin Islands	Strait of Georgia	2.86	4
Portland Island	Strait of Georgia	3.04	4
Maud Island	Strait of Georgia	3.09	4
Coal Island	Strait of Georgia	3.14	4
Bowyer Island	Strait of Georgia	3.15	4
Discovery - Chatham Islands	Southern Shelf	3.18	4
Forward Harbour	Northern Shelf	3.25	4
Maple Bay	Strait of Georgia	3.25	4
Thormanby Island	Strait of Georgia	3.25	4
Sooke Bay	Southern Shelf	3.39	3, 4
Queen's Reach East	Strait of Georgia	4.52	3
Pam Rock	Strait of Georgia	5.65	3
Skookumchuck Narrows	Strait of Georgia	13.22	3
Walkem Islands to Hemming Bay	Strait of Georgia	13.59	3

Home ranges do not tell the complete story, however, as results from acoustic tagging suggest. For example, there is considerable variation in home range size for Black Rockfish (0.02-2.7 km^2). Some Black Rockfish occasionally foray several kilometres away or periodically relocate. Females had longer absences during winter reproductive seasons. To summarize, Black Rockfish home ranges, although small, may be ephemeral and open to relocation over various distances (Parker et al. 2007). A more accurate description for Black Rockfish may be a bimodal distribution of movement whereby 60 to 90% of individuals are residential and 10 to 40% migrate depending on the geographic area and age structure of the population (Green et al. 2014), as well as seasonality (Green and Starr 2011). Wallace et al. (2010) reported 85% of the recoveries of tagged Black Rockfish were within 20 km of their release location, and some fish displayed significant movements. The mean home range of Blue Rockfish is also small (0.23 km^2), but as many as 30% of tagged Blue Rockfish shifted their core home range area, generally during the upwelling season. Some fish moved up to 3.1 km when in residence (Green et al. 2014). Ten percent of Blue Rockfish movement studies have reported larger movements (as great as 41 km; Freiwald 2012). Although inshore rockfish generally have small home ranges, there appears to be variability in home range size and fish may sometimes foray away from their small home ranges. Furthermore, rockfish may periodically relocate to new locations, and some fish seem to migrate considerable distances. For these reasons very small RCAs may not provide sufficient protection for rockfish throughout their lives even if they do have small home ranges as many fish at some point may move outside protected areas and be subject to fishing mortality (Green et al. 2014, Tolimieri et al. 2009).

Our approach in this review, based on the continued decline of inshore rockfish populations, is to consider spillover of adult fish from protected areas as negative rather than positive, and we suggest options for decreasing spillover, at least in the near future. Small protected areas will export more adults which may benefit surrounding fisheries at the expense of conserving species within their boundaries. Intermediate-sized protected areas may or may not retain enough fish to be self-sustaining; however, they might provide some benefit to surrounding fisheries through spillover of adults (Halpern and Warner 2003). Large protected areas likely will retain most adult fish and few will spill over into adjacent fished areas. There are, however, challenges associated with implementing large protected areas.

1.2.4 Conclusions

- Many RCAs are small, especially those in the Strait of Georgia Bioregion and the Inside Management Area.
- Many RCAs are smaller than minimum sizes recommended for MPAs (5, 10, 13, 23-80, 100 km^2).
- Inshore rockfish have small home ranges; therefore, small RCAs may provide conservation benefits to them. Nevertheless, some RCAs may be too small resulting in many fish moving beyond boundaries into fished areas. RCAs smaller than 3.4 km^2, and especially 0.8 km^2, and those where fished boundaries are closer than 0.5 km, may experience high spillover which might negate conservation benefits.
- Even though most inshore rockfish have small home ranges, tagging studies provide evidence rockfish often move beyond their home ranges. Larger RCAs are precautionary and provide numerous conservation benefits.
- To accommodate fish larvae dispersal, marine protected areas need to be large. A well-designed network of many small protected areas may achieve the same conservation benefits as a few large ones.

1.2.5 Recommendations

1. Minimum sizes for RCAs based on MPAs and adult rockfish movements could be 0.8, 3.4, 5, 6.2, 10, 13, or 23 km^2. Three RCAs are smaller than 0.8 km^2 (Hardy Bay – Five Fathom Rock, Bentinck Island, and Passage Island). A precautionary minimum RCA size might be at least 3.4 km^2 to conserve inshore rockfish. Consider increasing the size of RCAs listed in Table 3 with priority given to those RCAs that meet the four small size criteria, followed by three criteria, etc.
2. Based on rockfish movements, a minimum distance from the center to the nearest fished boundaries should be at least 0.5 km, and possibly further to be precautionary. Consider adjusting boundaries in RCAs to ensure they meet the minimum distance.

1.2.6 Knowledge Gaps and Research Recommendations

- As a precautionary measure, determine an interim minimum size for RCAs based on adult rockfish movements.
- Irrespective of RCA size, as a precautionary measure determine an interim minimum distance to fished boundaries in RCAs.
- Over the long-term, resolving the above two points may involve acoustic tagging studies to determine how frequently individual rockfish shift from one home site to another over the course of their lifetime, whether dispersal is linear over time or occurs at irregular frequencies, and what proportions of populations undertake shifts in home ranges over time (Green et al. 2014).
- Compare large versus small no-take RCAs with similar habitat, and of the same age, to examine the effect of RCA size on rockfish density and diversity.

1.3 ROCKFISH HABITAT

An important attribute is the presence of rockfish habitat in RCAs (Parnell et al. 2006). We define rockfish habitat as benthic areas (rocky reefs, kelp forests, eelgrass beds, and glass sponge reefs) that are important to the various life stages of inshore rockfish (Frid et al. 2018, Dunham et al. 2018).

1.3.1 Methods

Rocky reef data

Two substrate models were used to predict the presence of rocky reef habitat. One model utilized multi-beam data at 5×5m resolution, the other model utilized coast-wide bathymetry data at 20×20m resolution. These models were originally developed by Haggarty (2015) and Haggarty and Yamanaka (2018) to model substrates along the BC Coast within depths of 0 to 250 m. For both models, we used versions updated by DFO in 2017 to further isolate substrates within a 5 to 250 m depth zone based primarily on habitat characteristics for Yelloweye (COSEWIC 2008) and Quillback (COSEWIC 2009) Rockfishes as described by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Multi-beam modeled data do not encompass the entire BC Coast and cover only certain areas in the South Coast. Multi-beam data have been collected in 96 RCAs and are not available for 68 RCAs, 48 of which are located in the South Coast and 20 in the Central and North Coasts. For the 68 RCAs with no coverage of high resolution multi-beam modeled data, we used the coast-wide modeled data at 20×20m resolution to conduct our analysis.

Haggarty (2015) noted the rocky reef 20×20m resolution model performed well inshore where RCAs are located, but did not perform as well away from shore. This type of model also underestimates rocky reef habitat in steep sloping areas such as in coastal fjords and Johnstone Strait. In general, measuring rocky reef habitat in inlets is challenging because both models use horizontal areas and do not incorporate the three dimensional nature of inlet habitats. For these reasons, the amount of rocky reef habitat in inlets may be less accurate than in other areas.

Lastly, due to its coarser resolution, the 20×20m resolution model generally overestimates the amount of rocky reef habitat in RCAs compared to the higher resolution model.

Models were provided as raster layers. Since other datasets used for analyses were vector based, we converted the rocky reef habitat model layers into polygons.

Eelgrass bed and kelp canopy data

For eelgrass beds and kelp canopies, we used spatial layers (polygons) available from the BC Marine Conservation Analysis (BCMCA) Atlas and the Province of BC's Coastal Resource Information Management System (CRIMS). We also included eelgrass bed and kelp canopy data obtained from Harper and Morris (2014); however, these are represented as linear features and therefore have no associated area measurement. In order to assign area to line data, we applied a 20 m buffer around the features with the rationale being one of the rocky reef models used 20×20m resolution bathymetry data. Please note a 20 m buffer may not adequately capture the extent of all eelgrass and kelp line features intended by these datasets. Depths at which these features may be present were also not considered in our analysis. In addition, eelgrass/kelp line data generally follow shorelines which may not align perfectly with RCA coastlines due to different sources of coastlines used in the datasets. We attempted to align the eelgrass/kelp line data to RCA boundaries as much as possible.

The steps used to generate areas for line data are as follows:

1. In ArcGIS, those RCAs that intersected kelp/eelgrass line features were selected (20 RCAs have kelp, 14 RCAs have eelgrass).
2. Kelp/eelgrass line features were edited to better align with RCAs. Kelp/eelgrass lines surrounding each RCA were selected and manually moved to align with RCA boundaries.
3. Kelp/eelgrass line features were buffered by 20 m.
4. Buffered line features were clipped by the RCAs and inside areas calculated.

The 20 RCAs where kelp line data were buffered include Brooks Bay, Checleset Bay, Dunira, Frederick Island, Goose Island, Goschen, Hodgson Reefs, Holberg Inlet, Kitasu Bay, Lyell Island, McMullin Group, Otter Passage, Porcher Peninsula, Scott Islands, Smith Sound, South Moresby, Stephens Island, Top Knot, West Banks Island, and West Calvert. The 14 RCAs where eelgrass line data were buffered include Brooks Bay, Checleset Bay, Dunira, Fish Egg Inlet, Kitasu Bay, Lyell Island, McMullin Group, Otter Passage, Smith Sound, South Moresby and Top Knot. Results from this analysis should be considered approximate due to the nature of the data and the fact that they use a different coastline than the RCA dataset.

Eelgrass and kelp canopy data (Table 1) have not been ground-truthed and are somewhat outdated. Furthermore, for some eelgrass beds and kelp, the linear extent would simply capture presence and absence, but not areal extent which will sometimes underestimate or overestimate values. Consequently, there are several uncertainties associated with the calculated areas of eelgrass beds and kelp canopies in RCAs.

Glass sponge reef data

We used the West Coast sponge reef dataset provided by the Geological Survey of Canada, Natural Resources Canada (NRCan). The dataset delineates the distribution of glass sponge reefs along the BC Coast which were mapped using high resolution multi-beam bathymetry data. The presence of sponge reefs were confirmed in most cases by Remotely Operated Vehicles (ROVs) and/or acoustic methods (NRCan 2018). For our analysis, we also incorporated a dataset included as part of a DFO Science Response (DFO 2018) which consists of 22 sponge aggregations (bioherms and gardens) recently identified in Howe Sound. Some of these aggregations have been assigned live reef status, some are data-deficient and require further ground-truthing, and some are protected by bottom-contact fishing closures. It should be acknowledged that, although datasets are available on the geological signature of sponge reefs, minimal visual surveys have been done to date to confirm their current condition and characteristics, such as live sponge cover and associated biodiversity.

Determining the proportion and area of rockfish habitat in RCAs

Benthic habitat datasets (rocky reef, kelp canopy, eelgrass bed, and sponge reef) were combined to create four layers to represent rockfish habitat. Table 4 summarizes the rockfish habitat layers and the particular combination of habitat type datasets used.

Table 4: Benthic habitat datasets combined to create rockfish habitat layers. Layers ultimately used in our assessment are shaded.

Rockfish Habitat Layer	Habitat Type Datasets Merged Together	Comments
Habitat5m	Rocky reef 5×5m, sponge reefs, eelgrass (polygons), kelp (polygons)	Covers a portion of the BC South Coast in 96 RCAs (68 RCAs have no coverage). Clipped to the extent of the rocky reef modeled data.
Habitat5m_EK20m	Rocky reef 5×5m, sponge reefs, eelgrass (polygons and line data buffered by 20 m), kelp (polygons and line data buffered by 20 m)	Covers a portion of the BC South Coast in 96 RCAs (68 RCAs have no coverage). Clipped to the extent of the rocky reef modeled data. Used to report final results for 96 RCAs.
Habitat20m	Rocky reef 20×20m, sponge reefs, eelgrass (polygons), kelp (polygons)	Coast-wide coverage.
Habitat20m_EK20m	Rocky reef 20×20m, sponge reefs, eelgrass (polygons and line data buffered by 20 m), kelp (polygons and line data buffered by 20 m)	Coast-wide coverage. Used to report final results for 68 RCAs with no high resolution rocky reef modeled data.

GIS analyses were conducted on each of the four rockfish habitat layers to determine the area of rockfish habitat within bioregions/management areas and RCAs. We used the following steps to conduct our GIS analyses:

1. To determine rockfish habitat in management areas:
   a. The PFMAs dataset was used to delineate the Inside and Outside Management Areas. Each PFMA was assigned to either Inside or Outside waters and then merged to create a new layer consisting of two polygons representing the Inside and Outside Management Areas.

   b. Each habitat layer (Habitat5m, Habitat5m_EK20m, Habitat20m, and Habitat20m_EK20m) was intersected with the new layer to determine rockfish habitat areas overlapping the two management areas.
   c. Proportions and areas were calculated for overlap habitat areas using the 'Calculate Geometry' function in ArcGIS.
2. To determine rockfish habitat in bioregions:
   a. Each habitat layer was intersected with the bioregions dataset to determine the area of rockfish habitat overlapping each bioregion.
   b. Proportions and areas were calculated for overlap habitat areas using the 'Calculate Geometry' function in ArcGIS.
3. To determine rockfish habitat in RCAs:
   a. Each habitat layer was intersected with the RCA dataset to determine the area of rockfish habitat overlapping RCAs.
   b. Proportions and areas were calculated for overlap habitat areas using the 'Calculate Geometry' function in ArcGIS.

We compared results derived for each of the rockfish habitat layers. We discovered data gaps when applying the various rockfish habitat layers; for example, some RCAs, such as Halibut Bank, have virtually no rockfish habitat according to the coarser resolution modeled data whereas the higher resolution model results showed considerably more rockfish habitat. We also needed to incorporate the 20 m buffered eelgrass/kelp line data since excluding these data would leave out important habitat in some RCAs, such as Scott Islands, where these habitat line features exist. For these reasons we concluded using the Habitat5m_EK20m and Habitat20m_EK20m layers would be most appropriate for reporting our results. Using both rockfish habitat layers provide spatial coverage for all RCAs coast-wide; for 96 RCAs, results were derived using the Habitat5m_EK20m layer, for 68 RCAs results were derived using the Habitat20m_EK20m layer because no multi-beam data exist. For the remainder of this paper, the Habitat5m_EK20m and the Habitat20m_EK20m layers are simply referred to as the 5×5m and 20×20m habitat models. Table 18 lists each RCA and the type of habitat model used (20 or 5).

We considered three metrics for rockfish habitat:

1. the proportion of individual RCAs comprised of rockfish habitat,
2. the total area of rockfish habitat in individual RCAs, and
3. habitat isolation and spillover. The California Marine Life Protection Act Size and Spacing Analysis used guidelines for both the percent and total area of habitat protected because a small MPA may protect a large fraction of habitat, but an insignificant amount of habitat, whereas a large MPA may protect a low proportion, but large amount of habitat. Edgar et al. (2014) identified habitat isolation as a key MPA feature.

1.3.2 Proportion of rockfish habitat

On average, 26% of the area covered by a particular RCA is comprised of rockfish habitat (Table 5).

Table 5. Proportion (%) of RCAs comprised of rockfish habitat, and the proportion of rockfish habitat protected in RCAs, by bioregion and management area as determined by habitat models.

Bioregion / Management Area	Sum RCA Size (km^2)	Sum Area of Rockfish Habitat in RCAs (km^2)	% RCA Area that is Rockfish Habitat	Total Rockfish Habitat (km^2) in Bioregion / Mgmt Area[1]	% Total Area Rockfish Habitat Protected in RCAs
Strait of Georgia	937.7	142.5	15.2	688.2	20.7
Southern Shelf	560.8	153.5	27.4	1444.3	10.6
Northern Shelf	3320.3	957.9	28.8	6265.8	15.3
Inside	1551.8	283.9	18.3	1501.6	18.9
Outside	3267.0	970.0	29.7	6896.6	14.1
All RCAs	4818.8	1253.9	26.0	8398.3	14.9

[1]Rockfish habitat based on rocky reef 20×20m, sponges, eelgrass and kelp (with line data buffered 20 m)

Used the coast-wide total for Inside/Outside management areas.

Bioregions dataset derived from Open Government.

Inside/Outside management dataset derived from PFMAs dataset which corresponds to 1:50K watersheds.

Adjusted rockfish habitat in each bioregion by using its proportion (%) coast-wide and applied that percentage to the total management area.

The proportion of RCAs that is rockfish habitat is lower in the Strait of Georgia Bioregion and Inside Management Area compared to other bioregions and the Outside Management Area (Table 5).

The proportion of the total area of a RCA that is rockfish habitat ranges from approximately 1% (Baynes Sound – Ship Point) to 98% (Race Rocks). The California MLPA considered a rare habitat such as kelp forests to be present in a MPA if it covered at least 10% of the protected area (California MLPA Advisory Team 2006). There are 34 RCAs (21%) that contain less than 10% rockfish habitat and therefore by the definition above may contain a small amount of habitat (Table 6). Ninety-one RCAs (55%) have less than 20% rockfish habitat. Most RCAs (148; 90%) contain less than 50% rockfish habitat.

RCAs in the Inside Management Area protect 18.9% of total rockfish habitat, less than the 28% initially estimated by Yamanaka and Logan (2010) who used lower resolution bathymetry data which would tend to overestimate the amount of habitat. Regardless, considerably less habitat than the desired conservation target of 30% is currently being protected in Inside waters. RCAs in the Outside Management Area protect 14.1% of available rockfish habitat, similar to the 15% estimated by Yamanaka and Logan (2010). Note that 20×20m resolution data common in Outside waters may overestimate the amount of habitat, similar to the very coarse resolution data used to establish RCAs. The desired conservation target in Outside waters is 20%, somewhat higher than what is currently protected.

1.3.3 Area of rockfish habitat

There is a considerable range in the area of rockfish habitat in RCAs (0 to 211.5 km^2); however, most RCAs (123 RCAs; 75%) contain less than 5 km^2 of rockfish habitat (Figure 4).

Table 6. RCAs where the proportion (%) of rockfish habitat is less than 10%.

RCA	Bioregion	RCA Area (km^2)	% Rockfish Habitat
Baynes Sound - Ship Point	StG	2.53	1.0
Eastern Burrard Inlet	StG	2.75	2.3
Wakeman Sound	NS	12.47	2.8
Loughborough Inlet	NS	37.14	2.8
Kanish Bay	StG	7.99	2.8
Oyster Bay	StG	9.14	2.9
Forward Harbour	NS	3.25	3.0
Galiano Island North	StG	9.76	3.5
Lasqueti South -Young Point	StG	9.27	4.2
Dinner Rock	StG	6.66	4.3
Port Elizabeth	NS	6.03	4.6
Ajax / Achilles Bank	StG	73.91	4.7
Halibut Bank	StG	33.04	4.9
Thompson Sound	NS	13.95	5.1
Upper Call Inlet	NS	21.05	5.5
Bond Sound	NS	3.82	6.0
Departure Bay	StG	2.7	6.1
McCall Bank	StG	13.43	6.3
Northumberland Channel	StG	14.82	7.4
Trincomali Channel	StG	21.73	7.7
Greenway Sound	NS	17.89	8.0
Kwatsi Bay	NS	3.43	8.4
Domett Point	StG	2.06	8.5
Gull Rocks North	NS	5.85	8.7
Mid Finlayson Arm	StG	1.92	8.8
Mitlenatch Island	StG	24.92	8.9
Deepwater Bay	StG	1.82	9.3
Scott Islands	NS	339.17	9.3
Mariners Rest	StG	1.86	9.3
Burgoyne Bay	StG	2.57	9.4
West Bay	StG	1.06	9.4
Viscount Island	NS	21.86	9.6
Bute Inlet North	StG	46.24	9.7
Maud Island	StG	3.09	9.9

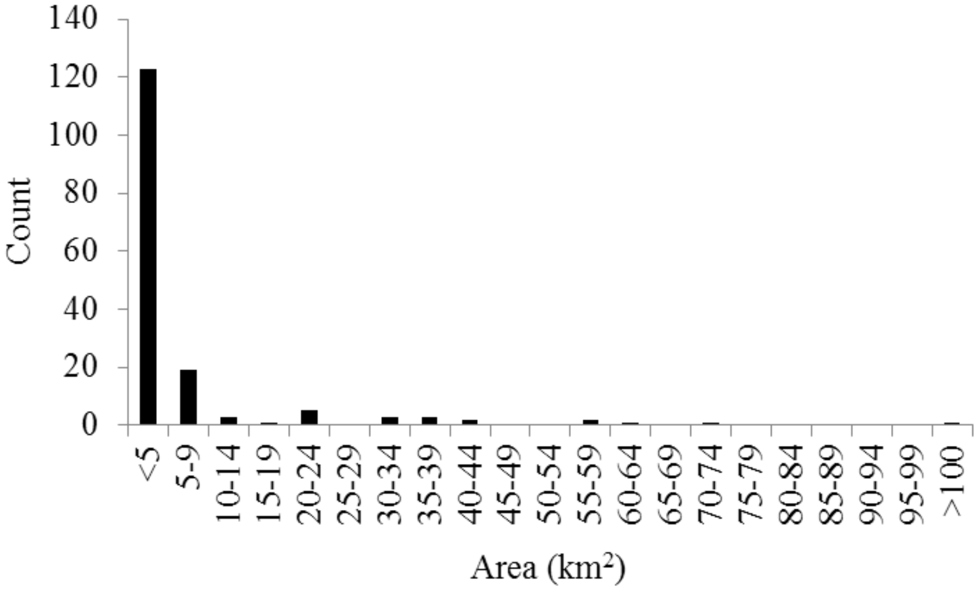

Figure 4. Frequency distribution of rockfish habitat area in RCAs.

The mean area of rockfish habitat in these 123 RCAs is 1.5 ± 0.12 km^2 (mean ± SE). Collectively RCAs protect 1,254 km^2 of rockfish habitat, most (90.6%) of which is rocky reef (Table 7). The area of rockfish habitat protected in RCAs is considerably higher in the Northern Shelf Bioregion and Outside Management Area (Tables 5, 7). However, rockfish habitat in 68 RCAs in the South, Central, and North Coasts were determined using the lower resolution (20×20m) model derived from bathymetry and substrate data rather than the higher resolution multi-beam model which may inflate the area of rockfish habitat in these particular RCAs. Individual RCAs in the Southern Shelf contain nearly twice as much habitat compared to RCAs in the Strait of Georgia Bioregion (Table 7).

If the minimum overall size of RCAs discussed previously (0.8 or 3.4 km^2) is applied to rockfish habitat rather than simply overall RCA size, then many RCAs do not contain these minimum areas of rockfish habitat. Fifty-one RCAs (31%) contain less than 0.8 km^2 of rockfish habitat. There are three RCAs whose overall area is less than 0.8 km^2. One hundred and five RCAs (64%) contain less than 3.4 km^2 of rockfish habitat within their boundaries. There are 38 RCAs whose overall area is less than 3.4 km^2. RCAs containing less than 0.8 km^2 of rockfish habitat within their boundaries are listed in Table 8.

Note the area of rockfish habitat calculated in RCAs is simply the total amount of habitat present and does not take into account important habitat features like *quality* and *continuity.* Habitat quality in RCAs may be one of the most important features determining their effectiveness (Haggarty 2014). Rocky reef includes smooth bedrock and structurally complex boulder pile; however, the latter is much more valuable to many rockfish species (Frid et al. 2018). Rockfish home ranges also tend to be smaller where habitat is good compared to low relief habitat. Glass sponge reefs can be detected as a geological signature even with little live reef, or reefs may have many confirmed living sponges as determined by research surveys. Rockfish prefer live reefs, but the quality of glass sponge reef habitat was not assessed in this report. Continuity of habitat might also be important; a RCA that has several small patches of rockfish habitat might not provide the same conservation benefit as a RCA with the same area of habitat that exists as a continuous patch.

Table 7: Area (km²) of RCAs comprised of rockfish habitat types determined by habitat models.

Bioregion / Management Area	Rocky Reefs	Kelp	Eelgrass	Sponge Reefs	Total[1]	Median RCA Size (km²)	Median Area of Rockfish Habitat (km²)
Strait of Georgia (84 RCAs)	124.7	16.5	6.5	1.8	142.5	6.7	1.0
Southern Shelf (19 RCAs)	132.9	33.8	4.2	0.0	153.5	8.2	1.9
Northern Shelf (61 RCAs)	878.6	117.7	12.0	6.1	957.9	17.8	4.5
Inside (128 RCAs)	248.6	44.6	6.7	1.9	283.9	8.2	1.2
Outside (36 RCAs)	887.6	123.3	16.0	6.1	970.0	61.0	17.0
All RCAs	1136.2	167.9	22.7	7.9	1253.9	10.8	1.9
Proportion (%) of All RCAs	23.6	3.5	0.5	0.2	26.0	-	-
Number of RCAs	164	83	37	15	164	-	-

[1]Areas overlapping between habitat types were removed.

Table 8: RCAs containing less than 0.8 km² of rockfish habitat. Concerns include the absence of rockfish and spillover. S are high ratio values (>1.58 in Table 10, and Table 11) which may indicate high spillover.*

RCA	Bioregion	Area (km^2)	Habitat Area (km^2)	Habitat area (%)	Concern: Absence; Spillover
Hardy Bay - Five Fathom Rock	NS	0.13	0.02	12.69	S*
Baynes Sound - Ship Point	StG	2.53	0.03	1.01	A, S*
Eastern Burrard Inlet	StG	2.75	0.06	2.34	S*
Forward Harbour	NS	3.25	0.10	2.97	A
West Bay	StG	1.06	0.10	9.39	S
Upper Centre Bay	StG	1.13	0.14	11.97	S
Bentinck Island	SS	0.55	0.16	28.45	A
Departure Bay	StG	2.70	0.16	6.06	A, S*
Mid Finlayson Arm	StG	1.92	0.17	8.79	S*
Deepwater Bay	StG	1.82	0.17	9.27	A, S
Mariners Rest	StG	1.86	0.14	7.70	S*
Domett Point	StG	2.06	0.18	8.54	A, S*
Kanish Bay	StG	7.99	0.23	2.84	S
Bond Sound	NS	3.82	0.23	6.01	A, S*
Burgoyne Bay	StG	2.57	0.24	9.36	A, S
Oyster Bay	StG	9.14	0.27	2.94	S
Passage Island	StG	0.75	0.23	30.85	S*
Port Elizabeth	NS	6.03	0.27	4.56	A
Kwatsi Bay	NS	3.43	0.29	8.37	A
Dinner Rock	StG	6.66	0.29	4.32	A, S
Maud Island	StG	3.09	0.30	9.85	S
Galiano Island North	StG	9.76	0.34	3.46	A
Wakeman Sound	NS	12.47	0.35	2.81	A
Patey Rock	StG	0.91	0.37	41.18	S*
Lasqueti South -Young Point	StG	9.27	0.39	4.18	A
Maple Bay	StG	3.25	0.40	12.44	S
Indian Arm - Twin Islands	StG	2.86	0.40	14.15	S
Menzies Bay	StG	3.91	0.41	10.46	A
Haddington Passage	NS	2.47	0.41	16.53	A, S*
Bedwell Harbour	StG	2.50	0.43	17.27	A
Gull Rocks North	NS	5.85	0.51	8.70	A, S*
Belleisle Sound	NS	5.13	0.52	10.04	A
Mackenzie - Nimmo	NS	3.97	0.53	13.25	A
West Vancouver	StG	2.82	0.54	19.08	S*
Duntze Head(Royal Roads)	SS	0.90	0.56	62.18	S*
Becher Bay East	SS	1.01	0.57	56.49	S*

RCA	Bioregion	Area (km^2)	Habitat Area (km^2)	Habitat area (%)	Concern: Absence; Spillover
Queen's Reach West	StG	3.49	0.58	16.63	S
Brentwood Bay	StG	3.40	0.59	17.22	S*
Savoie Rocks - Maude Reef	StG	1.74	0.61	34.77	A, S*
Russell Island	StG	2.43	0.63	25.96	S*
Bowyer Island	StG	3.15	0.65	20.72	S*
Woolridge Island	StG	3.79	0.66	17.28	S*
De Courcy Island North	StG	4.02	0.69	17.14	S
Trial Island	SS	0.83	0.69	83.84	S*
Thompson Sound	NS	13.95	0.71	5.08	A
Chrome Island	StG	3.88	0.73	18.70	A, S
Thurston Bay	StG	6.61	0.73	11.09	S
Coffin Point	StG	4.32	0.77	17.90	A, S*
Queen's Reach East	StG	4.52	0.77	17.13	S*
Reynolds Point - Link Island	StG	4.26	0.78	18.31	S*

We examined maps of RCAs listed in Table 8 and compared their boundaries to the extent and distribution of rockfish habitat, and have indicated whether the absence of rockfish or spillover might be of concern. RCAs with very little habitat may contain few fish and have limited conservation benefit. RCAs with lengthy boundaries that intersect rockfish habitat may experience more spillover since fish might be moving around on reefs that exist both inside and outside the RCA. Those RCAs with high ratio values (discussed below: Habitat Isolation) have been highlighted in Table 8 to corroborate the concern of higher spillover.

RCAs which are larger in size and contain very little rockfish habitat may not support many rockfish (e.g. Wakeman Sound) and might be good candidates to be moved to other locations where there is considerably more rockfish habitat and potentially higher fish abundances. In contrast, RCAs which are smaller in size and contain a higher proportion of rockfish habitat may experience higher rates of spillover as habitats often exist on both sides of boundaries (e.g. Upper Centre Bay RCA). These RCAs might be good candidates to have their boundaries adjusted to incorporate more reef and potentially isolated the reef within the RCA.

Glass sponge reefs are sensitive benthic habitats which provide excellent habitat for rockfish (Dunham et al. 2018). Fifteen RCAs have a combined total of 7.9 km^2 of documented biologically significant glass sponge reefs within their boundaries (Table 9). The largest area of sponge reef is in Gull Rocks South RCA where 3.3 km^2 of reef covers 16% of the protected area.

Presently, under the current management regime, glass sponge reefs are not completely protected in RCAs since bottom contact fishing gear (e.g. crab and prawn traps) are allowed. Consequently, incorporating sponge reefs in RCAs will not significantly increase the protection of sponge reefs; in fact, because protection measures in glass sponge reef closures are stronger than for RCAs, the protection of sponge reefs from bottom contact fishing might improve the protection of rockfish and their habitat in RCAs. Consideration should be given as to whether RCAs with sensitive benthic habitats such as glass sponge reefs should be provided the same protection standards as what exists in glass sponge reef closures. Unknown small glass sponge reefs and sponge gardens likely exist in RCAs, and more restrictions for gear that contact the bottom would help protect these kinds of sensitive benthic habitats.

Table 9. RCAs with glass sponge reefs within their boundaries.

RCA	Bioregion	RCA Area (km^2)	Sponge Area (km^2)	Sponge Area (%)	Comments
Gull Rocks South	Northern Shelf	20.86	3.34	16.0	
Stephens Island	Northern Shelf	111.98	2.22	2.0	North boundary could be moved to incorporate more reef
Ajax / Achilles Bank	Strait of Georgia	73.91	0.94	1.3	Southeast boundary could be moved slightly to incorporate entire sponge reef
Gull Rocks North	Northern Shelf	5.85	0.42	7.2	
Lions Bay	Strait of Georgia	4.84	0.32	6.6	North boundary could be moved to incorporate one reef
Bowyer Island	Strait of Georgia	3.15	0.14	4.4	
West Vancouver	Strait of Georgia	2.82	0.13	4.6	South boundary could be moved to incorporate more reef
Passage Island	Strait of Georgia	0.75	0.14	18.7	Considerably more reefs exist around this RCA which protects only a small proportion. Boundary could be expanded in most directions. However, most reefs are covered by existing bottom contact fishery closures except for some data-deficient reefs located north and east of the RCA
Goletas Channel	Northern Shelf	36.69	0.07	0.2	
Pam Rock	Strait of Georgia	5.65	0.07	1.2	
Goose Island	Northern Shelf	105.47	0.04	0.04	East boundary could be moved to include three reefs
North Danger Rocks	Northern Shelf	128.82	0.03	0.02	Large sponge reefs exist nearby to the west that are protected by the Hecate Strait/Queen Charlotte Sound MPA
Hodgson Reefs	Northern Shelf	11.48	0.02	0.2	West boundary could be moved to incorporate more reefs
Bell Chain Islets	Strait of Georgia	13.02	0.02	0.15	Several reefs located to the north are protected by bottom contact fishery closures
Mariners Rest	Strait of Georgia	1.86	0.03	1.6	Sponge reefs require further ground-truthing (data-deficient).

1.3.4 Habitat isolation (and spillover)

We assessed two metrics related to habitat isolation as excessive spillover of mature fish may decrease the conservation benefit of RCAs to rockfish (Haggarty 2015, Edgar et al. 2014).

Boundary to area ratio

The shape of a reserve influences the ratio of boundary to area/volume which, in turn, affects the degree of species retention versus spillover and the ease of compliance and enforcement. The more perimeter edge a reserve has, the more it will export larvae and adults to the surrounding area (Roberts et al. 2003). Furthermore, longer perimeter edge allows for more 'fishing the line' whereby bait can draw animals out of the protected area or fishing gear can drift into the area. Haggarty et al. (2016) found that RCAs with a longer perimeter were more likely to be recreationally fished than those with a short boundary. Consequently, biodiversity objectives are better served by protected areas that have higher area/volume and minimized edges, whereas fisheries benefits will be greater for protected areas that have shapes with a greater edge to volume ratio (Fernandes et al. 2012, Gaines et al. 2010, McLeod et al. 2009). RCAs with lower water boundary to area ratios may protect rockfish better and promote recovery; these areas are generally larger and have proportionally shorter water boundaries which may limit the degree of spillover. In contrast, RCAs with higher values likely experience higher spillover and more fishing along boundaries; these areas are generally smaller with proportionally longer water boundaries.

We used the following equation to calculate the boundary to area ratio (from Bartholomew et al. 2008):

Ratio = Reserve Perimeter (RP) / Total reserve Area (RA)

Methods

Since most RCAs have boundaries in water and against land (along the shore and islands), we focused on water boundaries as this is where fish can move across and fishing may occur. For each RCA, the length of the boundary in the water divided by RCA area is a measure that shows the edge to area ratio.

In GIS, we calculated the approximate lengths of the perimeters for each RCA and then separated boundaries in water and those against land. To determine the lengths of boundaries in water, we:

1. Converted the RCA polygon layer to linear features using the 'feature to line' ArcGIS tool.
2. Split the linear features at the vertices using the 'split line at vertices' tool.
3. Selected and deleted all shoreline segments. This was done with an initial selection of all records with lengths less than 10 m. Those remaining needed to be selected and deleted manually. This attribute table was summarised and joined to the RCA layer. Water boundary length for each RCA was calculated by subtracting on-shore length from total length.

Results

Values ranged from 0.02 (Princess Louisa Inlet RCA, a relatively small RCA with a very short water boundary across the entrance to the inlet) to 9.67 (Hardy Bay – Five Fathom Rock RCA, the smallest RCA which is completely encircled by a water boundary). RCAs with ratio values greater than 1.42 are listed in Table 10 (Please refer to Table 16 for an explanation of the ratio value 1.42). The conservation benefits of these RCAs might improve if their areas are increased. RCAs with ratio values in Table 10 are also identified in Table 8 to help prioritize the selection of RCAs based on the area of rockfish habitat.

Length of boundary intersecting rockfish habitat ratio

If edge permeability is low, then reserves with boundaries that conform to natural habitat edges are more likely to retain fish and show higher density and larger average sizes (Chapman and Kramer 2000) and are therefore more effective (Edgar et al. 2014). In contrast, reserve boundaries that intersect habitats should have high permeability and facilitate movement of fish into surrounding fished areas at that boundary (Roberts 2000). Bartholomew et al. (2008) provided evidence that reducing reserve boundary intersections with reef habitat may improve fish protection and conservation. Reserves which have boundaries that correspond to natural reef habitat boundaries such as sandy habitats may have higher recovery rates than reserves where boundaries intersect reef habitat.

Methods

Previously determined RCA water boundaries were used to calculate boundary lengths that intersect rockfish habitat. For 96 RCAs, water boundaries were intersected with the Habitat5m_EK20m layer; for the other 68 RCAs with no multi-beam data, the Habitat20m_EK20m layer was used. We then calculated the length of intersecting RCA water boundaries for the habitat layers.

We used the following ratio as a measure of the amount of boundary that intersects with habitat (from Bartholomew et al. 2008):

Ratio = Reserve boundary that intersects reef habitat (HI) / reef habitat area within the reserve (HA)

Results

Larger values indicate there is a higher proportion of water boundary that intersects rockfish habitat. RCAs with high ratio values may not contain isolated habitats and spillover may be higher; consequently, these RCAs may experience lower densities and sizes of fish, and lower recovery rates. Lower values indicate there is a shorter distance of water boundary that intersects with habitat. RCAs with the highest ratio values (≥1.3; third quartile) are listed in Table 11.

Table 10. RCAs with boundary (in the water) to area ratio values greater than 1.42. The higher the ratio, potentially the higher the degree of spillover.

RCA	Bioregion	Area (km^2)	Boundary Length In Water (km)	Ratio Water Boundary to Area
Hardy Bay - Five Fathom Rock	NS	0.13	1.26	9.67
Trial Island	SS	0.83	3.85	4.64
Patey Rock	StG	0.91	3.94	4.33
Passage Island	StG	0.75	2.88	3.84
Danger Reefs	StG	1.48	5.28	3.57
Haddington Passage	NS	2.47	8.07	3.27
Becher Bay East	SS	1.01	3.21	3.18
Race Rocks	SS	2.75	8.29	3.01
Bowyer Island	StG	3.15	9.36	2.97
Baynes Sound - Ship Point	StG	2.53	7.18	2.84
Portland Island	StG	3.04	8.61	2.83
McNaughton Point	StG	2.2	6.16	2.80
Duntze Head (Royal Roads)	SS	0.9	2.50	2.78
Domett Point	StG	2.06	5.45	2.65
Mid Finlayson Arm	StG	1.92	4.74	2.47
Discovery - Chatham Islands	SS	3.18	7.17	2.26
Pam Rock	StG	5.65	11.72	2.07
Savoie Rocks - Maude Reef	StG	1.74	3.57	2.05
Mariners Rest	StG	1.86	3.78	2.03
Sooke Bay	SS	3.39	6.72	1.98
Heriot Bay	StG	5.13	9.88	1.93
West Vancouver	StG	2.82	5.41	1.92
Gull Rocks North	NS	5.85	11.08	1.89
Bond Sound	NS	3.82	7.22	1.89
Ruxton - Pylades Island	StG	6.81	11.94	1.75
Eastern Burrard Inlet	StG	2.75	4.75	1.73
Bentinck Island	SS	0.55	0.94	1.71
Queen's Reach East	StG	4.52	7.70	1.70
Departure Bay	StG	2.7	4.51	1.67
Vargas Island to Dunlap Island	SS	2.84	4.74	1.67
Cracroft Point South - Sophia Islands	NS	2.7	4.43	1.64
Woolridge Island	StG	3.79	6.10	1.61
Ballenas Island	StG	5.8	9.26	1.60
Russell Island	StG	2.43	3.87	1.59
Oyster Bay	StG	9.14	14.41	1.58
Thormanby Island	StG	3.25	4.99	1.53
Reynolds Point - Link Island	StG	4.26	6.50	1.53
McCall Bank	StG	13.43	19.62	1.46
Mayne Island North	StG	7.06	10.25	1.45
De Courcy Island North	StG	4.02	5.81	1.45

Table 11. Ratio of RCA boundary (in the water) that intersects with rockfish habitat. RCAs with high ratio values (≥1.3) and more than 0.5 km² rockfish habitat are listed.

RCA	Bioregion	Overall Size (km²)	Ratio Boundary / Area
Discovery - Chatham Islands	SS	3.18	3.34
Becher Bay East	SS	1.01	3.12
Race Rocks	SS	2.75	2.78
Cracroft Point South - Sophia Islands	NS	2.7	2.73
Trial Island	SS	0.83	2.67
Thormanby Island	StG	3.25	2.61
Duntze Head (Royal Roads)	SS	0.9	2.60
Reynolds Point - Link Island	StG	4.26	2.48
Russell Island	StG	2.43	2.47
Brentwood Bay	StG	3.4	2.36
Portland Island	StG	3.04	2.32
Sooke Bay	SS	3.39	2.22
Vargas Island to Dunlap Island	SS	2.84	2.08
McNaughton Point	StG	2.2	2.02
West Vancouver	StG	2.82	1.90
Coal Island	StG	3.14	1.71
Carmanah	SS	8.22	1.69
Coffin Point	StG	4.32	1.56
Browning Passage - Hunt Rock	NS	9.99	1.55
Walken Island to Hemming Bay	StG and NS	13.59	1.54
Danger Reefs	StG	1.48	1.54
Copeland Islands	StG	15.28	1.49
Hodgson Reefs	NS	11.48	1.43
Prevost Island North	StG	9.13	1.33

1.3.5 Conclusions

- RCAs need to protect significant areas of high quality rockfish habitat (rocky reef, kelp forests, eelgrass beds, sponge reefs). No matter their size, RCAs which contain very little rockfish habitat will likely provide limited conservation benefit to inshore rockfish. For this reason the amount of high quality rockfish habitat in RCAs is an important ecological attribute.
- Considerably more rockfish habitat and overall area is protected in the Northern Shelf Bioregion and Outside Management Area. RCAs in the Outside Management Area protect 14% of available rockfish habitat which is less than the desired 20% target. RCAs in the Inside Management Area protect 19% of rockfish habitat, considerably less than the desired 30% target.
- Many RCAs might contain very little rockfish habitat. According to habitat models, 75% of RCAs contain, on average, 1.5 km² of rockfish habitat. Approximately 31% of RCAs contain less than 0.8 km² of rockfish habitat compared to 2% whose overall size is less than 0.8 km². Most of the rockfish habitat in RCAs is rocky reef; we did not differentiate the types of

rocky reef, whether it is complex reefs or smooth bedrock, the former being much more important to rockfish. Consequently, many RCAs might contain very little high quality rocky reef habitat.

- The conservation benefit of some RCAs may increase by having their boundaries adjusted to incorporate more rockfish habitat. Smaller RCAs with limited areas of rockfish habitat may have a higher proportion of habitat, yet spillover could be occurring where RCA boundaries intersect habitat patches and fish can move back and forth between protected and fished areas. Boundaries of these RCAs could be adjusted to incorporate entire habitats. Similarly, boundaries of some RCAs could be adjusted to encompass nearby glass sponge reefs which are important habitat for rockfish.
- The conservation benefit of RCAs which contain very little rockfish habitat, and none exists nearby, might increase if they are moved to different locations where there is more habitat. Rockfish likely do not live in RCAs where there is no rockfish habitat. In contrast, RCAs with a higher proportion of rockfish habitat, but contain few fish may have been overexploited and fish may return in the future.
- Two metrics, the boundary to area ratio and the length of boundary intersecting rockfish habitat ratio, were used to evaluate habitat isolation and spillover. Higher ratio values may indicate less habitat isolation and potentially more spillover.

1.3.6 Recommendations

1. Consider implementing a long-term monitoring program to evaluate whether RCAs are achieving their conservation objectives.
2. Consider increasing the area of rockfish habitat protected in RCAs in the Inside and Outside Management Areas to achieve the desired conservation targets of 30% and 20%, respectively. Please refer to recommendations in Chapter 5 for further refinement related to this recommendation.
3. Consider adjusting boundaries or moving RCAs confirmed to contain less than a threshold minimum area of rockfish habitat.
4. Consider adjusting boundaries of seven RCAs (Hodgson Reefs, Goose Island, Passage Island, West Vancouver, Lions Bay, Ajax/Achilles Bank, Stephens Island) to encompass nearby glass sponge reefs.
5. Strengthen management restrictions in RCAs related to bottom contact fishing gear to provide better protection for sensitive benthic habitats such as glass sponge reefs and gardens, and corals.
6. Consider increasing the size of RCAs that have comparatively higher boundary to area ratio values. Furthermore, consider adjusting the boundaries of RCAs whose boundaries intersect with rockfish habitat so boundaries conform better with habitat edges.

1.3.7 Knowledge Gaps and Research Recommendations

- Ground-truth RCAs using non-invasive visual survey methods (ROV, tow/drop cameras, scuba) to collect relevant ecological data. Data can also be obtained from sponge reef research and other DFO programs that have used ROVs. Ground-truthing RCAs is important for:
    - increasing our understanding how rockfish associate with different types of habitats.

- determining the presence, quality, and degree of patchiness of rockfish habitat. RCAs should be evaluated not just based on the presence/absence of rocky habitat, but also on the quality/structural complexity of that habitat. Those RCAs with the smallest amount of habitat predicted by models as outlined in Table 8 should be highest priority for investigation.
- verifying the predictive capabilities of rockfish habitat models and improve them as new data become available.
- determining the presence and abundance of rockfish (species, size, sex), as required by OEABCM criteria for conservation and stock management objectives.

- Determine the minimum area of rockfish habitat in RCAs to justify the current configuration or existence of RCAs at their current locations.
- Improve the resolution of modelled rockfish habitat in 68 RCAs by:
  - obtaining existing multi-beam data for 20 RCAs in the Northern Shelf Bioregion, and model rockfish habitat using these higher resolution data rather than the coarser resolution 20×20m coast-wide substrate model
  - collecting multi-beam data in 48 RCAs where none currently exists.

1.4 DEPTH

Inshore rockfish are typically found at depths shallower than 200 m, but have been observed deeper (Table 12). Black, Copper, and China Rockfishes are normally found at depths shallower than 50 m (Frid et al. 2018, Frid et al. 2016, Haggarty et al. 2016b, Burt et al. 2014, Lotterhos and Markel 2012, Markel 2011, Parker et al. 2007, Johnson et al. 2003, Love et al. 2002). Quillback, Tiger, Brown, Deacon, and especially Yelloweye Rockfishes are normally found between 50 and 100 m, and often deeper (Frid et al. 2018, Frid et al. 2016, Haggarty et al. 2016b, Burt et al. 2014, Love et al. 2002).

Importantly, size and age of Quillback and Yelloweye Rockfishes are positively correlated with depth (Frid et al. 2016, Johnson et al. 2003). Frid et al. (2016) reported Yelloweye were 59% larger at 90 m than at 30 m, and Quillback was 18% larger and average age was 8.8 years older at 90 m than at 30 m depths. Fecundity of these species increases with maternal size or age (McGreer and Frid 2017); therefore, more fecund females likely live in deeper water.

Acoustic tagging provides insights into depth movements of rockfish. Green et al. (2014) observed Blue Rockfish at shallower depths during the day than night, likely indicative of diurnal feeding. Over longer time scales, Blue Rockfish were detected at deeper depths during upwelling periods and with increased wave heights. Daily and seasonal vertical movements of Blue Rockfish may be influenced by upwelling conditions and local prey abundance. Similar to Blue Rockfish, other rockfish species also likely inhabit a range of depths important for feeding opportunities and surviving changing environmental conditions.

*Table 12. Life history characteristics of inshore and nearshore shelf rockfishes in BC. Group (Gp): In=Inshore, Sh=Shelf. Subgenus (SG): a= Sebastosomus, b= Pteropodus, c= Sebastichthys, d= Sebastopyr, e= Rosicola, f= Hispaniscus, g=Acutomenthum, h=Sebastodes. Niche: M=Mid-water, B=Benthic. Movement: Horizontal (H), Vertical (V): H=High, M=Medium, L=Low, U=Unknown. *Juveniles are found in shallower water (Hannah and Rankin 2011, Hyde and Vetter 2007, Love et al. 2002, Matthews 1990).*

Gp	SG	Species	Depth Range (m)	Typical Depth (m)	Niche	Habitat	Max Size (cm)	Max Age	Move-ment H/V
In	A	Black *(S. melanops)*	0-366	0-100	M	Kelp, high and low relief reefs, high current	69	50	M/M
In	A	Blue/ Deacon (*S. mystinus/ S. diaconus)*	0-549	0-90	M	Kelp, high relief, exposed reefs	53	44	M/M
Sh	A	Yellowtail (*S. flavidus*)	0-549	90-180*	M	High relief and sheer rock walls	66	64	H/H
In	B	Copper (*S. caurinus*)	0-183 m	0-90	B	Kelp, boulder fields and high and low relief reef	66	50	M/M
In	B	Quillback (*S. maliger*)	0-274	0-150	B	Kelp, boulder fields and high and low relief reef, sponges	61	95	L/L
In	B	China (*S. nebulosus*)	3-128	10-100	B	High relief rock with high current	45	79	L/L
In	B	Brown (*S. auriculatus*)	0-135	0-120	B	High and low relief reefs, sand	56	34	L/L
In	C	Tiger (*S. nigrocinctus*)	18-298	50-200	B	High-relief, high complexity reef	61	116	L/L
In	D	Yelloweye (*S. ruberrimus*)	15-549	50-200*	B	High-relief, high complexity reef	91	118	L/L
Sh	E	Vermillion *(S. miniatus)*	6-436	50-300	B	High relief rocks	76	60	L/L
Sh	E	Canary (*S. pinniger*)	0-838	100-200*	B	Pinnacles, high, exposed rock	76	84	H/H
Sh	F	Greenstriped (*S. elongatus*)	12-495	100-250	B	Boulders, cobble, rock rubble, mud	43	54	U/U
Sh	G	Widow (*S. entomelas*)	24-549	140-210	M	School over rock outcrops, boulders and high relief	59	60	U/H
Sh	H	Bocaccio (*S. paucispinis*)	122-478	50-250	B/M	High relief rocks, boulders, mud	91	50+	H/H

1.4.1 Methods

Datasets

To determine depth ranges in RCAs, two DEM bathymetry rasters were used:

- Derived 20 m DEM bathymetry raster (Davies et al. in prep). Constructed using point soundings data from the Canadian Hydrographic Service (CHS) and datasets from the Province of BC. Coverage exists as five separate layers by region: Haida Gwaii, North Coast, South Coast, West Coast Vancouver Island, and Strait of Georgia.
- 3 arc second DEM bathymetry raster converted to 80 m (NOAA National Centers for Environmental Information and National Geophysical Data Center, 2013). Coverage exists as a single coast-wide layer.
- Although the 20 m raster has higher resolution, it existed as several layers resulting in overlaps between regions and coverage was not available for all RCAs. The 80 m raster has lower resolution, but it provided coverage for those RCAs not covered by the 20 m raster. Both the 20 m and 80 m rasters were used for the analysis in order to provide full coverage for all RCAs.

Data preparation

The bathymetry raster layers were converted to polygon layers and depth values were reclassified from 0 to 500 m using 50 m intervals. Bathymetry polygon layers were clipped to remove any land areas. This was achieved using the PFMA dataset and a high water mark coastline dataset from CHS. For the 20 m polygon layers where there were overlaps between regions, some areas were clipped to avoid double-counting depth classes. For example, the 20 m polygon layer for Haida Gwaii overlapped significantly with the North Coast 20 m polygon layer. To avoid double-counting depth classes in these areas, the Haida Gwaii area overlapping the North Coast was removed from further analysis. Additionally, areas of the 80 m layer included in the 20 m layers were removed to obtain areas not covered by the 20 m layers. Offshore areas in the 80 m layer where inshore rockfish habitats are not found were also removed from further analysis.

Spatial analysis

All bathymetry polygon layers, including the 20 m layers by region (due to overlaps), were intersected with RCAs. For those RCAs located in two regions, each RCA was reviewed to determine which region had better coverage and only one depth was assigned to avoid double-counting.

- Becher Bay East: used 20 m WCVI instead of StG
- Bentick Island: used 20 m WCVI instead of StG
- Race Rocks: used 20 m StG instead of WCVI
- Sooke Bay: used 20 m StG
- Walken Island: used 20 m Haida Gwaii instead of StG

RCAs were then intersected with the 80 m bathymetry layer where no 20 m bathymetry coverage was available. A summary was produced to determine the total area for each depth class by RCA.

To determine depth ranges by PFMA and Inside/Outside Management Areas, the 20 m bathymetry layers for all five regions, and the 80 m bathymetry layers (only used the portion not covered by 20 m coverage) were merged into a single layer. The resulting layer was dissolved to avoid double-counting depth classes where 20 m region layers overlapped. As several regions have different depth classes in some areas, the best depth class may not have been chosen during the dissolving process. However, overall differences were likely insignificant. The resulting layer was then intersected with PFMAs and Inside/Outside Management Areas. A summary of the total areas by depth class was generated.

1.4.2 Results

RCAs are more often situated in shallow compared to deep water. The mean size of RCAs is 29 km^2, and almost half of this area (47%) is shallower than 50 m, and 76% of this area is shallower than 100 m (Table 13). Most of the area in RCAs (88%) is less than 150 m deep. RCAs tend to be shallower in the Southern Shelf Bioregion with 94% of their area less than 100 m deep. RCAs in the Strait of Georgia Bioregion cover more range of depths; 30% of RCA area is deeper than 150 m. RCAs in the Outside Management Area have a higher proportion of area at depths shallower than 50 m compared to RCAs in the Inside Management Area, and little area deeper than 150 m.

Twenty RCAs (12%) are not deeper than 50 m and 19 more have less than 10% of their area deeper than 50 m (Table 14). Therefore, at least 39 RCAs (24%) likely do not provide optimal depth coverage for Yelloweye, Quillback, and Tiger Rockfishes. Fifty-nine RCAs (36%) are not deeper than 100 m.

Table 13. Mean proportion (%) of RCA area in various depth ranges (m).

Bioregion / Management Area	Mean Area (km^2)	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	>400
Strait of Georgia	11.1	32.5	19.5	16.2	12.4	7.6	4.0	2.7	1.4	1.8
Southern Shelf	29.4	58.2	35.7	2.8	1.4	1.1	0.1	-	-	-
Northern Shelf	54.1	48.9	31.2	12.1	4.1	1.3	0.4	0.4	0.1	-
Inside	12.1	37.0	19.5	15.7	11.5	6.3	3.2	2.4	1.1	1.1
Outside	90.3	51.5	34.2	10.0	2.5	0.7	0.1	0.04	-	-
All RCAs	29.2	46.8	29.4	11.8	5.4	2.5	1.1	0.8	0.4	0.4

Table 14. RCAs that protect shallow water not deeper than 50 m, and those where less than 10% of their area is deeper than 50 m. These RCAs likely do not provide optimal depth coverage for Yelloweye and Quillback Rockfishes. Area is in km².

RCA	Bioregion	Area Overall	Area 0-50 m	Area 50-100 m	Area >50 m	% RCA area >50 m
Hardy Bay - Five Fathom Rock	Northern Shelf	0.1	0.10	0	0	0
Bentinck Island	Southern Shelf	0.5	0.48	0	0	0
Trial Island	Southern Shelf	0.8	0.80	0	0	0
Duntze Head (Royal Roads)	Southern Shelf	0.9	0.89	0	0	0
Russell Island	Strait of Georgia	2.4	2.30	0	0	0
Gabriola Passage	Strait of Georgia	2.6	2.41	0	0	0
Departure Bay	Strait of Georgia	2.7	2.68	0	0	0
Portland Island	Strait of Georgia	2.9	2.70	0	0	0
Forward Harbour	Northern Shelf	3.2	2.85	0	0	0
Discovery - Chatham Islands	Southern Shelf	3.2	2.86	0	0	0
Mackenzie - Nimmo	Northern Shelf	4.0	2.97	0	0	0
Coal Island	Strait of Georgia	3.1	3.08	0	0	0
Sooke Bay	Southern Shelf	3.4	3.33	0	0	0
Dare Point	Southern Shelf	3.5	3.45	0	0	0
Chrome Island	Strait of Georgia	3.9	3.78	0	0	0
Susquash	Northern Shelf	8.1	7.63	0	0	0
Carmanah	Southern Shelf	8.2	7.88	0	0	0
Drury Inlet - Muirhead Islands	Northern Shelf	11.6	10.64	0	0	0
Lower Clio Channel	Northern Shelf	13.9	13.02	0	0	0
Pachena Point	Southern Shelf	19.1	18.88	0	0	0
Savoie Rocks - Maude Reef	Strait of Georgia	1.7	1.65	0.01	0.01	0.6
Hodgson Reefs	Northern Shelf	11.5	10.51	0.10	0.10	0.9
Upper Centre Bay	Strait of Georgia	1.1	1.01	0.01	0.01	0.9
Broken Islands Group	Southern Shelf	39.6	38.65	0.42	0.42	1.1
Race Rocks	Southern Shelf	2.7	2.67	0.05	0.05	1.9
Porcher Peninsula	Northern Shelf	50.0	48.73	1.29	1.29	2.6
West Bay	Strait of Georgia	1.1	0.88	0.03	0.03	2.7
Menzies Bay	Strait of Georgia	3.9	3.15	0.11	0.11	2.8
Vargas Island to Dunlap Island	Southern Shelf	2.8	2.72	0.08	0.08	2.9
Frederick Island	Northern Shelf	113.3	109.21	3.49	3.49	3.1
Becher Bay East	Southern Shelf	1.0	0.92	0.04	0.04	4.0
Haddington Passage	Northern Shelf	2.5	2.35	0.12	0.12	4.8
Port Elizabeth	Northern Shelf	6.0	5.48	0.30	0.30	5.0
Browning Island to Raynor Group	Northern Shelf	16.6	14.83	0.93	0.93	5.6
Eastern Burrard Inlet	Strait of Georgia	2.7	2.51	0.16	0.16	5.9
Brooks Bay	Northern Shelf	72.2	63.64	5.30	5.30	7.3
Saltspring Island North	Strait of Georgia	8.4	7.49	0.65	0.65	7.7
Cracroft Point South - Sophia Islands	Northern Shelf	2.7	2.29	0.24	0.24	8.9
Bedwell Harbour	Strait of Georgia	2.5	2.13	0.21	0.23	9.2

In contrast, three RCAs (Heriot Bay, Lasqueti South-Young Point, and Malaspina Strait) have no area, and several others have very little area, shallower than 50 m (Table 15).

Table 15. RCAs with the least amount of area (km^2) at depths ranging from 0 to 50 m. These RCAs likely do not provide optimal depth coverage for Black, China, and Copper Rockfishes.

RCAs	Bioregion	Area Overall	Area <50 m
Heriot Bay	Strait of Georgia	5.1	0
Lasqueti South -Young Point	Strait of Georgia	9.3	0
Malaspina Strait	Strait of Georgia	28.3	0
Sinclair Bank	Strait of Georgia	19.2	0.09
Domett Point	Strait of Georgia	2.1	0.11
Hardy Bay - Five Fathom Rock	Northern Shelf	0.1	0.13
Gull Rocks North	Northern Shelf	5.9	0.17
McCall Bank	Strait of Georgia	13.4	0.21
Sisters Islets	Strait of Georgia	10.7	0.32
Patey Rock	Strait of Georgia	0.9	0.36
Passage Island	Strait of Georgia	0.8	0.43
Bentinck Island	Southern Shelf	0.5	0.48
Mid Finlayson Arm	Strait of Georgia	1.9	0.50

RCAs where there is essentially no habitat less than 50 m are generally located away from land out in the middle of deeper water bodies. These few RCAs likely do not encompass all depths important to Black, China, and Copper Rockfishes.

RCAs are more often located in shallower (<100 m) than deeper areas. Conservation benefits of particular RCAs could be improved by extending their boundaries to include rockfish habitat in deeper water. To adequately protect inshore rockfish, depths to at least 200 m should be protected, and even deeper if considering other species of rockfish. Unfished depths greater than 50 m are especially important to protect Quillback and Yelloweye Rockfishes which are targeted by all fisheries (commercial, recreational, and First Nations) and are currently experiencing conservation concerns as abundances remain at historical low levels. Extending RCA boundaries into greater depths is precautionary because size, age, and fecundity of certain rockfish species are positively correlated with depth (Frid et al. 2016, Johnson et al. 2003). Furthermore, RCAs should encompass the range of depths required by individuals for foraging and movements related to upwelling events, storms, etc. If increasing the overall size of particular RCAs is a consideration, then area expansion should be focused to incorporate rockfish habitat throughout a range of depths, include deeper water. This would improve rockfish conservation by protecting more area of critical rockfish habitat, and likely serve to better isolate continuous patches of habitat which will decrease spillover.

1.4.3 Conclusions

- Black, Copper, and China Rockfishes are normally found at depths shallower than 50 m; Quillback, Yelloweye, Tiger, Brown, and Deacon Rockfishes are often found at depths greater than 50 m.
- Size, age, and fecundity of particular rockfish species increase with depth.
- Rockfish require a range of depths for feeding opportunities and to survive environmental conditions.
- RCAs more often protect shallower areas which are prime habitat for Black, Copper, and China Rockfishes.

- At least 24% of RCAs do not protect habitat in deeper waters utilized by Quillback, Yelloweye, Tiger, Brown, and Deacon Rockfishes.
- Depth analyses included all areas within RCA boundaries and were not restricted to rockfish habitat. Recall much of the area in RCAs is not suitable rockfish habitat. RCAs that meet depth criteria may actually not meet the criteria if analyses were constrained to rockfish habitat only.

1.4.4 Recommendation

To improve protection of inshore rockfish species found in deeper water (>50 m), consider adjusting boundaries, and possibly increasing the size, of suitable RCAs to incorporate additional high quality rockfish habitat located at a greater range of depths (at least to 200 m), and isolate continuous habitat within boundaries. Prioritize those RCAs that currently do not protect depths greater than 50 m, and those where less than 10% of their area encompasses depths deeper than 50 m. If particular shallow RCAs are considered to be acceptable, then it should be acknowledged they may not support the recovery of the largest and most fecund individuals for Quillback and Yelloweye Rockfishes (and likely other species).

1.4.5 Knowledge Gap and Research Recommendation

- Determine the area of high quality rockfish habitat at the various depth categories, not simply overall area, currently protected in RCAs.

1.5 CONNECTIVITY

Connectivity is the demographic exchange of migrants between reserves (the source-to-destination matrix of settlers to a series of subpopulations that comprise a metapopulation connected through larval dispersal; Lotterhos et al. 2014). Connectivity is determined by the larval dispersal kernel (the two-dimensional distribution of larval settlement originating from a single-source population; Leis et al. 2003).

There is an important distinction in how migration of individuals affects the genetic structure versus the demographics of a population, and this distinction has important implications for network design. Genetic connectivity depends primarily on the absolute number of dispersers among populations, whereas demographic connectivity depends on the relative contributions of immigrants and local recruitment to population growth rates (Lowe and Allendorf 2010). Genetic connectivity can be maintained with a few settlers whereas demographic connectivity requires many more settlers.

Larvae dispersal is important when considering MPA connectivity. MPA guidelines all reference the importance of considering the scale at which a species' larvae disperses (Burt et al. 2014). To ensure viable populations can persist within its boundaries, the size of an MPA should be at least as large as the average dispersal distance of larvae (Hastings and Botsford 2006). Very large protected areas designed to retain fish larvae within their boundaries may not be practical to implement. Instead, smaller protected areas connected in a network and spaced appropriately may be able to retain pelagic larvae that originated elsewhere within their boundaries. Thus smaller protected areas connected in a well-designed network can function more like larger protected areas if larvae and juveniles end up spending most of their time in the protected areas.

Pelagic larval duration (PLD) of inshore rockfish species ranges from one to six months (five of eight species are one to two months; Lotterhos and Markel 2012, Markel 2011, Yamanaka et al. 2006, McCain et al. 2005, Miller and Shanks 2004, Love et al. 2002). Copper Rockfish has the shortest PLD (32-88 days; Markel 2011, Love et al. 2002) and Blue and Black Rockfishes have the longest (up to five or six months; Miller and Shanks 2004, Love et al. 2002). PLD can be a crude indicator of dispersal potential (Shanks et al. 2003); therefore, long larval durations potentially imply long dispersal distances (100+ km). However, it is often acknowledged that realized larval dispersal distance is only partly explained by larval duration (variation in PLD accounts for approximately 50% of variation in dispersal distance) and that larval behaviour, oceanography and current regimes, as well as environmental conditions (e.g. temperature, local sources of entrainment) can significantly influence dispersal distance (Shanks 2009).

In fact, larvae may disperse far shorter distances than their lengths of pelagic phase might suggest. Lotterhos et al. (2014) reported Black Rockfish larvae experience northerly transport early in their PLD, and then southerly transport later in their PLD, and this could result in minimal net alongshore transport. They found the scale of dispersal for Black Rockfish to be 6–184 km per generation. Miller and Shanks (2004) found Black Rockfish larval dispersal distances were shorter (<120 km) than previously assumed based on models of passive dispersal. Johansson et al. (2008) suggested Copper Rockfish may undergo far less dispersal than their two to three month pelagic phase might suggest. In order to disperse alongshore, rockfish larvae must first disperse offshore (Largier 2003) because a boundary layer of 'sticky water' within one to three kilometers of shore greatly reduces advection and favours diffusive dispersal and may entrain larvae for up to one month (Zeidberg and Hamner 2002). Fish larvae movements are typically believed to be between 50 and 200 km (Shanks 2009). Petersen et al. (2010) used floats to simulate rockfish larvae transport; in 35 days the floats moved about 50 km nearshore.

Lotterhos et al. (2014) used genetic techniques to estimate the average dispersal distance for Black Rockfish in BC (6-184 km per generation) and concluded the distance between RCAs to facilitate connectivity should be no greater than 100 km. They concluded, from the perspective of gene flow, the distance between RCAs is probably sufficient to maintain genetic integrity of Black Rockfish species in BC. Based on currently known scales of larval dispersal, MPAs should be placed within 50 to 100 km of each other (CDFG 2008). When specific data (on larval dispersal) is lacking, nearshore MPA sites should be spaced not further than 50 km apart to maintain connectivity of most short to moderate larval dispersing species (OSPAR 2007). Johansson et al. (2008) suggested reserves should be spaced by at least the mean dispersal distance of the lowest dispersing species. As mentioned, Copper Rockfish have the shortest (one to three months) PLD. In one month, floats simulating rockfish larvae moved about 50 km (Petersen et al. 2010). The MPA network guideline for spacing in California of having MPAs within 50-100 km of each other was based on models of larval transport and syntheses of larval dispersal distance estimates for marine fish, invertebrate, and seaweed species (Shanks et al. 2003). Burt et al. (2014) suggest that having MPAs spaced within 20-100 km (or closer) of each other provides a good initial guideline for network design and evaluation within BC. For all these reasons, we considered two key distances (100 and 50 km) related to fish larvae dispersal and whether there is a RCA nearby.

1.5.1 Methods

We determined connectivity between RCAs using the distance over water between nearby RCAs (Haggarty 2014, Lotterhos et al. 2014). To measure RCA spacing, we created a line shapefile and drew lines or multipart lines using the 'snap to nearest feature' tool to find the closest edge of each conservation area. The length of each line was then calculated in kilometers using the 'calculate geometry' tool in ArcGIS 10.1. Distances were then exported to a spreadsheet and statistics were generated.

1.5.2 Results

RCAs in the Inside Management Area are on average 8.5±9.2 km from one another (max = 77 km). RCAs in the Outside Management Area are 38.6±45.1 km from one another (max = 217 km).

Using the scale of dispersal for Black Rockfish, Lotterhos et al. (2014) reported that RCAs in BC are potentially connected by demographically relevant dispersal within a generation because the distance among RCAs is generally less than 100 km. The most isolated RCA is Frederick Island on the northwestern tip of Haida Gwaii. The closest RCAs to it on Haida Gwaii (South Moresby) and the mainland (Dunira) are 217 and 165 km away, respectively. South Moresby RCA is 93 km from the nearest RCA on Haida Gwaii (Lyell Island) which is, in turn, 86 km from the nearest RCA on the mainland. Consequently, the three RCAs on Haida Gwaii are generally isolated from each other as well as from the mainland.

Considering distances between 50 and 100 km, a barrier to connectivity in the central coast might exist between McMullin Group RCA and Kitasu Bay/Aristazabal Island RCAs because of Milbanke Sound (a distance of 53 km). Furthermore, both McMullin Group/Goose Island RCAs and Kitasu Bay RCA are 20 to 50 km from only one nearby RCA.

Three connectivity gaps may exist on the WCVI. Along the southern shore of Vancouver Island in the Juan de Fuca Strait, Sooke Bay RCA and Carmanah RCA are separated by a distance of 71 km. The Broken Group Islands RCA is 59 km from three small, more inland RCAs near Tofino, and 93 km from Estevan Point RCA. Although the West of Bajo Reef RCA is connected to Estevan Point RCA to the south, it is 65 km from Checleset Bay RCA to the north, separated by Esperanza Inlet and Kyuquot Sound. West of Bajo Reef RCA is somewhat isolated because only one RCA lies within 20 to 50 km away.

In general, RCAs located at the heads of inlets tend to be further away from other RCAs and may experience less larvae input from other areas. Bute Inlet North RCA is 77 km from the nearest RCA (Octopus Islands to Hoskyn Channel). Three RCAs (Queens Reach East and West, and Princess Louisa Inlet) close together at the head of Jervis Inlet are collectively 56 km from the nearest RCA. Similarly, Holberg Inlet RCA is 53 km from the nearest RCA.

1.5.3 Barriers to connectivity

Connectivity between RCAs is likely to be even less for adults and larvae if rockfish habitat is only considered instead of simply water pathways. Considering only the water distance between RCAs ignores aspects of connectivity between rockfish habitats, as breaks in habitat may prove to be barriers to dispersal of adults and larvae. The Strait of Georgia ‘deep-basin’ estuary oceanographic domain acts as a dispersal barrier from the outer coastal waters via the Juan de Fuca Strait suggesting that dispersal is restricted regionally by major oceanographic features. Yelloweye Rockfish in Inside waters have been shown to be a distinct genetic population from Outside waters, but the homogenous population structure in the outside waters of BC indicates that no other barriers to dispersal exist in BC, at least for Yelloweye Rockfish (Siegle et al. 2013). Blue Rockfish are separated into two populations: Washington–Oregon (North) and California (South) which might be due to biogeographic barriers like the Cape Mendocino upwelling and the Mendocino Escarpment, a submarine ridge that limits available nearshore habitat (Cope 2004). The Copper Rockfish population in Puget Sound is also distinct compared to that on the outer coast, and the Gulf Islands population is somewhat in between (Buonaccorsi et al. 2002). Johansson et al. (2008) suggest habitat continuity is important in Oregon for gene flow in Copper Rockfish. Discrete barriers along the coast, more likely sand rather than upwelling and, in particular, sand habitat between Newport and Coos Bay seem to restrict dispersal. Lotterhos et al. (2012) suggest Copper Rockfish larvae are more susceptible to large sand barriers than Black Rockfish larvae. Upwelling regions and geographical headlands may also form barriers to larvae dispersal (Lotterhos et al. 2014). Habitat barriers that may prevent dispersal of inshore rockfish are important to consider in network design. Furthermore, depleted rockfish populations may not be quickly reseeded from other areas if habitat barriers exist that impede larvae dispersal (Buonaccorsi et al. 2002).

Lotterhos et al. (2014) suggest a comprehensive RCA network should meet the following minimum criteria:

1. Protected areas should be located in all upwelling bioregions;
2. Protected areas should contain representative habitats for different species and life stages;
3. A network should be self-sustaining regardless of outside populations and, therefore, protected areas should be spaced by at least the mean dispersal distance of the lowest dispersing species;
4. Protected areas should be distributed along the coast at various distances from headlands to account for retention and/or high variance in reproductive success caused by uncertainty in oceanographic conditions.

The importance of each RCA's contribution to network persistence will depend on rockfish density, age structure, and fine-scale patterns of dispersal caused by oceanographic currents and features such as retention zones.

1.5.4 Conclusions

- Demographic connectivity is an important consideration for network design.
- We considered distances of 50 and 100 km to be relevant for the dispersal distance of inshore rockfish propagules.
- Connectivity between RCAs was determined by measuring the closest distance by water between RCAs (Lotterhos et al. 2014, Haggarty 2014).
- RCAs are generally closer together in the Inside Management Area.
- Gaps in connectivity (more than 50 km) exist for RCAs in Haida Gwaii, the central coast, along the west coast of Vancouver Island, and at heads of long inlets.
- The analysis of connectivity includes only RCAs, not other protected areas.
- Connectivity of rockfish habitat is important as breaks in habitat caused by oceanographic features like upwelling, extensive sandy areas, and headlands may be barriers to dispersal for adults and larvae.

1.5.5 Recommendations

1. Consider strengthening protection measures for isolated RCAs where it may be more challenging for fish larvae to disperse to, in particular the three RCAs in Haida Gwaii, especially Frederick Island, and RCAs located near the heads of long inlets such as Bute (Bute Inlet North), Holberg (Holberg Inlet), and Jervis (Queen's Reach East and West, and Princess Louisa Inlet) Inlets.
2. Consider creating additional RCAs or integrate other protected areas to ensure distances between RCAs are no more than 50 km to facilitate larval dispersal for many species of inshore rockfish between protected areas:

a. on the west side of Haida Gwaii between South Moresby Island and Frederick Island RCAs,

b. in the central coast in Milbanke Sound between McMullin Group and Aristazabal Island RCAs,

c. on the WCVI:

   i. along the north shore of the Juan de Fuca Strait between Sooke and Carmanah,
   ii. between the Broken Group Islands and Estevan Point,
   iii. between Bajo Reef and Checleset Bay.

1.5.6 Knowledge Gaps and Research Recommendations

- Conduct a least-cost path analysis that incorporates rockfish habitat rather than simply water pathways to improve the analysis of RCA connectivity.
- Include other protected areas which effectively conserve rockfish and their habitats in analyses of connectivity.
- Include oceanographic models as water movements will influence larval distribution and affect connectivity between areas.
- Identify barriers to the dispersal of rockfish larvae such as sandy areas, upwelling regions, and headlands.
- Use genetic techniques and physical tags to estimate dispersal distances of rockfish species. Each of these techniques is applicable to a particular temporal scale, and both have value to a full understanding of dispersal dynamics (Berntson and Moran 2009).

CHAPTER 2: INDEX OF OVERALL CONSERVATION STATUS

By assigning scores to the various attributes, we were able to combine attributes into a single index which allowed us to rank and prioritize RCAs. Attributes, their associated metrics, and key values are summarized in Table 16. Each attribute category, derived from key values, was assigned a score (Table 17). The attribute “overall size” was not included in the additive scoring, the rationale being RCA size is highly correlated with “area of rockfish habitat” (77% of the variability in habitat area is explained by RCA size) and therefore including both attributes was considered to be redundant. Attributes were not weighted, but can be weighted in the future if particular ones are determined to be higher priority for management. We assumed RCAs with lower attribute scores are less likely to conserve rockfish and their habitats; consequently, these RCAs should be prioritized for further evaluation regarding boundary changes or relocation. Haggarty (2015) found a relationship between RCA effectiveness and a similar conservation score.

2.1 METHOD FOR SCORING

Each attribute and its corresponding metrics were scored between zero and one, with zero being the least desirable (Table 17). Scores were based on corresponding bin values which were determined from the literature or calculations (in Table 16). Scores assigned between zero and one for a particular metric reflect the number of bins and how bin values correlate to rockfish conservation.

2.2 RESULTS

Additive scores could theoretically range from zero to seven, with zero being undesirable (assumed to have lower conservation benefit to rockfish) and seven being the most desirable (assumed to have higher conservation benefit). The mean score is 4.1 (range = 1.63 to 6.01). Scores are highest in the Northern Shelf Bioregion (mean = 4.68) and lower in the Southern Shelf (mean = 3.79) and Strait of Georgia (mean = 3.77) Bioregions. These scores suggest RCAs in the Northern Shelf Bioregion may provide higher conservation benefit to rockfish compared to RCAs in other bioregions. Values for all RCAs are listed by bioregion in Table 18 in rank order beginning with the lowest scoring RCA (1.63), Hardy Bay – Five Fathom Rock in the Northern Shelf Bioregion. This RCA, and others near the top of the list, scored poorly on most attributes except connectivity. In general, these RCAs are small and shallow with potentially fished boundaries not far from the center, and contain little rockfish habitat that may not be well isolated within their boundaries meaning there may be a high degree of spillover. RCAs with the lowest scores in the Southern Shelf and Strait of Georgia Bioregions are Bentinck Island (2.0) and Mariners Rest (1.85), respectively. Of those RCAs scoring three or lower, 23 are located in the Strait of Georgia Bioregion, seven are in the Southern Shelf Bioregion, and five are in the Northern Shelf Bioregion. These 35 lowest scoring RCAs may have lower conservation benefit for rockfish and should be prioritized for further evaluation as to whether adjustments to boundaries or locations are warranted.

Table 16. Key values used to provide thresholds for scoring attributes and their metrics. Bolded values are used as ideal attribute criteria (Chapter 3).

Attribute	Metric		Key Values	Rationale	Comments
Size	Minimum MPA		**5**, 10, 13, 23-80, 100 km^2	DFO (2017[2]), Burt et al. (2014), Edgar et al. (2014), California MLPA Advisory Team (2006)	5 km^2 is based on fish movements; other values are related to biodiversity
	Rockfish movements		3.4-15, 6.2, 78.5 km^2	Hannah and Rankin (2011)	Minimum size of MPAs that provide some protection to rockfish = 3.4 A circle with a diameter of 2.8 km (home ranges of various rockfish species; radius 1.4 km) = 6.2 A circle with a radius of 5 km = 78.5
	Distance to fished boundary		≥**0.5** km from center to nearest boundary **0.8** km^2	Dunham (2018)	Minimum RCA size might be 0.8 km^2 (area of a circle with radius = 0.5 km; mean home ranges for rockfish)
Rockfish Habitat	Proportion		≥**10%**	California MLPA Advisory Team (2006)	
	Area		0.8, **3.4**, 5, 6.2 km^2	Hannah and Rankin (2011), California MLPA Advisory Team (2006)	
	Spillover	Boundary to area ratio	1.42, **1.58**, 1.92, 3.93	C/A	Based on area (A) and circumference (C) of circles with Area Key Values
		Boundary intersecting habitat ratio	**0.28**, 0.7, 1.24	Quartiles	Derived from calculated RCA ratio values
Depth	50 m depth categories		% RCA in each depth category **0-200** m	Frid et al. (2016), Haggarty et al. (2016), Burt et al. (2014), Lotterhos and Markel (2012), Markel (2011), Love et al. (2002)	
Connectivity	Distance to nearest RCA		20, **50**, 75, 100 km	Lotterhos et al. (2014), Burt et al. (2014), CDFG (2008), OSPAR (2007)	

Table 17. Scores assigned to ecological attribute categories and used to calculate an index of overall conservation status for Rockfish Conservation Areas. Scores range between 0 and 1.

Distance (km) from the center to nearest fished boundary: Score Bin 0 < 0.5 0.50 = 0.5 to 0.99 0.75 = 1 to 1.49 0.90 = 1.5 to 2.0 1 > 2 • mean home ranges of six rockfish species <0.5 km • used 0.5 km categories	***Proportion (%) of rockfish habitat:*** Score Bin 0 < 10% 0.10 = 10 to 20 0.30 = 20.1 to 30 0.40 = 30.1 to 40 0.50 = 40.1 to 50 0.60 = 50.1 to 60 0.70 = 60.1 to 70 0.80 = 70.1 to 80 0.90 = 80.1 to 90 1 = 90.1 to 100 • 10% or less considered virtually absent • used 10% categories
Area (km^2) of rockfish habitat: Score Bin 0 < 0.8 0.25 = 0.81 to 3.39 0.75 = 3.4 to 4.99 0.90 = 5 to 6.19 1 > 6.2 • four key small protected area sizes (km^2): 0.8, 3.4, 5.0, 6.2; see Table 2 for rationale	***Boundary to area ratio:*** Score Bin 0 > 3.93 0.25 = 1.92 to 3.93 0.50 = 1.58 to 1.91 0.75 = 1.42 to 1.57 1 < 1.42 • Based on areas and circumferences of circles 0.8, 3.4, 5.0, and 6.2 km^2; see Table 2 for rationale
Boundary intersecting habitat ratio: Score Bin 0 > 1.24 0.33 = 0.70 to 1.24 0.66 = 0.28 to 0.69 1 < 0.28 • quartiles (25% = 0.28, 50% = 0.70, 75% = 1.24) derived from calculated RCA ratios	***Depth (m):*** Score Bin 0-0.20 = 0 to 50 0-0.20 = 50 to 100 0-0.20 = 100 to 150 0-0.20 = 150 to 200 0-0.20 > 200 • most RCAs have more than one depth category • score assigned is equal to the % of area in each category; maximum score for each category is 0.20 even if the % of area in the depth category is >20% • final score is sum of all categories
Connectivity (km): Score Bin 0 > 100 0.25 = 75 to 100 0.50 = 50 to 74.9 0.75 = 20 to 49.9 1 < 20 • values between 20 and 100 km with a focus on two key distances, 50 and 100 km	

Table 18a: Ecological attribute values, additive scores, and rank for RCAs in the Northern Shelf Bioregion. RCAs are listed in rank order beginning with the lowest score to highlight those areas which may have lower conservation benefit to rockfish.

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Hardy Bay - Five Fathom Rock	0.1	0.2	12.7	0.0	9.7	0.9	100	15.5	1.63	133	5
Haddington Passage	2.5	0.6	16.5	0.4	3.3	3.5	99	10.3	2.10	126	20
Cracroft Point South - Sophia Islands	2.7	0.5	38.2	1.0	1.6	2.7	94	4.9	2.44	122	5
Gull Rocks North	5.9	0.9	8.7	0.5	1.9	1.1	66	21.0	2.51	120	20
Bond Sound	3.8	0.5	6.0	0.2	1.9	1.9	37	4.3	2.58	117	20
Forward Harbour	3.3	3.0	3.0	0.1	0.2	1.7	89	1.6	3.20	98	20
Hodgson Reefs	11.5	1.3	19.2	2.2	0.9	1.4	92	12.0	3.30	94	20
Port Elizabeth	6.0	1.4	4.6	0.3	0.1	0.6	96	12.4	3.66	82	5
Browning Passage - Hunt Rock	10.0	1.0	33.3	3.3	0.9	1.5	71	3.5	3.75	79	5
Mackenzie - Nimmo	4.0	1.7	13.2	0.5	0.5	0.6	74	2.9	3.86	74	20
Havannah Channel	32.1	0.4	18.4	5.9	0.4	0.8	61	3.8	4.06	68	5
Eden-Bonwick-Midsummer-Swanson Islands	68.7	0.4	35.6	24.4	0.6	0.7	97	1.6	4.14	65	5
Kwatsi Bay	3.4	1.4	8.4	0.3	0.4	0.6	39	4.3	4.19	64	20
Drury Inlet - Muirhead Islands	11.7	1.8	11.7	1.4	0.2	0.1	92	20.9	4.20	63	20
Lower Clio Channel	13.9	2.6	15.9	2.2	0.2	0.4	94	4.7	4.21	62	5
Thompson Sound	14.0	2.5	5.1	0.7	0.5	0.4	23	6.1	4.22	61	20
Frederick Island	113.9	3.2	36.1	41.1	0.3	0.3	99	165.0	4.26	60	20
Wakeman Sound	12.5	2.4	2.8	0.4	0.2	0.6	24	13.0	4.32	58	20
Viscount Island	21.9	3.0	9.6	2.1	0.3	1.2	41	1.7	4.34	57	5
Nowell Channel	12.5	0.8	33.0	4.1	0.7	0.7	96	1.6	4.40	56	20
West Cracroft Island - Boat Bay	3.6	0.6	51.9	1.9	1.4	1.2	64	4.9	4.44	54	5
Chancellor Inlet East	3.5	2.1	27.1	0.9	0.5	0.6	94	2.8	4.53	52	20
Brooks Bay	72.3	0.9	12.3	8.9	0.4	0.6	95	9.9	4.53	52	5

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Belleisle Sound	5.1	2.0	10.0	0.5	0.0	0.3	43	13.0	4.54	51	20
Browning Island to Raynor Group	17.4	0.9	49.3	8.6	0.8	0.8	95	3.6	4.59	49	20
Wellborne	23.0	1.7	12.0	2.7	0.2	0.3	65	1.6	4.64	48	20
Burley Bay - Nepah Lagoon	10.7	2.3	11.6	1.2	0.2	0.3	88	2.9	4.76	43	20
South Moresby	132.9	3.3	31.1	41.3	0.2	0.3	94	93.0	4.76	43	20
Greenway Sound	17.9	1.9	8.0	1.4	0.1	0.1	53	13.7	4.91	39	20
Topknot	96.1	4.2	10.4	10.0	0.3	0.4	98	21.2	4.91	39	5
Susquash	8.1	0.6	44.2	3.6	1.1	0.2	94	11.7	4.95	37	20
Dickson - Polkinghorne Islands	15.9	1.4	47.6	7.6	0.6	0.7	96	3.8	4.99	35	20
Upper Call Inlet	21.1	7.5	5.5	1.2	0.0	0.1	52	3.8	5.01	34	20
Bate - Shadwell Passage	17.8	1.5	25.1	4.5	0.5	0.6	95	3.2	5.01	34	5
Shelter Bay	15.6	1.4	27.1	4.2	0.7	0.7	68	1.4	5.06	33	5
Salmon Channel	14.1	1.6	28.3	4.0	1.1	1.2	41	2.1	5.06	33	20
Lyell Island	331.8	8.3	18.2	60.5	0.2	0.1	68	86.0	5.07	32	20
Loughborough Inlet	37.1	13.1	2.8	1.1	0.0	0.2	44	12.8	5.10	30	20
McMullin Group	68.8	3.6	56.8	39.1	0.5	0.5	94	53.0	5.12	29	20
Scott Islands	339.2	6.5	9.3	31.5	0.2	0.1	94	24.0	5.20	27	5
Fish Egg Inlet	28.2	1.0	23.8	6.7	0.1	0.1	84	27.0	5.22	26	20
Chancellor Inlet West	13.9	3.0	17.6	2.4	0.3	0.2	46	2.8	5.23	25	20
Numas Islands	28.9	2.3	14.3	4.1	0.8	0.3	17	7.7	5.24	24	20
Holberg Inlet	22.5	4.5	27.1	6.1	0.1	0.1	77	52.8	5.29	22	20
Storm Islands	37.3	1.9	38.2	14.2	0.7	0.9	52	5.5	5.29	22	20
Bolivar Passage	16.7	1.4	58.1	9.7	0.9	0.9	70	4.2	5.33	21	5
Weynton Passage	17.6	1.6	43.4	7.6	1.1	1.2	75	7.6	5.34	20	5
Smith Sound	69.8	3.8	31.6	22.0	0.4	0.3	83	27.0	5.36	19	20
Otter Passage	162.5	3.7	23.8	38.7	0.3	0.3	50	44.0	5.50	17	20

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Goschen	14.5	1.7	58.9	8.5	0.8	0.4	100	10.0	5.56	14	20
North Danger Rocks	128.8	4.3	15.1	19.5	0.4	0.1	76	5.0	5.63	12	20
Goletas Channel	36.7	7.2	19.7	7.2	0.2	0.1	19	1.4	5.64	11	5
Gull Rocks South	20.9	1.9	24.7	5.2	0.9	0.1	80	17.0	5.64	11	20
West Calvert	57.1	2.4	42.0	24.0	0.4	0.1	99	27.0	5.65	10	20
Stephens Island	112.0	5.1	34.1	38.2	0.4	0.3	76	10.0	5.70	9	20
West Aristazabal Island	493.1	5.5	42.9	211.5	0.2	0.1	85	29.0	5.80	7	20
Goose Island	105.5	3.9	52.8	55.6	0.5	0.2	93	33.0	5.81	6	20
Kitasu Bay	64.8	2.3	22.4	14.5	0.3	0.2	63	29.0	5.81	6	20
Porcher Peninsula	50.1	2.1	61.5	30.8	0.5	0.2	100	4.0	5.90	4	20
West Banks Island	154.5	3.6	48.0	74.2	0.4	0.1	98	5.0	5.92	3	20
Dunira	79.0	3.3	39.4	31.1	0.4	0.3	69	12.0	6.01	1	20

Table 18b: Ecological attribute values, additive scores, and rank for RCAs in the Southern Shelf Bioregion. RCAs are listed in rank order beginning with the lowest score to highlight those areas which may have lower conservation benefit to rockfish.

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Bentinck Island	0.6	0.4	28.5	0.2	1.7	3.6	96	0.9	2.00	130	20
Becher Bay East	1.0	0.4	56.5	0.6	3.2	3.1	96	4.7	2.05	128	20
Trial Island	0.8	0.4	83.8	0.7	4.6	2.7	100	4.2	2.10	126	5
Duntze Head (Royal Roads)	0.9	0.3	62.2	0.6	2.8	2.6	99	8.8	2.15	125	5
Sooke Bay	3.4	0.3	57.1	1.9	2.0	2.2	98	10.8	2.30	124	20
Discovery - Chatham Islands	3.2	0.8	47.4	1.5	2.3	3.3	89	3.3	2.70	114	5
Vargas Island to Dunlap Island	2.8	0.9	30.1	0.9	1.7	2.1	100	2.8	2.85	109	20
Race Rocks	2.8	0.6	97.9	2.7	3.0	2.8	100	0.9	3.20	98	5
Saranac Island	10.9	1.0	11.0	1.2	0.8	1.2	99	1.2	3.58	84	20
Dare Point	3.5	0.8	51.0	1.8	1.4	1.0	99	3.0	3.88	73	20
Carmanah	8.2	0.6	54.2	4.5	1.3	1.7	96	3.0	4.05	69	20
Bedwell Sound	15.4	3.7	12.2	1.9	0.2	0.3	99	1.2	4.41	55	20
West of Bajo Reef	41.8	2.1	18.9	7.9	0.8	1.0	100	23.2	4.58	50	20
Pachena Point	19.3	1.2	45.3	8.7	0.7	0.7	99	12.4	4.78	42	20
Folger Passage	17.0	1.3	26.5	4.5	1.1	0.5	89	1.8	4.87	41	5
Checleset Bay	149.4	4.7	14.3	21.4	0.2	0.3	98	9.9	5.51	16	5
Estevan Point	186.3	5.1	30.8	57.4	0.3	0.2	100	23.2	5.55	15	20
Broken Group Islands	39.7	2.0	60.4	23.9	0.5	0.5	99	1.8	5.56	14	5
D'Arcy Island to Beaumont Shoal	53.9	1.2	21.0	11.3	0.9	0.2	49	3.3	5.93	2	5

Table 18c: Ecological attribute values, additive scores, and rank for RCAs in the Strait of Georgia Bioregion. RCAs are listed in rank order beginning with the lowest score to highlight those areas which may have lower conservation benefit to rockfish.

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Mariners Rest	1.9	0.5	9.3	0.2	2.0	1.3	66	3.6	1.85	132	5
Patey Rock	0.9	0.4	41.2	0.4	4.3	1.5	100	9.3	1.90	131	5
Mid Finlayson Arm	1.9	0.3	8.8	0.2	2.5	2.0	47	5.5	2.03	129	5
Passage Island	0.8	0.4	36.3	0.3	3.8	4.1	91	0.4	2.08	127	5
Danger Reefs	1.5	0.4	29.2	0.9	3.6	1.5	99	0.7	2.15	125	20
McNaughton Point	2.2	0.4	37.0	0.8	2.8	2.0	92	3.0	2.34	123	5
Russell Island	2.4	0.8	26.0	0.6	1.6	2.5	96	2.5	2.50	121	5
Savoie Rocks - Maude Reef	1.7	0.4	34.8	0.6	2.1	0.6	98	3.0	2.51	120	20
Departure Bay	2.7	0.9	6.1	0.2	1.7	0.9	99	3.1	2.53	119	5
West Vancouver	2.8	0.6	19.1	0.5	1.9	1.9	62	0.4	2.57	118	5
Baynes Sound - Ship Point	2.5	0.5	1.0	0.0	2.8	0.0	100	4.5	2.65	116	5
Oyster Bay	9.1	1.1	2.9	0.3	1.6	1.3	96	5.0	2.69	115	5
West Bay	1.1	0.7	9.4	0.1	0.7	2.6	83	3.0	2.70	114	5
Reynolds Point - Link Island	4.3	0.7	18.3	0.8	1.5	2.5	98	5.7	2.75	113	20
Chrome Island	3.9	0.7	18.7	0.7	1.4	1.2	97	3.0	2.80	112	20
Upper Centre Bay	1.1	0.6	12.0	0.1	0.8	2.7	93	3.0	2.80	112	5
Pam Rock	5.7	0.3	18.2	1.0	2.1	1.0	49	1.2	2.81	111	5
Maud Island	3.1	0.5	9.9	0.3	1.1	2.7	91	1.9	2.83	110	5
Bedwell Harbour	2.5	0.7	17.3	0.4	1.0	2.0	94	2.2	2.89	108	5
Portland Island	3.0	0.6	60.5	1.8	2.8	2.3	93	2.2	2.90	107	5
Eastern Burrard Inlet	2.8	0.6	2.3	0.1	1.7	0.3	99	5.9	2.92	106	5
Domett Point	2.1	0.6	8.5	0.2	2.6	0.7	13	3.7	2.95	105	5
Coffin Point	4.3	0.9	17.9	0.8	1.4	1.6	98	0.8	3.00	104	20
De Courcy Island North	4.0	0.8	17.1	0.7	1.4	1.0	97	1.2	3.02	103	20
Brentwood Bay	3.4	0.8	17.2	0.6	1.3	2.4	94	5.5	3.04	102	5

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Burgoyne Bay	2.6	0.9	9.4	0.2	0.9	2.2	67	3.1	3.11	101	5
Menzies Bay	3.9	0.9	10.5	0.4	0.7	0.9	84	1.9	3.13	100	20
Walken Island to Hemming Bay	13.6	0.2	23.1	3.1	1.3	1.5	71	2.2	3.19	99	5
Coal Island	3.1	0.6	25.6	0.8	1.4	1.7	99	2.2	3.25	97	5
Heriot Bay	5.1	0.7	21.1	1.1	1.9	1.1	6	4.4	3.27	96	5
Queen's Reach East	4.5	0.4	17.1	0.8	1.7	0.3	20	1.4	3.27	96	5
Woolridge Island	3.8	0.9	17.3	0.7	1.6	0.8	43	3.6	3.29	95	5
Indian Arm - Twin Islands	2.9	0.9	14.1	0.4	1.0	1.7	44	3.7	3.34	93	5
Maple Bay	3.3	0.7	12.4	0.4	0.5	1.1	93	2.5	3.35	92	5
Thurston Bay	6.6	0.5	11.1	0.7	0.5	1.2	84	2.2	3.41	91	5
Trincomali Channel	21.7	0.7	7.7	1.7	0.5	1.2	99	0.9	3.48	90	5
Dinner Rock	6.7	0.8	4.3	0.3	1.1	0.9	47	7.5	3.49	89	5
Thormanby Island	3.3	0.9	30.3	1.0	1.5	2.6	72	3.0	3.52	88	5
Bowyer Island	3.2	0.6	20.7	0.7	3.0	0.4	44	1.1	3.53	87	5
Ballenas Island	5.8	1.1	22.0	1.3	1.6	1.3	31	2.4	3.55	86	5
Deepwater Bay	1.8	0.7	9.3	0.2	0.7	0.6	95	6.8	3.56	85	5
Galiano Island North	9.8	0.9	3.5	0.3	0.9	0.4	97	9.4	3.56	85	5
Ruxton - Pylades Island	6.8	0.6	29.3	2.0	1.8	0.3	99	1.6	3.61	83	20
Prevost Island North	9.1	1.6	20.0	1.8	1.4	1.3	94	2.5	3.67	81	5
Kanish Bay	8.0	2.2	2.8	0.2	0.3	1.0	94	7.4	3.70	80	5
Skookumchuck Narrows	13.2	0.4	15.6	2.1	1.1	0.3	45	8.7	3.75	79	20
Lasqueti South -Young Point	9.3	1.5	4.2	0.4	1.3	1.0	9	2.4	3.76	78	5
Gabriola Passage	2.7	1.0	49.5	1.3	0.6	0.8	93	1.2	3.78	77	5
Queen's Reach West	3.5	0.5	16.6	0.6	1.3	0.8	43	3.5	3.83	76	5
Nanoose - Schooner Cove	12.0	1.2	15.7	1.9	0.9	1.0	97	2.4	3.84	75	5
McCall Bank	13.4	1.0	6.3	0.8	1.5	0.6	44	4.6	3.89	72	5
Northumberland Channel	14.8	1.2	7.4	1.1	0.7	0.8	68	3.1	3.93	71	5

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Pasley Island	12.0	1.5	19.6	2.4	0.9	1.1	77	5.3	4.03	70	5
Lions Bay	4.8	0.8	17.1	0.8	1.2	0.7	32	1.1	4.10	67	5
Halibut Bank	33.0	1.2	4.9	1.6	1.0	0.8	27	4.6	4.13	66	5
Saltspring Island North	8.5	1.8	17.2	1.5	0.6	0.5	97	0.0	4.19	64	20
Navy Channel	8.3	1.8	14.8	1.2	0.6	0.5	98	2.9	4.31	59	5
Valdes Island East	10.1	1.0	19.8	2.0	0.9	0.5	71	7.2	4.40	56	5
Davie Bay	10.2	0.9	12.0	1.2	0.9	0.5	40	5.7	4.41	55	5
Nelson Island	8.7	1.5	25.2	2.2	0.5	0.3	87	3.6	4.49	53	20
Hardy Island	16.0	0.9	11.3	1.8	0.7	0.1	27	4.0	4.54	51	5
Copeland Islands	15.3	1.0	22.8	3.5	1.3	1.5	56	3.8	4.64	48	5
Bell Chain Islets	13.0	0.9	45.8	6.0	1.0	0.9	95	2.9	4.67	47	5
Bute Inlet North	46.2	5.7	9.7	4.5	0.1	0.1	32	77.4	4.70	46	5
Thetis-Kuper Islands	25.7	1.0	22.0	5.7	0.9	0.9	95	0.7	4.71	45	5
Malaspina Strait	28.3	1.7	10.5	3.0	0.8	0.1	0	3.6	4.72	44	5
Mayne Island North	7.1	0.6	54.3	3.8	1.5	0.7	94	0.0	4.72	44	5
Sinclair Bank	19.2	2.1	11.9	2.3	0.9	0.6	16	3.8	4.76	43	5
Indian Arm - Crocker Island	9.0	3.2	11.9	1.1	0.3	0.3	50	3.7	4.88	40	5
Sabine Channel-Jervis-Jedediah Islands	22.4	1.6	20.0	4.5	0.7	1.0	67	2.4	4.94	38	5
Sisters Islets	10.7	1.6	19.4	2.1	1.2	0.2	12	4.3	4.97	36	5
Mitlenatch Island	24.9	2.3	8.9	2.2	0.8	0.2	20	5.0	4.99	35	5
Brethour,Domville,Forrest,Gooch Islands	18.8	1.5	32.3	6.1	0.9	0.9	85	2.7	5.08	31	5
Pendrell Sound	15.3	5.4	16.3	2.5	0.1	0.1	35	6.7	5.19	28	5
Teakerne Arm	8.4	2.6	15.6	1.3	0.2	0.1	42	8.6	5.19	28	5
Read - Cortes Islands	30.3	2.2	15.7	4.7	0.4	0.3	28	4.4	5.20	27	5
Ajax / Achilles Bank	73.9	1.8	4.7	3.5	0.7	0.1	27	4.3	5.28	23	5
Hotham Sound	22.4	3.0	18.6	4.2	0.2	0.1	25	9.0	5.46	18	5

RCA	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Princess Louisa Inlet	6.3	4.1	41.7	2.6	0.0	0.0	52	1.4	5.46	18	20
Octopus Islands to Hoskyn Channel	35.9	7.2	15.7	5.6	0.1	0.2	87	4.5	5.51	16	5
Lasqueti Island South	18.5	1.6	21.0	3.9	0.7	0.6	35	6.2	5.55	15	5
South Saturna	30.9	2.3	12.6	3.9	0.5	0.3	48	2.2	5.60	13	5
Salmon Inlet	17.5	5.7	22.1	3.9	0.1	0.1	27	8.7	5.79	8	20
Desolation Sound	60.0	3.6	13.8	8.3	0.2	0.2	33	3.8	5.84	5	5

RCAs with the highest scores by bioregion are Dunira in the Northern Shelf Bioregion, Desolation Sound in the Strait of Georgia Bioregion, and D'Arcy Island to Beaumont Shoal in the Southern Shelf Bioregion (Table 19). Of the 26 RCAs that are ranked in the top 20, 15 are located in the Northern Shelf Bioregion. These RCAs may be locations where rockfish conservation and population rebuilding are more likely to succeed as long as poaching and permitted fishing activities are kept to a minimum. These RCAs could be considered as models for others.

2.2.1 Conservation score (from Haggarty 2015)

In order to evaluate RCAs in terms of habitat quality and protection afforded to fish, Haggarty (2015) calculated a Conservation Score for each of the 144 RCAs in southern BC. This score included the following features that have been linked to RCA performance: area of the RCA, area of habitat (rocky reef), percent habitat, habitat isolation, rockfish bycatch in prawn traps, recreational compliance (determined from aerial surveys), and connectivity. For the final score, Haggarty added each of the feature scores without weighting. The lowest possible score is 8 and the highest is 24. The mean Conservation Score for all RCAs was 18.6. No RCA received the lowest or highest possible score, the range observed was 15 to 22. RCAs with the lowest scores (15 to 17) are listed in Table 20. These RCAs generally are small in overall size, contain a small area of rockfish habitat, a low proportion of the RCA is rockfish habitat, and habitat is not isolated. Often there was low compliance of the recreational fishery, and higher rates of bycatch in prawn traps. To develop her Conservation Score, Haggarty (2015) used somewhat different scoring categories than we did, and also included other important features such as rockfish bycatch and recreational compliance. Nevertheless, our two approaches identified eight RCAs where the conservation benefit to rockfish could be improved:

- Hardy Bay – Five Fathom Rock
- Patey Rock
- Bentinck Island
- Passage Island
- Haddington Passage
- Sooke Bay
- Russell Island
- Maud Island

Table 19. The twenty highest ranked RCAs according to their additive attribute scores. These RCAs may provide the most conservation benefit to rockfish.

RCA	Bio-region	Overall Size (km^2)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km^2)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Dunira	NS	79.0	3.3	39.4	31.1	0.4	0.3	69	12.0	6.01	1	20
D'Arcy Island to Beaumont Shoal	SS	53.9	1.2	21.0	11.3	0.9	0.2	49	3.3	5.93	2	5
West Banks Island	NS	154.5	3.6	48.0	74.2	0.4	0.1	98	5.0	5.92	3	20
Porcher Peninsula	NS	50.1	2.1	61.5	30.8	0.5	0.2	100	4.0	5.90	4	20
Desolation Sound	StG	60.0	3.6	13.8	8.3	0.2	0.2	33	3.8	5.84	5	5
Goose Island	NS	105.5	3.9	52.8	55.6	0.5	0.2	93	33.0	5.81	6	20
Kitasu Bay	NS	64.8	2.3	22.4	14.5	0.3	0.2	63	29.0	5.81	6	20
West Aristazabal Island	NS	493.1	5.5	42.9	211.5	0.2	0.1	85	29.0	5.80	7	20
Salmon Inlet	StG	17.5	5.7	22.1	3.9	0.1	0.1	27	8.7	5.79	8	20
Stephens Island	NS	112.0	5.1	34.1	38.2	0.4	0.3	76	10.0	5.70	9	20
West Calvert	NS	57.1	2.4	42.0	24.0	0.4	0.1	99	27.0	5.65	10	20
Goletas Channel	NS	36.7	7.2	19.7	7.2	0.2	0.1	19	1.4	5.64	11	5
Gull Rocks South	NS	20.9	1.9	24.7	5.2	0.9	0.1	80	17.0	5.64	11	20
North Danger Rocks	NS	128.8	4.3	15.1	19.5	0.4	0.1	76	5.0	5.63	12	20
South Saturna	StG	30.9	2.3	12.6	3.9	0.5	0.3	48	2.2	5.60	13	5
Goschen	NS	14.5	1.7	58.9	8.5	0.8	0.4	100	10.0	5.56	14	20
Broken Group Islands	SS	39.7	2.0	60.4	23.9	0.5	0.5	99	1.8	5.56	14	5
Estevan Point	SS	186.3	5.1	30.8	57.4	0.3	0.2	100	23.2	5.55	15	20
Lasqueti Island South	StG	18.5	1.6	21.0	3.9	0.7	0.6	35	6.2	5.55	15	5
Checleset Bay	SS	149.4	4.7	14.3	21.4	0.2	0.3	98	9.9	5.51	16	5
Octopus Islands to Hoskyn Channel	StG	35.9	7.2	15.7	5.6	0.1	0.2	87	4.5	5.51	16	5
Otter Passage	NS	162.5	3.7	23.8	38.7	0.3	0.3	50	44.0	5.50	17	20

RCA	Bio-region	Overall Size (km²)	Distance to Fished Boundary (km)	Habitat %	Habitat Area (km²)	Ratio Boundary to Area	Ratio Boundary Intersect Habitat	Depth (%<100m)	Distance to nearest RCA (km)	Score	Rank	Habitat Model
Hotham Sound	StG	22.4	3.0	18.6	4.2	0.2	0.1	25	9.0	5.46	18	5
Princess Louisa Inlet	StG	6.3	4.1	41.7	2.6	0.0	0.0	52	1.4	5.46	18	20
Smith Sound	NS	69.8	3.8	31.6	22.0	0.4	0.3	83	27.0	5.36	19	20
Weynton Passage	NS	17.6	1.6	43.4	7.6	1.1	1.2	75	7.6	5.34	20	5

Table 20. RCAs with the three lowest Conservation Scores (15 to 17; from Haggarty 2015).

RCA	Conservation Score	Rationale for low Conservation Score
Dinner Rock	15	Habitat area, % habitat, rec compliance, by-catch
Northumberland		% habitat, isolation, rec compliance
Trincomali		% habitat, isolation, rec compliance
Copeland		Isolation, rec compliance, bycatch
West of Bajo Reef	16	Habitat area, % habitat
Maud Island		Habitat area, % habitat, rec compliance
Galiano Island N		Habitat area, % habitat, rec compliance
Top Knot		% habitat, isolation, rec compliance
Lasqueti-Young Pt		Habitat area, % habitat
Haddington	17	Habitat area, % habitat
Sooke Bay		Habitat area, % habitat
Deepwater Bay		Habitat area, % habitat, rec compliance
Hardy-Five Fathom		Size, habitat area
Loughborough Inlet		Habitat area, % habitat
Coffin Point		Habitat area, % habitat
Bentinck Island		Size, habitat area, isolation
Passage Island		Size, habitat area
Russell Island		Habitat area, % habitat
Patey Rock		Size, habitat area
Octopus to Hoskyn		Rec compliance, bycatch
Saltspring N		Rec compliance
Valdes Island East		Rec compliance
Ballenas Island		Rec compliance
Nanoose-Schooner		Rec compliance
Hardy Island		Isolation
Thetis-Kuper		Rec compliance, bycatch

2.3 CONCLUSIONS

Based on additive scores (≤3) of select ecological attributes, the following RCAs ranked 104 to 133 may have lower conservation benefit for rockfish and their habitats:

Strait of Georgia	***Southern Shelf***	***Northern Shelf***
Mariners Rest	Bentinck Island*	Hardy Bay - Five Fathom Rock*
Patey Rock*	Becher Bay East	Haddington Passage*
Mid Finlayson Arm	Trial Island	Cracroft Point South – Sophia Islands
Passage Island*	Duntze Head (Royal Roads)	Gull Rocks North
Danger Reefs	Sooke Bay*	Bond Sound
McNaughton Point	Discovery – Chatham Islands	-
Russell Island*	Vargas Island to Dunlap Island	-
Savoie Rocks – Maude Reef	-	-
Departure Bay	-	-
West Vancouver	-	-
Baynes Sound – Ship Point	-	-
Oyster Bay	-	-
West Bay	-	-
Reynolds Point – Link Island	-	-
Chrome Island	-	-
Upper Center Bay	-	-
Pam Rock	-	-
Maud Island*	-	-
Bedwell Harbour	-	-
Portland Island	-	-
Eastern Burrard Inlet	-	-
Domett Point	-	-
Coffin Point	-	-

*RCAs identified as having low conservation scores by Haggarty (2015).

More RCAs in the Northern Shelf Bioregion may provide higher conservation benefit to rockfish than in other bioregions.

2.4 RECOMMENDATIONS

1. Use existing survey data to test whether the ranking system used in this report accurately describes the conservation status or effectiveness of RCAs.
2. Further evaluate those RCAs which have the lowest attribute scores to determine how to improve their conservation benefit to rockfish. Before implementing boundary changes or relocating RCAs, consider improving compliance and conducting ecological monitoring.

2.5 KNOWLEDGE GAPS AND RESEARCH RECOMMENDATIONS

- Conservation scores can be made more robust by considering other relevant criteria such as rockfish bycatch, compliance, and external risks including pollution and climate change. Research should be conducted to collect this type of information in all RCAs. There is some literature about compliance in southern RCAs being poor in certain locations (Lancaster et al. 2017, Haggarty et al. 2016b).
- The merit of the attributes considered in this report with regard to rockfish conservation is unknown. To evaluate the attributes, rockfish stock assessment and habitat surveys could be conducted in RCAs which have the lowest and highest conservation scores, and at outside control sites, to quantify and compare the effectiveness of these RCAs.

CHAPTER 3: EVALUATING THE RCA NETWORK AGAINST IDEAL ATTRIBUTE CRITERIA

To be precautionary, RCAs should encompass a minimum amount of rockfish habitat so fish spend most of their lives within RCA boundaries, and RCA size should be somewhat larger than the area of habitat to minimize spillover of mature fish. Furthermore, boundaries should be configured in such a way as to encompass entire reefs rather than partial reefs to limit the degree of spillover. Inshore rockfish utilize a range of depths so RCAs should be sufficiently large and orientated as such to encompass both shallow and deeper areas. Fished boundaries should not be too close to centers of RCAs to ensure fish are not baited out by people fishing along boundaries. RCAs need to be strategically located so they are connected in a network to ensure some rockfish propagules spend most of their lives in the safety of protected areas.

3.1 METHOD FOR SCORING

Based on literature reviews and authors' expertise, we evaluated RCAs against the following ideal ecological attribute criteria (see also Table 16):

- minimum size is 5 km^2
- distance to the nearest fished boundary is greater than 0.5 km
- minimum area of rockfish habitat is 3.4 km^2
- boundary to area ratio is less than 1.59
- boundary intersecting rockfish habitat ratio is less than 0.28
- depth ranges from 0 to 200 m
- distance to the nearest RCA is less than 50 km.
- Schematics of well-designed and poorly designed RCAs are illustrated in Figure 5.

3.2 RESULTS

Fourteen RCAs (8.5%) meet all of the ideal attribute criteria for; five in the Strait of Georgia Bioregion (Ajax/Achilles Bank, Desolation Sound, Hotham Sound, Salmon Inlet, South Saturna), one in the Southern Shelf Bioregion (D'Arcy Island to Beaumont Shoal), and eight in the Northern Shelf Bioregion (Dunira, Fish Egg Inlet, Goletas Channel, Goose Island, Kitasu Bay, North Danger Rocks, West Aristazabal Island, West Banks Island). These are highly ranked RCAs with all but three scoring in the top ten.

Thirty-four RCAs (21%) meet all but one ideal criteria and consequently are good candidates for realistic improvement (Table 21). Minimum area of rockfish habitat is an important criterion; RCAs without significant areas of rockfish habitat will not likely protect many rockfish. Ten RCAs do not have the minimum amount of rockfish habitat; six are in the Strait of Georgia Bioregion (Hardy Island, Mitlenatch Island, Pendrell Sound, Princess Louisa Inlet, Sisters Islets, Teakerne Arm) and four are in the Northern Shelf Bioregion (Chancellor Inlet West, Greenway Sound, Loughborough Inlet, Upper Call Inlet). The conservation benefit of these RCAs would be increased if they protected more rockfish habitat. Fourteen RCAs, five in the Strait of Georgia and nine in the Northern Shelf, may experience higher spillover and might benefit from having their boundaries aligned better with habitat edges. Eight RCAs, one in the Strait of Georgia (Octopus Islands), two in the Southern Shelf (Checleset Bay and Estevan Point), and five in the Northern Shelf, may benefit from increasing the range of depth they cover, if possible. Two RCAs, Bute Inlet North and Lyell Island, might benefit from having other RCAs located closer.

Thirty-six RCAs (22%) meet five out of seven criteria (Table 22). Most of these RCAs might benefit from having their boundaries aligned better with habitat features to limit spillover of adult fish. Furthermore, many of these RCAs would benefit from increasing the amount of habitat they protect in deeper waters.

By improving the above mentioned 70 RCAs, plus the 14 RCAs which already meet the ideal criteria, then 84 RCAs (51%) could potentially provide considerable conservation benefit to rockfish, as long as permitted human activities are having negligible impacts and compliance is high.

Twenty-nine RCAs (18%) meet four out of seven ecological attribute criteria. Twenty-eight RCAs (17%) meet three out of seven criteria. Twenty-three RCAs (14%) meet only one or two of the ideal criteria (Table 23). Essentially the best quality of these RCAs is they are well connected and within 50 km from another RCA. Although one third of these RCAs are sufficiently wide, most still likely experience high spillover of adult fish. In addition, many are small in size and contain little rockfish habitat that does not extend to an appropriate depth.

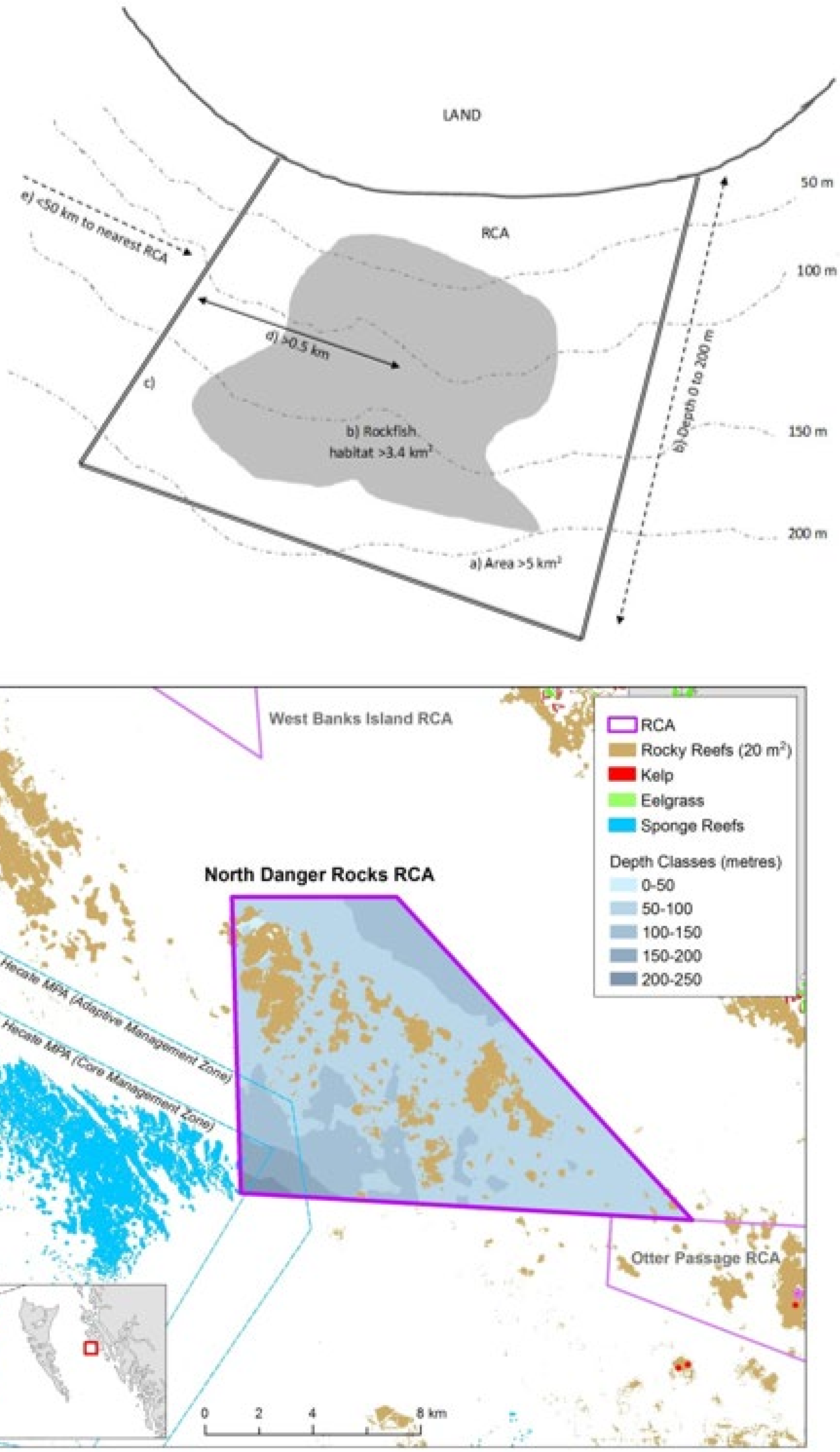

Figure 5a. Characteristics of a well-designed RCA: a) fairly large, b) encompasses a large area of rockfish habitat over a broad depth range, c) boundary does not intersect habitat so spillover is limited, d) fished boundaries are far away from the center of the RCA, and e) the protected area is near other RCAs. North Danger Rocks RCA has characteristics of a well-designed RCA.

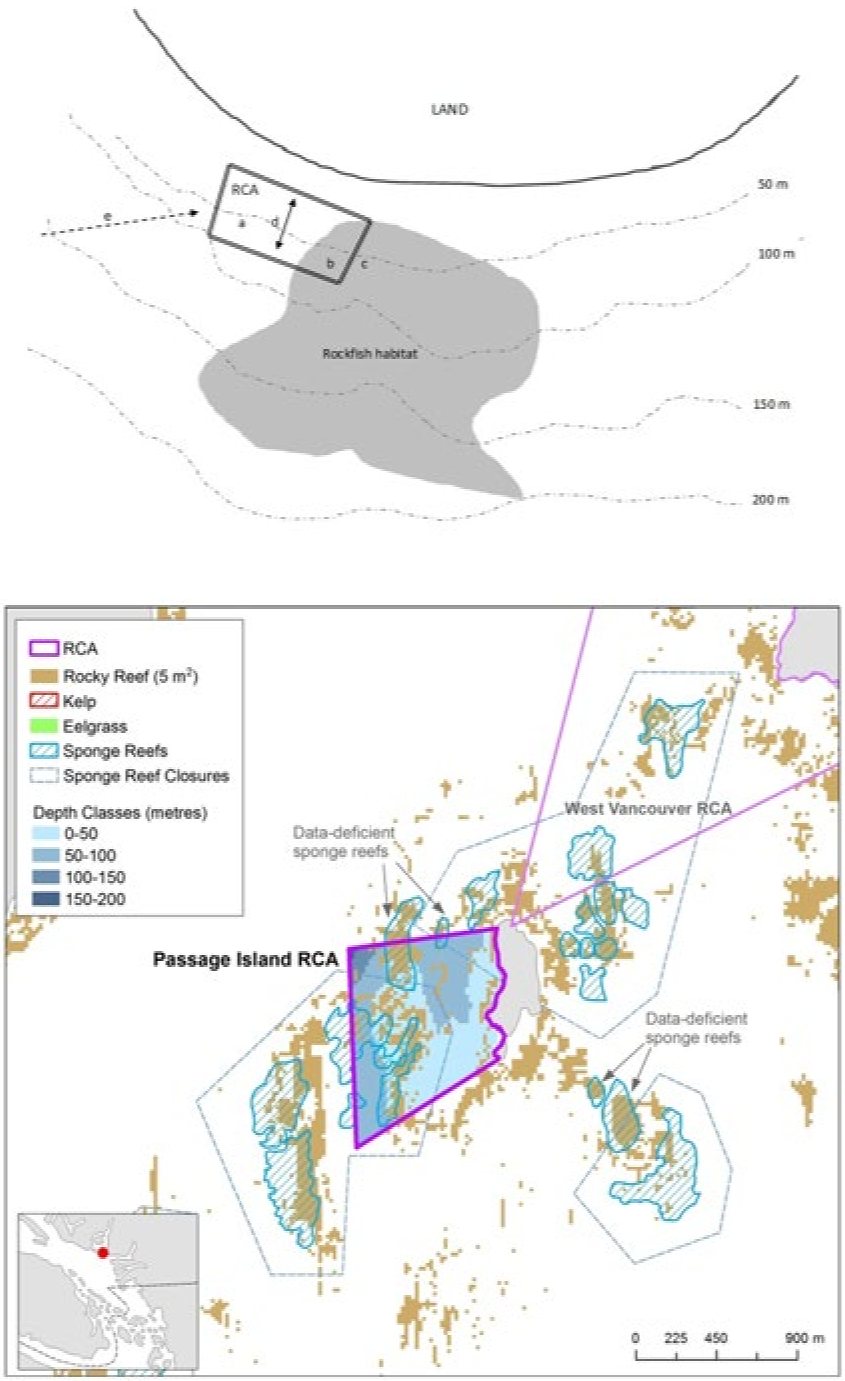

Figure 5b. Characteristics of a poorly designed RCA: a) small, b) encompasses a small area of rockfish habitat over a narrow depth range, c) boundary intersects habitat so spillover occurs, d) fished boundaries are too close to the center of the RCA, and e) the protected area is far away from other RCAs. Passage Island RCA has characteristics of a poorly designed RCA.

Table 21. RCAs meeting six out of seven ideal ecological attribute criteria.

Bioregion	RCA	Size	Distance to Boundary	Habitat Area	Ratio Edge to Area	Ratio Edge Intersect Reef	Depth	Connectivity
Strait of Georgia	Brethour,Domville,Forrest,Gooch Islands	√	√	√	√		√	√
	Bute Inlet North	√	√	√	√	√	√	
	Copeland Islands	√	√	√	√		√	√
	Hardy Island	√	√		√	√	√	√
	Lasqueti Island South	√	√	√	√		√	√
	Mitlenatch Island	√	√		√	√	√	√
	Octopus Islands to Hoskyn Channel	√	√	√	√	√		√
	Pendrell Sound	√	√		√	√	√	√
	Princess Louisa Inlet	√	√		√	√	√	√
	Read - Cortes Islands	√	√	√	√		√	√
	Sabine Channel-Jervis-Jedediah Islands	√	√	√	√		√	√
	Sisters Islets	√	√		√	√	√	√
	Teakerne Arm	√	√		√	√	√	√
Southern Shelf	Checleset Bay	√	√	√	√	√		√
	Estevan Point	√	√	√	√	√		√
Northern Shelf	Bolivar Passage	√	√	√	√		√	√
	Chancellor Inlet West	√	√		√	√	√	√
	Greenway Sound	√	√		√	√	√	√
	Gull Rocks South	√	√	√	√	√		√
	Loughborough Inlet	√	√		√	√	√	√
	Lyell Island	√	√	√	√	√	√	
	Numas Islands	√	√	√	√		√	√
	Otter Passage	√	√	√	√		√	√
	Porcher Peninsula	√	√	√	√	√		√
	Salmon Channel	√	√	√	√		√	√

Bioregion	RCA	Size	Distance to Boundary	Habitat Area	Ratio Edge to Area	Ratio Edge Intersect Reef	Depth	Connectivity
	Scott Islands	√	√	√	√	√		√
	Shelter Bay	√	√	√	√		√	√
	Smith Sound	√	√	√	√		√	√
	Stephens Island	√	√	√	√		√	√
	Storm Islands	√	√	√	√		√	√
	Susquash	√	√	√	√	√		√
	Upper Call Inlet	√	√		√	√	√	√
	West Calvert	√	√	√	√	√		√
	Weynton Passage	√	√	√	√		√	√

3.3 RECOMMENDATIONS

1. Consider improving the conservation benefits of particular RCAs to rockfish, including those listed in:
   a. Table 21 which meet all but one ideal criteria. Consider prioritizing those ten RCAs that do not have the minimum amount of rockfish habitat.
   b. Table 22 which meet five of seven criteria.
2. Further evaluation is warranted for, at minimum, the 23 RCAs listed in Table 23 to determine whether they would benefit from having their boundaries adjusted, or whether they should be moved to better locations, or possibly removed from the network.

Table 22. RCAs meeting five out of seven ideal ecological attribute criteria.

Bioregion	RCA	Size	Distance to Boundary	Habitat Area	Ratio Edge to Area	Ratio Edge Intersect Reef	Depth	Connectivity
Strait of Georgia	Bell Chain Islets	√	√	√	√			√
	Davie Bay	√	√		√		√	√
	Dinner Rock	√	√		√		√	√
	Halibut Bank	√	√		√		√	√
	Indian Arm - Crocker Island	√	√		√		√	√
	Malaspina Strait	√	√		√	√		√
	Mayne Island North	√	√	√	√			√
	McCall Bank	√	√		√		√	√
	Northumberland Channel	√	√		√		√	√
	Sinclair Bank	√	√		√		√	√
	Thetis-Kuper Islands	√	√	√	√			√
	Thurston Bay	√	√		√		√	√
	Valdes Island East	√	√		√		√	√
Southern Shelf	Broken Group Islands	√	√	√	√			√
	Carmanah	√	√	√	√			√
	Folger Passage	√	√	√	√			√
	Pachena Point	√	√	√	√			√
	West of Bajo Reef	√	√	√	√			√
Northern Shelf	Bate - Shadwell Passage	√	√	√	√			√
	Belleisle Sound	√	√		√		√	√
	Brooks Bay	√	√	√	√			√
	Browning Island to Raynor Group	√	√	√	√			√
	Burley Bay - Nepah Lagoon	√	√		√	√		√
	Dickson - Polkinghorne Islands	√	√	√	√			√
	Drury Inlet - Muirhead Islands	√	√		√	√		√
	Goschen	√	√	√	√			√

Bioregion	RCA	Size	Distance to Boundary	Habitat Area	Ratio Edge to Area	Ratio Edge Intersect Reef	Depth	Connectivity
	Havannah Channel	√		√	√		√	√
	Holberg Inlet	√	√	√	√	√		
	McMullin Group	√	√	√	√		√	
	Nowell Channel	√	√	√	√			√
	South Moresby	√	√	√	√		√	
	Thompson Sound	√	√		√		√	√
	Topknot	√	√	√	√			√
	Viscount Island	√	√		√		√	√
	Wakeman Sound	√	√		√		√	√
	Wellborne	√	√		√		√	√

Table 23. RCAs that only meet one or two out of seven ideal ecological attribute criteria.

Bioregion	RCA	Size	Distance to Boundary	Habitat Area	Ratio Edge to Area	Ratio Edge Intersect Reef	Depth	Connectivity
Strait of Georgia	Baynes Sound - Ship Point					√		√
	Danger Reefs							√
	Departure Bay		√					√
	Eastern Burrard Inlet		√					√
	Mariners Rest							√
	McNaughton Point							√
	Mid Finlayson Arm						√	√
	Passage Island							√
	Patey Rock							√
	Portland Island		√					√
	Russell Island		√					√
	Savoie Rocks - Maude Reef							√
Southern Shelf	Becher Bay East							√
	Bentinck Island							√
	Discovery - Chatham Islands		√					√
	Duntze Head (Royal Roads)							√
	Race Rocks		√					√
	Sooke Bay							√
	Trial Island							√
	Vargas Island to Dunlap Island		√					√
Northern Shelf	Cracroft Point South - Sophia Islands							√
	Haddington Passage		√					√
	Hardy Bay - Five Fathom Rock							√

CHAPTER 4: POTENTIAL CHANGES TO RCAs TO IMPROVE THEIR CONSERVATION BENEFIT TO ROCKFISH

In order to prioritize RCAs for further investigation regarding potential changes, RCAs can be assessed against individual attributes (size, rockfish habitat, depth, and connectivity) or by their additive scores which considered multiple attributes. Regardless of the approach, lower ranked RCAs may have their conservation benefit to rockfish increased through a strategic change. The shape and/or size of a RCA can be modified by adjusting boundaries. A more drastic measure might involve moving a particular RCA to a new location. The conservation benefit to rockfish of all attributes in RCAs, except connectivity, can be improved by adjusting boundaries and changing configurations (Table 24). Specifically, increasing the size of RCAs is an effective way to potentially resolve concerns with most attributes. In principle, we believe the size of RCAs should not be decreased where possible. RCAs with very little rockfish habitat may need to be relocated if additional habitat does not exist at their current locations. Concerns about connectivity may be resolved by creating new RCAs and strategically locating them throughout the network where gaps exist. Generally, for those RCAs that score poorly for multiple attributes, and these concerns cannot be resolved at their current locations by adjusting boundaries, then they should be moved, or possibly removed from the network. It might be beneficial to remove the poorest performing RCAs and compensate for their loss by increasing the size of other promising RCAs, or by adding new RCAs. Ideally any changes to existing RCAs ultimately should not produce a net decrease in the collective area currently protected in the network.

Table 24. Potential changes (and implications) to Rockfish Conservation Areas (RCAs) which may help to improve attributes important to rockfish conservation.

Attribute	Metric		Changes to RCAs	Implications for RCAs
Size	Minimum size criteria		Adjust boundary	Change in configuration resulting in an increase in size
	Distance to nearest boundary		Adjust boundary	Change in configuration, size could remain the same or increase
Rockfish habitat	Proportion of habitat		Adjust boundary, move	Change in configuration, size could remain the same, increase, or decrease; relocation
	Area of habitat		Adjust boundary, move	Change in configuration, size could remain the same or increase; relocation
	Habitat isolation	Edge to area ratio	Adjust boundary	Change in configuration likely resulting in an increase in size
		Edge intersecting habitat ratio	Adjust boundary	Change in configuration, size could remain the same or increase
Depth	Depth categories		Adjust boundary	Change in configuration likely resulting in an increase in size
Connectivity	Distance to nearest RCA		Create new RCAs	Additions to the network

CHAPTER 5: PROTECTED AREAS OTHER THAN RCAs

Areas with rockfish habitat and high abundances of rockfish no doubt exist outside RCAs. Such areas, if their locations are studied, may be candidates to include in the network by adjusting boundaries of nearby RCAs to incorporate such areas, or by moving problematic RCAs to these locations. Here we focus on the presence of rockfish habitat that exists in protected areas outside RCAs, the rationale being that rockfish protection could be increased in other protected areas if deemed necessary.

5.1 METHODS

To determine the amount of rockfish habitat outside RCAs that is within other protected areas, we used the coast-wide 20×20m rockfish habitat layer (Habitat20m_EK20m), as well as the CARTS dataset which contains protected areas data from all federal, provincial, and territorial jurisdictions (CCEA 2017). We were unable to use the higher resolution rockfish habitat layer (Habitat5m_EK20m) containing multi-beam data since we could not confirm the 5×5m coverage in areas outside the 48 RCAs located in the South Coast (Haggarty 2018). Using ArcGIS, we intersected the 20×20m rockfish habitat layer with the CARTS dataset to determine rockfish habitat overlapping all protected areas. RCAs intersecting habitat areas were removed and the GIS areas of the remaining overlap areas were calculated.

5.2 RESULTS

There are 169 protected areas under provincial and federal jurisdiction that contain rockfish habitat (total area within these protected areas is 1,941 km^2; Table 25). Of the provincial protected areas, conservancies contain the largest overall area of rockfish habitat (690 km^2). Of the federal protected areas, Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, Gwaii Haanas National Marine Conservation Area (NMCA), and Scott Islands Marine National Wildlife Area (mNWA) encompass the most rockfish habitat (420, 290, and 160 km^2, respectively). Twenty-three protected areas contain more than 10 km^2 of rockfish habitat and account for approximately 1,760 km^2 or 91% of rockfish habitat available in protected areas outside RCAs (Table 26). Fourteen of the 23 protected areas are provincial conservancies. Thirty-eight areas contain at least 3.4 km^2 of rockfish habitat (total 1,856 km^2) and 73 protected areas have at least 1 km^2 of habitat.

The Province of BC does not have the jurisdiction to manage fisheries; therefore, rockfish and their habitat are not protected from fishing pressure in provincial protected areas. In contrast, rockfish and their habitat are somewhat protected in Fisheries and Oceans glass sponge reef protected areas, which is a significant area of rockfish habitat (431 km^2). In the Strait of Georgia and Howe Sound Glass Sponge Reef Conservation Areas (OEABCM area), bottom contact fishing gear are prohibited, but salmon trolling and hook and line are permitted. Approximately 16-17% of Gwaii Haanas NMCA provides some protection to rockfish and their habitat (14% is designated as RCAs and 2-3% [six areas, two which overlap with one RCA] is closed to commercial and recreational fishing; Gwaii Haanas NMCA Management Plan 2010). There are four small areas in the NMCA outside RCAs, or approximately 2% (up to 5.8 km^2), that provide some protection to rockfish. In total, federal MPAs, NMCAs, mNWAs, and OEABCMs provide some protection to approximately 880 km^2 of rockfish habitat outside RCAs (Table 27), which increases the amount of protected habitat from 1,254 km^2 to 2,134 km^2.

RCAs and federal areas that contribute to achieving the marine conservation targets (MCT) have management measures in place to protect inshore rockfish and their habitat. Therefore, 19.6% of rockfish habitat in Inside waters is afforded some protection (Table 27), an amount considerably less than the desired conservation target of 30%. In order to reach the target, an additional 156 km^2 of rockfish habitat will need to be protected in Inside waters. One way to achieve this is to adequately protect rockfish habitat that already exists in all protected areas outside RCAs. In contrast, 26.7% of rockfish habitat in Outside waters is currently protected (Table 27), a higher amount (by 460 km^2) than the desired conservation target of 20%. Overall, RCAs (14.9%) and federal MCT areas (10.5%) currently protect 25.4% of total rockfish habitat.

Table 25. Rockfish habitat (20×20m habitat model only) in protected areas outside RCAs. Area in km².

Jurisdiction		Type of Protected Area	n	Overall Area Mean	Overall Area Total	Rockfish Habitat Area Mean	Rockfish Habitat Area Total
Provincial	BC Parks	Provincial Park	78	8.2	638.6	1.9	146.1
		Conservancy	47	67.1	3153.4	14.7	689.9
		Ecological Reserve	18	28.3	508.9	4.8	86.6
		Protected Area	2	0.8	1.7	0.3	0.6
	BC Provincial Administered Conservation Lands	Wildlife Management Area	7	43.3	303.4	8.8	61.5
Federal	Parks Canada	National Marine Conservation Area	1	3500	3500	289.6	289.6
		National Park	2	115.5	231	35.1	70.1
	Fisheries and Oceans	Marine Protected Area	1	2409.9	2409.9	420.1	420.1
		OEABCM – Glass Sponge Reef Closures	9	3.2	29	1.2	10.8
	Canadian Wildlife Service	Migratory Bird Sanctuary	3	5.2	20.8	2	5.9
		National Wildlife Area	1	11546	11546	159.6	159.6
Total			169	132.2	22342.7	11.5	1940.8

Table 26. Protected areas not including RCAs that contain at least 3.4 km² of rockfish habitat.

Name	Type of Protected Area	Size (km²)	Rockfish Habitat (km²)
Hecate Strait / Queen Charlotte Sound Glass Sponge Reefs	Marine Protected Area	1502.4	420.1
Gwaii Haanas	National Marine Conservation Area	3500.0	289.6
Scott Islands	Marine National Wildlife Area	11546.0	159.6
Duu Guusd	Conservancy	841.8	143.0
Hakai Luxvbalis	Conservancy	691.8	113.7
Daawuuxusda	Conservancy	457.9	89.5
Pacific Rim	National Park	225.0	69.1
Checleset Bay	Ecological Reserve	329.1	67.9
Ugwiwey/Cape Caution	Conservancy	154.4	55.8
Gitxaala Nii Luutiksm/Kitkatla	Conservancy	158.7	47.3
Lax Kwaxl/Dundas-Melville Islands	Conservancy	95.4	36.3
Boundary Bay	Wildlife Management Area	115.3	36.2
K'uuna Gwaay	Conservancy	131.6	28.2
Ksgaxl/Stephens Island Group	Conservancy	46.3	27.8
Cape Scott	Provincial Park	52.0	26.4
Nang Xaldangaas	Conservancy	98.0	24.4
Mahpahkum-Ahkwuna/Deserters-Walker	Conservancy	64.4	23.7
Kunxalas	Conservancy	123.6	21.2
Lax Ka'gass/Campania	Conservancy	34.3	17.6
Banks Nii Luutiksm	Conservancy	35.4	17.3
Vargas Island	Provincial Park	42.6	17.0
Broughton Archipelago	Provincial Park	99.1	16.6
Monckton Nii Luutiksm	Conservancy	26.0	11.3
Flores Island	Provincial Park	29.9	9.5
Bligh Island	Provincial Park	30.3	9.4
Tofino Mudflats	Wildlife Management Area	12.3	9.1
Roberts Bank	Wildlife Management Area	87.7	8.5
Nuchatlitz	Provincial Park	16.1	8.1
Hecate Strait / Queen Charlotte Sound Glass Sponge Reefs	Marine Protected Area	907.6	6.9
Brooks Peninsula Park [a.k.a. Muqqiwn]	Provincial Park	38.6	6.6
Fiordland	Conservancy	76.0	6.3
God's Pocket	Provincial Park	14.9	6.2
Victoria Harbour	Migratory Bird Sanctuary	18.1	5.4
Strait Of Georgia And Howe Sound Glass Sponge Reef Conservation Areas	Other Effective Area-Based Conservation Measure	7.6	5.0
Maquinna	Provincial Park	13.7	4.4
Catala Island	Provincial Park	7.0	3.9
Parksville-Qualicum Beach	Wildlife Management Area	9.5	3.5
Sturgeon Bank	Wildlife Management Area	77.6	3.4

5.3 RECOMMENDATIONS

1. Consider protecting an additional 156 km^2 of rockfish habitat in the Inside Management Area if protecting 30% of rockfish habitat is the desired conservation target.
2. Consider increasing protection for rockfish and their habitat in protected areas outside RCAs. To prioritize, consider the following:
   a. Sites in the Inside Management Area.
   b. Federal areas in Gwaii Haanas NMCA, Scott Islands mNWA, and Pacific Rim National Park.
   c. Provincial areas in conservancies (especially Duu Guusd, Hakai Luxvbalis, Daawuuxusda), Checleset Bay Ecological Reserve, Boundary Bay Wildlife Management Area, and Broughton Archipelago Provincial Park. If applying management changes to a type of protected area is more preferable than to single protected areas of various types, then increase protection for rockfish in all provincial conservancies using fisheries closures.
   d. Select sites listed in Table 26 to fill gaps and improve connectivity of the RCA network.

5.4 KNOWLEDGE GAPS AND RESEARCH RECOMMENDATIONS

- Identify marine areas outside RCAs that contain excellent rockfish habitat and high densities of rockfish. Such areas might exist in protected areas or elsewhere. Seek input from First Nations and stakeholders such as the dive community, citizen scientists, and the recreational and commercial sectors.
- Evaluate protected areas outside RCAs according to the same approach used in this paper to identify those areas with the highest conservation benefit to rockfish.

Table 27. Rockfish habitat (area [km^2] and proportion [%]) in RCAs and other protected areas.

Bioregion / Management Area	Total Rockfish Habitat	Rockfish Habitat in RCAs	Rockfish Habitat in Federal MCT Areas[1]	Rockfish Habitat in all Protected Areas Outside RCAs[2]	% Rockfish Habitat in RCAS	% Rockfish Habitat in RCAs and Federal MCT Areas	% Rockfish Habitat in all Protected Areas
Strait of Georgia	688.2	142.5	10.9	80.8	20.7	22.3	32.5
Southern Shelf	1444.3	153.5	0.0	227.1	10.6	10.6	26.4
Northern Shelf	6265.8	957.9	868.8	1632.9	15.3	29.2	41.3
Inside	1501.6	283.9	10.9	147.1	18.9	19.6	28.7
Outside	6896.6	970.0	869.1	1793.7	14.1	26.7	40.1
Total	8398.3	1253.9	880.0	1940.8	14.9	25.4	38.0

[1]Federal MCT protected areas include Gwaii Haanas NMCA, Scott Islands marine NWA, Hecate Strait MPA, and Strait of Georgia Glass Sponge Reefs.
Amounts derived from intersecting rockfish habitat (20×20m) in federal MCT protected areas with bioregions and management area datasets.
Rockfish habitat in RCAs has been excluded from these areas.
Amount derived from sum of all rockfish habitat (based on 20×20m model) in federal MCT protected areas.
Adjusted rockfish habitat area by using its proportion (%) of coast-wide (management area and bioregions totals) and applied that % to the correct coast-wide total (880 km^2).

[2]Rockfish habitat based on 20×20m habitat model. Includes rockfish habitat in all protected areas coast-wide that are located outside RCAs.
Amounts derived from intersecting with management areas and bioregions datasets which have different sources of coastlines.
To make coast-wide totals match between bioregions and management areas, determined the % of habitat by the various management areas/bioregions and applied that % to the correct total (1940.8 km^2).

CHAPTER 6: CONCLUSIONS

The main management objective of RCAs is to conserve a portion of inshore rockfish populations and their habitat. Abundances of many rockfish species are currently low and rebuilding these populations is critical. In order to effectively conserve species, RCAs must contain relevant high quality habitat and significant numbers of all life stages of rockfish, including large, older individuals, and provide refuge from fishing pressure so mortality from human activities is negligible.

Many RCAs are smaller than the minimum size recommended for MPAs to conserve biodiversity. Although rockfish have small home ranges, and will benefit from smaller areas where spatial protection is afforded, RCAs cannot be too small or sometime in their lifetime fish will eventually move beyond boundaries into fished areas. To compensate for their small size, RCAs need to be strategically located in a network to retain propagules. RCAs must protect relevant high quality habitat utilized by various inshore species found throughout a broad range of depths. RCAs scoring low for particular ecological attributes may have lower conservation benefit and be less effective at protecting rockfish and their habitats. These RCAs warrant further investigation to determine how to improve their conservation benefit to rockfish. Existing surveys and data can be used to test the efficacy of our ranking system. Although particular RCAs might be improved by adjusting their boundaries or relocating them, consider improving compliance and introducing some form of ecological monitoring. If configuration changes are deemed necessary, boundaries can be adjusted to increase RCA size, incorporate more habitat (including that in deeper waters), and better isolate habitat to limit spillover of mature fish. Moving RCAs to better locations will help if an insignificant amount of rockfish habitat exists inside particular RCAs and nearby, and this important deficiency cannot be mitigated by adjusting boundaries. Ground-truthing RCAs using non-destructive sampling methods will provide essential data regarding fish density and habitats, and will inform decisions regarding boundary changes or relocation.

Global assessments of MPAs have unfortunately shown that a metric such as the percent of area protected can be a misleading indicator of MPA effectiveness (Edgar et al. 2014, Mora et al. 2006). At least ten years after implementation, the RCA network in BC could benefit from strategic changes to particular RCAs in order to improve protection of rockfish. Input from First Nations and stakeholders regarding the appropriate strategic changes are critically important at this time to help enhance conservation efforts for inshore rockfish and their habitats.

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APPENDIX: HABITAT TYPE MAP EXAMPLES OF LOW SCORING RCAs

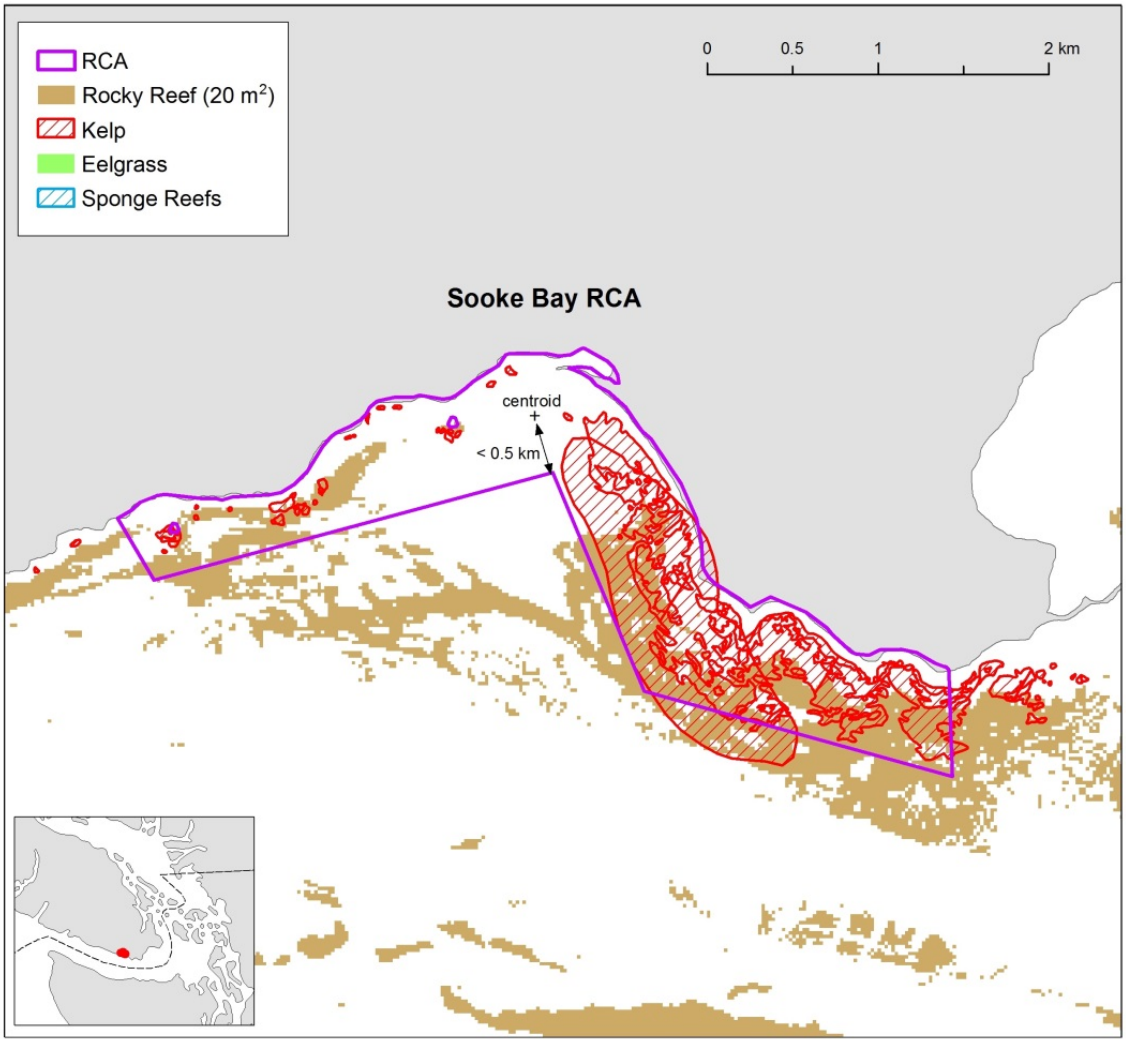

Figure A1. RCA where the distance from the center to the nearest boundary is <0.5 km.

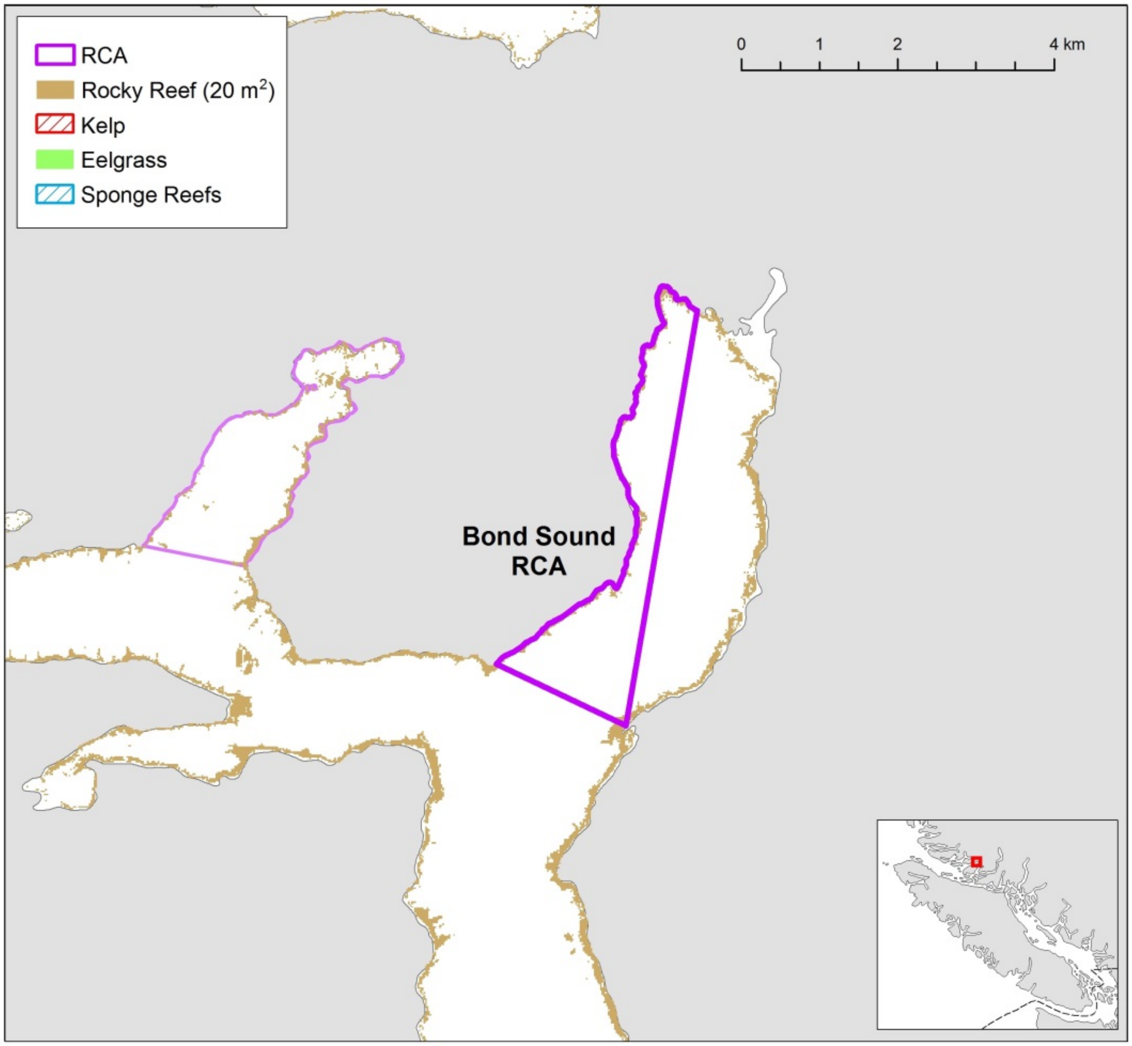

Figure A2. RCA with a low proportion of rockfish habitat.

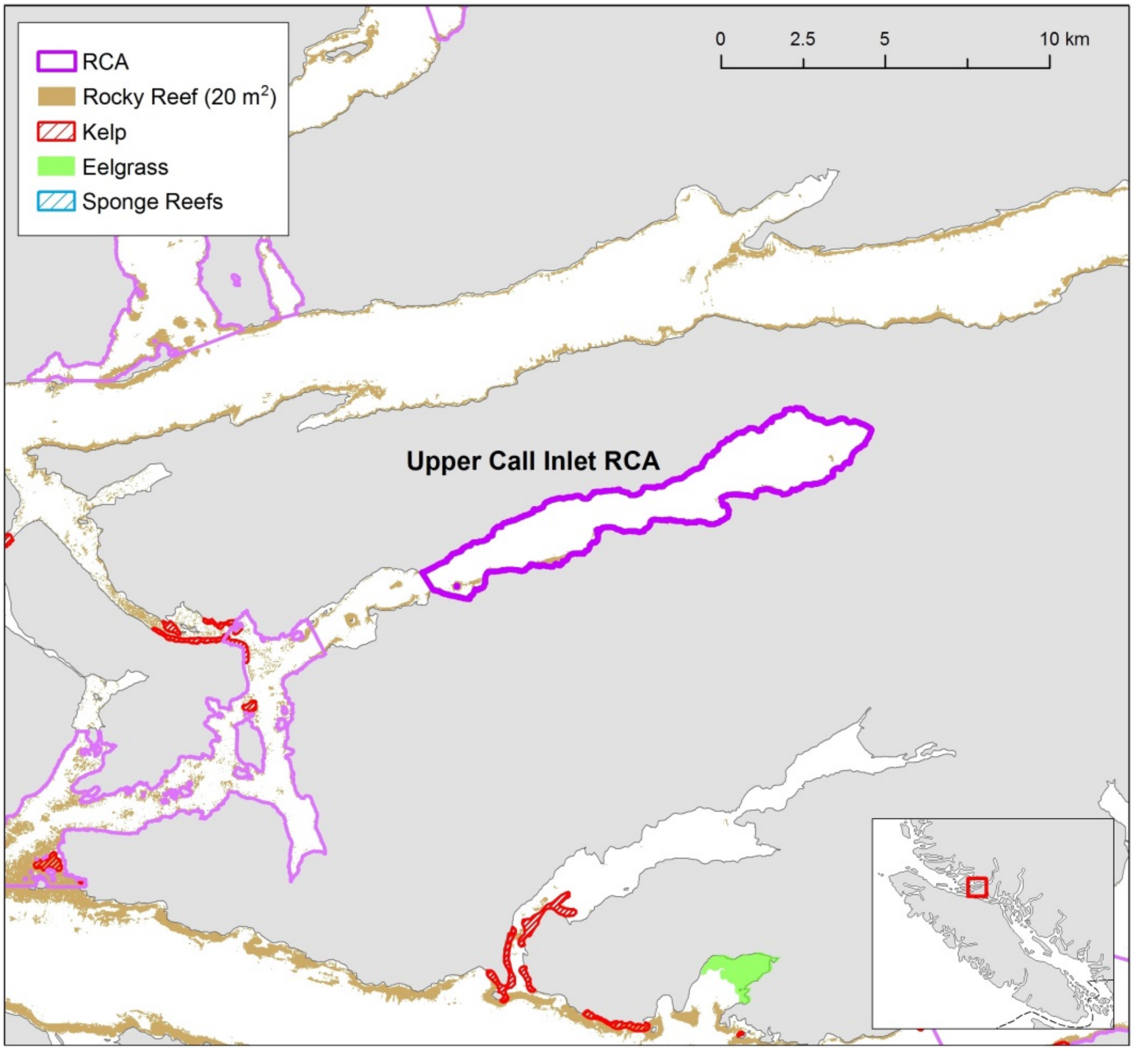

Figure A3. RCA with very little rockfish habitat.

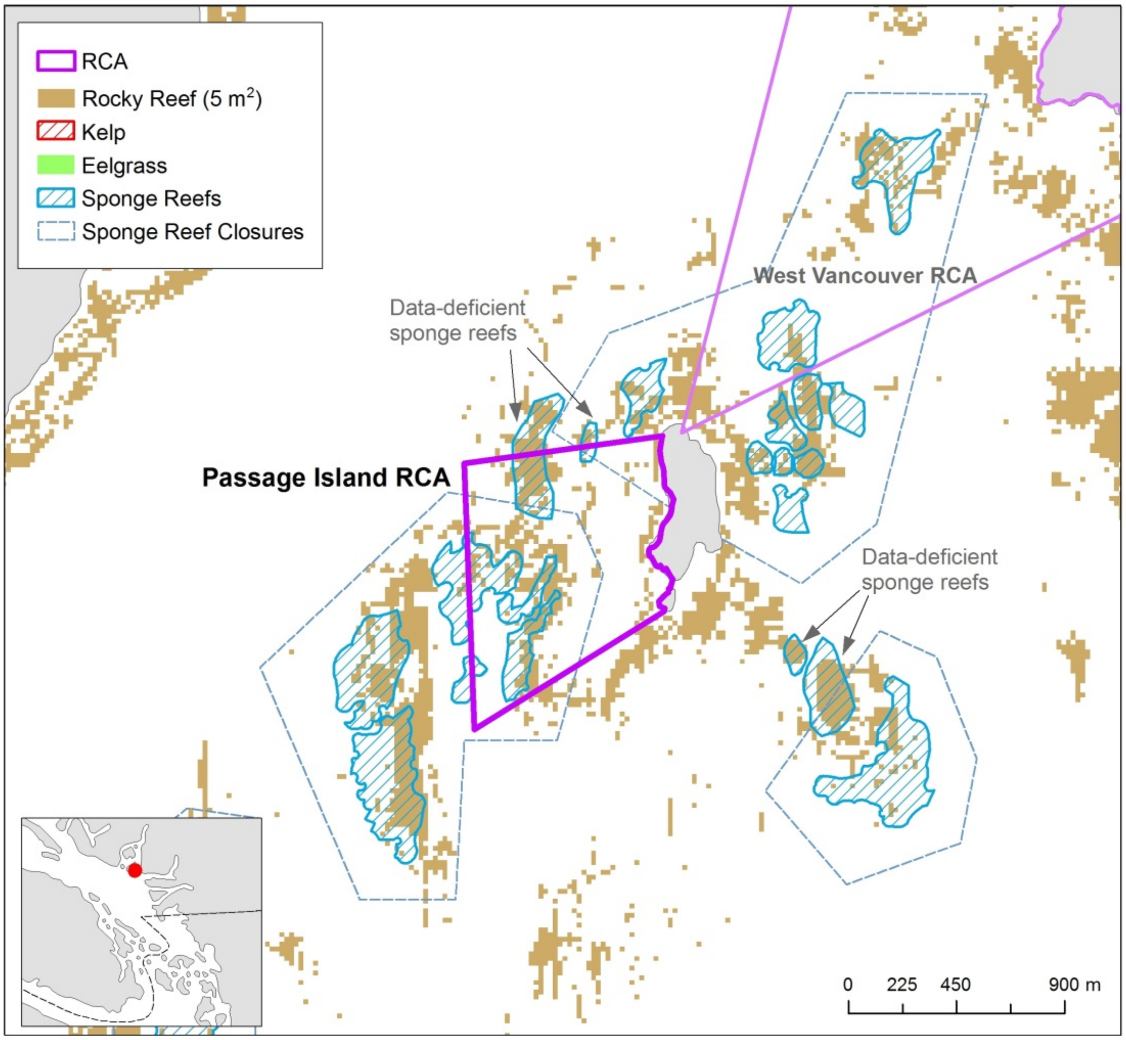

Figure A4. RCA where the boundary intersects glass sponge reef habitat.

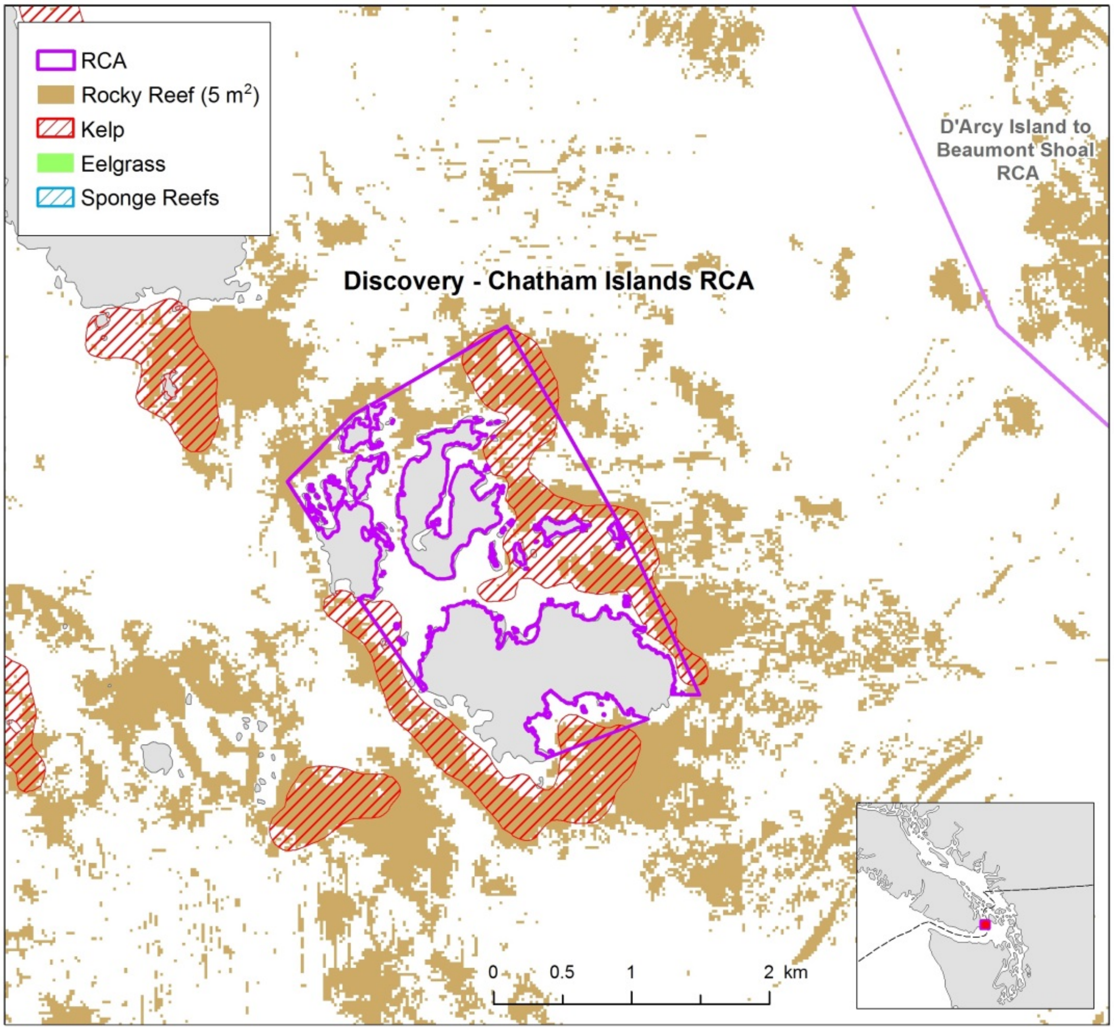

Figure A5. RCA where the boundary intersects rocky reef habitat.

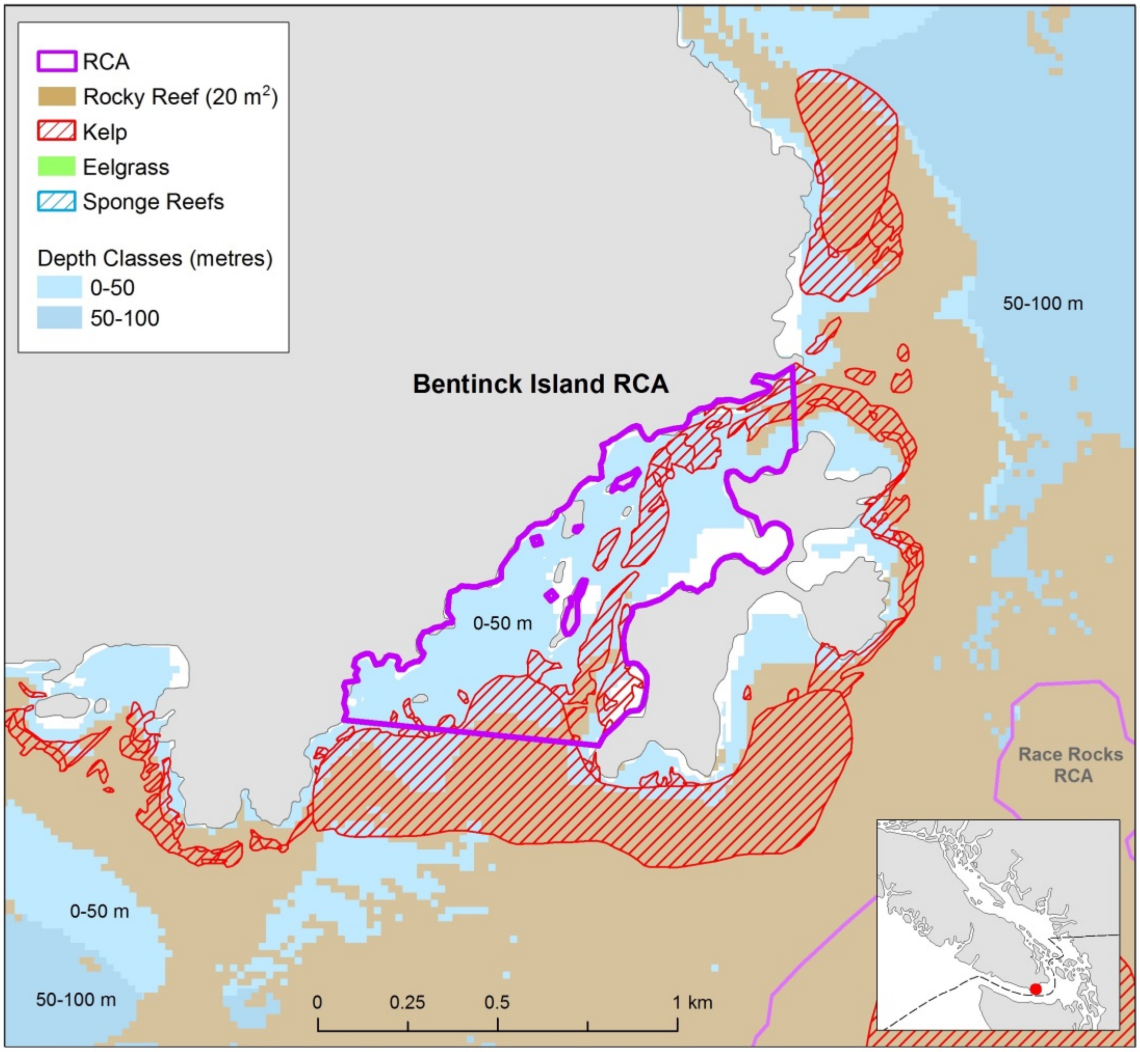

Figure A6. RCA that encompasses shallow (<50 m) water only.