NRC
NATURAL RESOURCES CONSULTANTS, INC.

4039 21st Ave. W, Suite 404
SEATTLE, WASHINGTON 98199-1252, U.S.A.
TELEPHONE: (206) 285-3480
TELEFAX: (206) 283-8263
E-Mail: kantonelis@nrccorp.com

# FINAL REPORT

# IDENTIFYING ROCKFISH HOT SPOT AREAS IN PUGET SOUND THROUGH A SPATIAL ANALYSIS OF "GREY" DATA

PREPARED FOR:
NOAA PROTECTED RESOURCES DIVISION &
NORTHWEST STRAITS FOUNDATION

PREPARED BY:
NATURAL RESOURCES CONSULTANTS, INC.
K. Antonelis, J. Drinkwin, P. Rudell, M. Shipley

September 30, 2016

IDENTIFYING ROCKFISH HOT SPOT AREAS IN PUGET SOUND THROUGH A SPATIAL ANALYSIS OF "GREY" DATA

**Abstract**

As ongoing research continues to feed the conservation efforts and decision making processes related to rockfish species (*Sebastes ssp.*) in Puget Sound, there is continued interest in summarizing and quantifying historical information related to rockfish habitat and their areas of occurrence. This, in part, is due to the relative paucity of existing empirical data on the rockfish in Puget Sound; making every form of available data more valuable. Studies utilizing reviews of 'grey' literature and interviews with local experts and resource users have highlighted the value of local ecological knowledge (LEK), and its use in conservation management. In this study we used a Geographic Information System to spatially analyze rockfish data from two datasets compiled from (a) historical fishing guide books with maps depicting rockfish fishing areas, with publish dates ranging from 1971 to 2008, and (b) interviews with 55 regional fishers and researchers, each producing hand-drawn rockfish area maps in hard-copy form. A hot spot analysis produced Rockfish Hot Spot Areas (RHA) for four groups of rockfish independently; general rockfish (non-ESA listed), yelloweye rockfish, canary rockfish, and bocaccio. General Rockfish RHA's were the most common (n = 97), accounting for 80% of the total RHA area, with a range throughout the five main sub-basins of Puget Sound. Of the ESA listed species, Yelloweye RHA's were most predominant (n = 60), but with the smallest mean area per RHA (0.80 $km^2$) of the four groups. Canary and Bocaccio RHA's covered approximately the same amount of area in total (15 $km^2$), yet there were four times as many Canary RHA's (n = 12) as Bocaccio RHA's (n = 3). The majority of RHA's (84%) overlapped NOAA designated critical habitat (55% in deepwater and 29% in nearshore). The mean depths of RHA's per group ranged from -52.4 m (Bocaccio) to -100.9 m (Yelloweye), and the mean depth of all RHA's combined was -67.8 m. Rockfish Hot Spot Areas reported here represent the spatial distribution of rockfish *hot spots* throughout Puget Sound as defined by the combined LEK from regional experts; providing a valuable addition to the best available data used in managing the conservation of rockfish in Puget Sound.

## Introduction

This study compiles data from a variety of untraditional sources, such as grey literature, expert elicitation, and local ecological knowledge (LEK) to identify areas in Puget Sound where rockfish listed under the Federal Endangered Species Act occur historically. These data were merged and analyzed to identify areas where spatial clustering occurred. The resultant *hot spots* were developed to add to the suite of rockfish related data in the region used to refine understanding of historical rockfish population abundance, distribution, and habitat use.

Total rockfish abundance in Puget Sound has declined approximately 70 percent in the last 40 years (Drake et al. 2010).[1] Of the 28 species of rockfish present in Puget Sound, 13 are listed as state Species of Concern by the Washington Department of Fish and Wildlife (Palsson et al 2009, WDFW 2016). In 2010, the National Oceanic and Atmospheric Administration (NOAA) listed yelloweye rockfish (*Sebastes ruberrimus*) and canary rockfish (*S. pinniger*) as threatened, and bocaccio rockfish (*S. paucispinis*) as endangered under the federal Endangered Species Act (ESA) (NOAA 2010). NOAA designated Critical Habitat (CH) for these species in November 2014 (NOAA 2014). Designated CH are areas where the species are currently found or areas that have been deemed essential for species conservation. Because the listed rockfish use different habitats during different life history stages, their designated CH was divided between Nearshore CH and Deepwater CH (Figure 1). In March 2011, WDFW finalized a Puget Sound Rockfish Conservation Plan, which identifies goals and actions necessary to protect existing stocks of rockfish, rebuild depleted stocks, and provide sustainable fishing opportunities.[2] WDFW's plan is a multi-species plan, in that its goals and actions address all stocks of rockfish in Puget Sound. Since initial listing of the three species under the ESA, new genetic analysis has shown that Puget Sound/Georgia Basin canary rockfish are not a Distinct Population Segment (DPS) as defined by the ESA (Andrews et al. 2015), and NOAA proposed to remove canary rockfish from the Federal List of Threatened and Endangered Species in July 2016 (NOAA 2016). Most recently, NOAA released a Draft Rockfish Recovery Plan for Puget Sound/Georgia Basin yelloweye and bocaccio rockfish (NMFS 2016).

Of the various stressors identified in the WDFW and NOAA recovery plans, overfishing is recognized as the primary cause of rockfish decline in Puget Sound (Palsson et al 2009, WDFW 2011, NOAA 2016). As a group, rockfish are vulnerable to overfishing for a variety of reasons, including high site fidelity and increased fecundity associated with older, larger females (which are more likely to be harvested); and rockfish occupy similar habitat and depths as lingcod and halibut, and are commonly taken as bycatch in these fisheries. Additionally, rockfish suffer high mortality from barotrauma when captured as bycatch and released. Over the years, WDFW has placed increasing restrictions on commercial and recreational fishing targeting rockfish and on other fishing known to cause rockfish bycatch. Fishing restrictions include complete prohibition on targeting rockfish within Puget Sound and a 120-foot depth limit to bottom fishing (WDFW 2010, WDFW 2014). Other stressors, including water and sediment pollution, derelict fishing gear, and climate change are also identified in the NOAA and WDFW rockfish recovery plans.

Both plans recognize the need to build a more comprehensive understanding of historic and current rockfish occurrence in Puget Sound in order to assist in future conservation, monitoring and research efforts, and ensure appropriate biological criteria is used for downlisting and delisting species under the ESA. Current efforts by WDFW, NOAA, and other partners to document rockfish abundance,

[1] In this report, Puget Sound refers to Washington State marine waters east of Green Point, approximately halfway between Ediz Hook and Dungeness Spit in the Eastern Strait of Juan de Fuca; the area within US defining the Distinct Population Segment (DPS) for the three rockfish species listed under the ESA.

[2] In the WDFW Puget Sound Conservation Plan and in this report, Puget Sound rockfish refers to all stocks of rockfish found in Puget Sound, rather than the single species commonly known as Puget Sound rockfish (*Sebastes emphaeus).*

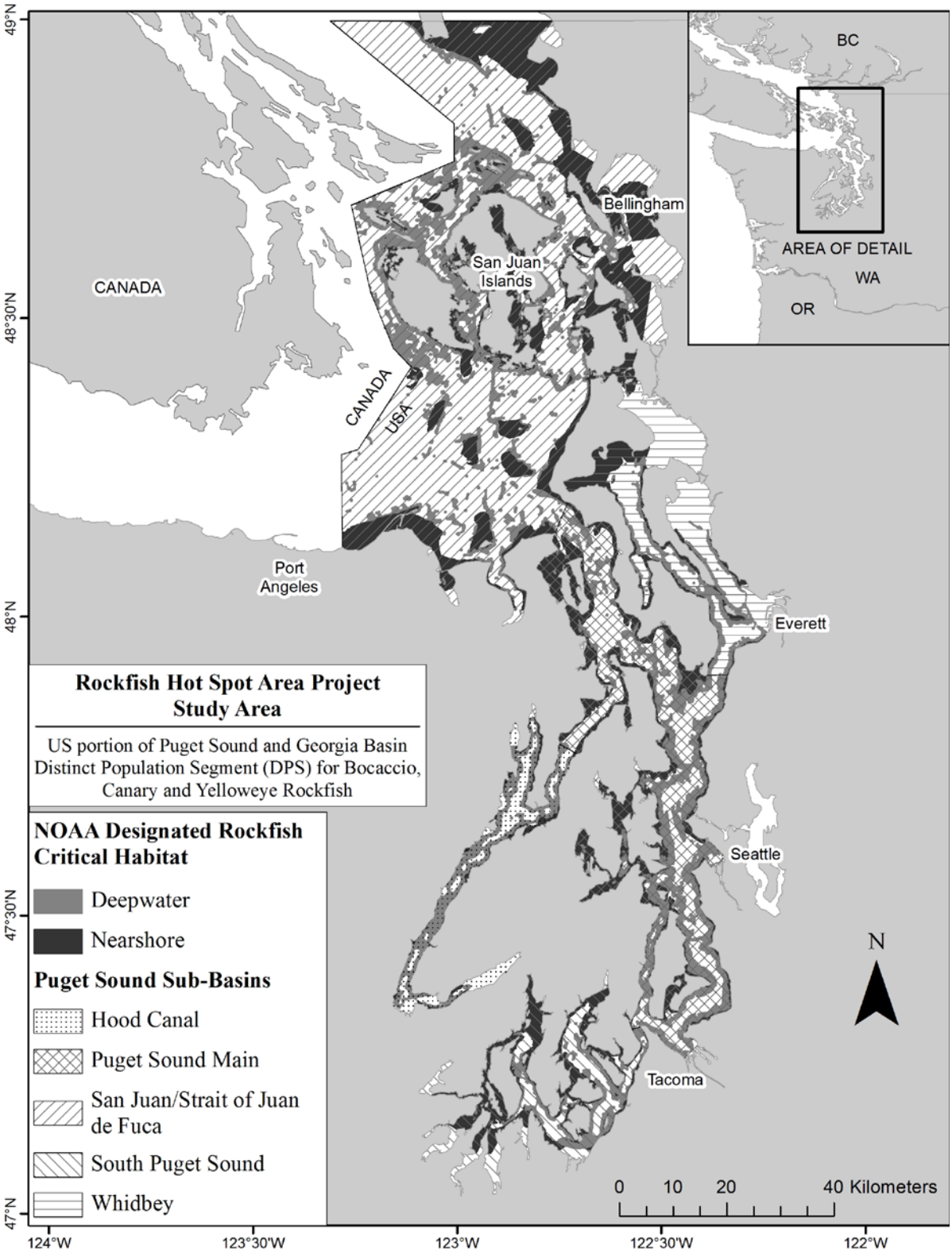



*Figure 1. Project study area showing NOAA designated rockfish critical habitat and Puget Sound biogeographic sub-regions.*

distribution, and habitat use employ systematic surveys with drop cameras, remotely operated vehicles (ROV's), hook and line surveys and trawl surveys. The NOAA Recovery Plan specifically calls out a need to better understand historic rockfish occurrence in order to compare current populations to a baseline, to inform recovery and delisting criteria. NOAA Recovery Plan action number 1.3 calls for an assessment of historical fishing and scientific records in the grey literature. To date, Beaudreau and Levin (2014) and Beaudreau and Whitney (2016) compiled recreational fishing effort data by location over 70 years through interviews and a mapping exercise with fishers, divers, and researchers. They showed that the areas where fishers fish for rockfish have remained relatively stable over 50 years, with heavy emphasis on the west side of San Juan Island and the south side of Whidbey Island (Possession Point/Bar). They also showed that the species now listed under the ESA were historically less abundant than other rockfish species.

This study builds on Beaudreau and Whitney's (2016) GIS mapping strategies, using a suite of tools in ArcGIS, including the Spatial Analyst Extension, to map and identify *hot spots* of historical rockfish occurrence using two datasets compiled from a variety sources, including grey literature, expert elicitation, and LEK. Special attention is placed on areas where multiple sources identify occurrences of rockfish. These datasets were compiled, georeferenced, and analyzed using geographic information systems (ArcGIS 10.2) to map areas in Puget Sound where high occurrence of rockfish are indicated from multiple sources to identify priority areas for rockfish conservation efforts; hereon referred to as Rockfish Hot Spot Areas (RHA).

## Data and Methods

*Description of datasets used*

Puget Sound Fishing Areas, grey literature dataset (PSFA): In 2013 NOAA supported a project to develop GIS shapefiles of PSFA's digitized from a variety of print sources (1971-2008) that include maps of fishing areas. The list of sources used and explanations of how the source data was converted to a GIS dataset is included in Appendix A. Maps from the sources were selected based on region and species covered. Printed maps were scanned and georeferenced in ArcGIS 10.0, and overlaid on NOAA nautical charts. Fishing areas were digitized into a vector-based map layer of polygons. Attributes include details associated with each fishing area polygon. Coordinate system information for the data as provided are as follows:
Geographic Coordinate System: GCS_WGS_1984
Projected Coordinate System: World_Mercator
Projection: Mercator

Rare rockfish use in Puget Sound LEK dataset (RLEK): In 2014 NOAA partnered with Jason Lim and Dr. David Fluharty, from the University of Washington, to gather data through interviews on historical habitat use for multiple groundfish species, including canary, yelloweye, and bocaccio rockfish in Puget Sound. A total of 55 individuals with specialized knowledge acquired through fishing, diving, or scientific research were interviewed (spatial research was reviewed and approved by the University of Washington Human Subjects Division). Because many rockfish species look similar and the misidentification of rockfish is common (Sawchuck et al. 2015), Lim started the interview by presenting pictures of rockfish (and the other fish species of interest) to verify that interviewees only identified spatial data for species in which they had experience with. The interviewees indicated where they had harvested or observed these species by drawing symbols, lines, and polygons on hard copies of numerous charts of Puget Sound. If the species were encountered in fisheries, individuals identified the general method used. In addition to rockfish, this dataset included lingcod (*Ophiodon elongates*), sablefish

(*Anoplopoma fimbria*), Pacific cod (*Gadus microcephalus*), kelp beds, shipwreck, and artificial reef areas. The hard copy charts were scanned into digital format (Adobe PDF) and georeferenced in ArcGIS.

Bathymetry: Complete bathymetric raster coverage at 30 meter resolution was provided by NOAA (Davies 2009). This dataset represents a mosaic of the best available bathymetry for the US portion of the Salish Sea (Puget Sound) as of June 2009. It was developed by NOAA using a variety of sources (bathymetry, digital elevation, and satellite data) referenced to North American Datum of 1983, with the spatial reference set to NAD_1983_UTM_Zone_10N.

Rockfish Critical Habitat: Provided by NOAA Fisheries West Coast Region Rockfish in Puget Sound website[3]. Final ArcGIS shapefiles for nearshore and deepwater CH were produced by NOAA through the analysis and combination of multiple datasets related to benthic habitat types. Rugosity values ≥ 0.001703 were termed *high rugosity* and used as the base component for the deepwater (adult) critical habitat designation. Additional data contributions to the deepwater CH designation were identified rocky habitats in the San Juan Islands, and credible observations of the three ESA listed species. Deepwater CH ranges are -30 m and deeper. The nearshore CH was developed through analysis of multiple layers within the Washington State Shorezone Inventory, including kelp and various sand/gravel/rock shoreline geomorphic types. The maximum depth of the nearshore CH is -30 m. The complete description of both nearshore and deepwater CH shapefile construction can be found in the associated metadata that accompanies the shapefiles. Coordinate system information for the data as provided are as follows:
Geographic Coordinate System: GCS_North_American_1983
Projected Coordinate System: NAD_1983_Albers
Projection: Albers

The locations and abundance of RHA's are described relative to bathymetry, both nearshore and deepwater designated CH, and five biogeographic sub-basins. These five sub basins are: San Juan/Strait of Juan de Fuca Basin, Puget Sound Main Basin, Whidbey Basin, South Puget Sound, and Hood Canal (Figure 1). These sub-basins are largely defined by sills that restrict water exchange, in combination with other factors, such as bathymetry, to create ecologically unique conditions (NOAA 2014). The division of sub-basins and CH used in this study are the same as described by NOAA (2014), yet they differ slightly from the Management Units used by NOAA in its Draft Rockfish Recovery Plan, as in this study we maintain the separation of the Puget Sound Main Basin and the Whidbey Basin.

*Data preparation and Analysis*

Spatial data contributions from each interview participant in the RLEK dataset were digitized into polygons in a vector-based map layer (shapefile) in ArcGIS 10.2. When original data were represented as symbols (i.e., lines, dots, #'s, and X's), a minor level of interpretation and translation was used to ensure dataset conformity for analysis. All polygons were developed with a variety of data fields related to source, species presence, and other features; however for the primary purpose of this research we focused on one field defining the type of rockfish present. Yelloweye, bocaccio, and canary rockfish were identified as such in a designated data field, while all other rockfish were categorized as General Rockfish. All fishing areas in the PSFA that included mention of rockfish were noted as such, then assigned one of the four rockfish groups as described above. Attributes within the PSFA dataset were analyzed for rockfish occurrence and those polygons were identified as such in a designated data field. Both RLEK and PSFA datasets were projected to the NAD_1983_UTM_Zone_10N projected coordinate system for consistency during analysis.

[3] http://www.westcoast.fisheries.noaa.gov/protected_species/rockfish/critical_habitat_info.html

For both datasets, four rockfish groups were analyzed: General, Yelloweye, Canary, and Bocaccio RHA's, the size distribution of polygons was summarized per species and per participant (RLEK) or data source (PSFA). Only polygons depicting rockfish occurrence were exported from the two datasets (PSFA and RLEK) and merged into one shapefile for the development of RHAs.

All rockfish areas from the combined dataset were overlain on a uniform grid covering Puget Sound marine waters. The grid cell size of 0.3 km x 0.3 km (0.09 $km^2$) was chosen to resemble the mode of the distribution of rockfish polygon areas from the RLEK dataset (Beaudreau & Whitney 2016). In identifying the most appropriate cell size for analysis we considered the relatively small home range and habitat use areas associated with rockfish in Puget Sound (Love et al. 2002; Tolimieri et al. 2009), and the potential error associated with converting hand-drawn maps to digital shapefiles. Frequency of occurrence of rockfish areas per grid cell was calculated for each rockfish group with the spatial join function in ArcGIS 10.2, and grids with value of zero were removed. The Hot Spot Analysis tool with Getis-Ord Gi* statistical model was used to identify statistically significant areas where clustering of high occurrence values are present (hot spots) for each rockfish group analyzed. Weighted features from each group were analyzed using the polygon contiguity parameter so that computations per cell included only those cells sharing an edge or corner with the target cell. The false discovery rate (FDR) correction was applied to filter out cells with falsely high significance. Clusters of cells (hot spots) with significant spatial clustering values (99% confidence level, z-score > +2.58, p-value < 0.01) were merged to form independent polygons built from neighboring (edges and corners) hot spot cells. The set of independent hot spot polygons built for each rockfish group were identified as RHAs.

Rockfish Hot Spot Areas were developed for general rockfish, yelloweye, canary, and bocaccio. Summary statistics were calculated for each group of RHAs per basin. The RHAs were overlaid on NOAA designated deepwater and nearshore rockfish CH, and the percentage of RHA area per type per basin within the CH was calculated and summarized. Using the *Extract by mask* tool in ArcGIS Spatial Analyst we extracted data from the bathymetry raster dataset where they overlaid RHA's, and their values were summarized per RHA group per basin. All bathymetric raster data with a depth value > 0 m was deleted from the dataset and not used in analysis. Analysis of bathymetric values and CH within RHA's per sub-basin was conducted to explore noticeable physical differences within RHA's in different regions of Puget Sound, which could assist in ongoing and future research related to rockfish habitat characterization. It should be noted that the proposal by NOAA Fisheries to delist the canary rockfish from the ESA came amid the current research project and we chose to proceed in developing Canary RHA's; understanding that in the future they may be deemed less important in the context of protected resources than the Yelloweye or Bocaccio RHA's.

**Results**

Digitized data from the RLEK dataset extended from Point Roberts, near the US-Canada border, down to the Olympia area in South Puget Sound, with heavy overlap in some expected areas such as the San Juan Islands and Possession Point/Bar. A total of 4,018 polygons were developed across the dataset for all categories, 1,894 (47%) of which represented rockfish presence. Non-rockfish species (lingcod, P. cod, and sablefish) represented 42% of the total number of polygons; and kelp, shipwrecks, riptides, and artificial reefs made up the other 19%. Fifty four (98%) of the 55 interviewees provided areas of occurrence for at least one rockfish species. Yelloweye, canary, and bocaccio areas were consistently smaller than the general rockfish and other species areas provided by respondents, with the mean polygon size per participant for each ESA listed species below 10 $km^2$ (Figure 2).

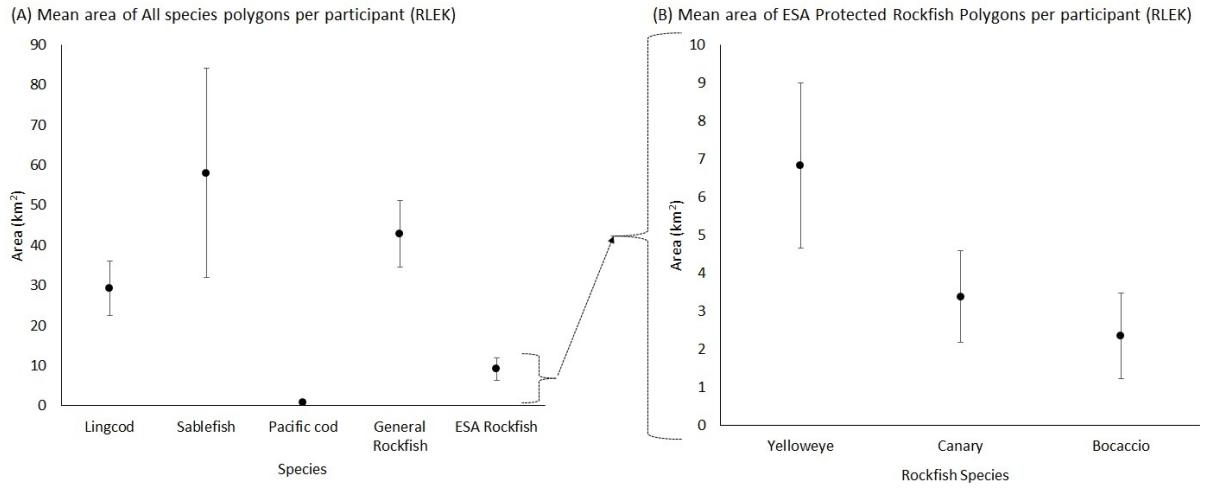



*Figure 2. Size of combined polygon area per species per participant in RLEK dataset. Plots on left show mean (± SE) area per participant per group analyzed, with ESA listed rockfish areas combined. Plots on right show mean (± SE) area for ESA rockfish species only.*

Rockfish areas from the PSFA dataset were larger and more generalized in spatial extent than the RLEK dataset, with approximately 17% of the total number of rockfish polygons covering approximately 30% more total area than contributions from the RLEK dataset (Table 1). Polygons representing general rockfish covered the largest amount of combined area in each of the two datasets, followed by yelloweye. The combined area of canary rockfish polygons from the RLEK dataset was more than twice that of the PSFA, while the combined area of bocaccio polygons from RLEK were less than half that of the PSFA (Table 1).

*Table 1. Comparison of RLEK and PSFA datasets. Number of polygons, total area, mean area and Standard Error (SE) for rockfish groups identified for analysis.*

| | RLEK | | | | PSFA | | | |
|---|---|---|---|---|---|---|---|---|
| Group | Number of Polygons | Combined Area (km²) | Mean Area per Polygon (km²) | SE | Number of Polygons | Combined Area (km²) | Mean Area per Polygon (km²) | SE |
| General Rockfish | 1,507 | 2,230.49 | 1.48 | 0.10 | 281 | 3,324.71 | 11.83 | 3.40 |
| Yelloweye | 241 | 321.24 | 1.33 | 0.14 | 18 | 86.06 | 4.78 | 0.88 |
| Canary | 126 | 111.57 | 0.89 | 0.11 | 12 | 45.77 | 3.81 | 0.75 |
| Bocaccio | 20 | 30.69 | 1.53 | 0.75 | 16 | 80.48 | 5.03 | 2.16 |
| ALL ROCKFISH | 1,894 | 2,693.99 | 1.42 | 0.08 | 327 | 3,537.02 | 10.82 | 2.93 |

Combined and counted by grid, polygons from the two datasets produce a heat map of areas of coincidence where the multiple sources contributing to the research agreed upon areas of rockfish occurrence (Figure 3). The heat map in many ways resembles a *hot spot* chart, and can serve the purpose of visually identifying locations where rockfish occur or have occurred. However, the goal of the analysis is to identify RHA's exhibiting statistically significant spatial clustering based on weighted data per group, therefore the merged and gridded data underwent a hot spot analysis. Hot spot analysis was not conducted on the non-rockfish species (i.e., lingcod, sablefish, Pacific cod) or habitat (i.e., kelp, shipwrecks) data provided in the RLEK dataset; their digitized polygons are shown in Appendix B and C.

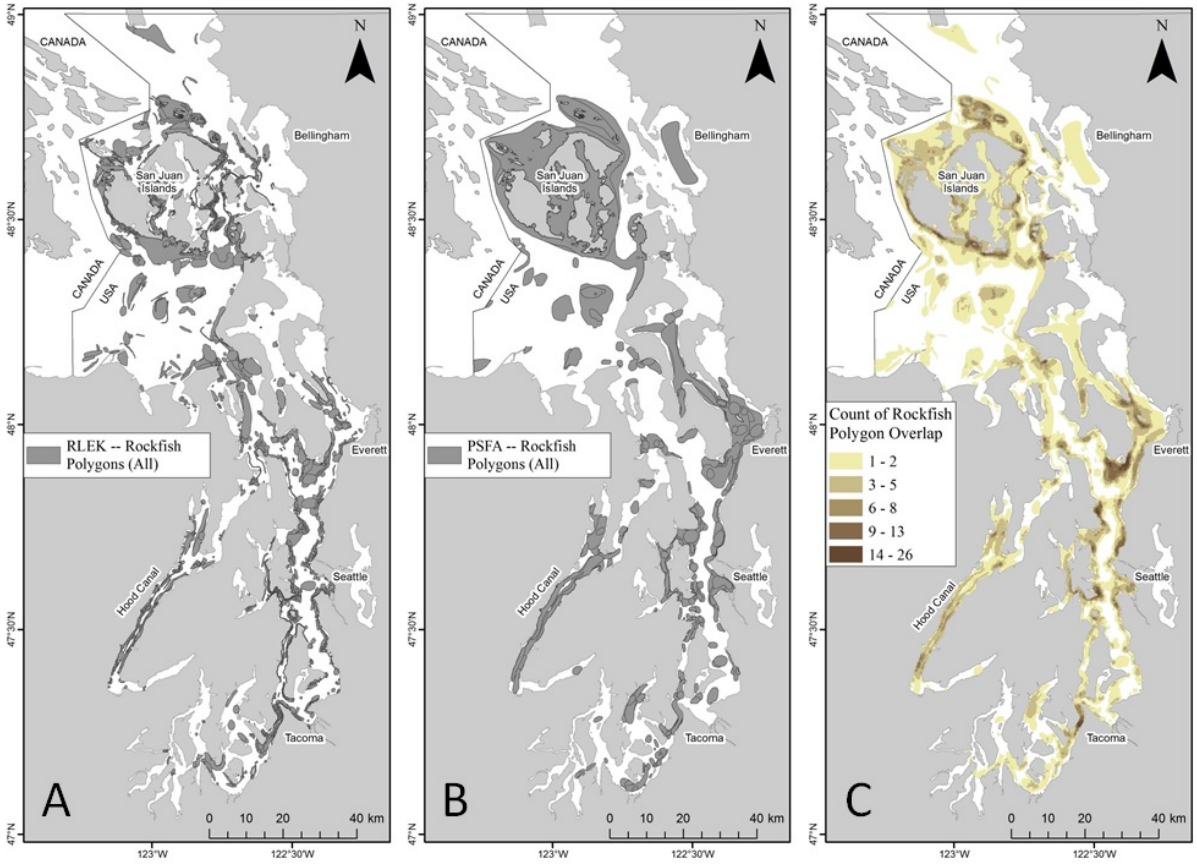
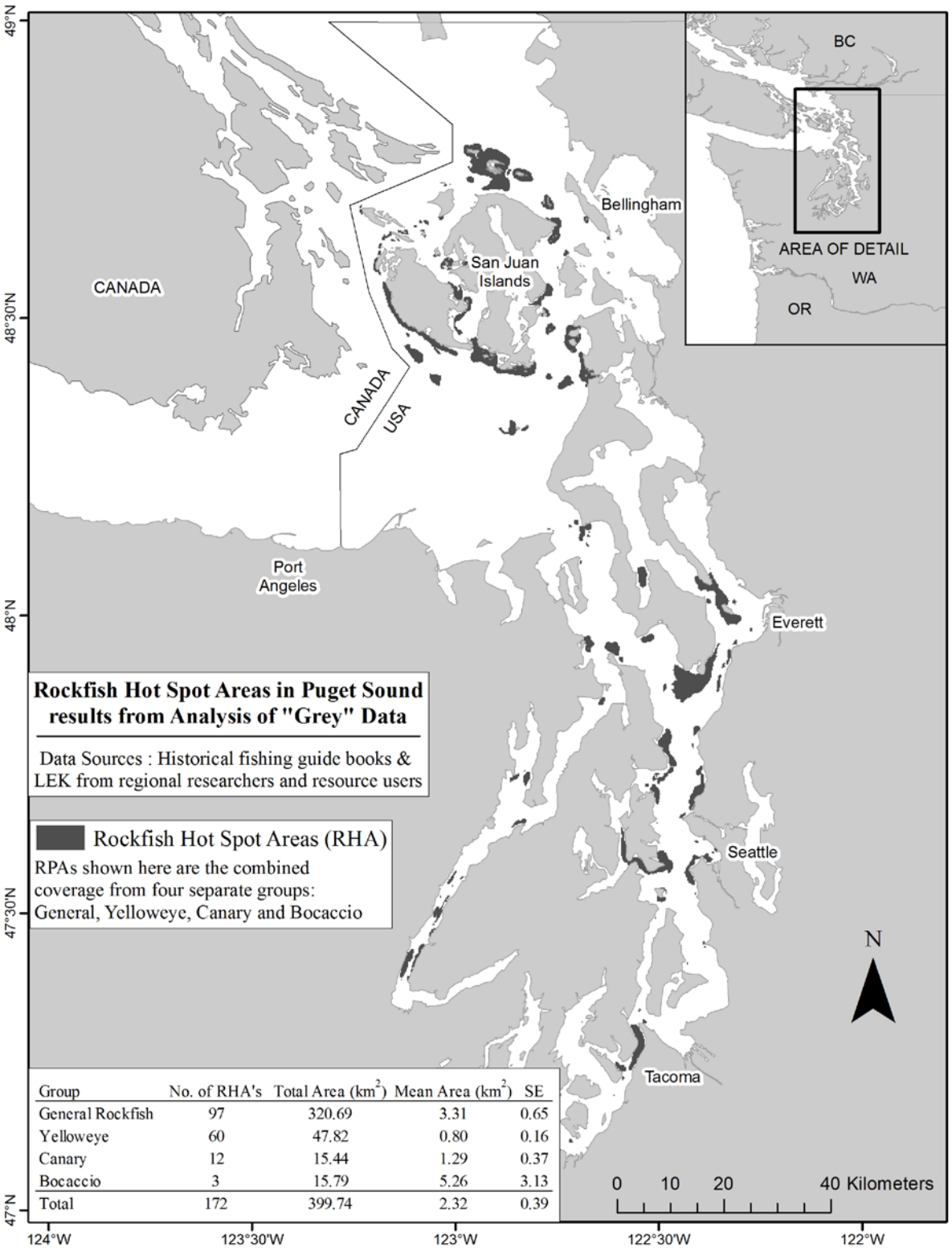



*Figure 3. Spatial distribution of all rockfish polygons from (A) RLEK and (B) PSFA datasets after digitization. The combined, gridded data produces a 'heat map' showing areas of concentration based on count of polygon overlap.*

*Rockfish Hot Spot Areas*

The hot spot analysis produced a total of 172 statistically significant hot spot clusters we identified as RHA's across all groups. The mean area of all RHA's was 2.32 km$^2$ (± 0.39 SE), and including overlap between groups, the RHA's covered a total area of 399.74 km$^2$. Rockfish Hot Spot Areas per group ranged in total count from a low of three (Bocaccio) to a high of 97 (general), and in area from a low of 15.44 km$^2$ (canary) to a high of 320.69 km$^2$ (General) (Figure 4).

General Rockfish RHA's were the only group to appear in all five biogeographic basins of Puget Sound, while Yelloweye RHA's occur in all but the South Puget Sound Basin. Canary RHA's appeared in the San Juan/Strait of Juan de Fuca, Whidbey, and the Puget Sound Main Basins; and Bocaccio RHA's only appeared in the Whidbey and Puget Sound Main Basins (Figure 5). The greatest amount of RHA total area within a basin occurs in the San Juan/Strait of Juan de Fuca (187.04 km$^2$) followed by the Puget Sound Main (133.91 km$^2$). Less total RHA area appears in the Whidbey (43.86 km$^2$), Hood Canal (21.11 km$^2$), and South Puget Sound Basins (13.83 km$^2$). When compared to the total area of the basin, the RHAs covered 11.1% of the Puget Sound Main Basin, 7.0% of the Hood Canal Basin, 6.9% of the Whidbey Basin, 5.4% of the San Juan/Strait of Juan de Fuca Basin, and 3.1% of the South Puget Sound Basin.




| Group | No. of RHA's | Total Area (km$^2$) | Mean Area (km$^2$) | SE |
|---|---|---|---|---|
| General Rockfish | 97 | 320.69 | 3.31 | 0.65 |
| Yelloweye | 60 | 47.82 | 0.80 | 0.16 |
| Canary | 12 | 15.44 | 1.29 | 0.37 |
| Bocaccio | 3 | 15.79 | 5.26 | 3.13 |
| Total | 172 | 399.74 | 2.32 | 0.39 |

*Figure 4. Spatial distribution of combined Rockfish Priority Areas (RHA) for general rockfish, yelloweye, canary and bocaccio. Inset table summarizes number and size of RHAs by group.*

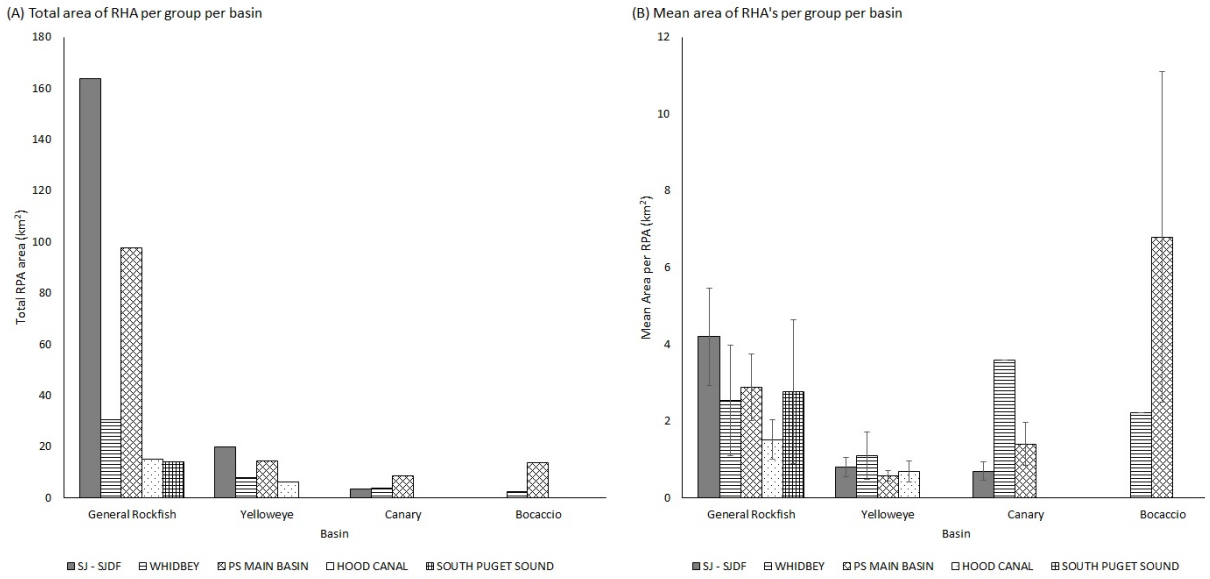



*Figure 5. (A) Total and (B) mean (+- SE) area of RHA's per group per basin.*

General Rockfish RHA's are the largest and most widespread of the groups, with the heaviest concentration in and around the San Juan Islands. Large continuous RHA's occur along the entire southern shoreline of Lopez Island (26.17 $km^2$), surrounding Sucia and Patos Islands (41.54 $km^2$), and along the south and west facing shoreline of San Juan Island (17.62 $km^2$). Several smaller (< 10 $km^2$) RHA's occur in the San Juan/Strait of Juan de Fuca Basin, along steep shorelines, islets, and reefs (Figure 6A). No RHAs occur north of Sucia and Patos Islands. Further south, large General Rockfish RHA's appear off south Whidbey Island at Possession Point/Bar (27.49 $km^2$), around Camano Head and Gedney Island (18.28 $km^2$), southern Bainbridge Island (16.92 $km^2$), and the Tacoma Narrows (11.27 $km^2$). Scattered along the shorelines of the Puget Sound Main, Hood Canal, and southern Whidbey Basins are several smaller General Rockfish RHA's (Figure 6B).

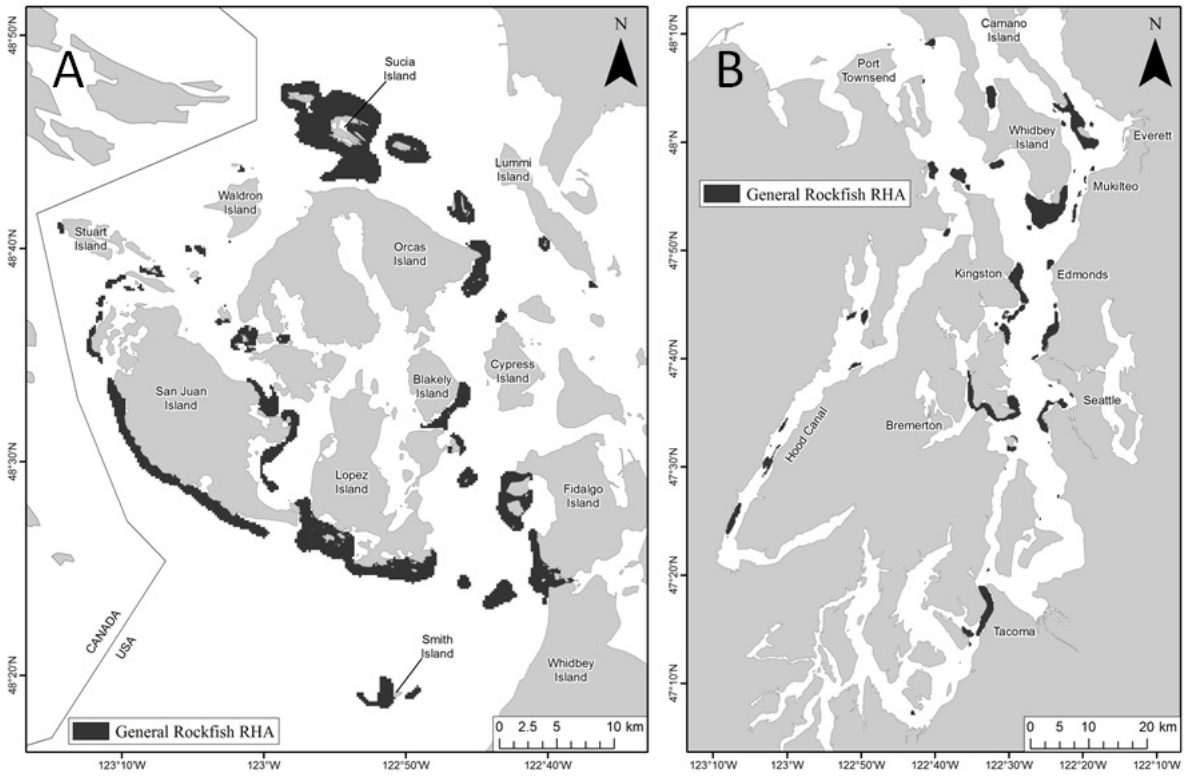



*Figure 6. Spatial distribution of General Rockfish RHA's in (A) San Juan/Strait of Juan de Fuca Basin, and (B) Whidbey, Puget Sound Main, Hood Canal and South Puget Sound Basins.*

General Rockfish RHA's inside deepwater CH ranged from 37% in the South Puget Sound Basin to 75% in the Hood Canal Basin. In the nearshore CH, General Rockfish RHA's ranged from 4% in Hood Canal to 44% in the Puget Sound Main Basin. The San Juan/Strait of Juan de Fuca Basin had the least amount of General Rockfish RHA's outside any CH with 13%, while in the South Puget Sound Basin 43% of the General Rockfish RHA's landed outside both nearshore and deepwater CH (Figure 7A).

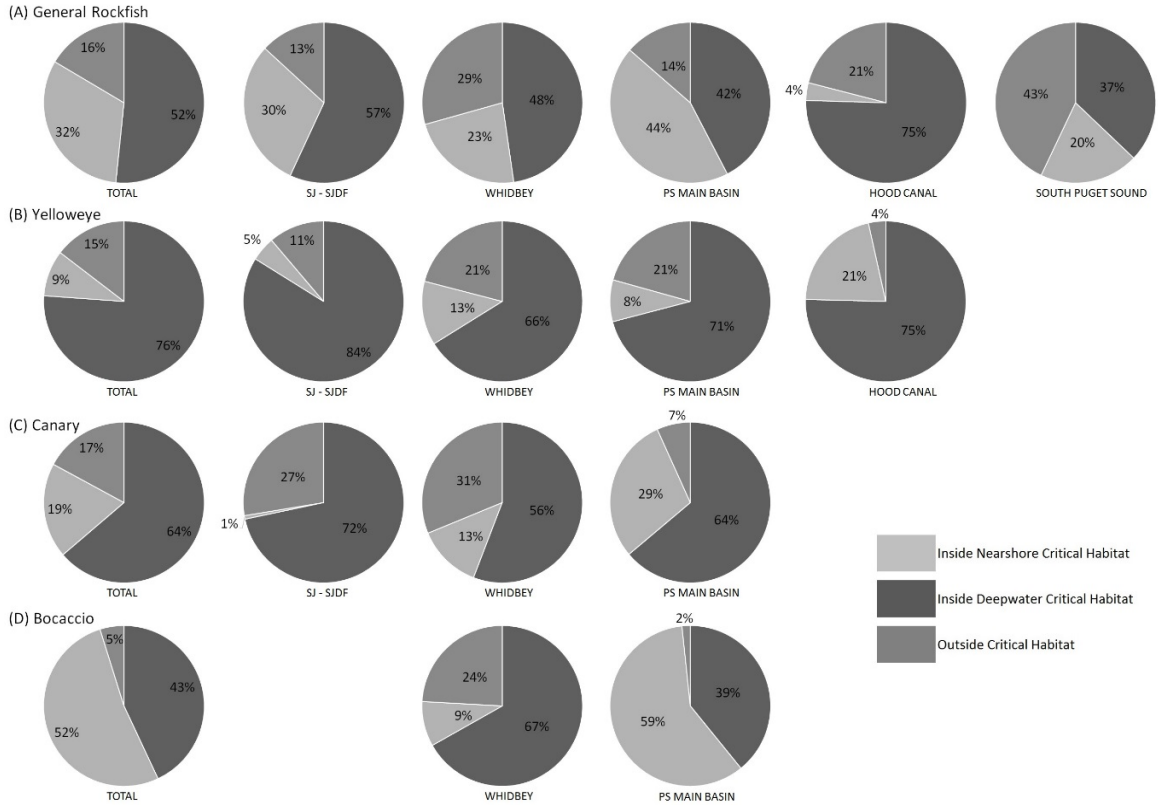



*Figure 7. Percentage of RHA's within NOAA designated Deepwater and Nearshore Critical Habitat for Rockfish by group by basin.*

The mean depth value within General Rockfish RHA's was -63.0 m; greater than Bocaccio RHA mean depth, but less than those of Yelloweye RHA's and Canary RHA's (Figure 8A. General Rockfish RHA's exhibited the widest range of depth values between all groups (Figure 8B). Within General Rockfish RHA's, the greatest depth range occurred in the San Juan/Strait of Juan de Fuca Basin (0 to -326 m), and the smallest range was seen in the South Puget Sound Basin (0 to -111 m) (Figure 8C). General Rockfish RHA depths were concentrated at deeper depths in the Hood Canal Basin than in any other basin (Figure 8C).

The greatest total area of Yelloweye RHA's occurs in the San Juan/Strait of Juan de Fuca Basin. Yelloweye RHA's often occur adjacent to, or partially overlap General Rockfish RHA's, yet coverage is much sparser. The two largest Yelloweye RHA's (5.96 $km^2$ and 3.46 $km^2$) occur near Middle Bank in Haro Strait, south of San Juan Island, and are isolated, with no neighboring RHA's from another group (Figure 9A). To the south, Yelloweye RHA's are mostly scattered. However, groupings occur at Admiralty Head, in the area from southern Camano Island to the southern reaches of Possession Bar, between Edmonds and Seattle, and through the southern section of Hood Canal (Figure 9B). The largest Yelloweye RHA (6.99 $km^2$) occurs at Possession Point along the southeast side of Whidbey Island, and straddles the Whidbey and Puget Sound Main Basins.

(A) All Rockfish Groups (mean depth)

| Basin | General | Yelloweye | Canary | Bocaccio | Total |
|---|---|---|---|---|---|
| | Mean Depth (m) | | | | |
| HOOD CANAL | -120.1 | -77.0 | - | - | -109.0 |
| PS MAIN BASIN | -51.0 | -99.2 | -79.1 | -40.9 | -57.4 |
| SJ-SJDF | -63.4 | -104.4 | -128.6 | - | -68.0 |
| S. PUGET SOUND | -45.8 | - | - | - | -45.8 |
| WHIDBEY | -79.3 | -113.7 | -135.0 | -122.9 | -84.1 |
| Grand Total | -63.0 | -100.9 | -100.0 | -52.4 | -67.8 |

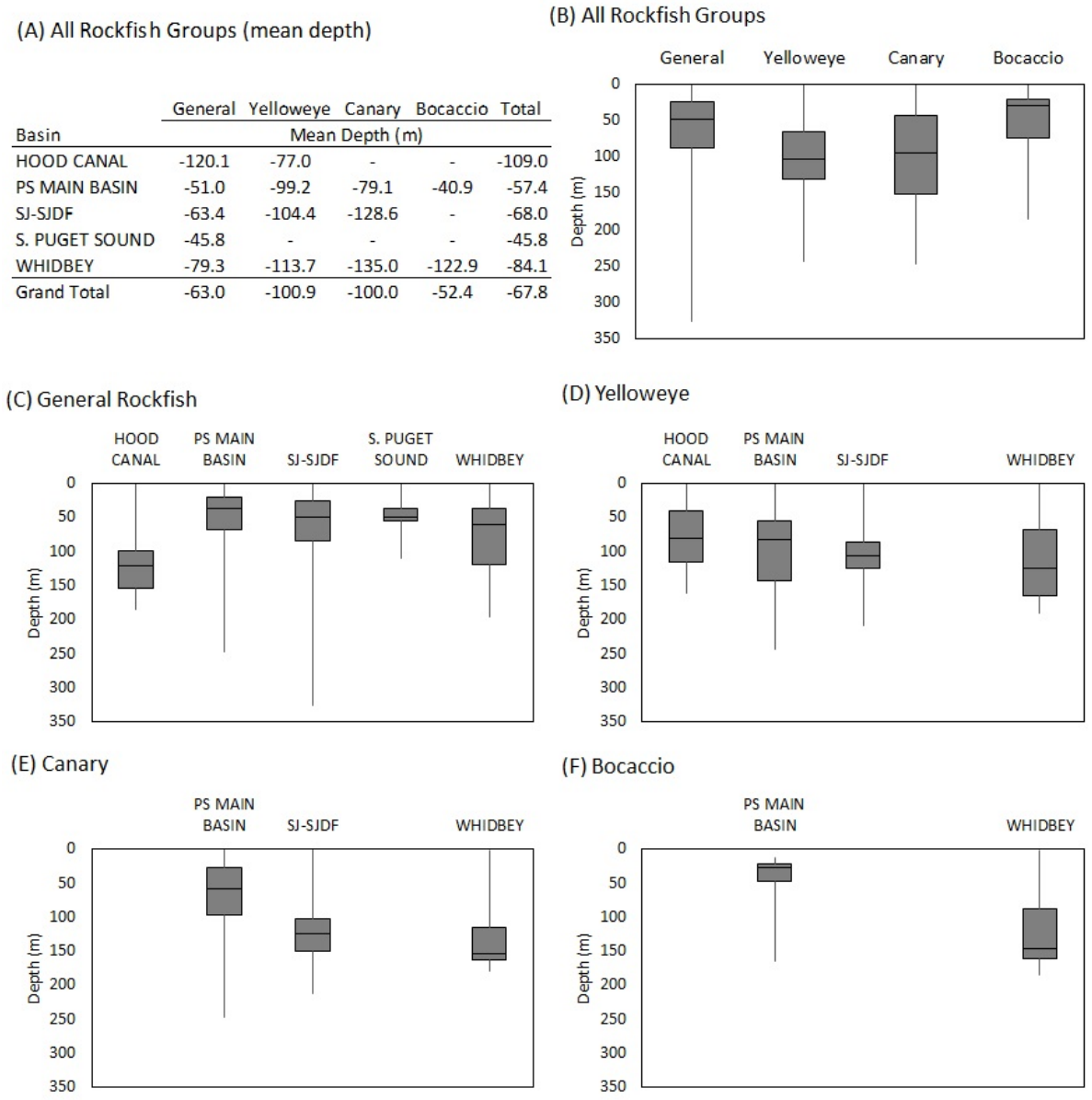



*Figure 8. (A) Mean depth values within RHA's per group per basin. Box and whisker plots depicting bathymetric values summarized within RHA's (B) per group total and (C-F) per basin per group. Boxes represent the interquartile range with solid line representing median values. Whiskers represent the min to max range of data summarized.*

Thirty six (60%) of the 60 total Yelloweye RHA's either fully or partially overlap General Rockfish RHA's. The remaining twenty-four (40%) RHA's do not intersect General Rockfish RHA's, but mostly occur in the same general vicinity. Seven (12%) Yelloweye RHA's overlap with Canary RHA's, and three (5%) intersect Bocaccio RHA's. Yelloweye RHA's were most consistently inside deepwater CH, with a low of 66% in the Whidbey Basin to a high of 84% in the San Juan/Strait of Juan de Fuca Basin. The total percentage of Yelloweye RHA's within deepwater CH was 76%. Only 9% of the total Yelloweye RHA's were within nearshore CH; a low percentage that coincides with the fact that no nearshore CH is designated for yelloweye rockfish in Puget Sound. By basin the values ranged from 5% in the San Juan/Strait of Juan de Fuca Basin to 21% in the Hood Canal Basin. Only 4% of Yelloweye

RHA's were outside all designated CH in Hood Canal and 21% were outside CH in both the Puget Sound Main and Whidbey Basins (Figure 7B).

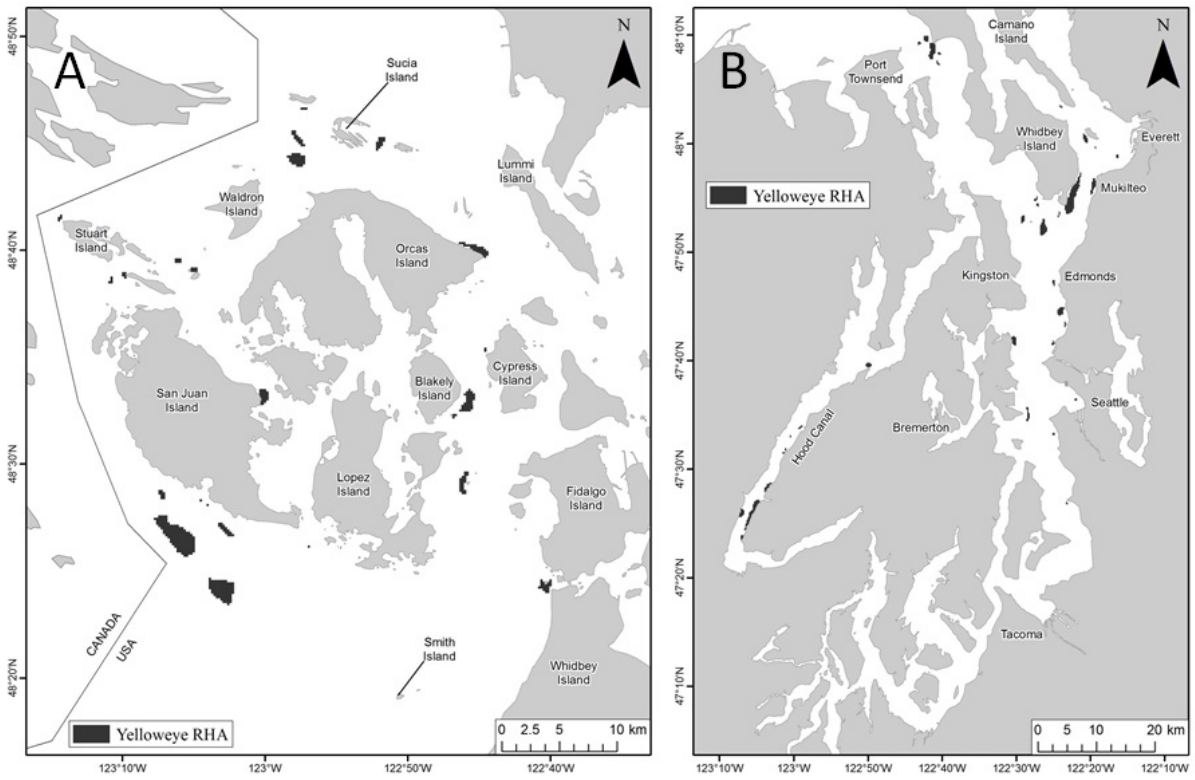



*Figure 9. Spatial distribution of Yelloweye RHA's in (A) San Juan/Strait of Juan de Fuca Basin, and (B) Whidbey, Puget Sound Main, Hood Canal and South Puget Sound Basins.*

Bathymetric values summarized in the Yelloweye RHA's were the deepest of all groups, with a mean of -100.9 m, just below the Canary RHA's mean depth of -100.0 m (Figure 8A), and the widest range occurred in the Puget Sound Main Basin with depth values ranging from 0 to -244 m. The most consistent depth values within Yelloweye RHA's appear in the San Juan/Strait of Juan de Fuca Basin (Figure 8D).

Five (42%) of the 12 total Canary RHA's occur in the San Juan/Strait of Juan de Fuca Basin, accounting for 3.45 km$^2$ (22%) of the total Canary RHA area. They are present off of southern Sucia Island, southern Waldron Island, the northeast corner of Orcas Island, and off the south shore of San Juan Island between False Bay and Eagle Point (Figure 10A). The largest Canary RHA (3.59 km$^2$) appears on the west side of the southern end of Camano Island in the Whidbey Basin. The remaining six (50%) Canary RHA's occur in the Puget Sound Main Basin; the two largest occur just outside Kingston (3.40 km$^2$) and off the southeastern tip of Bainbridge Island (3.18 km$^2$). The others, all of which are < 1 km$^2$ appear at Admiralty Head, western Possession Bar, Shilshole Bay, and Point Defiance (Figure 10B). The Canary RHA at Point Defiance is the only one of the 12 total that does not intersect any General Rockfish RHA's. Five (42%) of the Canary RHA's overlap with Yelloweye RHA's, and three (25%) intersect Bocaccio RHA's.

Canary RHA's that occurred within deepwater CH ranged from 56% in Whidbey Basin to 72% in San Juan/Strait of Juan de Fuca Basin. Only 1% of Canary RHA's in San Juan/Strait of Juan de Fuca overlap nearshore CH, and 29% of the Canary RHA's in the Puget Sound Main Basin occur inside nearshore CH.

Per basin, the least amount of Canary RHA's outside all CH was in the Puget Sound Main (7%), while 27% and 31% of the Canary RHA's in the San Juan/Strait of Juan de Fuca and Whidbey Basins, respectively, were outside designated CH (Figure 7C). The mean depth within Canary RHA's was -100.0 m in total, with the greatest range of values occurring in the Puget Sound Main Basin (0 to -247 m). Summarized bathymetric values in the San Juan/Strait of Juan de Fuca and Whidbey Basins (mean = -128.6 m and -135.0 m respectively) are similar when compared to those in the Puget Sound Main Basin (mean = -79.1), as can be seen in Figure 8E.

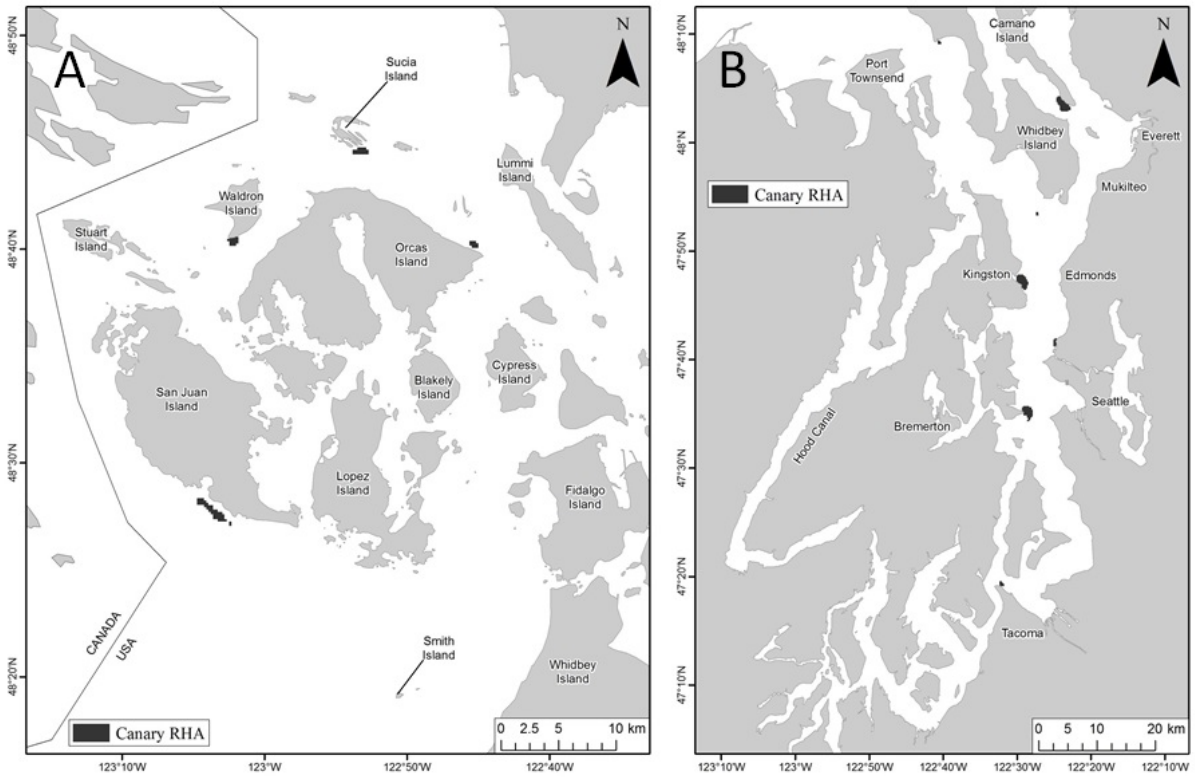



*Figure 10. Spatial distribution of Canary RHA's in (A) San Juan/Strait of Juan de Fuca Basin, and (B) Whidbey, Puget Sound Main, Hood Canal and South Puget Sound Basins.*

The largest (12.89 km$^2$) of the three Bocaccio RHA's covers much of Possession Bar in the Puget Sound Main Basin, and is much larger in area than the Yelloweye and Canary RHA's that it intersects. The other two Bocaccio RHA's appear along the southwest end of Camano Island, and offshore from Kingston (Figure 11). The Bocaccio RHA's at Possession Bar and Camano Island intersect RHA's from each of the other groups, while the one near Kingston intersects General and Canary, but not Yelloweye RHA's. Bocaccio RHA's only occur in the Puget Sound Main and Whidbey Basins, where the percentage within CH varies greatly, as 67% of Bocaccio RHA's in the Whidbey Basin are inside deepwater CH and 39% of those in the Puget Sound Main Basin are within deepwater CH. Only 9% of Bocaccio RHA's in the Whidbey Basin overlap nearshore CH, while 59% of those in the Puget Sound Main Basin occur in nearshore CH. Two percent (2%) of the Bocaccio RHA's in the Puget Sound Main Basin are outside all designated CH, while 24% of those in the Whidbey Basin are outside CH (Figure 7D).

The Bocaccio RHA's exhibited the shallowest mean depth of all the groups, at 52.4 m, and there is a drastic difference in depth values inside Bocaccio RHA's between the two basins in which they appear. The mean and median values in the Puget Sound Main Basin are shallow, at -40.9 m and -27 m respectively, while in the Whidbey Basin the mean depth is -122.9 m and the median is -146 m (Figure

8F). These differences can be explained mostly by small amount of Bocaccio RHA's that exist, and the fact that the largest of the three RHA's which accounts for 82% of the total, occurs across nearly the entire flat and relatively shallow portion of Possession Bar in the Puget Sound Main Basin.

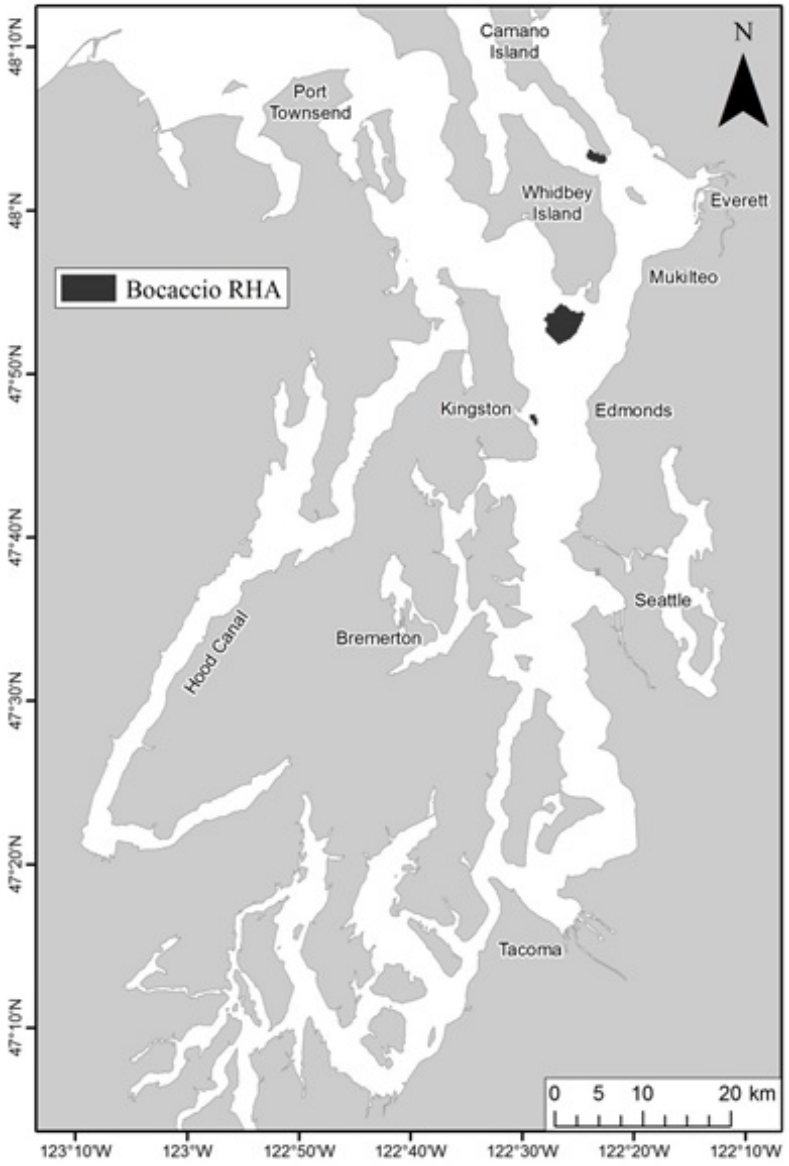



*Figure 11. Spatial distribution of Bocaccio RHA's in Whidbey and Puget Sound Main Basins.*

**Discussion**

The variance in the amount of data provided by contributors was evident between groups and species, yet enough combined data was available to produce RHA's for the three ESA listed rockfish, as well as the General Rockfish group. Not surprisingly, the majority of RHA's were within either deepwater or nearshore CH as currently defined by NOAA, and in most cases the portions of RHA's outside CH were adjacent to RHA portions that fell within designated CH. Bocaccio were the only group with the majority

(52%) of RHA distribution within nearshore CH; a result heavily weighted by the vast RHA covering the relatively shallow flats of Possession Bar. This feature also influenced the depth values for the Bocaccio RHA's. A further analysis of the three Bocaccio RHA's separately may prove to be useful in understanding bocaccio preferred habitats.

The spillover of some Yelloweye, Canary, and Bocaccio RHA's outside CH could reflect certain limitations associated with analysis of LEK data of this type. For example, nearshore CH was designated for canary rockfish and bocaccio because the juveniles of each species can utilize this area. Local Ecological Knowledge could be limited for this lifestage as they are less likely to be caught in fisheries, many juvenile rockfish are difficult to distinguish to species (and therefore reported in interviews), and each species have likely been historically rare relative to more abundant rockfish species. In addition, several portions of areas from the original hand-drawn charts showing rockfish occurrence were drawn onshore, intersecting land features. Once digitized, these features were clipped by shoreline and while all data outside marine waters were deleted, much of the remaining data abutted the shoreline. Contributed data intersecting the shoreline could be deliberate, accidental, or a function of scale (i.e., thick pens, coarse maps, etc.). We know of some reasons why data would be closer to shore than expected when considering the typical depth ranges of rockfish species. In many Puget Sound locations, rockfish habitat is a very short distance from the shoreline due to steep rocky slopes such as those present along the southwest shores of San Juan Island. Also, in the RLEK dataset, hand-drawn areas were not distinguishable between juvenile and adult rockfish areas, and some areas may have been drawn closer to the shoreline to represent occurrence of juvenile rockfish. However, because the PSFA dataset provided reference to historical fishing areas, we presume that they included only adult rockfish occurrence areas, as fishing effort has not traditionally targeted juvenile rockfish. Additionally, it seems natural in fishing and other maritime activities for people to use landmarks to reference events or observations, and this tendency may be reflected in data being skewed towards the shoreline where more familiar points of reference appear. Nevertheless, when analyzing data, we did not speculate the reasons why data abutted the shoreline, and therefore did not adjust edges of the data except to ensure that they extend on to land beyond the shoreline.

The bathymetric analysis at RHA's provided some other notable results that could be investigated further through analysis of other existing datasets. One being that the General Rockfish RHA's inside Hood Canal Basin (mean = -120 m) were much deeper than the General Rockfish RHA depths in the other four basins (mean = -79 m to -46 m). Additionally, Yelloweye RHA's exhibit the most consistency in depth summaries across all basins where they occur. Yelloweye RHA's were also consistently the smallest of the four groups (mean area = 0.80 $km^2$ ± 0.16 SE), suggesting that contributors provided greater precision when identifying yelloweye locations. From strictly a visual perspective one potential pattern emerges in spatial distribution of the RHA's; the largest RHA's or clusters of RHA's seem to occur in areas where two or more water bodies converge, often on the south side of a land mass, or where tidal currents are reputably strong. These locations include:

- south and west San Juan Island and west Lopez Island where Haro Strait and Strait of Juan de Fuca converge,
- south Lopez Island – Rosario Strait area where Rosario Strait converges with Strait of Juan de Fuca,
- south Camano Island and Gedney Island where Saratoga Pass and Possession Sound converge,
- south Whidbey, where Admiralty Inlet, Possession Sound converge into central Puget Sound,
- the series of islands north of Orcas Island, including Sucia and Patos where the Strait of Georgia converges with Boundary Pass and Rosario Strait,
- south Bainbridge Island, where Rich Passage converges with Port Orchard, and central Puget Sound,
- and the Tacoma Narrows.

This subtle pattern could be investigated further through exploration and analysis of oceanographic and environmental datasets beyond those related to benthic habitat; such as tidal current velocity and direction, sea water temperature and sea water chemistry.

## Conclusion

Rockfish Hot Spot Areas developed here package and summarize LEK of Puget Sound marine waters from multiple sources into a dataset representing statistically significant spatial clustering of historic rockfish occurrence. The intent of developing the RHA's was to define the spatial extent of rockfish occurrence areas from LEK that were not represented in the form of empirical data. The results build upon recent research spatially delineating historical rockfish fishing and occurrence locations by adding contributions from researchers and identifying areas specific to the three ESA-listed species independently. Rockfish Hot Spot Areas were not designed to replace CH designations, or the spatial bounds used to identify rockfish conservation zones or marine protected areas; rather, to be used as a tool to further refine the understanding of characteristics that constitute present and historical rockfish habitat in Puget Sound; and can be added to the growing suite of information used by resource managers to prioritize research and conservation efforts and future habitat suitability modeling. This type of quantified LEK and historical data can be used within a broad range of research projects, from simple exploratory surveys to inclusion in sophisticated predictive models.

## Acknowledgements

We would like to thank Dan Tonnes at the NOAA Protected Resources Division for the compilation of datasets and technical support. Thanks to Jason Lim for conducting the interviews that provided the RLEK dataset, and to all the study participants who contributed their knowledge. Thanks to Emily Whitney for digitizing the PSFA dataset.

**References**

Andrews, K., K. Nichols, A. Elz, N. Tolimieri, C. Harvey, D. Tonnes, D. Lowry, R. Pacunski, and L. Yamanaka. 2015. Cooperative research: ESA-listed Puget Sound rockfish. PowerPoint presentation for the NWFSC Rockfish Biological Review Team, November 13, 2015.

Beaudreau, A.H. and P.S. Levin. 2014. Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. Ecological Applications. Volume 24, Issue 2, pages 244-256.

Beaudreau, A.H. and E. J. Whitney. 2016. Historical Patterns and Drivers of Spatial Changes in Recreational Fishing Activity in Puget Sound, Washington. PLoSONE11 (4):e0152190. doi:10.1371/journal.pone.0152190.

Davies, J. 2009. *30m Bathymetry Mosaic for the WA Salish Sea*. NOAA (National Oceanic and Atmospheric Association) Fisheries. Metadata. Accessed February 23, 2011.

Drake J. S., E. A. Berntson, J. M. Cope, R. G. Gustafson, E. E. Holmes, P. S. Levin, N. Tolimieri, R. S. Waples, S. M. Sogard, and G. D. Williams. 2010. Status of five species of rockfish in Puget Sound, Washington: Bocaccio (Sebastes paucispinis), Canary Rockfish (Sebastes pinniger), Yelloweye Rockfish (Sebastes ruberrimus), Greenstriped Rockfish (Sebastes elongatus) and Redstripe Rockfish (Sebastes proriger). U.S. Department of Commerce, NOAA Technical Memorandum. NMFSNWFSC-108, 234 pages.

Love, M.S., Yoklavich, M. and Thorsteinson, L.K., 2002. *The rockfishes of the northeast Pacific*. Univ of California Press.

National Marine Fisheries Service. 2016. Draft Rockfish Recovery Plan: Puget Sound / Georgia Basin yelloweye rockfish (*Sebastes ruberrimus*) and bocaccio (*Sebastes paucispinis*). National Marine Fisheries Service. Seattle, WA.

NOAA. "Endangered and Threatened Wildlife and Plants: Threatened Status for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye and Canary Rockfish and Endangered Status for the Puget Sound/Georgia Basin Distinct Population Segment of Bocaccio Rockfish; Final rule," 75 Federal Register 81 (28 April 2010) pp. 22276-22290.

NOAA. "Endangered and Threatened Species; Designation of Critical Habitat for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye Rockfish, Canary Rockfish and Bocaccio; final rule," 79 Federal Register 219 (13 November 2014) pp. 60842-68087.

NOAA. "Endangered and Threatened Species; Removal of the Puget Sound/Georgia Basin Distinct Population Segment of Canary Rockfish From the Federal List of Threatened and Endangered Species, and Removal of Designated Critical Habitat, and Update and Amend the Listing Descriptions for the Yelloweye Rockfish DPS and Bocaccio DPS; Proposed Rule, Request for Comments," 81 Federal Register 129 (6 July 2016), pp. 43979-43985.

Palsson, W. A., T. Tsou, G. G. Bargmann, R. M. Buckley, J. E. West, M. L. Mills, Y. W. Cheng, and R. E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. Washington Department of Fish and Wildlife, FPT 09-04, Olympia, WA

Sawchuk, J.H., Beaudreau, A.H., Tonnes, D. and Fluharty, D., 2015. Using stakeholder engagement to inform endangered species management and improve conservation. *Marine Policy*, *54*, pp.98-107.

Tolimieri N, Andrews K, Williams G, Katz S, Levin PS (2009) Home range size and patterns of space use by lingcod, copper rockfish and quillback rockfish in relation to diel and tidal cycles. Mar Ecol Prog Ser 380:229-243

Washington State Department of Fish and Wildlife. 2010. Rule-making order, CR-103e, emergency rule closing several commercial fisheries in Puget Sound. Order No. 10-191.

Washington State Department of Fish and Wildlife. 2011. Final Puget Sound Rockfish Conservation Plan: Policies, Strategies and Actions. Washington Department of Fish and Wildlife Fish Program, Olympia, WA.

Washington Department of Fish and Wildlife. 2016. Washington State Species of Concern List. http://wdfw.wa.gov/conservation/endangered/lists/search.php?searchby=AnimalType&search=Fish&orderby=ScientificName%20ASC . (Accessed August 17, 2016).

Washington Department of Fish and Wildlife (WDFW) 2014. 2011/2012/2013/2014 Sportfishing regulations and rules pamphlet. http://wdfw.wa.gov/publications/01185/wdfw01185.pdf. (Accessed August 20, 2014).

**Appendix A** - Sources for "Puget Sound Fishing Areas" Shapefiles, notes provided by Emily Whitney (developed August 2013).

DNR. 1972. Washington Marine Atlas. State of Washington, Department of Natural Resources, Division of Marine Land Management, Olympia, WA.

These maps were scanned by Greg Williams and Anne Beaudreau. The data source is listed as "several agencies and individuals". Two types of maps were included, non-salmon sport fishing and commercial otter trawl areas. For shapefile consistency, only the fishing areas were digitized on the commercial maps; those areas closed to trawls were not digitized.

Haw, F. and R. Buckley. 1971. Saltwater Fishing in Washington. Stanley M. Jones, Seattle, WA.

For this source, the fishing area description is summarized in the map notes. Note that only the fishing areas delineated on the map were digitized. The text gave general descriptions of bottom fishing and trout fishing areas, such as "in the vicinity of Bainbridge Island" or "the Tacoma Narrows" (Haw 97). Thus only salmon fishing areas were digitized. These general bottomfish and trout fishing areas, however, could be digitized later with a degree of interpretation.

Martinis, J. 2008. Saltwater Fishing Journal. Evergreen Pacific Publishing, Mukilteo, WA.

This source provides additional details about how to fish the areas, including lures and tide cycle, beyond what is summarized in the attribute table.

Olander, D. 1991. Northwest Coastal Fishing Guide**.** Amato Publications, Portland, OR.

Additional information about the seasonality of the fishing areas, not included in the attribute table, is found in the table that accompanies each map. The dot marked area notes in the "Map Notes" field refer to the "best" fishing months and the hash marked area notes refer to the "fair" fishing months as described by species and region in the tables.

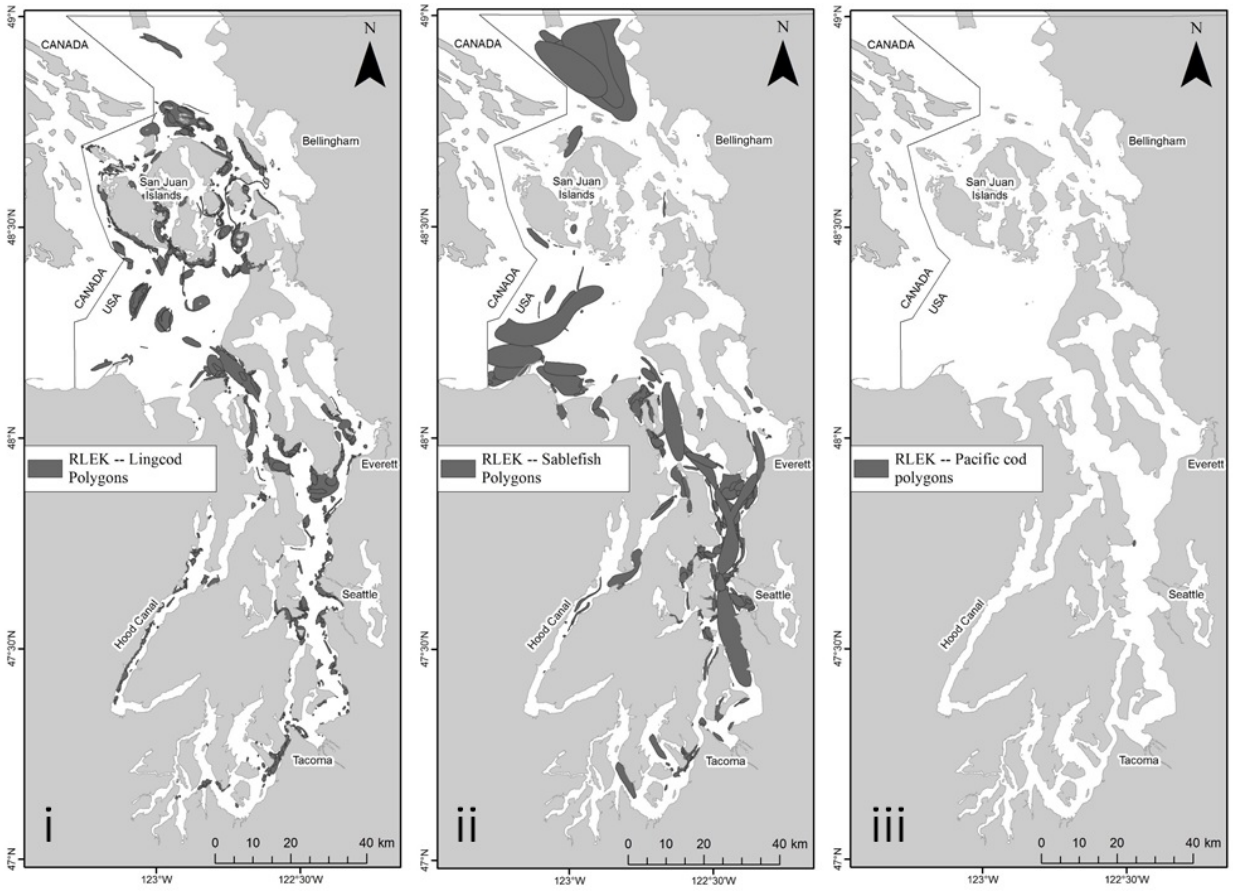
Squire, J.L., Jr. and S.E. Smith. 1977. Anglers' guide to the United States Pacific coast**.** U.S. Department of Commerce, NOAA, National Marine Fisheries Service. Seattle, WA. 139 pp.

This source outlines both general and specific fishing areas. General salmon fishing areas (marked in light blue on the original maps) cover a larger geographic extent and are not species specific. Other areas are salmon species specific (dark blue) and may fall within the broader salmon fishing areas.

Washington, P.M. 1977. Recreationally Important Marine Fishes of Puget Sound, Washington**.** U.S. Department of Commerce, NOAA, National Marine Fisheries Service, Seattle, WA. 122 pp.

This report compiled fishing area locations from a variety of data sources including the NMFS Marine Recreational Fisheries Surveys (1973-1976), literature reviews, and U of W (University of Washington) logs. These sources are listed in the report by species. Only a selection of the species included in this report were digitized. The rockfish NMFS fishery survey areas are also reported the 1978 report "A Biological Report on Eight Species of Rockfish (*Sebastes spp.*) from Puget Sound" by Washington, Gowan and Ito. For this reason, only the 1977 report was digitized.

**Appendix B** – Digitized polygons representing non-rockfish fish species documented in RLEK dataset; (i) lingcod polygons, (ii) sablefish polygons, (iii) Pacific cod polygons (only one)



**Appendix C** – Digitized polygons representing kelp beds and shipwrecks documented in RLEK dataset; (i) kelp bed polygons, (ii) shipwreck polygons.