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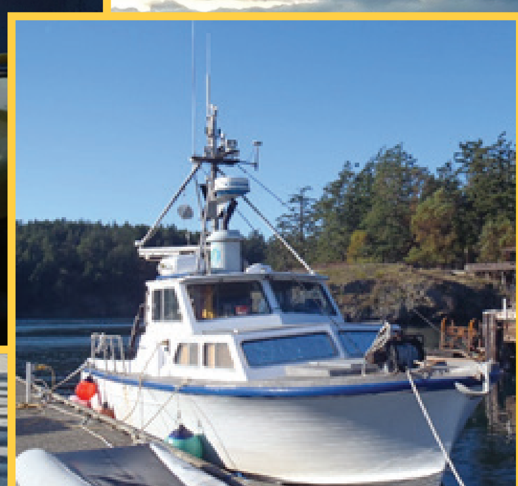

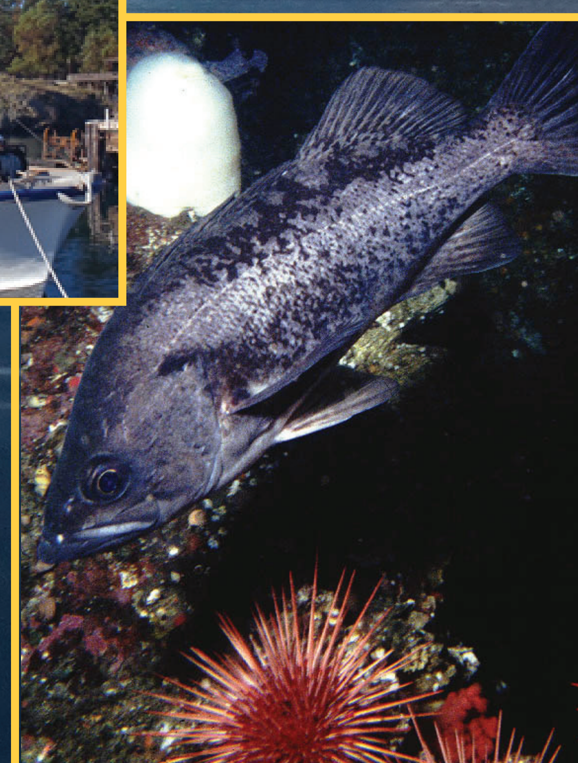

Washington Department of FISH AND WILDLIFE
Fish Program
Fish Management Division

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Executive Summary

In 2009 the Washington Department of Fish and Wildlife (WDFW) determined that the abundance of several rockfish species in the southern Salish Sea had decreased dramatically since the 1970s and that, for numerous additional species, existing data were insufficient to fully evaluate stock status. This lack of data stemmed, in large part, from the association of rockfishes with complex, untrawlable habitats within which appropriate survey tools (e.g., drop cameras, submersibles) and sampling designs had not been systematically deployed. Having already acknowledged the negative bias in abundance estimates of rockfish from existing trawl survey data, and anticipating the listing of some rockfish species under the Endangered Species Act (ESA), the WDFW began experimenting with visual survey techniques (e.g., drop cameras, submersibles, remotely operated vehicles [ROVs]) in the early 1990s. In 2008 the WDFW used extensive mapping data derived, in large part, from prior visual and multibeam acoustic survey efforts to conduct a stratified random survey of high-relief, rocky habitats in the San Juan Islands (SJI) with an ROV.

This report details the results of a complementary pilot survey conducted in the SJI in 2010 utilizing an ROV deployed following a systematic random sampling design to survey the same geographic region sampled in 2008, but sample all available habitat types. Systematic sampling does not require intimate knowledge of the distribution of habitat to generate statistically valid estimates of abundance, provided sample size is sufficient to representatively assess the diversity of available habitat types. This sampling approach is especially useful when *a priori* knowledge upon which to delineate habitat strata is incomplete or missing entirely, as is the case for much of the southern Salish Sea. If this sampling design were to prove statistically robust and logistically feasible, it could be expanded to the whole of Washington's inland marine waters such that bottomfish abundance and distribution would be assessed with a single sampling tool, with consistent selectivity and bias.

To assist in evaluating the required sampling intensity to be applied in future surveys, the SJI region was divided into Eastern and Western strata, and the sample spacing varied between the two. A systematic grid was generated, with a random starting point, and survey sample locations were set at each intersection point of the grid in both geographic strata. The grid spacing was more dense in the Western region because rocky habitats were previously documented to be more prevalent there. Edge correction, including an ocean buffer, was developed. The total effective survey area for the combined SJI region was 104 hectares.

During this pilot survey, a total of 179 stations were sampled and 54 taxonomic groupings of fishes and invertebrates were observed in the combined regions. The highest rockfish abundance estimate was for Puget Sound rockfish at 6.7 million individuals. The abundance estimates calculated from this survey for most rockfish species were comparable to the 2008 ROV survey results that targeted rocky habitat in the SJI region, though the 2010 estimates typically had higher coefficients of variation. Additionally, several soft-bottom species were regularly observed and individuals of species putatively associated only with rocky habitats were observed over these same soft bottoms. The highest identified flatfish estimate was English sole at 3.1 million individuals. Abundance estimation for all species was a function of the habitat sampled, the intensity of sampling, and the encounter rate of detectable individuals. The diversity of species for which valid estimates could be made was substantially higher with the systematic design (this study) than with the focused, stratified design employed in 2008, which only sampled rocky habitats, with only a 6% increase in staffing and fieldwork-related costs.

We conclude that:

i) Rockfish and greenling population abundance estimates generated with the systematic survey design had reasonable precision, but bias correction may be needed to account for selectivity associated with organism behavior and crypticity, as is typical for visually based survey methods.

ii) Most flatfish population estimates had acceptable coefficient of variation values (<40%), but issues with detectability require that all estimates be considered conservative approximations. Effectively, these species were encountered at a high enough rate to make statistical estimates but small, buried, and otherwise visually undetectable individuals were missed, meaning the estimates are incomplete.

iii) Most of the invertebrate population abundance estimates had acceptable coefficient of variation values (<40%), included sampling of depths inaccessible to SCUBA-based survey methods, and should prove useful for management.

iv) The cost of implementing a systematic survey in areas without sufficient benthic habitat mapping data is not substantially greater than conducting a stratified random survey on select habitats and may serve as a viable option for expansion to the whole of the southern Salish Sea, allowing population estimation for bottomfish on diverse habitats with a single tool.

v) For rare species, like ESA-listed Bocaccio and Yelloweye Rockfish, additional survey design methods will need to be considered, including species distribution models, which evaluate the likelihood of habitat suitability from existing fish presence and/or absence data in correlation with various habitat attributes.

This study confirmed that an ROV can be used to conduct a reliable, region-wide population abundance survey for benthic fishes and macroinvertebrates, despite the lack of dependable habitat information throughout the entire region. However, several logistical contraints will need to be carefully considered to obtain ensure encounter rates and between-site variability are adequately high and low, respectively, at a more extensive geographic scale.

Introduction

Of paramount importance to the effective conservation and/or sustainable exploitation of any living natural resource is an understanding of spatiotemporal distribution patterns exhibited by the population (Brand et al. 2007; Kruse et al. 2008; Rassweiler et al. 2012; Gorman et al. 2013). Without understanding whether, when, and where to permit harvest effort, as well as how resource extraction impacts the population as a whole, management strategies must necessarily be cautious to avoid overexploitation, and harvest opportunity may be foregone as a consequence. In both terrestrial and marine environments a broad array of both consumptive and purely observational methods to document species distribution and abundance have been employed for centuries, ranging from simple natural history, to various forms of telemetric tracking, to life history-based models that are sensitive to temporal variation in environmental parameters (Caughley et al. 1976; Caughley 1977; Block et al. 1992; Francis and Hare 1994; Hirzel et al. 2002; Abascal et al. 2011). Many of these methods depend on direct visual observation of individuals throughout the range of the population in question. In marine environments, especially offshore, deep-water locales, such visually-based techniques have lagged behind their terrestrial counterparts due to demands placed on personnel and technology by physical parameters such as temperature, salinity, and pressure. Even with the development of appropriate technological solutions, the cost of deploying such tools often proves to be prohibitive (e.g., Karpov et al. 2006; Pacunski et al. 2008; Yoklavich et al. 2015). In recent decades advances in drop camera, manned submersible, remotely operated vehicle (ROV), and autonomous underwater vehicle (AUV) technology have greatly decreased in cost and increased the feasibility of these survey options (Hannah and Blume 2012; NRC 2013), especially when considering the exploitation of financially lucrative resources (Batker et al. 2010).

In addition to employing consumptive methods like trawling and longlining (e.g., Palsson et al. 2002; 2003; 2009; Williams et al. 2010; Williams et al. 2011; Blaine et al. 2020) and "hands-on" methods like tagging (e.g., Bargmann 1980; Mathews and Barker 1983; Davis 1986; Wallace et al. 2010) to evaluate the distribution and abundance of marine fishes along the outer Washington coast and in the southern Salish Sea, over the past four decades the Washington Department of Fish and Wildlife (WDFW) has utilized a variety of purely visual-based survey techniques and study designs (Palsson et al. 1998; Jagielo et al. 2003; Parra and Palsson 2007; Pacunski et al. 2008; Washington Department of Fish and Wildlife 2011; Pacunski et al. 2013; LeClair et al. 2018). Tools employed have included SCUBA diving, towed cameras, tethered drop cameras, manned submersibles, and, since 2004, ROVs. Sampling designs have variously utilized transect and/or point data collected at haphazard, random, uniform, and fixed index stations on scales that have ranged from isolated reefs, to sub-basin-specific depth strata, to entire sub-basins of Puget Sound. The tools and sampling designs employed typically derive from a combination of the nature of the research questions being asked, the presumed geospatial range of the population under investigation, and logistical considerations associated with the availability of personnel and funding (Barry and Baxter 1993; Adams et al. 1995; Reynolds et al. 2001; Nasby-Lucas et al. 2002; Karpov et al. 2006; Pacunski et al. 2008).

Over approximately two months in 2008, the WDFW conducted an ROV-based survey of marine fishes in the San Juan Islands (SJI), WA that expressly focused on nearshore, rocky substrate (i.e., bedrock, boulder, and cobble) (Figure 1) that ongoing bottom trawl-based monitoring was unable to access (Pacunski et al. 2013). Substrate polygons were delineated based on existing information gleaned from backscatter data from multi-beam sonar systems and previous nearshore rocky surveys conducted by the WDFW (Palsson et al. 2009). The survey employed a SeaEye Falcon® ROV and consisted of 207, approximately 12-15-minute strip transects at locations selected using a stratified random design, with shallow and deep stations being distinguished by the 120-foot (36.6-m) isobath (Figure 1). The goals of this study were to document distribution, estimate abundance (with error quantification), and determine the degree of macro- and microhabitat associations for all possible species of marine fish encountered, with an emphasis on rockfishes (*Sebastes* spp.) and greenlings (Hexagrammidae) in untrawlable habitat. Evaluating these particular taxa was stressed as a consequence of their fishery and ecological importance (Harvey et al. 2010; WDFW 2011; Harvey et al. 2012), documented co-occurrence and predator/prey interactions (Beaudreau and Essington 2007; Love et al. 2002), and stock status (Palsson et al. 1997; 2009; Drake et al. 2010). Additionally, previous population estimation methods employed by the WDFW, specifically trawl, SCUBA, and drop camera surveys, had been judged inadequate for producing abundance estimates for species occurring in high-relief, deep-water (i.e., beyond safe SCUBA depth) habitats (Adams 1995; Bargmann 1998; Palsson et al. 2009). Unconsolidated (i.e., soft), trawlable habitats were not sampled, despite making up the majority of the available habitat is the SJI, because existing bottom trawling methods were deemed to adequately sample bottomfishes here. This meant that unconsolidated habitats were combined into a zero-sample stratum for which the simplifying assumption was made that rocky-associated species would occur only in minimal abundance. The 2008 survey was successful in meeting its habitat association and abundance estimate goals for nearly 40 encountered species (Pacunski et al. 2013); however, the precision of the abundance estimates was less than desirable (CV<25%), except for the most commonly encountered species, due largely to limits in sample size and encounter rates.

Based on the largely successful utilization of an ROV to survey benthic marine stations throughout the SJI in 2008, and desiring to use a single survey technique to adequately evaluate the distribution and abundance of all species of benthic/demersal marine fishes in the future, the WDFW began exploring novel survey designs. Criteria for design selection included the ability to: 1) generate unbiased, and reasonably precise, abundance estimates for all possible benthic fish species; 2) survey all surveyable habitats, and presumably all species assemblages, in approximate proportion to their occurrence in the environment when adequate habitat maps were unavailable; and 3) complete the survey and analysis in a timely manner (<2 yrs) using consistently available time, person-power, and financial resources. The sampling design eventually judged to most adequately meet these criteria was systematic sampling, as employed heavily in microscopy (Gundersen 1987; Gundersen 1999; Howard 2005) and forest ecology/mapping (Russ 1990; Rudemo 1998; Wulfsohn, 2010). A systematic survey plan begins with selection of a random starting location followed by superimposition of a uniform grid over the survey area, with one grid vertex overlaying this random point. Sample locations occur at the intersection of grid lines, with grid spacing determined by the scale of the object being interrogated (e.g., trees, cells, habitat patches).

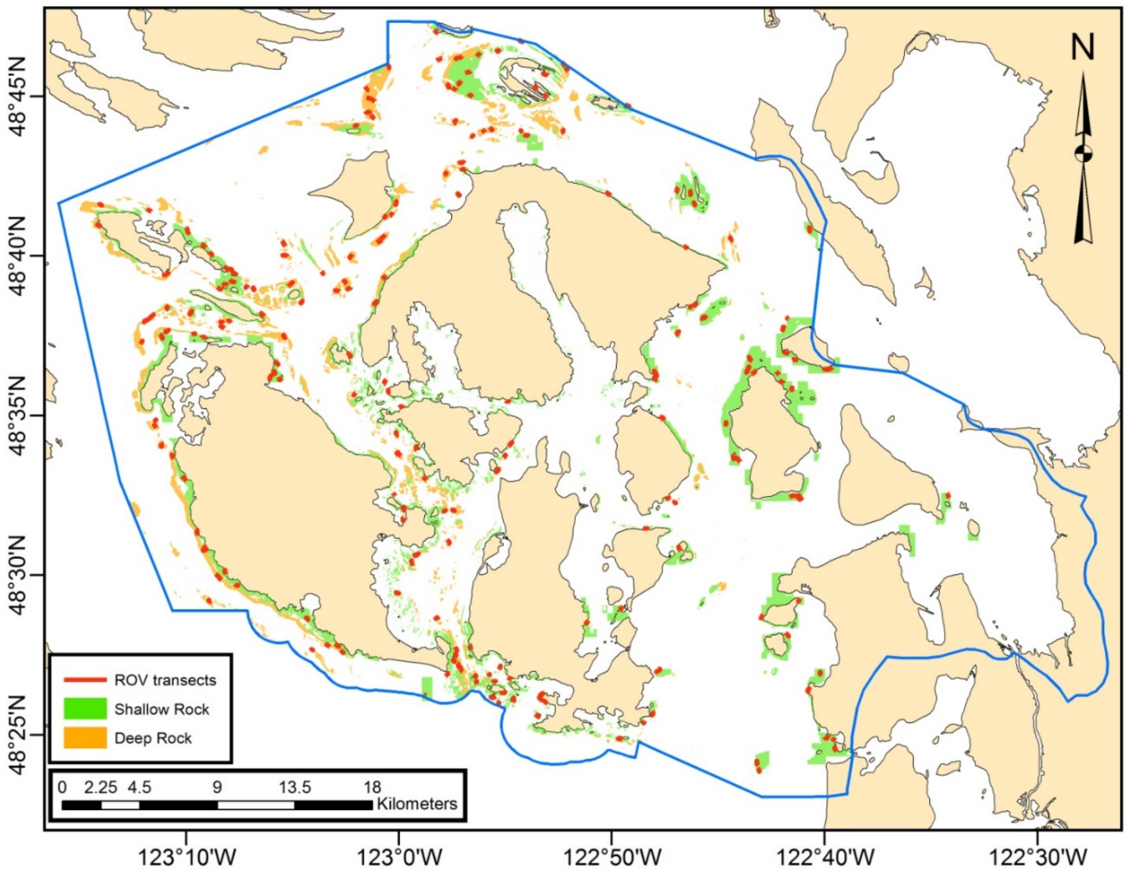

Figure 1. Rocky habitat polygons of the San Juan Islands sampled in 2008 (from Pacunski et al. 2013). ROV transect paths shown in red.

In 2010 the WDFW conducted a study to explicitly compare ROV-based abundance estimates for benthic fishes derived from a habitat-focused, stratified random survey design (2008) with those derived from a systematic survey design with identical geographic scope in the SJI. Furthermore, knowing that rocky habitats were more prevalent in the western portion of the SJI, the spacing of the uniform grid used to place sampling locations varied between the eastern and western regions of the survey area (Figure 2). Presuming that the effort level proved sufficient to representatively sample available habitat types in each region, and produce high enough encounter rates for key species to generate statistically defensible estimates of abundance, this approach was intended to assist in identifying suitable sample site spacing for future surveys. Specific survey goals of the study were to:

1) document the presence, depth distribution, and habitat associations of all encountered bottomfish species;

2) produce sub-regional (Eastern and Western) abundance estimates, with quantified error, for all encountered bottomfish species and then combine these to produce SJI-wide estimates;

3) compare the species composition and abundance estimates from 2008 with those from 2010 to identify strengths and weaknesses of each survey design;
4) evaluate the costs and logistical details of each survey to identify factors limiting survey feasibility and select a preferred approach that meets both scientific and management needs; and
5) make a management recommendation regarding the expansion of the chosen approach to the whole of Washington waters of the southern Salish Sea (i.e., greater Puget Sound).

If fully successful, this survey would bring the WDFW one step closer to realizing the goal of using a single survey tool with consistent encounter and detection rates to assess bottomfish in Washington's inland marine waters on an appropriate timescale to inform management needs identified in the Puget Sound Groundfish Management Plan (Bargmann 1998) and other regional planning and resource management documents.

Methods

Survey location, design, and equipment

The 2010 ROV survey was conducted entirely within the SJI region in Washington State (Figure 2), which coincided with the area sampled in 2008. Results of the 2008 ROV survey showed that most rock-associated species, including ESA-listed Bocaccio *Sebastes paucispinis* and Yelloweye Rockfish *S. ruberrimus* (NMFS 2010), occurred mainly in the western SJI (Pacunski et al. 2013). This knowledge was used to partition the SJI into Eastern and Western strata to increase the probability of encountering target species and maximize survey efficiency, and to allow comparison of sample grid density. As noted above, this also facilitated assessment of sample site spacing by varying potential encounter rate and sampling intensity in a semi-predictable way. Stations were placed along a systematic grid from a random starting point, with Eastern stations spaced at 3,000 m intervals and Western stations spaced at 2,100 m intervals (Figure 2). Based on the mean length of ROV transects in the 2008 survey (~500 m), no stations were placed within 250 m of the SJI perimeter boundary to ensure that transects did not stray outside of the survey area. The planar surface areas of the Eastern and Western strata were 50,850 ha and 53,164 ha, respectively, and were used as the basis for expanding the density estimates calculated from the survey. Based on the number of survey days available and an expected average sampling rate of 5.5 stations/day, the final design included 175 stations: 61 in the Eastern stratum and 114 in the Western stratum.

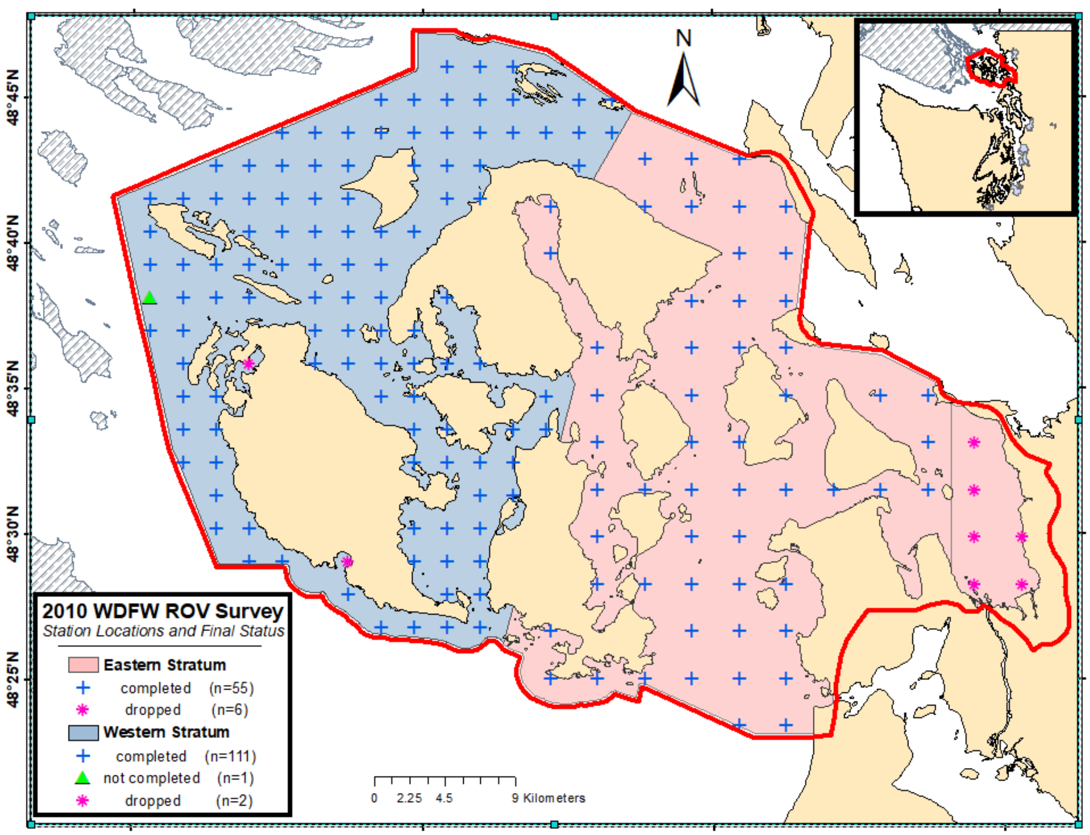

Figure 2. Locations of ROV transects in the 2010 survey of the San Juan Islands (SJI), WA.

The survey utilized the WDFW ROV “Yelloweye,” the same Saab Seaeye Falcon ROV used in the 2008 survey, but with an additional lighting package that comprised three 180-lumen constant-intensity LED lights mounted ~40 cm forward of and 10 cm above the camera on a custom-built frame (Figure 3). The lights were aimed downward to provide maximum lighting for data-collection and to minimize backscatter in turbid water conditions. Video data was collected with a 0.35-lux high-resolution (540 lines) electronic color camera mounted on a tilt motor at the front of the vehicle, with the camera angle maintained at -45-50 degrees below horizontal unless needed for organism identification or obstacle avoidance. A pair of 5-mW green lasers mounted in parallel at a separation distance of 10 cm were projected into the center of the camera’s field of view to aid in estimating transect width and fish lengths. The ROV was tracked from the support vessel with a Linkquest® USBL acoustic positioning system. Hypack 2010 Hydrographic Survey software® was used to calculate the true position of the ROV in real time and overlay the positions of the ROV and support vessel on the survey map to aid in navigation. The support vessel utilized was the 12-m R/V MOLLUSCAN.

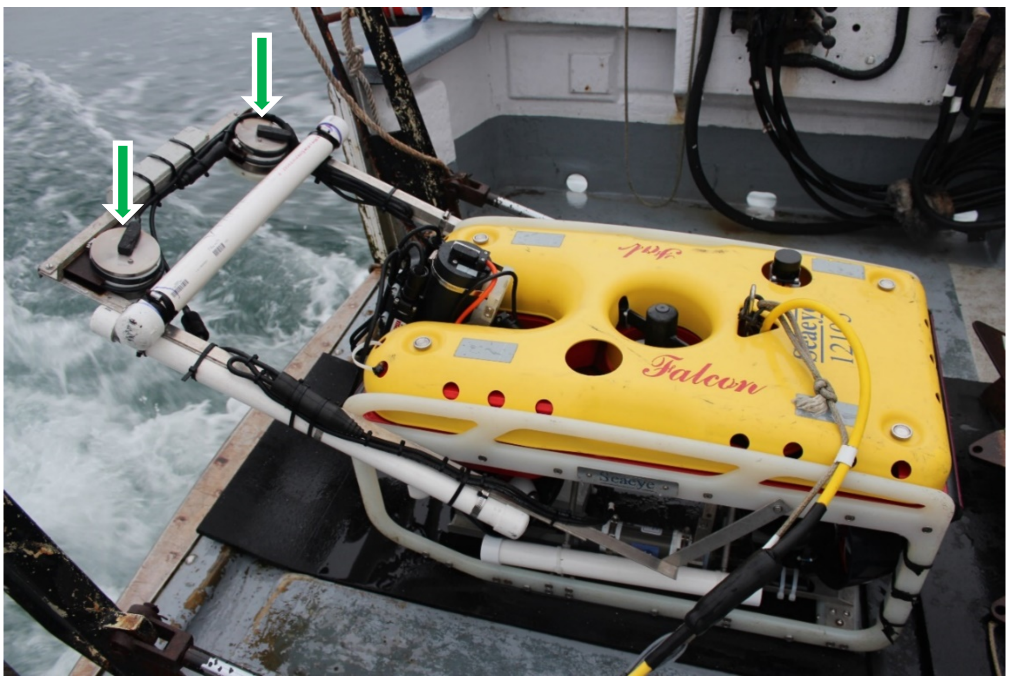

Figure 3. The WDFW Saab Seaeye Falcon remotely operated vehicle – ROV “Yelloweye” – with the modified light bar. *(Note: photo shows the bar fitted with two lights [arrows] because no photo was available showing the 3-light arrangement).*

ROV transect protocol

The ROV deployment and recovery procedures were the same as those described for the 2008 SJI survey in Pacunski et al. (2013), and Pacunski et al. (2016). A strip transect approach was employed at each station with a target transect duration of 30 minutes, regardless of ROV direction or path. Transects were typically driven into the prevailing current up to a maximum current speed of ~1 knot, with the vehicle’s speed over ground averaging approximately 0.25-0.33 m/s. Occasionally, when current velocities exceeded 1 knot and logistics precluded a likely return to a station, transects were conducted by drifting with the current, using the ROV thrusters to slow the vehicle sufficiently to capture usable video. Most transects were oriented parallel to the nearest shoreline, at a relatively consistent depth, except when prevented by current velocity and direction or navigational hazards (e.g, buoys, fishing operations, anchored vessels). Under normal conditions, a 30-minute transect flown at the target speed ranged from 500-600 m in length. Whenever possible, transects were driven such that they intersected or came as close as practicable to the designated station location. Transects were not conducted at depths <9.1 m (30 feet) to avoid shoreline obstructions and the potential for entanglement in kelp.

Video collection and review

Video imagery was recorded onto Hi-8 videotapes or as MPEG2 digital video using a Diamond One-Touch video capture system. Compression loss during the digital recording process resulted in imagery that was of slightly lower resolution than the videotaped imagery, but any difference in video quality was considered to have had negligible effects on data collection during the review process. The standard video overlay included vehicle depth (in meters) and attitude (pitch and roll, in degrees) data. This was augmented by a PISCES video overlay system that imprinted each video with an additional unique station identifier, local time, and ROV position (latitude/longitude) on the recorded image (Figure 4). Following the survey, the transect videos were reviewed to identify and enumerate fish and commercially important invertebrates, and to categorize substrate composition. The two most dominant substrate types (primary and secondary) were characterized using the percent composition method of Stein et al. (1992) and modified habitat subclasses of Greene et al. (1999). Substrate categories consisted of mud (M), sand (S), pebble/gravel (PG), cobble (C), shell/shell hash (H), bedrock (R), and boulder (B).

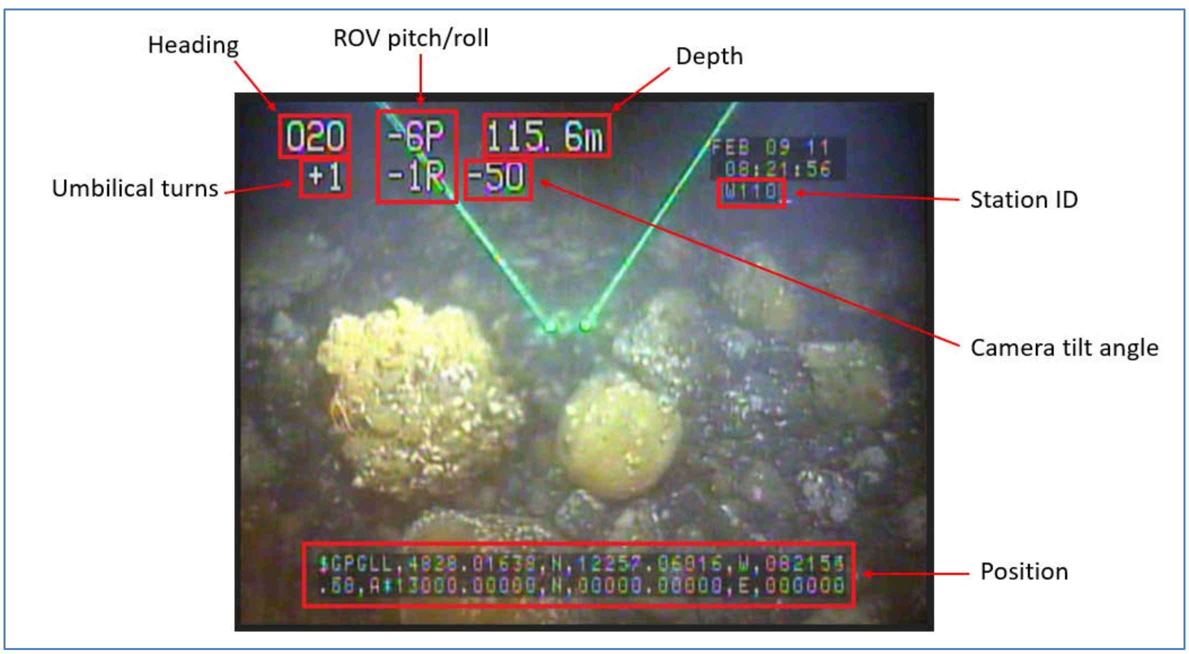

Figure 4. Example of video image with overlay.

At every 30±5 seconds of elapsed video time (i.e., a video 'segment'), the video reviewer recorded the video and local times, ROV position and depth, laser width (as measured in cm on the reviewer's screen), and apparent substrate types into a Microsoft Access® database. Within each video segment, all fish and select invertebrates were identified to the lowest discernable taxonomic level. High priority taxa included all rockfishes (except Puget Sound Rockfish), greenlings, Cabezon, sharks, skates, Spotted Ratfish, octopus, and any unique or rare species encountered. Each encounter with these species was entered into the database with the video and local times, ROV position and depth, and associated substrate information. All other fishes and select commercially important invertebrate species, such as Dungeness Crab, Red Sea Urchin, and California Sea Cucumber, were entered into the database either as a count-per-segment ("segment sum") or as "present" within the segment. In order for an organism to be included in the count, a minimum of half its body length, regardless of orientation, had to pass through the area on the video screen that fell below the horizontal plane of the laser dots. Due to intermittent problems with the ROV lighting package throughout the survey, the quality of the collected video varied and occasionally impaired the reviewers' ability to detect or accurately identify fish and substrates. Segments in which these issues were significant, or when video quality was poor or unusable for any other reason (e.g., ROV off bottom, high turbidity), were excluded from the analyses, and the area swept within the transect was adjusted accordingly (see below).

Area swept and abundance estimates

ROV transect lines were produced from the Hypack® tracking data, as described in Pacunski et al. (2016). In summary, raw tracking data were clipped to match video transect start/end times and remove segments of unusable video, edited in Hypack® and/or ArcGIS to remove spurious location fixes, and smoothed in ArcGIS using the PAEK algorithm before a final transect length was calculated. The transect width for each video segment, excluding segments where the video was deemed unusable, was calculated using the projected laser dots on the video, following the methods of Pacunski et al. (2008). Individual segment measurements within each transect were then averaged to produce a mean transect width. The area swept for each transect (A_i) was the product of the mean transect width ($\overline{W}_i$) and the smoothed transect length (L_i). Taxon densities for individual transects (D_i) were estimated by dividing the species count (C_i) by the transect area:

$$D_i = \frac{C_i}{L_i\overline{W_i}} = \frac{C_i}{\overline{A_i}}$$

The mean stratum density ($\overline{D_s}$) for a given taxon was then the sum of the individual transect densities divided by the number of transects (N_s):

$$\overline{D_s} = \frac{\sum_{i=1}^{N} D_i}{N_s}$$

The variance of the mean stratum density was calculated as:

$$Var(\overline{D_s}) = \frac{\sum_{i=1}^{N}(D_i - \overline{D_s})^2}{N_s - 1}$$

Total abundance (P) in numbers of individuals was the product of the stratum surface area (SA_s) and the mean taxon density (D), with variance calculated as the product of surface area and the variance of mean stratum density:

$$P_s = SA_s\overline{D_s}\,; Var(P_s) = SA_s\, Var(\overline{D_s})$$

Coefficients of variation for each taxon (as percentages) were calculated as the standard deviation of mean stratum density ($\overline{D}$) divided by the product of the square root of the station count (N) multiplied by the mean stratum density ($\overline{D}$):

$$CV = \frac{\sqrt{Var(\overline{D})}}{\sqrt{N} * \overline{D}} * 100$$

Combined variance and coefficient of variation values for the entire region were calculated as a weighted average of the values calculated separately for the Eastern and Western strata.

Habitat associations

To examine associations of fish species with specific substrate types, non-metric multidimensional scaling (NMDS) was implemented in Primer 6®. Transect-specific counts of each species were first standardized and square-root transformed, then a resemblance matrix was calculated based on Bray-Curtis Similarity. Patterns within the NMDS plot were then further investigated using primary habitat type for each species observation as a covariate. To simplify graphical representation of the results, species were grouped into higher order categories (i.e., family) when considerable overlap in habitat association was present.

Fiscal and logistical evaluation

In order to assess the overall cost and logistical efficiency of both the current systematic random survey and the habitat-stratified random survey conducted in 2008 (Pacunski et al. 2013), WDFW financial records, staff timesheets, vehicle records, vessel records, and travel logs were audited to obtain data describing operational activities. While the geographic scope of the area surveyed was the same, staffing and travel costs to plan and execute each survey were expected to differ substantially given variation in pre-survey modeling needs, the dispersion level of sampling stations, the complexity of habitat encountered (and therefore the time needed to conduct video review), and other factors. Because staffing, fuel, and travel costs vary from year to year with inflation, weather, and other economic and physical drivers, data were summarized as units of effort (e.g., staff hours) or outlay (e.g., gallons of fuel) and then a consistent cost per unit was applied for each category to facilitate direct comparison between survey designs using a standardized dollar value. A number of costs associated with both the 2008 and 2010 survey designs were not considered here, including ROV maintenance and upgrades, vessel upkeep and moorage, statistical analysis, and report writing. Regardless of the survey design selected, these factors were expected to remain relatively consistent and, therefore, represent fixed encumbrances of funds/staff.

Results

The survey began on 13 September 2010 and concluded on 15 April 2011 with a total of 46 sampling days. Fifty-five transects were completed in the Eastern stratum and 110 in the Western stratum (Figure 2, Appendix A). Sampling was conducted almost exclusively during the period between sunrise and sunset. One station in the Western stratum could not be sampled due to weather and logistical constraints. Five stations in the Eastern stratum and two stations in the Western stratum were too shallow to be sampled (<5 fa) and were excluded from the survey. The total area of the Eastern stratum was recalculated to account for the dropped stations, but the area covered by the dropped Western stations was considered negligible and no area adjustments were made. Overall, transect widths ranged from 1.04-2.97 m ($\overline{x}$= 1.62 m, SD = 0.36 m); transect lengths ranged from 142-702 m ($\overline{x}$= 411 m, SD = 76 m); and area swept per transect ranged from 181-1,775 m^2 ($\overline{x}$= 674 m^2, SD = 225 m^2) (Appendix A). The mean transect length of Western stratum stations was slightly longer than, and significantly different from, the mean for Eastern stratum stations (420 m v. 393 m, *t-test* P = 0.016). The mean transect width of Western stations was significantly greater than Eastern stations (1.72 m v. 1.42 m, *t-test* P < 0.0001), which can be attributed to the greater proportion of complex habitat encountered in the Western stratum. On such rugose habitat, the ROV was driven slightly higher off-bottom to navigate the terrain. Transect depths ranged from 9-292 m ($\overline{x}$= 87 m, SD = 4.3 m), with 80% of the transects occurring at depths less than 140 m (Figure 4). On average, stations in the Western stratum were significantly deeper than those in the Eastern stratum (48.3 m v. 106.8 m, *t-test* P < 0.0001).

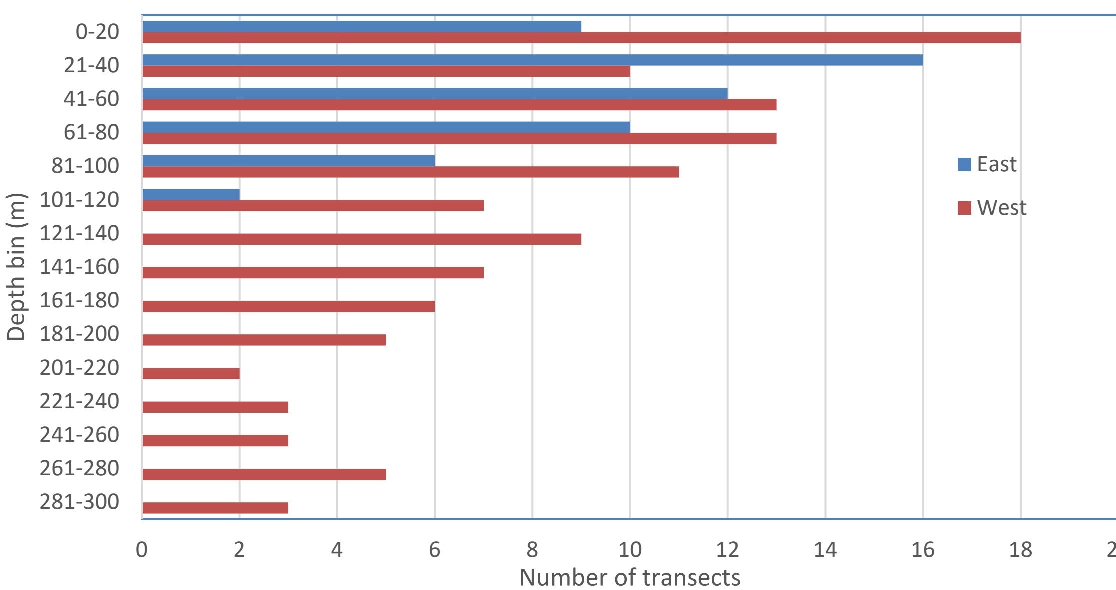

Figure 5. Number of transects by stratum and 20 m depth bin based on average transect depth.

Substrate composition

Overall the dominant primary (>50%) substrates in the SJI were sand and mud, accounting for 30% and 20%, respectively, of the 10,030 segments evaluated from the video (Figure 5). Pebble (including gravel), cobble, and bedrock were encountered in similar proportions and comprised

43% of the segment total, with shell/shell hash (6%) and boulders (2%) being the least common substrates. Sand was the dominant substrate in the Western stratum, whereas mud was dominant in the Eastern stratum (Figure 6). Cobble and pebble-gravel substrates were more common in the Eastern stratum and bedrock was over four times more common in the Western stratum. Shell/shell hash was more common in the Western stratum and present in similar proportion to cobble. Boulder habitats were uncommon in both strata.

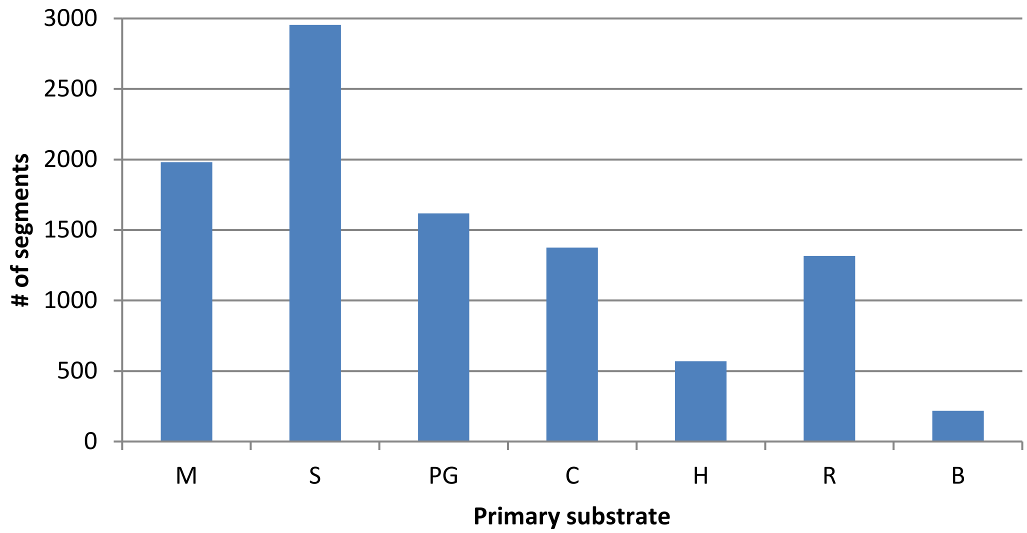

Figure 6. Number of video segments by primary substrate type (M = mud, S = sand, PG = pebble/gravel, C = cobble, H = shell/shell hash, R = bedrock, B = boulder).

Forage fish and unidentified fishes

Data were collected on all fishes encountered; however, a number of factors complicated the reviewers' ability to identify some fish to the species level, including small body size (generally ≤10 cm total length [TL]), cryptic coloration, poor lighting conditions, and reaction to the ROV. Pacific Herring *Clupea pallasii*, smelts (family Osmeridae), and Northern Anchovy *Engraulis mordax* share similar morphologies and schooling behaviors, and differentiating these forage fishes to the species level from video images can be extremely difficult. These pelagic species often exhibit strong avoidance behaviors to the lights and lasers, thus biasing any counts that may be obtained. Additionally, they may enter the viewing screen multiple times from different angles or be present in such large numbers and/or above the view of the ROV, making it impossible to obtain accurate counts. These species were, therefore, only recorded as "present" in the database. Benthic fishes that could not be identified were entered into the database as "unidentified fish", and while many were likely small-bodied fishes, others may have been juveniles of larger-bodied species. Future surveys utilizing improved lighting and camera systems may be helpful in resolving some of these issues, but for this study all forage fishes and unidentified fishes were excluded from the analyses.

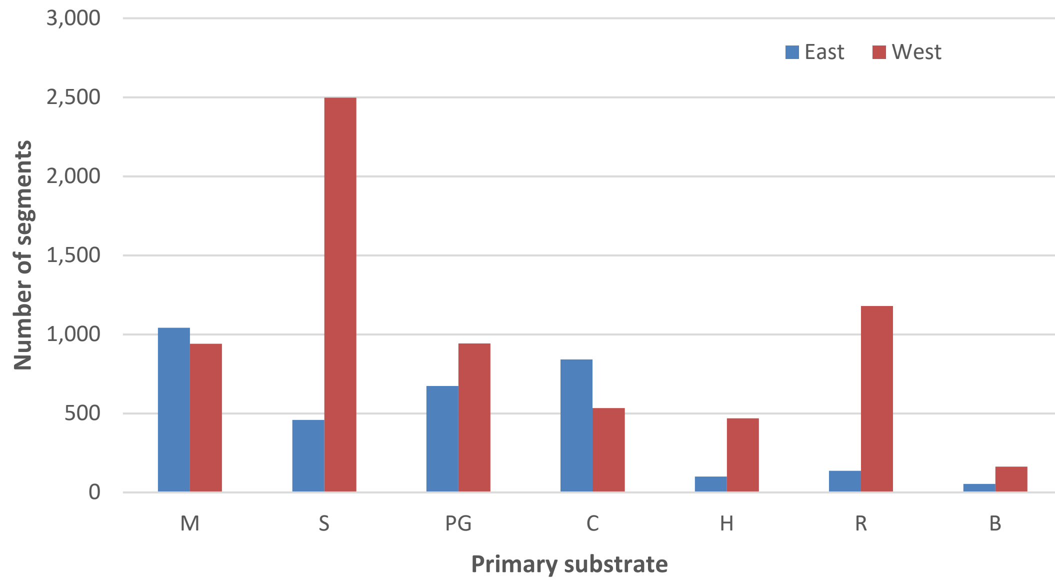

Figure 7. Proportion of primary substrate types by stratum (M = mud, S = sand, PG = pebble/gravel, C = cobble, H = shell/shell hash, R = bedrock, B = boulder).

All other fish

In total, 6,192 fish representing 50 taxa were enumerated from the video, with 40 taxa identified to species. As a group, rockfishes (*Sebastes* spp.) were most abundant, comprising 24.4% of the total count. Unidentified rockfishes and Puget Sound Rockfish *Sebastes emphaeus* accounted for 50.4% and 39.7% of all rockfishes observed, respectively. Nearly all unidentified rockfishes were small (<10 cm TL) and co-occurred on transects with positively identified adult Puget Sound Rockfish. The Puget Sound Rockfish is one of the smallest rockfish species and is known to occur in schools of mixed age/size classes. We surmise that many, if not all of the unidentified rockfish co-occurring with adult Puget Sound Rockfish were juveniles of that species. Some larger-bodied adult rockfish were also difficult to discern. For instance, reviewer confidence in distinguishing between Copper and Quillback Rockfish was occasionally low, especially for early life history phases when they appear very similar in gross morphology. The two species are also known to form hybrids within Puget Sound, which can further complicate species assignment, even when viewed clearly (Schwenke et al. 2018). Additionally, adults of both species (as well as some others) are often strongly associated with the bottom and may be obscured in crevices, caves, or heavily vegetated substrates. Thus, some of the larger-bodied rockfish were also classified as "unidentified rockfish" and all estimates of occurrence and abundance presented here should be considered minimum estimates. Quillback Rockfish *S. maliger* accounted for 7.1% of the rockfish total with the remaining 3.7% of rockfishes composed of Copper *S. caurinus*, Yelloweye *S. ruberrimus*, Greenstriped *S. elongatus*, Canary *S. pinniger*, Redstripe *S. proriger*, Tiger *S. nigrocinctus*, Vermilion *S. miniatus*, and Yellowtail Rockfishes *S. flavidus*. Gadids (family Gadidae) were only slightly less prevalent than rockfishes, comprising 24.1% of the total fish count. Six Pacific Cod *Gadus macrocephalus* were identified from the video; however, most gadids (99.6%) were small (~10-15 cm) and could not be identified below the Family level. The majority of these fish were assumed to be Walleye Pollock *G. chalcogrammus* based on the results of WDFW trawl surveys conducted in the same region in 2001 (Palsson et al. 2003), 2004 and 2006 (Blaine et al. 2020), and 2008-11 (Blaine et al. in prep). Pricklebacks (family Stichaeidae) and flatfishes (families Pleuronectidae and Bothidae) accounted for 21% and 15% of the total fish count, respectively, with the remaining 16% consisting of greenlings (family Hexagrammidae), eelpouts (family Zoarcidae), Spotted Ratfish *Hydrolagus colliei*, sculpins (family Cottidae), perches (family Embiotocidae), skates (family Rajidae), and miscellaneous other fish

ESA-listed rockfish

ESA-listed rockfish were only encountered at stations in the Western stratum: two Canary Rockfish (subsequently delisted in 2017) at one station, and 16 Yelloweye Rockfish spread over 12 stations (Figure 7). No Bocaccio were observed. All ESA-listed rockfish were observed at depths greater than 40 m (131 ft) and in direct association with bedrock or boulder, which was the primary substrate on all transects containing these species, with the exception of three Yelloweye Rockfish.

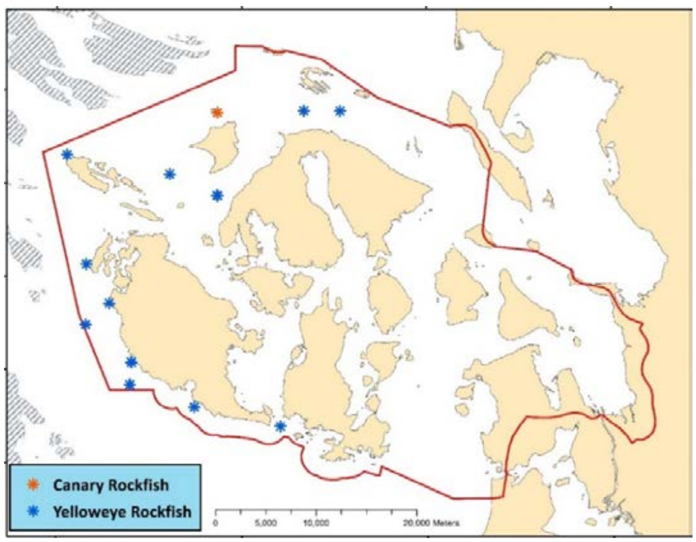

Figure 8. Approximate locations of ESA-listed rockfish observed during the 2010 SJI survey.

Table 1. Population estimates for key fish and invertebrate taxa.

Common Name	Taxon	Number observed	Eastern stratum population estimate (CV)	Western stratum population estimate (CV)	Combined (CV)
Flatfish - unidentified	Pleuronectiformes	386	2,594,446 (27%)	2,012,690 (21%)	4,607,135 (22%)
C-O Sole	*Pleuronichthys coenosus*	1	0	14,886 (71%)	14,886 (71%)
Dover Sole	*Microstomus pacificus*	62	360,701 (70%)	382,942 (28%)	743,643 (49%)
English Sole	*Parophrys vetulus*	299	1,206,736 (40%)	1,940,811 (26%)	3,147,547 (32%)
Pacific Sanddab	*Citharichthys sordidus*	2	0	24,180 (57%)	24,180 (57%)
Rex Sole	*Glyptocephalus zachirus*	111	184,397 (64%)	819,018 (26%)	1,003,415 (32%)
Rock Sole	*Lepidopsetta sp.*	62	323,719 (42%)	321,182 (30%)	644,901 (36%)
Starry Flounder	*Platichthys stellatus*	7	60,225 (72%)	13,057 (74%)	73,282 (73%)
Rockfish - unidentified	Sebastidae	835	593,110 (68%)	4,693,283 (50%)	5,286,393 (56%)
Canary Rockfish	*Sebastes pinniger*	2	0	9,759 (100%)	9,759 (100%)
Copper Rockfish	*Sebastes caurinus*	28	130,182 (82%)	141,021 (37%)	271,203 (48%)
Greenstriped Rockfish	*Sebastes elongatus*	1	0	4,319 (100%)	4,319 (100%)
Puget Sound Rockfish	*Sebastes emphaeus*	506	5,029,978 (70%)	1,677,323 (54%)	6,707,301 (60%)
Quillback Rockfish	*Sebastes maliger*	97	451,170 (53%)	418,052 (30%)	869,223 (41%)
Redstripe Rockfish	*Sebastes proriger*	1	0	8,533 (100%)	8,533 (100%)
Tiger Rockfish	*Sebastes nigrocinctus*	1	18,355 (100%)	0	18,355 (100%)
Vermilion Rockfish	*Sebastes miniatus*	1	0	11,249 (100%)	11,249 (100%)
Yelloweye Rockfish	*Sebastes ruberrimus*	16	0	114,494 (33%)	114,494 (33%)
Yellowtail Rockfish	*Sebastes flavidus*	1	0	5,373 (100%)	5,373 (100%)
Spotted Ratfish	*Hydrolagus colliei*	114	50,550 (59%)	839,816 (25%)	890,365 (37%)
Skate - unidentified	Rajidae	4	14,082 (100%)	23,854 (58%)	37,936 (61%)
Big Skate	*Beringraja binoculata*	5	18,488 (100%)	32,644 (50%)	51,092 (60%)
Longnose Skate	*Beringraja rhina*	5	0	40,200 (44%)	40,200 (44%)
Sandpaper Skate	*Bathyraja kincaidii*	3	0	29,237 (57%)	29,237 (57%)
Gadid - unidentified	Gadidae	1,461	5,991,479 (23%)	9,208,810 (16%)	15,200,289 (19%)
Pacific cod	*Gadus macrocephalus*	6	0	47,038 (41%)	47,038 (41%)
Greenling - unidentified	Hexagrammidae	19	62,091 (50%)	118,112 (34%)	108,203 (41%)

Common Name	Taxon	Number observed	Eastern stratum population estimate (CV)	Western stratum population estimate (CV)	Combined (CV)
Kelp Greenling	*Hexagrammos decagrammus*	122	460,427 (37%)	605,602 (27%)	1,066,029 (32%)
Lingcod	*Ophiodon elongatus*	23	77,034 (64%)	137,639 (25%)	214,673 (34%)
Longspine Combfish	*Zaniolepis latipinnis*	1	0	7,140 (100%)	7,140 (100%)
Painted Greenling	*Oxylebius pictus*	2	12,773 (100%)	0	12,773 (100%)
White-spotted Greenling	*Hexagrammos stelleri*	20	84,244 (50%)	92,490 (39%)	176,734 (41%)
Sculpin - unidentified	Cottidae	202	1,813,199 (17%)	801,246 (20%)	2,614,445 (18%)
Buffalo Sculpin	*Enophrys bison*	14	142,442 (46%)	41,315 (48%)	183,758 (47%)
Cabezon	*Scorpaenichthys marmoratus*	2	7,156 (100%)	7,083 (100%)	14,239 (100%)
Great Sculpin	*Myoxocephalus polyacanthocephalus*	16	92,808 (62%)	91,209 (32%)	184,018 (44%)
Pacific Staghorn Sculpin	*Leptocottus armatus*	3	0	21,747 (74%)	21,747 (74%)
Red Irish Lord	*Hemilepidotus hemilepidotus*	47	841,443 (52%)	61,891 (45%)	903,335 (48%)
Perch - unidentified	Embiotocidae	8	0	50,956 (63%)	50,956 (63%)
Shiner Perch	*Cymatogaster aggregata*	3	62,468 (100%)	0	62,468 (100%)
Striped Sea Perch	*Embiotoca lateralis*	6	0	45,538 (93%)	45,538 (93%)
Snake Prickleback	*Lumpenus sagitta*	671	7,294,576 (43%)	2,785,421 (48%)	10,079,998 (44%)
Decorated Warbonnet	*Chirolophis decoratus*	2	18,139 (100%)	9,904 (100%)	28,043 (100%)
Eelpout - unidentified	Zoarcidae	178	721,101 (65%)	1,286,214 (51%)	2,007,316 (56%)
Northern Ronquil	*Ronquilus jordani*	55	0	415,479 (45%)	415,479 (45%)
Plainfin Midshipman	*Porichthys notatus*	1	0	7,150 (100%)	7,150 (100%)
Poacher - unidentified	Agonidae	11	0	93,949 (40%)	93,949 (40%)
Snailfish - unidentified	Liparidae	47	33,200 (100%)	367,144 (37%)	400,344 (64%)
Cancer crab - unidentified	Cancridae	78	751,856 (31%)	231,057 (34%)	982,922 (32%)
Dungeness Crab	*Metacarcinus magister*	173	1,615,323 (33%)	734,136 (28%)	2,349,459 (30%)
Red Rock Crab	*Cancer productus*	72	521,227 (48%)	300,207 (42%)	821,434 (44%)
Tanner Crab	*Chionoecetes bairdi*	115	1,116,476(45%)	450,468(40%)	1,566,944(41%)
California Sea Cucumber	*Parastichopus californicus*	3,794	28,176,837 (39%)	13,258,341 (23%)	41,435,179 (27%)
Red Sea Urchin	*Mesocentrotus franciscanus*	2,538	10,225,383 (47%)	11,570,444(27%)	21,795,827(36%)

Abundance of key fish taxa

Unidentified gadids were the most abundant fish taxa, with an estimated 15.2 million±19% fish in the SJI (Table 1). As a group, an estimated 13.3 million rockfishes inhabit the SJI, with Puget Sound Rockfish and unidentified rockfishes accounting for 50.4% and 39.7% of this total, respectively. Quillback Rockfish were the most abundant large-bodied rockfish (869,223±41%), followed by Copper Rockfish (271,203±48%) and Yelloweye Rockfish (114,494±33%) (Table 1). Abundance estimates for the remaining rockfish species were based on a single observation within a single stratum, and were much lower. Flatfishes were the next most abundant taxa at an estimated 10.3 million individuals, with unidentified flatfishes and English Sole *Parophrys vetulus* comprising 45% and 31% of this total, respectively. Rex Sole *Glyptocephalus zachirus* (1.00 million±32%), Dover Sole *Microstomus pacificus* (743,643±49%), and Rock Sole *Lepidopsetta spp.* (644,901±36%) comprised 23% of total flatfishes (Table 1). Snake Prickleback *Lumpenus saggita* was the most abundant individual species identified, with an estimated population of 10.10 million±44% fish. Nearly 4 million sculpins were estimated from the survey, with 2.61 million±18% (67%) being unidentified. Red Irish Lord *Hemilepidotus hemilepidotus* were the most abundant identifiable sculpin species at 903,335±48% fish, while estimates for Great Sculpin *Myoxocephalus polyacanthocephalus* and Buffalo Sculpin *Enophrys bison* were nearly identical at ~184,000±45% fish each. An estimated 1.65 million greenlings inhabit the SJI, with nearly 65% of this group composed of Kelp Greenling *Hexagrammos decagrammus* (1.07 million fish±32%). Lingcod *Ophiodon elongatus* (214,673±34%), White-spotted Greenling *H. stelleri* (176,734±41%), and unidentified greenling (180,203±41%) accounted for 35% of Hexagrammidae, while Painted Greenling *Oxylebius pictus* (12,773±100%) were seldom encountered (Table 1). Eelpouts were also relatively abundant at an estimated 2.01 million±56% fish.

The abundance of several of the more common fish species varied between strata, with more Snake Prickleback and Puget Sound Rockfish occurring in the Eastern stratum and more Gadidae and English Sole in the Western stratum. Coefficients of variation (CVs) for most taxa were lower in the Western stratum. Total CVs for the most common taxa, which generally had more consistent encounter rates, and taxa with low transect count variability ranged from 22-42%, whereas less common and rarer taxa had CVs from 58-100%.

California Sea Cucumber *Parastichopus californicus* and Red Sea Urchin *Mesocentrotus franciscanus* are two important, commercially harvested and actively managed invertebrate species, with survey estimates of 41.4 million±27% cucumbers and 21.8 million±36% urchins in the SJI (Table 1). Red Sea Urchin were observed at a maximum depth of 285 m, more than double the previously reported maximum depth for this species. California Sea Cucumber were observed at depths up to 292 m in this survey, which is consistent for the depth range reported for this species along the central California coast (Blaine 2011). Dungeness Crab *Metacarcinus magister* and, to a lesser extent, Tanner Crab *Chionoecetes bairdi* are harvested by both recreational and commercial fishers and had population estimates of 2.35 million±30% and 1.57 million±41%, respectively. Green Sea Urchin *Stongylocentrotus droebachiensis* and White Sea Urchin *S. pallidus* were observed in the survey but were patchily distributed and often occurred in large, separate and mixed species aggregations, confounding the reviewers' ability to accurately enumerate them from the video. For this reason, these species were usually recorded only as "present" and no population estimates were produced.

Fish-substrate associations

Observed fish taxa were condensed into nine major groups to examine their primary substrate associations: skates, eelpouts, pricklebacks, flatfishes, gadids, ratfish, sculpins, greenlings, and rockfishes. The NMDS analysis identified four major groupings at the 50% similarity level and seven groups at the 75% level (Figure 8). Skates comprised a solitary group and were predominantly associated with sand (Figure 9). Eelpouts also formed a solitary group and were associated mainly with mud and sand. Similarly, pricklebacks, gadids, and flatfishes occurred mainly on mud and sand but also used cobble, shell/shell hash, and bedrock substrates. Rockfishes, greenlings, sculpins, and ratfish formed a major grouping at the 50% level due to their occurrence on a greater diversity of substrates, but separated into smaller groups at the 75% level based on differential use of rocky substrates.

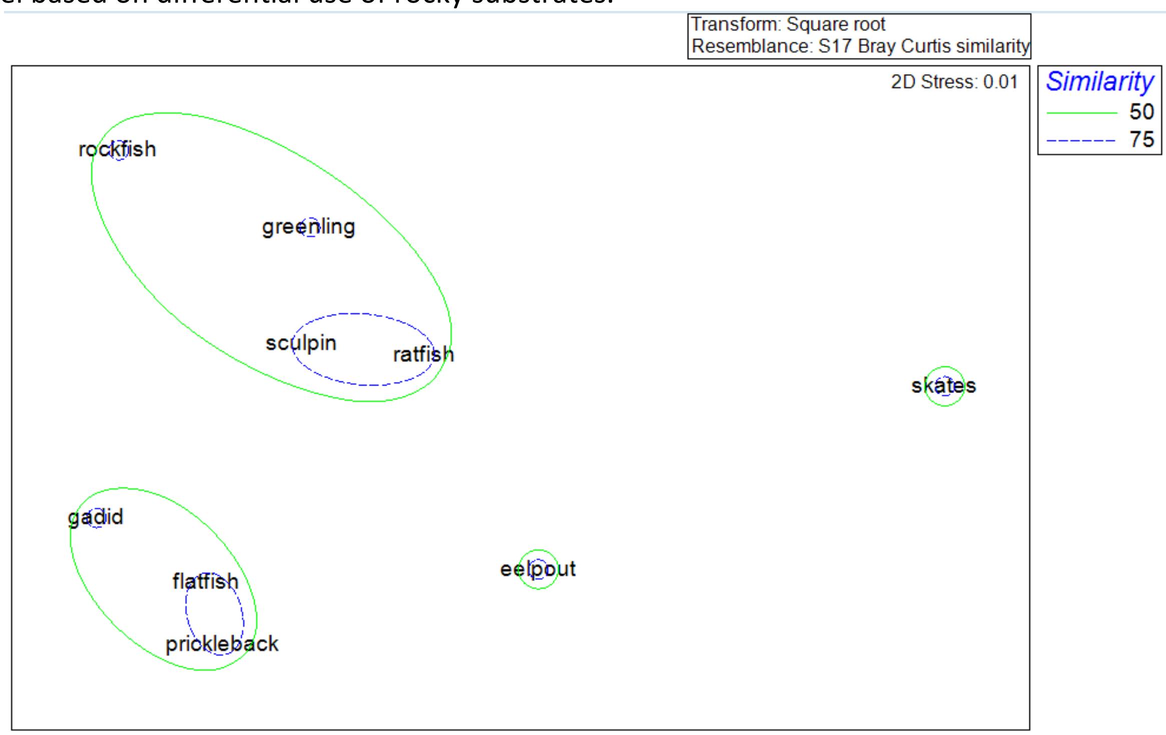

Figure 9. Non-metric multidimensional scaling (NMDS) plot of major fish taxa based on primary substrate type associations (with 50% and 75% similarity groupings).

Rockfish depth distributions

The depth distributions of Copper, Quillback, and Yelloweye Rockfish in 2010 were consistent with those observed during the 2008 SJI survey (Pacunski et al. 2013) (Figure 10). Copper Rockfish showed the shallowest distribution, with most observations occurring from 28–54 m ($\bar{x}$= 43 m). Quillback Rockfish were observed across a greater depth range but most observations were from 43-73 m ($\bar{x}$ = 63 m). Yelloweye Rockfish showed the broadest depth distribution, from 76-269 m, although most fish were observed between 106 and 220 m ($\bar{x}$ = 168 m). Puget Sound Rockfish were observed over the narrowest depth range, from 33-68 m, with the majority of observations between 46 and 55 m. Most unidentified rockfish were assumed to be Puget Sound Rockfish as noted above, and had a depth distribution that was slightly broader and deeper than Puget Sound Rockfish, but consistent with the range of this species in the SJI. One fish observed at 163 m was later determined to be a Redstripe Rockfish, and one fish observed at 226 m was strongly suspected to be a Yelloweye Rockfish as it occurred on a transect where three other Yelloweye Rockfish were observed. However, neither of these fish were included in estimating the population sizes of these species.

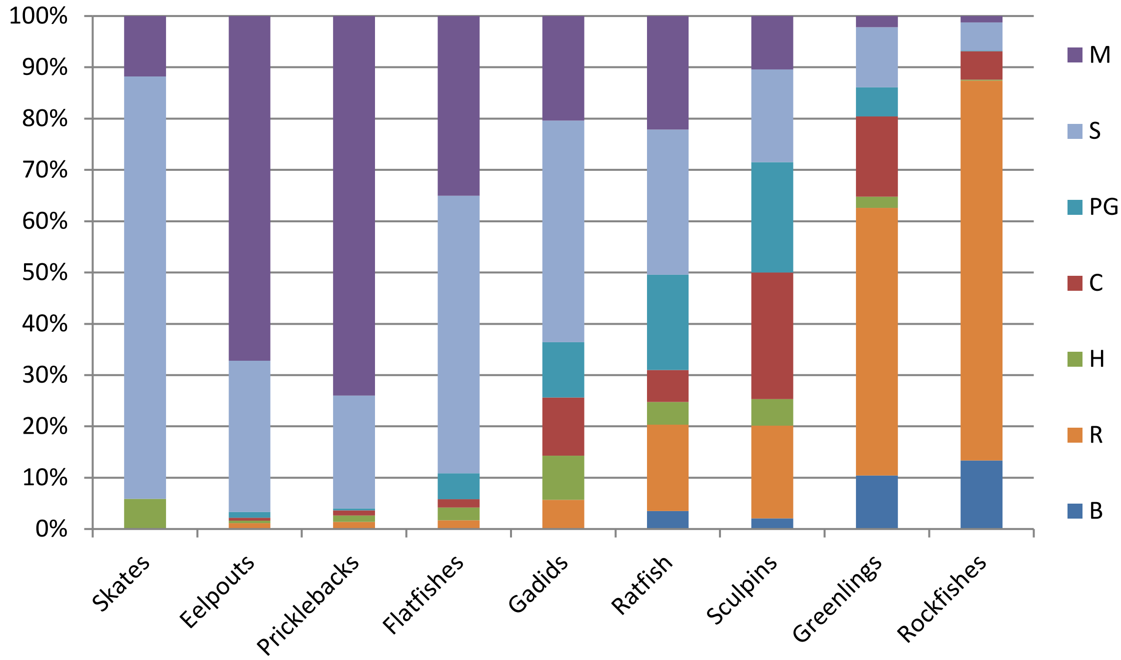

Figure 10. Proportional distribution of primary substrate association by major fish taxa in the 2010 SJI survey (M = mud, S = sand, PG = pebble-gravel, C = cobble, H = shell/shell hash, R = bedrock, B = boulder).

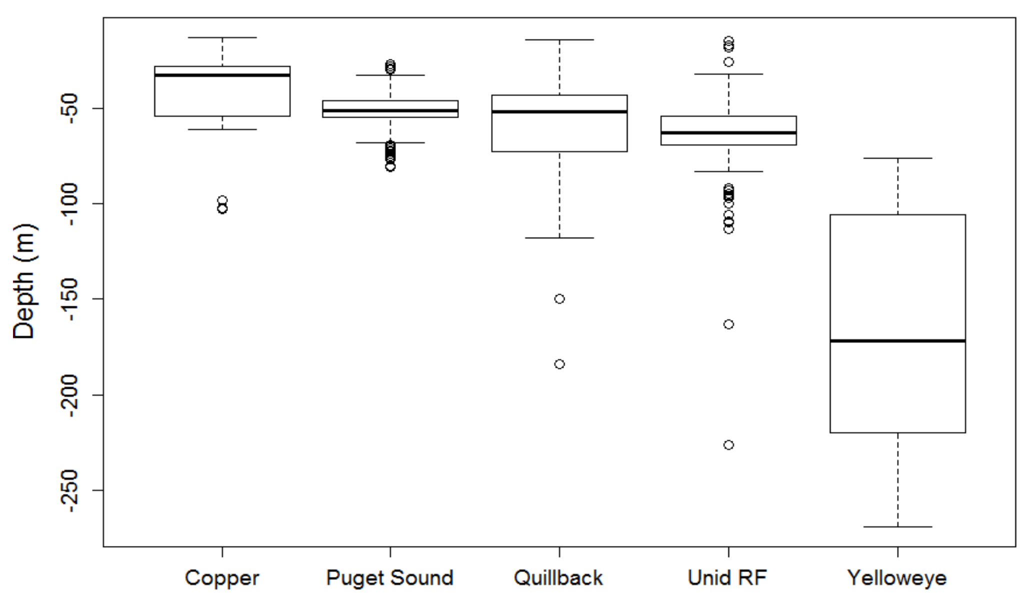

Figure 11. Depth distributions of major rockfish taxa in the 2010 SJI survey. Unid RF = Unidentified rockfish.

Comparison of survey designs

During the 2008 survey of the SJI region, sampling effort was restricted to high-relief, generally rocky substrate identified during previous multibeam bathymetric surveys (Greene et al. 1999; 2007), WDFW drop camera and trawl surveys, and NOAA bathymetric charts (Pacunski et al. 2013). As a result, the fish and invertebrate biodiversity observed in that survey was markedly restricted, intentionally ignoring flatfishes and other occupants of muddy and sandy habitats that are monitored using otter trawls (Blaine et al. 2020). Additionally, for species that occupy a broad diversity of habitat types, the 2008 survey considerably undersampled regional abundance (e.g., the Spotted Ratfish population was estimated at 122,123±25.6% in 2008 as opposed to 890,365±37% in 2010). For species occupying rocky habitats, which theoretically should have been adequately sampled by both the 2008 and 2010 designs, the rocky-focused design (2008) encountered a greater species diversity due to higher effort, but the all-habitats design (2010) regularly produced higher abundance estimates for the species encountered in both surveys (Table 2). This is largely attributable to the occasional occurrence of these species on both muddy/sandy patches between rocky habitat segments and, especially for unidentified and Quillback Rockfish, occurrence on mud-dominated transects. This variability in encounter probability across transects as a consequence of variation in habitat type, however, generally led to large CVs for most species in the current survey. This underscores the need to adequately plan for expected/modeled encounter rate and sampling density during survey design.

Table 2. Population estimates for key fish taxa generally associated with rocky substrates from both the rocky-focused (2008, Pacunski et al. 2013) and all-habitats design (2010, this study).

	Rocky Strata (2008)		All Habitats (2010)	
Species	**Abundance**	**CV**	**Abundance**	**CV**
Canary Rockfish	1,697	100	9,759	100
Copper Rockfish	545,859	14	271,203	48
Quillback Rockfish	440,372	11	869,223	41
Puget Sound Rockfish	4,503,755	22	6,707,301	60
Tiger Rockfish	7,561	45	18,355	100
Yelloweye Rockfish	47,407	25	114,494	33
Yellowtail Rockfish	35,705	65	5,373	100
Unidentified Rockfish	28,871	31	5,286,393	56
Kelp Greenling	680,779	8	1,066,029	32
Lingcod	170,526	12	214,673	34
Unidentified Greenling	9,101	49	108,203	41
White-spotted Greenling	30,564	26	176,734	31

Although the two surveys sampled the same geographic extent, implementing the current survey (all-habitats) required considerable additional outlay in terms of overall field hours (Table 3). Offsetting this, however, was the decreased time required to plan and design the survey, and to review and perform quality assessment/quality control (QA/QC) on video recordings. This review time reduction was largely due to the structural simplicity of the muddy and sandy habitats encountered in many areas. Organisms of interest were generally highly conspicuous on these habitats, and review time was generally limited to entering substrate information and screen width data because it did not require a rigorous search of cracks and crevices, which simply did not exist, to detect fish. In total, the elements of survey design and implementation associated specifically with the sampling design (see Methods for details) cost 6.1% less ($165,308 vs. $175,988) for the rocky-focused design in 2008. Depending on specific project goals, differences in documented species diversity, encounter rate of target species, estimates of CV, availability of personnel hours, and total cost can be combined to optimize sampling design. Given the desire to use a single sampling tool to adequately assess bottomfish distribution and abundance, these results demonstrate that, in the absence of adequate habitat maps for use in targeted stratification, it is possible to use a systematic sampling design to obtain population estimates without incurring substantial additional cost.

Table 3. Outlay, in terms of personnel hours, days of overnight travel, and fuel to implement both the 2008 (Pacunski et al. 2013) and 2010 surveys (top panel) and the cost in standardized dollars associated with these outlays (bottom panel).

Outlay		**2008 Survey**				**2010 Survey**			
		Survey Design	**Field Survey**	**Video Review**	**QA/QC**	**Survey Design**	**Field Survey**	**Video Review**	**QA/QC**
Staff	**Chief Scientist**	48	103	15	66	8	216	10	58
	Chief Analyst	32			15	8			19
	Ship Captain		297				388		
	Field Lead	8	296	55	37	8	340	39	34
	Field Assistant	23	194			26	255		
	Deckhand		590				751		
	Video Lead		38	326	133		60	277	94
	Video Technicians			1230				930	
	Total Staffing Hours	111	1518	1626	251	50	2010	1256	205
Travel	**Hotels & Per Diem**		84				132		
	Vehicle Fuel		218				340		
	Vessel Fuel		2565				4399		

Table 3. (continued)

Cost		2008 Survey				2010 Survey			
		Survey Design	Field Survey	Video Review	QA/QC	Survey Design	Field Survey	Video Review	QA/QC
Staff	**Chief Scientist**	$3,061	$6,569	$957	$4,209	$510	$13,776	$638	$3,699
	Chief Analyst	$2,041			$957	$510			$1,212
	Ship Captain		$12,670				$16,552		
	Field Lead	$459	$16,976	$3,154	$2,122	$459	$19,499	$2,237	$1,950
	Field Assistant	$1,251	$10,548			$1,414	$13,864		
	Deckhand		$18,125				$23,071		
	Video Lead		$1,720	$14,752	$6,018		$2,715	$12,534	$4,254
	Video Technicians			$37,786				$28,570	
	Total Staffing Cost	$6,812	$66,607	$56,648	$13,306	$2,893	$89,478	$43,978	$11,114
Travel	**Hotels & Per Diem**		$12,516				$12,481		
	Vehicle Fuel		$698				$1,088		
	Vessel Fuel		$8,721				$14,957		
	Total Travel Costs		$21,935				$28,525		
TOTAL DESIGN-BASED COST		$6,812	$88,542	$56,648	$13,306	$2,893	$118,003	$43,978	$11,114

Discussion

The primary goal of the 2010 survey was to evaluate the efficacy of a systematic survey design for assessing bottomfish abundance, especially for those species occupying high-complexity (i.e., untrawlable) habitats, in areas where substrate-based designs cannot be employed due to a lack of adequate mapping data. For the majority of encountered species, statistically valid abundance estimates were made, though coefficients of variation were generally higher than those generated with a stratified random design of high-relief habitats in the same geographic area in 2008 (Pacunski et al. 2013). Unlike the 2008 SJI survey that sampled only rock substrates (Pacunski et al. 2013), the current study design allowed population estimates to be made for key bottomfish and invertebrate taxa across the complete range of habitat types present in the region. Comprehensive coverage of available habitat is also crucial to generating abundance estimates for species putatively associated with rocky substrates but for which substantial portions of the population occur over soft, low-complexity habitats (e.g., Quillback Rockfish) (Krieger and Ito 1999). Estimates for some species, however, may be substantially biased as a result of detection efficiency and animal behavior (Lorance and Trenkel 2006; Stoner et al. 2008; Murphy and Jenkins 2010). As shown by Pacunski et al. (2016), which used the same ROV employed here, flatfish abundance cannot be reliably estimated due to low detection and identification rates, partially associated with burying behavior and crypticity, and abundance estimates are considered conservative values for management purposes. Greater confidence can be placed in the estimates for larger benthic fishes such as rockfishes, greenlings, and some large sculpins (e.g., Red Irish Lord) because they are more easily detected on the video image. However, because ROVs cannot be easily maneuvered to look under extreme overhangs or detect fish located deep in crevices, estimates for species that exhibit a preference for these habitats should also be considered conservative (e.g., Yelloweye and Tiger Rockfish) (Krieger and Ito 1999; Pacunski et al. 2008).

Dividing the SJI region into Eastern and Western strata for this survey allowed evaluation of the effects of sampling intensity and species-specific encounter rates on abundance estimation using a systematic random design, albeit with relatively limited sample size. For the vast majority of species that were encountered in both strata, the CVs were larger in the Eastern stratum (Table 1), in which sampling stations were more broadly dispersed, indicating less certainty about the abundance estimates. While some of this variation in estimation precision can be attributed to differences in the prevalence of specific habitat types between the strata (i.e, the Western stratum is known to contain more high-relief rock) and, therefore, the encounter rate of species associated with these habitats, CVs tended to be lower for flatfishes, skates, and other soft-bottom species in the Western stratum as well. Together, these trends support the assertion that increased sampling intensity leads to higher precision in abundance estimation even when nothing is known about the habitats being sampled. While this follows logically from simple sampling theory (Wisz et al. 2008), confirming this fact is crucial to securing funding and support for additional ROV-based survey efforts on larger geographic scales.

Abundance estimation in this study was problematic for rare species with low and/or highly variable encounter rates, including ESA-listed rockfishes. While Yelloweye Rockfish were detected at a rate capable of producing an acceptably precise population estimate, that was not the case for Bocaccio, which were never detected, or Canary Rockfish, which were only detected at one location (and were delisted in 2017). This result was similar to the 2008 survey that detected Bocaccio and Canary Rockfish at only two locations. Yelloweye Rockfish lead a predominantly benthic existence (Love et al. 2002) and have been observed with a number of underwater vehicles (UVs) within the Salish Sea (Richards 1986; Yoklavich et al. 2000; Pacunski et al. 2013; Haggarty et al. 2016). In contrast, Bocaccio and Canary Rockfish are described as schooling species that tend to occur slightly off-bottom to well above the bottom (Love et al. 2002). This behavior may place both species above the viewing window of most benthic-focused sampling vehicles and could account for their limited and lack of occurrence in the aforementioned studies and the 2008 and 2010 SJI surveys. Fish are affected by anthropogenic sounds (Popper and Hastings 2009) and display different responses to vessel noise (De Robertis and Handegard 2013) and underwater lighting (Rooper et al. 2015), and it is subsequently possible that Bocaccio, Canary Rockfish, and other species actively avoided the ROV. Haggarty et al. (2016), however, regularly encountered high densities of Canary Rockfish along the west coast of Vancouver Island (i.e., outside the Salish Sea) with a small ROV operated in a similar manner as the ROV in this study, and based on their results, we conclude that species behavior, both natural and anthropogenically induced, was unlikely to affect our ability to detect Bocaccio and Canary Rockfish. Instead, we hypothesize that the population abundance of these species was too low to be detected at the sampling frequencies used in the 2008 and 2010 SJI surveys. However, to account for behavioral uncertainties, it may be necessary to employ a multi-method approach for assessing these species in future surveys. Towed cameras may have reduced impacts on behavior from noise and have the ability to operate at greater speeds than the ROV, allowing fish to be detected before they can react, but they cannot be controlled as easily as the ROV, still require lights, and may be limited to use in less rugose habitats. Autonomous drop-cameras could be deployed in areas previously identified as potential rockfish habitat to assess presence/absence, and hydroacoustic methods could be used for identifying off-bottom rockfish aggregations, although additional work would be required to confirm species identification within acoustic targets (e.g., hook-and-line sampling, open cod-end trawling with cameras).

One unexpected benefit of the current study was the observation of California Sea Cucumber and Red Sea Urchin to maximum depths of 292 m and 285 m, respectively, and the generation of population estimates encompassing their full depth distributions. In contrast, stock assessments of California Sea Cucumber and Red Sea Urchin conducted by the WDFW are based on scuba surveys conducted at traditional harvest depths, typically <30 m, and management of these fisheries has historically been based only on the shallow-water component of their populations. The ability to survey deepwater sea cucumbers and urchins with the ROV provides previously unavailable information that expands our understanding of species distribution and population size in the SJI relative to harvest in shallow waters. For example, Carson et al. (2016) concluded that the density of California Sea Cucumber below harvestable depths might be too low to provide the fishery with a consistent supply of recruits, which resulted in changes to fishery management aimed at stabilizing CPUEs and protecting spawning biomass (H. Carson, Pers. Comm., 2018)[1].

Next steps

Assessing the abundance of species occurring in patchy distributions across spatially heterogeneous habitats is challenging (Miller and Ambrose 2000), especially when habitat and species distribution data are unavailable to aid in developing a reasonably informed survey design, and/or when species are rare. In the absence of such data, choosing an appropriate level of sampling effort often amounts to an informed guessing game, but ideally that effort should be capable of producing statistically valid population estimates while being balanced against time, budget, and resource (i.e., personnel and equipment) constraints. Coupled with knowledge from previous ROV surveys, these factors were used to design the current survey, which resulted in an acceptably precise population estimate for most "common" bottomfish and benthic macroinvertebrate species in the SJI, as well as Yelloweye Rockfish (33% CV), a species presumed to be at low population abundance levels in the SJI due to historic fishing impacts (Palsson et al. 2009; Drake et al. 2010; Williams et al. 2010). One notable exception, however, was the precision of the estimate for Copper Rockfish, the most abundant large-bodied rockfish in the SJI (Pacunski et al. 2013), which was poor to marginal (82% CV in Eastern stratum, 48% overall). We attribute this to the lower sampling rate in the shallow-water habitats preferred by this species (Figure 10); 22% of stations in the Eastern stratum and 36% of stations in the Western stratum were located at depths <26.6 m (120 ft). Thus, our results suggest that even what appears to be a reasonably designed survey may not be a tenable approach for assessing populations of highly-related species, and that alternative, species-specific sampling designs (or stratification) may be needed to produce acceptable estimates of population size.

The 2008 ROV survey in the SJI produced reasonably precise population estimates for many bottomfish species, but it required substantial prior knowledge of habitat distribution, as well as considerable investment of both time and resources to accomplish this goal (Pacunski et al. 2013; Table 3). The current survey required effectively no prior knowledge about the distribution of habitats but involved more time in the field transiting among stations. All told, these variations in survey design were separated by only 6% in overall cost, making the systematic design tenable when habitat information is unavailable. With regard to rare species, however, the 2010 survey covered only 18% of ESA-listed rockfish Distinct Population Segments (DPSs) within Washington waters, required 7 months to complete, and had insufficient encounter rates with both Bocaccio and Canary Rockfish to produce valid population estimates. Implementing the same study design (at the Western stratum sampling rate) across the remainder of the Washington DPSs is estimated to require 40-49 months for completion under optimal conditions. However, our experience working in the DPSs outside of the SJI suggests that suitable ESA-listed rockfish habitats will be more restricted than in the SJI and will require an even greater sampling effort to estimate abundance of Yelloweye Rockfish with acceptable precision, further extending the length and cost of the survey and far exceeding the time frame required to meet management

[1] Henry Carson, WDFW, Olympia, WA.

needs and recovery goals (Dan Tonnes, Pers. Comm. 2017)[2]. In the case of Bocaccio and Canary Rockfish, it is highly unlikely that any increase in sampling frequency would be useful until their populations increase to a level that a reasonable survey effort could detect.

From our results we conclude that, lacking adequate habitat maps, a systematic survey design is a practicable approach for providing timely and precise estimates of abundance for common bottomfish species using an ROV, provided sampling intensity is sufficiently high and encounter rate is both sufficiently high and consistent. We therefore recommend expanding this sampling design to the whole of Washington's inside waters as a trial, optimized to make use of available funding and staffing resources, to use a single sampling tool to assess bottomfish abundance and distribution at depths inaccessible to scuba and for which additional permitting is needed to facilitate use of hook-and-line or longline gear. While this approach is likely only to produce valid population estimates for "common" species, it will provide insight into habitat use patterns for species that occupy both high-relief, rocky areas and less complicated, soft bottoms. This knowledge may then be employed to develop correction factors for ROV-based abundance estimates focused on refined habitat-based strata, should sampling all habitats prove prohibitive. For rare species, such as ESA-listed rockfish, a different approach to survey design is needed to greatly enhance encounter rate. Unfortunately, accurate habitat maps of the southern Salish Sea seabed have yet to be produced, and there is no expectation that such maps will be available for at least a decade, thereby eliminating habitat-stratified survey designs from consideration.

One promising alternative to wide-spread knowledge of habitat is the use of species distribution models (SDMs) that utilize location records and environmental data to predict habitat suitability for a species or suite of species (Franklin 2009). One SDM based on the maximum entropy (Maxent) algorithm uses presence-only data and has been shown to have excellent predictive ability even at small sample sizes (Phillips et al. 2004, Wisz et al. 2008). This feature makes Maxent particularly attractive for modeling rare species where location records are sparse, such as the case with ESA-listed rockfish that are often associated with specific habitat features. The resultant model outputs can be easily adapted for use in the survey design process to stratify sampling efforts among areas of varying habitat suitability, thereby increasing the probability of detection and maximizing survey efficiency by reducing or eliminating the need to sample low-probability (i.e., "non-suitable") habitats. In fact, because SDMs can utilize multiple environmental inputs, including direct observations of substrate data from visual surveys, or hydroacoustics to predict habitat-suitability, SDM-based survey designs may prove superior to substrate-based designs that do not incorporate factors with potentially high predictive value. For this reason we also recommend exploring the use of SDMs for designing ESA-listed rockfish surveys not only in the southern Salish Sea, but across the entire range of the DPSs.

[2] Dan Tonnes, Rockfish Recovery Coordinator, NOAA Fisheries, Seattle, WA.

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Appendix

Appendix A. Detailed survey station data, including fish encounters for selected species groups, for stations sampled in the San Juan Islands in 2010. Additional data are available upon request.

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
E001	2/10/2011	396.7	610.0						sand
E002	2/11/2011	419.1	677.1						sand
E003	4/11/2011	385.3	545.5						cobble
E004	11/16/2010	516.1	987.6						sand/mud
E005	10/19/2010	403.8	470.1						mud
E006	10/19/2010	388.9	601.7	53	45			3	pebble/cobble
E007	10/18/2010	374.1	413.3						pebble/rock
E008	10/18/2010	390.5	460.1						mud
E009	11/16/2010	270.3	320.7						mud
E010	4/15/2011	354.8	518.8						pebble/cobble
E011	4/15/2011	320.6	444.0						mud
E012	11/16/2010	286.4	368.9						pebble
E013	4/14/2011	502.6	817.9						gravel/cobble
E014	10/6/2010	444.7	741.2	1				1	shell/shell hash
E015	10/20/2010	368.9	405.9						mud
E016	11/16/2010	354.9	500.8						cobble
E017	10/7/2010	455.8	790.5	1				3	cobble
E018	10/7/2010	445.9	584.6						cobble
E019	10/20/2010	398.9	468.3						mud
E020	11/16/2010	701.5	1291.9	2				10	bedrock
E021	10/6/2010	437.2	653.3					2	shell/shell hash
E022	10/5/2010	468.7	555.3						mud

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
E023	4/15/2011	243.4	296.0						mud
E024	10/20/2010	362.5	394.7						mud
E025	3/30/2011	342.4	642.7	3	3				cobble
E026	10/6/2010	449.6	510.7					1	shell/shell hash
E027	4/11/2011	141.7	176.6						mud
E029	10/7/2010	371.5	506.3						mud
E030	10/7/2010	330.1	503.7	60	30	21		3	cobble/boulder
E031	10/7/2010	374.0	387.6						pebble/cobble
E032	10/6/2010	398.2	495.0					1	pebble
E033	10/21/2010	391.5	612.4					8	cobble/pebble
E034	9/30/2010	446.5	723.8					3	cobble/pebble
E035	9/30/2010	431.0	714.8						cobble/pebble
E036	9/29/2010	405.5	522.8						mud
E038	10/21/2010	378.3	421.4						mud
E039	10/13/2010	376.2	494.9	1					rock/sand
E040	3/30/2011	380.5	516.3						pebble
E043	10/21/2010	425.6	496.3						mud/sand
E044	10/13/2010	495.3	656.5						sand
E045	10/13/2010	212.0	256.5	3		3			cobble
E046	10/13/2010	341.8	352.7						pebble/sand
E047	10/12/2010	404.1	525.7						mud
E050	11/2/2010	369.0	451.0					1	mud
E051	10/13/2010	334.6	396.7						pebble
E052	10/13/2010	379.8	409.4						pebble/shell/shell hash
E053	10/12/2010	429.0	500.8						mud
E054	10/13/2010	331.5	436.1	174	162			4	gravel/cobble/bedrock
E055	10/13/2010	400.5	622.9					7	cobble

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
E056	10/13/2010	368.0	509.7	4		4			cobble
E057	10/12/2010	492.4	704.2	3	2	1			pebble
E058	10/12/2010	444.7	556.9						pebble/gravel
E059	10/12/2010	421.0	501.2						sand
E060	10/12/2010	419.4	669.2	20	19	1		2	cobble/pebble
E061	10/12/2010	419.2	548.0						mud
W001	11/18/2010	401.4	625.0						pebble
W002	3/17/2011	479.8	870.2	7	1	1		6	bedrock/cobble
W003	3/17/2011	431.8	598.4						pebble/cobble
W004	3/29/2011	437.0	793.1						pebble/mud
W005	4/12/2011	436.5	689.0						pebble
W006	2/9/2011	423.3	650.8						sand/shell hash
W007	3/29/2011	554.5	1068.8					1	pebble/cobble
W008	3/29/2011	416.6	676.9					1	mud
W009	3/29/2011	356.0	563.5						cobble/pebble
W010	3/29/2011	421.3	682.4	64	64			4	mud
W012	4/12/2011	382.9	552.1	1		1			sand
W013	4/12/2011	592.0	966.6					1	cobble/pebble/rock
W014	11/18/2010	404.2	990.5	80	66	2		8	cobble/pebble/rock
W015	2/9/2011	493.3	1138.0						pebble/cobble
W016	2/9/2011	397.2	473.7						shell/shell hash
W017	4/13/2011	461.3	653.7						sand
W018	10/19/2010	435.7	760.4	12		1	1		bedrock
W019	2/10/2011	396.3	799.3	4					boulder/cobble
W020	10/19/2010	377.5	488.0	1			1		sand
W021	2/10/2011	395.5	647.3						sand
W022	2/10/2011	281.2	480.7						mud

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
W023	10/28/2010	480.6	636.9					1	mud
W024	4/12/2011	370.7	489.9						sand
W025	11/17/2010	354.7	509.2						sand
W026	2/17/2011	482.5	670.2						sand
W027	11/4/2010	362.7	431.6					2	sand
W028	11/18/2010	371.1	574.0						sand
W029	3/29/2011	430.3	723.3	2		1		6	sand/mud
W030	2/10/2011	395.0	675.9						sand
W031	11/3/2010	388.6	619.5	95	92		1	6	bedrock
W032	11/3/2010	612.8	1018.8					5	shell/shell hash
W033	10/28/2010	326.3	495.7						shell/shell hash/sand
W034	10/28/2010	415.4	649.6						sand
W035	11/17/2010	348.2	599.7						sand
W036	10/28/2010	520.1	758.0						sand
W037	4/12/2011	367.6	515.0						mud
W038	11/18/2010	492.4	628.2						sand
W039	11/4/2010	410.6	548.1					5	sand/bedrock
W040	1/4/2011	323.7	575.5						cobble
W041	11/3/2010	382.8	635.7	1				1	bedrock
W042	11/17/2010	478.0	771.1						sand
W043	4/12/2011	409.5	662.3	19		16	1	1	sand
W044	12/8/2010	317.7	413.6						sand
W045	12/8/2010	360.1	563.3						mud
W046	2/15/2011	360.6	518.7						shell/shell hash/pebble
W047	1/4/2011	534.7	793.5						pebble
W048	2/17/2011	522.3	745.7						mud
W049	2/17/2011	464.3	669.5						mud

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
W050	11/3/2010	322.2	585.6	140	17	115		4	bedrock
W051	3/3/2011	373.2	777.8	7	2			1	bedrock
W052	10/27/2010	465.6	629.0						shell/shell hash/pebble
W053	4/13/2011	448.9	651.6						sand
W054	11/4/2010	345.6	506.4	3			2		sand/bedrock
W056	3/1/2011	467.8	601.0						sand
W057	3/1/2011	484.4	899.4	383	1	377		4	bedrock
W058	3/15/2011	492.4	985.2	64		63		4	bedrock/gravel
W059	10/27/2010	390.1	607.7						pebble
W060	10/27/2010	380.0	463.3						mud
W061	10/27/2010	462.3	695.9						sand
W062	12/8/2010	310.5	395.0						mud
W063	3/3/2011	431.7	578.3						gravel
W064	2/17/2011	330.3	466.1						sand
W065	11/3/2010	410.2	585.9	22		21			shell/shell hash/cobble
W066	10/28/2010	320.7	477.4						sand/shell/shell hash
W067	10/28/2010	476.1	789.4					2	bedrock
W068	3/31/2011	402.7	715.2					1	mud
W069	2/16/2011	447.3	791.6	1			1	1	bedrock
W071	10/26/2010	527.8	752.0						sand/cobble
W072	10/27/2010	511.1	792.5						mud/shell/shell hash
W073	11/3/2010	377.0	470.5	2	2				sand/bedrock
W074	12/8/2010	597.9	1493.4					6	sand/bedrock
W075	12/8/2010	326.0	571.3	4		1		21	bedrock
W076	11/16/2010	294.8	429.7	24		21		5	sand
W077	2/16/2011	448.1	600.9						cobble/pebble
W078	2/16/2011	380.7	520.8						sand

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
W079	10/27/2010	477.7	712.1						sand
W080	11/15/2010	434.1	568.0						sand
W081	10/20/2010	366.5	423.4						sand
W082	3/14/2011	287.5	532.3						bedrock
W083	3/1/2011	423.2	798.0	3		1	1		bedrock
W084	11/3/2010	480.6	589.9						pebble/cobble
W085	10/26/2010	477.0	757.6					4	sand
W086	11/16/2010	417.7	712.4	10		6		9	bedrock/sand
W087	10/20/2010	429.6	556.2						sand
W088	3/28/2011	389.1	675.8	1			1		cobble
W089	3/28/2011	402.8	502.1						mud/pebble
W090	2/17/2011	382.1	710.2	2		2			bedrock/mud
W091	10/28/2010	357.9	499.7						pebble/shell/shell hash
W092	11/4/2010	365.5	449.9						sand
W093	11/4/2010	573.7	1010.6						sand
W094	3/16/2011	505.4	773.4						sand
W095	11/4/2010	565.4	693.4						shell/shell hash
W096	11/4/2010	507.0	759.0					6	sand
W097	3/16/2011	350.4	605.0					1	pebble/gravel
W098	3/16/2011	292.4	589.4	4		1	3		bedrock
W099	11/2/2010	256.3	335.2					1	sand
W100	1/3/2011	389.4	582.0						sand
W101	1/3/2011	333.7	486.8						pebble
W102	3/16/2011	373.3	851.8	2			2		bedrock/boulder
W103	3/16/2011	389.1	627.4						cobble/pebble
W105	11/2/2010	569.8	979.0					3	sand/mud
W106	2/8/2011	517.3	763.7						sand/shell/shell hash

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
W107	2/8/2011	336.5	581.5						shell/shell hash
W108	3/30/2011	478.7	1119.0	191		168	1	6	bedrock/boulder
W109	11/2/2010	578.5	1205.9					1	mud
W110	2/9/2011	383.3	715.1	1					boulder/cobble
W111	3/30/2011	385.0	566.4	6		3			mud/shell/shell hash
W112	11/2/2010	382.2	549.8						mud
W113	11/2/2010	451.2	1079.5						sand/gravel
W114	2/8/2011	433.0	1082.5	8		4	1	10	bedrock
TOTAL				**1,489**	**506**	**835**	**16**	**187**	

Station ID	Sample date	Transect length (m)	Transect area (m^2)	Total number of rockfish	Number of Puget Sound rockfish	Number of unidentified rockfish	Number of Yelloweye	Number of greenlings	Primary substrate
W107	2/8/2011	336.5	581.5						shell/shell hash
W108	3/30/2011	478.7	1119.0	191		168	1	6	bedrock/boulder
W109	11/2/2010	578.5	1205.9					1	mud
W110	2/9/2011	383.3	715.1	1					boulder/cobble
W111	3/30/2011	385.0	566.4	6		3			mud/shell/shell hash
W112	11/2/2010	382.2	549.8						mud
W113	11/2/2010	451.2	1079.5						sand/gravel
W114	2/8/2011	433.0	1082.5	8		4	1	10	bedrock
TOTAL				**1,489**	**506**	**835**	**16**	**187**