"Pinto Abalone Dive Transect Monitoring in Select Locations in Southeast Alaska"

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Introduction

Pinto abalone (*Haliotis kamtschatkana* Jonas 1845), a marine gastropod, range from Salisbury Sound, Alaska to Point Conception, California (Busch et al. 2014). In Alaska, pinto abalone have long been harvested for cultural and commercial purposes (Mills 1982). Commercial harvest in Southeast Alaska began in 1965 and closed in 1996, following an 89% decline in catch during peak harvest years 1978 - 1981 (Woodby et al. 2000, McDougall et al. 2006). Following the closure of the commercial fishery in Alaska, pinto abalone personal use limits were reduced from 50 per day (20 surrounding Sitka) to 5 per day after 2012 (Hebert 2014). No reporting is required for personal use and the size limit of 89 mm is loosely enforced (Scott Walker personal communication). Similar population declines followed pinto abalone fisheries in British Columbia, where all forms of harvest have been closed since 1990 and in Washington State, where there was no prior commercial harvest, but a recreational fishery, which was closed in 1994 following critical population declines. Despite closures, abalone have not fully recovered to populations pre-harvest (Donnellan and Hebert 2017, Rothaus et al. 2008) and pinto abalone in Washington continue to experience recruitment failure (Bouma 2012).

The reintroduction of sea otters (*Enhydra lutris*), is often highlighted as the major obstacle inhibiting abalone population recovery. Sea otters consume 20% of their body weight daily and are known predators of marine invertebrates (Costa 1982). Following the extirpation of otters in the late 1880's and reintroduction of 402 sea otters to select sites in Southeast Alaska in late 1960's, otter numbers have grown to over 27,000 (Pitcher 1989, Gill 2013). Following sea otter reintroduction, abalone populations took a significant dip and continue to face levels of predation from growing populations (Woodby et al. 2000). Still, Lee et al. (2016) find that sea otter populations in Haida Gwaii facilitate abalone persistence at low densities by indirectly promoting abalone habitat and food (i.e. macrocystis forests). Researchers find that abalone behavior is effected by otter presence. In California, researchers discovered that where otters were not present, black abalone were five times as likely to be outside of refuges than those in sea otter inhabited sites (Raimondi 2013). In nearby British Columbia, sea otter presence had a strong impact on exposed abalone count (Lee et al. 2016). In Sitka Sound, where otters are present, pinto abalone were found to seek refuge in area when refuge was available (White unpublished data). Sea otter predation alone does not explain the lack of abalone population recovery in areas around Ketchikan and North eastern Dixon Entrance, where otters have yet to establish (Scott Walker personal communication).

Continued population decline and perceived threats of sea otter and human take of abalone across their range prompted petitions to shift the definition of pinto abalone from a "Species of Concern" (NOAA 2004) to "Endangered" in the ESA. This follows the species listing in 2006 as "Endangered" by the IUCN List of Endangered species (McDougall et al. 2006). The key issue cited by the IUCN in their 2006 review of the species was a lack of current, comprehensive data on the species, particularly in Alaska (McDougall 2006). To bridge gaps in the species' historically data-poor region of Southeast Alaska, the Sitka Sound Science Center and ADF&G

dive researchers collaborated with the help of an Alaska SeaGrant award (No. R/100-03 "Coastal Resilience in Sitka Sound: Monitoring Pinto Abalone and Kelp Forests in a Changing Climate") to establish and survey 8 long term monitoring sites in Sitka Sound in the summer of 2015. Our Sitka surveys documented increases in pinto abalone juveniles from surveys in 2015 to 2016 along with habitat associations, where juvenile abalone (<50mm) were recorded more often in areas of fewer canopy kelps (Bell et al. 2018). However, these habitat associations were coarse and limited to Sitka Sound, but they provide a starting point for better characterization.

In the summer of 2016, ADF&G researchers established abalone surveys at 10 historical sites in Meares Pass along with 14 new and 1 historical site in Ketchikan (NMFS AKR-15-0824, Donnellan and Hebert 2017). There were concerning differences between abalone length frequencies from these surveys when compared to historical surveys spanning 1975 to 1995. Timed swims at Meares Pass showed an 89% decrease in abalone relative density from 1980 to 2016. Densities were recorded around $0.28/m^2$ and $0.17/m^2$ at sites in Ketchikan and Meares Pass respectively. Rothaus et al. found pinto abalone recruitment failure in Washington at NND below $0.33/m^2$ (2008). However, in British Columbia pinto abalone were recorded to have recruitment success at sites with densities as low as $0.12/m^2$ (Seamone and Boulding 2011). Therefore, it was not surprising that 2016 length frequency data provided evidence of recent recruitment at both survey areas. Size distributions of abalone showed somewhat more consistent recruitment at Gravina, and less consistent recruitment at Meares pass, where size classes 36mm to 40mm were reduced.

Despite concerns of sea otter and human consumption, these recent surveys of pinto abalone in Southeast Alaska and Haida Gwaii have shown an increase in recruitment of measureable (>2mm) young of the year (Dan Curtis personal communication 2018, Donnellan and Hebert 2016, Bell et al. 2018). In 2016 and 2017 we found that sites with the lowest densities 0.22 and 0.24 still had the highest counts of young of the year. Importantly the nearest neighbor distances at these sites were within than 1 meter, some as low as 0.2 meters (Seamone and Boulding 2011). Again, sites with densities as low as $0.12/m^2$ sites in British Columbia experienced recruitment, granted aggregations at these densities may succumb to recruitment failure with even the loss of a few individuals. While recruitment is necessary it is not sufficient to produce a stable population size structure. Notably, researchers recorded very few large abalone (> 100mm) in Meares Pass near Craig and Sitka Sound (Donnellan and Hebert 2017, Bell et al. 2018). Additionally, although there were increased juvenile abalone counts (described as < 50mm here), recorded during surveys in Sitka Sound, 90% of those abalone were below the 89mm harvest limit (Bell et al. 2018).

Abalone surveys in Sitka Sound, Meares Pass, and Ketchikan have been important in understanding abalone aggregations in their northern range, but they are still limited in scope. The deficiency of spatially explicit data on abalone density, size, age structure, and spatial distribution still constrains policy (e.g. the inability to determine ESA status) and informed management on sustainable take. During the summer of 2019 we extended abalone surveys across the species' northernmost range south to the Dixon Entrance and west to Prince of Wales, along with more comprehensive surveys of densities, recruitment, habitat associations, and nearest neighbor distances.

Objectives

Establish additional abalone monitoring surveys with contracted help from ADF&G dive researchers. Expand on the current surveys to better understand pinto abalone population dynamics in Southeast Alaska and to develop the most comprehensive comparison of pinto abalone across their northern-most range to date. Collect data that will amend deficiencies cited in pinto abalone status reviews and, finally, provide managers with a more spatially accurate depiction of these abalone populations. Specifically, we will establish transect surveys in locations in two regions: Prince of Wales and Dixon Entrance, Alaska.

Study Area/Site Selection

Pinto abalone monitoring sites were chosen in areas of Southeast Alaska that lacked statistically robust abalone surveys. The “Prince of Wales” region incorporates site groupings along the outer coast of Dall Island and Cordova Bay. The “Dixon Entrance” region includes sites around Percy Islands, Bee Rocks, and the southern coast of Duke Island (Table 1a/b Appendix A). These two areas have very different patterns of occupancy and current abundance of sea otters, have varying degrees of historic commercial harvest, and continue to experience subsistence and personal-use harvest of 5 abalone ≥ 89 mm per day.

Sites in each region were selected based on logistic constraints – such as safety, likelihood of completion given weather restrictions, number of divers available, and time. Where comprehensive historical data were present, sites were prioritized based on the previous estimates of highest recorded abalone count per minute (CPM). Sites were at least 100m from each other and selected in attempt to represent of the study area geomorphology. Sites in the Dixon Entrance region, where there are no historic surveys, were selected based on recent (2003 and earlier) notes on abalone presence and rough count (K. Hebert Personal Communication 2020).

Methods

During the summer of 2019, we implemented two survey methods to collect current abalone population data in areas of Southeast Alaska with historically high abalone abundance. Timed swims were repeated in areas where there were historic abalone data. Abalone density transects, were established at all timed swim sites in Prince of Wales and at sites in Dixon Entrance, Alaska. Density transects were designed to gather key demographic population metrics (See Appendix B for additional protocol).

Timed Swim Methods

The Alaska Department of Fish and Game (ADF&G) periodically surveyed sites in Southeast Alaska for abalone population size frequencies and “count per minute” from 1977 to 1989 (Larson and Blankenbeckler unpublished data). These historic sites offer unique insight on abalone populations during times of intensive commercial harvest, near the end of the commercial fishery, and before and after sea otter establishment. Some historic sites were recently resurveyed in Meares Pass, Prince of Wales and Gravina Island near Ketchikan during the summer of 2016 to provide a basis for historic comparisons and to enhance our understanding of pinto abalone population dynamics (Donnellan and Hebert 2017). Timed swim “transect” methods used in 2019 and 2016 surveys, were adapted from the historic surveys.

Timed swims were used by ADF&G divers in the past to roughly determine pinto abalone population size frequency and “catch” (i.e. count) per minute. During historic ADF&G surveys, divers swam in no known pattern for 30 minutes, collecting each abalone encountered, and measuring abalone at the surface. 2016 and 2019 surveys involved two divers working together. One diver kept time via stop watch, while the other surveyed for abalone. The abalone diver non-invasively searched sites in a zig-zag pattern, swimming as deep as 11 meters to as shallow as 1 meter. When the abalone diver found an individual they signaled the timing diver to stop the clock, then measured the abalone, recorded its length, depth and exposure to predation (via index). All data were collected underwater as opposed to measuring abalone at the surface. This was done to avoid cutting and fatally injuring an abalone during collection. Once abalone metrics were recorded the timing diver started the clock and the search for abalone continued until the timer reached 30 minutes, when the dive ended (additional methods in Appendix “Methods”). To eliminate survey bias, the same diver recorded abalone during both 2019 and 2016 surveys (Donnellan and Hebert 2017).

Density Transects, Other Field Sampling Methods

Fixed location strip transects provide a uniform sample area for repeated data collection and spatial information on a target species. At each site, we established two 2m x 20m transects run along a depth contour, parallel to the shore. One transect was “shallow” at 3m and one was “deep” at around 6m deep (relative to Mean Lower Low Water). Parallel transects with two depths profiles, placed within depths commonly preferred by abalone (~2-10 meters) provided a larger sample size and greater statistical power when evaluating abalone metrics (Appendix

"Methods"). Similar survey methods are used by pinto abalone researchers in Sitka Sound (Bell et al. 2018) and British Columbia (Lee et al. 2016).

Once transect location was determined, divers would deploy a pelican float to indicate its beginning. The GPS point of the pelican float was then recorded by the dive tender. Divers recorded the heading of their transect, then searched non-invasively (without turning rocks over or removing algae) for all abalone visible within a 1 meter swath. Aided by a PVC meter bar, divers measured abalone size (being careful to not cut abalone tissue), abalone depth, distance from transect tape (cm), distance along transect tape (0.00m), and the exposure index (1 – 3; "1" very hidden and hard to measure, "2" slightly cryptic and "3" completely exposed). They also recorded the algae and substrate they found directly beneath each abalone in two layers (i.e. Crustose Coralline Algae/Boulder). This provided information on size and site specific habitat preference. Divers targeted ≥ 35mm abalone in their searches as a primary goal, however if smaller abalone were seen were documented. Juvenile abalone are often cryptic, therefore divers may have overlooked some smaller individuals and densities of juvenile abalone (defined here as ≥ 35mm) will be considered minimum estimates.

Divers were also responsible for collecting habitat data in three layers, directly under the transect tape every half meter (i.e. Saccharina/Crustose Coralline/Bedrock). One diver collected habitat data every 1.0 meters and the other every 0.5 meters for a total of 20 points per diver and 40 habitat points per swath (i.e. 50% cover of habitat on transect). Divers noted observations of abalone predators along each transect (i.e. octopus, pycnopodia, large sculpins).

The habitat diver, then took 10 habitat association photos with a 0.5 x 0.5m photoplot and camera. Five of these photos had an abalone in the center and five "random" photos were taken at predetermined points along each transect (additional information in Appendix B). Notes on otters seen, their distance away, and their behavior were taken at each sample site prior to dive surveys. After survey stills were taken from photoplot footage and uploaded to ImageJ. A macro layer of crosshairs based on photo pixels was overlaid in ImageJ, then twenty points were surveyed for more specific algal species then were surveyed in situ (Appendix D for complete list). Additional information was collected from each photo including where along the transect each image was taken, number of cracks or crevices, number of kelp stipes, and primary and secondary substrate (based on a Wentworth scale of rock and particle sizes).

Adjustments to transects were made if divers found it difficult to establish a lower transect in areas of abalone habitat. The goal of targeting two survey depths was to isolate differences between deep (below 3m) and shallow areas, where abalone are more accessible to predators and have been found in have higher densities (Zhang 2007).

Statistical Methods

Timed Swim Statistical Methods

Historic size frequency data were taken from compiled Blankenbeckler and Larson data (unpublished) and sorted by site and year (Table 2). We compared 2019 size frequencies at sites to those recorded during historic surveys at 13 sites in locations (Port Bazan, Gooseneck, Cordova) in Prince of Wales, Alaska. Specifically, Kolmogorov–Smirnov (K-S) pairwise tests were used to compare size frequency distributions of timed swim surveys between years.

During historic timed swims, ADF&G divers focused on abalone target sizes of around 50mm and larger, however, if seen, divers would opportunistically record individuals that were < 50mm (Blankenbeckler and Larson 1980). Historically, most individual abalone recorded < 50mm were between 40mm and 50mm. Given this, there was potential concern over current surveyor biases towards all abalone sizes, including abalone < 50mm abalone. To insure accurate comparisons of size frequency and counts, we excluded individuals ≤ 40mm in size from the size frequency comparisons across all sampled years. Further, to test for difference in small individual abalone detection between sampling periods, we ran a K-S test comparison of current size frequencies (all sizes) to all historic size class frequencies (all sizes).

To estimate the potential difference in abalone abundance between periods we used results from the timed swim count surveys (number of abalone counted per minute: CPM). CPM was calculated by dividing the total the number of counted abalone by 30, the number of minutes per timed swim (Table 3). Current swim times were recorded longer than historic timed swims, which is artifact of measuring abalone in situ (as opposed to at the surface, done historically), however overall search time was fixed at 30 minutes (Table 1b). We used a mixed model to assess factors affecting CPM between time periods (historic, current) and size classes (juvenile ≤ 40mm and mature ≥ 41mm and interactions between time period and size class (Table 4). Site ID was set as a random effect. All data were log transformed to meet assumptions of normality and homoscedacity.

Comparison of 2019 size frequency to historic assessments at Prince of Wales Alaska

The use of timed swims at sites in Prince of Wales provided the ability to make comparisons to historic size frequencies and relative estimates of abalone abundance. However, timed swim estimation does not directly translate into density estimates and timed swims are more subject to observer bias. Quantitative estimates of density, location, and size on the other hand, may provide repeatable documentation of density and size as well as level of aggregation, nearest neighbor distances and habitat associations. One metric that was collected for both density assessments (in 2019) and historic CPM assessments was estimation of size structure.

To determine whether size structure differed between the two survey types we used a pairwise K-S test. Because the timed swim approach did not distinguish between shallow and deep we combined shallow and deep transects at sites for comparisons.

Comparison of current size frequencies and densities at Prince of Wales and Dixon Entrance

Recent surveys (Bell et al. 2018, Lee et al. 2016) have found differences in abalone size structure and abundances between shallow and deep transects in Sitka Sound, Alaska (Bell et al. 2018) and British Columbia, CA (Lee et al. 2016). Our density transects collected information on both size structure and density at shallow and deep transect at sites in Prince of Wales and Dixon Entrance. We ran KS tests to determine differences in size structures and a mixed model for density comparisons where density was the response variable, transect depth and location were predictor variables and site was a random effect (Table 5).

Abalone density and size frequency comparisons from S. Southeast Alaska sites surveyed in 2016 (Donnellan and Hebert 2017) and 2019

Donnellan and Hebert (2017) conducted abalone density and timed swim abundance surveys at sites with known, high historic counts of abalone in Meares Pass (Prince of Wales) and Gravina Island (near Ketchikan, Alaska) in 2016. Abalone density estimates were collected in typically 40 1m^2 quadrats that were placed along a transect perpendicular to shore and along a depth gradient. Using these data, we calculated the density of abalone per m^2 and compared these 2016 estimates to our 2019 abalone densities calculated from counts along 2x20m density transects. We also used an ANOVA to compare abalone average size per location for 2016 and 2019 surveys (Table 6) using log transformed data for assumptions of normality for density analyses. In addition, and as above, we compared size frequencies between 2016 and 2019 surveys using K-S tests.

Estimation and comparison of Nearest Neighbor Distances (NND)

We used the measurements of abalone along (x) and away from (y) each 2 x 20 meter transect to calculate Euclidian distances between all mature (≥ 41mm) abalone on a transect. These data were used to calculate nearest neighbor distances (NND) for each abalone and the proportion of abalone on a transect that were within 1 meter of another abalone. One meter has been used as a critical distance because based on hydrodynamic models that is the distance beyond which fertilization of broadcast spawned eggs and sperm is unlikely to occur (Denny and Shibata, 1989). Only mature abalone (≥ 41mm) were used in these analysis, as the focus of NND estimation is to assess a likelihood of successful reproduction from broadcast spawning. This attribute of population viability is best modeled by NND rather than density because, as noted, mature abalone must be within critical distances in order achieve fertilization success. These surveys were not designed to document or predict recruitment success, which is often confused with reproductive success because of the prevailing idea that most dispersal of abalone eggs and larvae is relatively local (Mcshane et al. 1988). For recruitment success, it is likely that density may be a better predictor than NND, in part because adult mucus appears to induce settlement of larvae (Slattery 1992) and because adult abalone density has been linked to maintenance of suitable biogenic surfaces for conspecific larval settlement (VanBlaricom et al. 2009).

In theory, increased density could be positively related to NND, where areas with higher densities are more likely to have close mature abalone. However, this assumes habitat quality is uniform across space. If habitat is not uniform, then density may not be related to NND across space. In example, consider a 10 x 10 m plot with 50 abalone. If habitat was of uniform quality, then individuals might be distributed in a uniform pattern, outside of periods of reproductive aggregation. Here the density would be exactly 0.5 abalone/m^2, but the neighbor distance could range from an average of 2 meters. By contrast if all high-quality habitat was found in a single 1 x 1 meter patch, the density of the 100 square meter plot would still be 0.5 abalone/m^2, but the average NND might be close to 0 meters (all touching at least one other individual).

We compared the proportion of individuals within 1m of another in each location to the mean abalone densities at those locations. Quantitative nearest neighbor distances were not recorded in 2016 surveys, however we did have qualitative estimates and were able to use these to rank all sites with respect to NND. We also ranked locations by density, which allowed us the ability to assess the relationship between NND and density, using ranks, for 7 locations (Table 10). Locations with the highest mean density and locations with the highest proportions of abalone within 1 meter of another abalone were ranked first (i.e. 1) and rank values ascended in order. These data were used in a linear regression with rank NND as the response and rank density as the predictor variables.

Finally, we assessed the relationship between recruitment (here defined as the number of individuals ≤ 40mm) and both NND (continuous) and raw density (continuous) using an ANCOVA approach with region (Prince of Wales or Dixon Entrance) as a categorical variable (Table 8).

Abalone use of substrate, biogenic habitat and refuge

Two methods were used to distinguish the use of available habitat by abalone along transects. First, using point contact methods, we recorded the precise biogenic habitat (mainly algae) and substrate types (based on a Wentworth scale of rock and particle sizes) under each abalone and, for comparison under every 0.5 meters of each transect. Pinto abalone can be a particularly motile study species, we therefore aimed to collect broader information than point contact could provide on substrate and algal assemblages with the inclusion of 0.5m x 0.5m photoplots. These photoplots allowed assessment of the "neighborhood" characteristics of both substrate and biogenic habitat. Here, photos were taken at random points assigned along a transect, and plots directly centered around abalone.

In addition to the evaluation of abalone association with physical substrate and biogenic habitat, we assessed potential associations with refuge (i.e. cracks or crevices) – which we refer to as exposure. Areas of refuge (primarily from predators) were defined according to the following exposure index: category 1: good refuge, category 2: moderate refuge, and category 3: poor refuge areas.

These attributes, substrate, biogenic habitat, and exposure along with region and observation type were used as predictor variables in log-linear models with counts as the response variable. Observation type included three levels: mature (≥41mm), juveniles (≤ 40mm) or general habitat. Inclusion of observation type allowed interaction terms to be built that tested hypotheses of interest. For example, the interaction between Observation Type and Substrate allowed us to test the hypothesis that use of substrate differed between (1) abalone and what was available and (2) adult and juvenile abalone. Note that main effects in the model are essentially dummy variables (Tables 11 – 14).

To make comparisons with other ranked metrics (i.e. abalone density rank, NND rank, human use and otter presence – see below) we ranked locations by exposure. Locations were ranked from 1-7 lowest values, 1 being those with the highest amount of refuge.

Effect of otter presence and human access on abalone populations

The data from locations surveyed in this project combined with the 2016 surveys, described above provided the opportunity to test for possible effects of human and otter effects on abalone populations. Sea otter occupancy and estimates of sea otter population size have not been done since 2010 in Southeast Alaska (USFWS 2014). However, sea otter density in areas of southern Southeast Alaska have been modeled, albeit with large confidence intervals (Tinker et al. 2019) indicating considerable uncertainty with respect to true population size. Hence, we focused efforts towards categorizing otter presence or absence along with general occupation time using available USFWS (2014) information, sightings during abalone surveys, and personal communication with those regularly working in the areas (W. Raymond, S. Walker, K. Hebert, personal communication). Using, this information we ranked all 7 locations as to probability of otter effects with 1 being the highest probability and 7 being the lowest.

In addition, we categorized sites by human access, again using multiple predictors of human effects such as distance of a location from communities, areas of known harvest and local human population. Locations considered to have the highest probability of human impacts were ranked from 1 (highest impact) to 7 (lowest). All ranked attributes are shown in Table 10.

Results

Timed Swim Surveys

Fourteen historic sites from Prince of Wales were resurveyed by timed swim assessment in 2019. Ten of those sites exhibited a significant difference in abalone size structure between time periods. Abalone sizes at these sites shifted from predominantly larger size classes historically, to smaller size classes in more recent surveys (Table 2, Appendix C). Two sites in Cordova Bay (site 42 and site 51) show significant shifts in the opposite direction. However, both comparisons should be viewed with caution due to very small samples sizes in current time periods. In addition, two sites (4 and 83) showed no significant change in size structure between years.

A total of 182 abalone were ≤ 40mm and therefore excluded from timed swim size frequency analyses. These individuals were excluded based on concerns over differences in detection probability for smaller individuals during historic surveys. 116 individuals were excluded from all historic surveys and 66 from 2019 surveys at the same sites. These numbers are somewhat misleading because overall numbers of abalone were much higher in historic sampling than in the 2019 assessment (Table 3). KS pair-wise tests showed significant differences in size structure between historic and current locations when individuals ≤ 40mm were included or excluded. Overall there were very few small abalone and many more large (> 41mm) and legal sized (≥89mm) abalone in historic surveys. 2019 timed swim surveys showed most sites with primarily smaller size classes. A single legally-sized abalone was recorded during 2019 surveys (site 41, 107mm, Appendix C). In addition, the median size documented by timed swims was larger historically than for the 2019 timed swims (Figure 1).

In the assessment of CPM as a function of time period, location, and size class, location was not significant by itself or as part of any interaction with time period or size class suggesting little spatial variation in abundance. However, there was a very significant interaction between time period and size class (p-value: <0.0003, Table 4), indicating that relationship between time period (current vs historic) and abalone abundance varied by size class (Figure 3): juvenile counts were very low in both historic and current assessments, whereas adult were much more common historically (Table 3). We note again that CPM data were log transformed to meet normality assumptions during these analyses.

Comparison of current size frequency from density transects to those from timed swim assessments at Prince of Wales

There was no difference between the size frequency distributions of abalone sizes recorded during timed swims and abalone sizes recorded on established density transects at the same sites in Prince of Wales in 2019 (KS test p-value 0.4300, Figure 4).

Comparison of 2019 densities and at Prince of Wales and Dixon Entrance

There were significant differences between Prince of Wales and Dixon Entrance regional surveys in overall abalone density (p-value < 0.0001, Figure 5). Results also indicated that there were no significant differences in densities based on depth (i.e. shallow, deep, Figure 6), or for the interaction between depth and region (Table 5).

Abalone densities comparisons at locations in S. Southeast Alaska sampled in 2016 and 2019

Locations across southern Southeast Alaska (surveyed in both 2016 and 2019) showed marked differences in abalone density and average size (density ANOVA p-value: < 0.0001, DF: 6,33, F: 6.7068; average size ANOVA p-value: < 0.0001, DF: 6, 977, F: 9.8727). Port Bazan had the lowest overall density followed by Gooseneck and Meares Pass (all within Prince of Wales Alaska). In contrast Bee Rock sites (n = 2), in the Dixon Entrance region, had the highest overall density (Table 6, Figure 7).

Comparison of current (2016 and 2019) size frequencies between S. Southeast locations

Locations surveyed within Prince of Wales region (i.e. Meares Pass, Port Bazan, and Gooseneck) did not show a significant shift in size frequencies whereas locations within Dixon Entrance showed significantly different size frequency shifts, where Bee Rocks had higher proportions of smaller abalone. Port Bazan and Gooseneck locations did not record significantly different size structures during 2019 surveys. Gravina Island showed increased counts of smaller size classes in all comparisons, except against Meares Pass (Table 7, Figure 8).

Nearest Neighbor Distance and recruitment (≤ 40mm) during 2019 surveys

As described above, abalone densities in Prince of Wales were low at all locations, still abalone recruitment was still noted at locations in the region (defined here as recorded counts of abalone ≤ 40mm). In our assessment 28.6 % of mature abalone (≥ 41mm) recorded in Prince of Wales and 91.6% of mature abalone in Dixon Entrance were less than 1 meter apart (Figure 9).

There was a significant and positive asymptotic relationship between density of adults and NND (% of individuals within 1 meter of another individual), demonstrating the predicted relationship between density and NND. For this analysis, to increase sample size and ensure analyses were robust, we included unpublished data in our recruitment and nearest neighbor analyses from Sitka Sound where abalone are much more abundant (Figure 10, Table 8). The assessment of the possible relationship between juvenile abalone numbers and NND and/or adult density provided interesting results. Region was significant with Sitka Sound having the highest juvenile counts, as expected. In addition, both density of adults and NND were strongly related to recruit numbers – but in opposing ways. Density was positively related to recruit numbers, while the proportion of adults within 1 meter of another adult (NND) was negatively related to number of recruits (Table 9).

Abalone Density and Nearest Neighbor relationship

In Southeast Alaska, nearest neighbor distance (rank) was positively and linearly related to abalone density (rank) at the location scale (Table 10, Figure 11). Recall that at the transect scale (Figure 10), this relationship was positively asymptotic. While both Figures 10 and 11 show positive relationships, the difference in the shape of the relationships may indicate differences in processes operating at different spatial scales dynamics.

Habitat Effect on Nearest Neighbor Distance

We found strong relationships between nearest neighbor distance and quality of refuge habitat at the location scale (based on exposure, Figure 12). As above, these comparisons were made based on rankings for these attributes for all surveyed locations in Southeast Alaska (Table 10). The key result is seemingly counter intuitive. However, locations with the highest proportion of good habitat had the lowest nearest neighbor distance. As described in the methods, section this is likely due to clustering of individuals in locations with mostly poor habitat and spacing of individual in locations with mostly good habitat.

Abalone use of available substrate and refuge

We tested for the relationship between abalone presence and the predictor variables: Region, Exposure, Substrate and abalone size (≤ 40mm, ≥ 41mm) and the interaction between variables. All interactions were significant (Table 11, Figure 13). The observed distribution of juvenile and adult abalone with respect to substrate is shown in Figure 13 along with the expected distribution (black bar ‘Habitat’) under the null hypothesis. This figure shows how the pattern of association differs for juveniles verses adults and how both differ from expected, available substrate in each region. Bedrock was the most common substrate type, at sites in Dixon Entrance and Prince of Wales. Boulders were the second most available substrate type in Prince of Wales followed by cobble, which was second most common in Dixon Entrance. There was a larger diversity of substrate type in Dixon Entrance. In these two regions, juvenile (≤ 40mm) and mature (≥ 41mm) abalone were found disproportionally on some substrates like bedrock. Mature abalone were next most often in boulder and juvenile next most often found in cobble (Figure 13).

A similar relationship was found with respect to exposure (Figure 16). Here vastly disproportionate numbers of abalone (both juvenile and adults) were found in good refuge habitat relative to the expected number based on the availability of good habitat. The distribution of refuge types (good, moderate, and poor) between regions was significantly different (Table 14). With respect to region, Dixon Entrance was characterized as having mainly poor habitat (very exposed to predation) and the Prince of Wales locations were characterized as having primarily moderate quality habitat, with lots of understory kelp acting as potential refuge (Figure 16).

Abalone use of biogenic habitat and refuge

We tested for the relationship between abalone presence and the predictor variables: Region, Exposure, Biogenic habitat and abalone size ($\leq$ 40mm, $\geq$ 41mm) and the interaction between variables (Table 12, Figure 14). All interactions were significant. In Prince of Wales and Dixon Entrance, abalone were disproportionality found on coralline crust, bare rock, non-coralline crust and incrusting invertebrates and overall less often found on *Laminaria* spp. and *Agarum* spp. There were fewer records of *Constantinea* spp. as a biogenic habitat, however abalone were found in similar amounts to the proportion of its cover. Juvenile abalone were more often than adult abalone to be found on bare rock, and were disproportionality on *Constantinea* spp where it was available (Figure 14).

Assessment at the neighborhood scale in Photoplots (Table 13, Figure 15) provided similar results to point contact methods. Overall photoplots determined pinto abalone used different biogenic habitats than that expected based on random sampling. Abalone were disproportionally found on non-coralline crust, incrusting invertebrates and *Laminaria*, but included a disproportionate association with *Macrocystis*, and detritus or dead material. (See Appendix B for the specific species lumped together for analyses).

Sea Otter and Human use effects on abalone densities

There was a significant inverse correlation between abalone density and respective sea otter occupation at locations in Southeast Alaska (Table 10, Figure 17) We found no relationship between human use and abalone densities (using rankings shown in Table 10)

Discussion

2019 surveys provided quantitative and repeatable methods for robust and essential metrics to abalone management at three of the four areas specified by NMFS, with an objective to establish and survey density transects. These newly established transects allow for determination of abalone size structure, density, recent recruitment (recorded as any abalone < 35mm) and certain physical factors (e.g. habitat quality) that may influence local abalone populations. When comparing these to available historic data or current data from different locations, we gained additional insight into the abalone population trajectory in Southeast Alaska.

A total of 8 density transects were established in the Prince of Wales region, all at sites with historical survey. Four of these sites were in Port Bazan and four in Gooseneck. There had been no quantitative historic sampling of abalone populations in the Dixon Entrance region, therefore we used notes of abalone presence or high density, taken by Alaska Department of Fish and Game divers during their urchin surveys in the area, to determine sites of historic abalone presence. In the Dixon Entrance region, we established five sites at Duke Island, two around

Percy Islands and two around Bee Rocks for a total of 9 sites. These regions have experienced very different levels of human access and sea otter occupation time (Tinker et al. 2019); these factors may have reduced abalone density and populations in the past (Woodby et al. 2000, Hebert 2014). For example, recent comparisons, made by M. Donnellan and K. Hebert (2017) report vastly different size structures and densities between Meares Pass, where otters are present and Gravina Island where otters are absent. We documented similar patterns during the 2019 surveys.

Two transects, one shallow and one deep, were surveyed in 2016 surveys at Meares Pass and Gravina Island (Donnellan and Hebert 2017). These parallel transects captured a greater number abalone for analyses and are a method used successfully in Sitka, British Columbia, and Washington (Rothaus et al. 2008, Abalone recovery team 2002). Donnellan and Hebert (2017) noted that most abalone were recorded within 2 – 5 meters depth. Hence, most 2019 transects were established within these depths. Interestingly, the 2019 surveys show no significant difference between shallow and deep transect size structure or density across locations and regions (Figure 6). Therefore, if future management of the species solely requires density and size frequency information at sites (i.e. management in CDFW 2005), and if time is limited, we suggest researchers survey only shallow transect at sites. However, if researchers are seeking to understand differences in abalone exposure, available habitat, and aggregation between depths, we suggest surveying both transects.

Differences between Prince of Wales and Dixon Entrance abalone populations were clear. An average of 1.8 abalone were recorded per transect in POW, whereas an average of 20.3 abalone were counted in each transect in the Dixon Entrance region. There were more large abalone in Dixon Entrance than in POW, but very few abalone above the legal harvest limit of 89 mm (29 in Dixon Entrance, 1 in POW) (Figure 5, Appendix D).

Prince of Wales density transects were established in areas sporadically surveyed from 1977 – 1986 via timed swim. We re-surveyed these using a timed swim method, identical to that used in 1977-1986, which provided important historical comparisons for a species with few baseline data. An additional five timed swim sites were resurveyed opportunistically during other 2019 abalone surveys within the Prince of Wales region, in Cordova Bay. The use of historic and current time swims allowed comparison of sizes and counts over time: abalone average sizes were smaller and abalone counts were lower during more recent surveys (Table 3).

Pairwise tests indicate that larger size classes were most common in historic site surveys and there was typically a decrease in abalone size at sites over time (Table 2, Appendix C). While, most sites were surveyed two times historically, during 1980 or 1981 and 1986, some were surveyed only once and one site (54) was surveyed 4 times, which allows more detailed speculation of cause and effect. Site 54 showed no difference between abalone size structure recorded in 1977, when the commercial harvest was underway, to that in 1979, the year commercial harvest peaked. However, and notably, far fewer abalone were recorded at the site in 1979 than in 1977. There was a significant shift to smaller size classes during 1981 surveys that may correspond to increased abalone harvest from the commercial fishery (Woodby et al. 2000). The size structure of abalone shifted towards larger sizes the following survey year (1986), which is somewhat confusing, but may be an artifact of commercial take limits assigned by

ADF&G in 1981 (ADF&G unpublished data). At one site in Cordova Bay (54) did not recover and size classes shifted yet again towards even smaller size classes from 1986 to 2019 (and fewer abalone were recorded, Appendix C), a decline that cannot be attributed to otter establishment as they did not likely show up near the site until 2002 or 2003 (USFWS 2014). However, these conjectures are based on snapshots in time of populations and are likely not wholly representative of the ongoing population dynamics in the region. Site 42 was one that did not follow trends. There were significantly more abalone in 2019 surveys (n = 39) than in its initial survey in 1981 (n = 1). This site was chosen due to its accessibility, while on a research cruise and not based on site selection priorities listed in the initial proposal for this research. This is only one site, but it provides motivation to examine more low density historic sites that were otherwise excluded from 2019 surveys. There is likely more spatially-specific variance in abalone population growth and size structure in Southeast Alaska.

Count per minute (CPM) comparisons showed no difference between juvenile abalone (≤41mm) CPM historically and 2019 juvenile CPM. However, we did find a large CPM difference for adults, with current estimates being less than 10% of previous counts (Table 3). We were concerned that current surveys might be less effective in assessing juveniles due to adult search image, therefore results, given this potential bias may indicate that adults are currently at population levels much lower than 10 percent of historic levels, while juveniles might be at levels greater than historic (Figure 3).

Donnellan and Hebert (2017) noted that adult abalone densities recorded in Gravina and Meares Pass locations were below the $0.2/m^2$ threshold cited for population collapse by recovery plans in California (CDFW 2005). Our 2019 showed abalone densities at Prince of Wales to be far below that threshold ($0.05/ m^2$), which is very concerning, however we note that even in these sites of extremely low adult density there was still some recorded juvenile abalone. Conversely, sites in Dixon Entrance had a mean adult density of $0.73/m^2$ and are not projected to be vulnerable to collapse based on CDFW threshold density (Appendix D).

It is important to point out that while density may be a better predictor of recruitment of abalone, some estimate of nearest neighbor distance (NND) is almost certainly a better predictor of successful reproduction and local supply of competent larvae to a region.

Increasing density was associated with increased proportion of individuals within a meter of another abalone at both the transect (Figure 10) and location (Figure 11) scale. Additionally, increasing adult densities corresponded strongly with increased juvenile densities, yet this was not the case for NND. Density of juveniles was negatively related to the proportion of individuals within a meter of another abalone (coefficient = -24.68, Table 9).

Locations where abalone populations had highest densities, particularly locations in the Dixon Entrance and Ketchikan regions (Figure 11) also had lower amounts of refuge, and higher amounts of poor habitat (Figure 12). These locations in Dixon Entrance and Ketchikan (Duke Island, Bee Rocks, Percy Islands, Gravina Island) also had the most abalone within one 1 meter of another adult. In these locations refuge is rare and most abalone, like in other locations, are disproportionately found in the refuges(Figure 16). This decreases the proportion of individuals within a meter of another abalone. By contrast where refuge areas are most common abalone likely disperse leading to a lower proportion of individuals within a meter of another abalone.

Abalone substrate use had clear patterns of use by size class, where juvenile abalone were found more often on bedrock, which also provided the least amount of refuge (Figure 13). This is reflected in Figure 10., where juvenile abalone are disproportionally found in poor refuge habitat, and where they may still find refuge with their small size and cryptic coloration. The incorporation of additional, site specific data on abalone substrate use may prove useful for abalone outplant plans or the development of additional monitoring sites.

These surveys provided insight on pinto abalone habitat associations through the lens of two survey types. Point contact surveys provided coarse baseline information on specific abalone locations relative to what biogenic habitat was available at a given site. By contrast, photoplots offered a finer taxonomic approach to sampling biogenic composition, at a larger spatial scale or neighborhood of the sampled abalone relative to available habitat. Photoplots were initially implemented because of their finer-scale focus and too picked up pinto abalone strongest associations (i.e. crustose coralline algae, non-coralline crust, bare rock; Figure 15). However, photoplots also allowed assessment of specific species associations including non-coralline crust types and pinto abalone strong association with detritus, more specifically drift kelp, which may have implications for abalone refuge use as abalone may, leave refuge to seek drift kelp more often in less dense areas of kelp, and kelp drift are few (Catton et al. 2016). An additional and important benefit of photoplots is their archival value; the photos are always available for resurvey, or revisit to determine additional metrics that may be of use for other investigations.

Pinto abalone across Southeast Alaska experience diverse and different effects on their populations. Sea otter and human effect are difficult, if not impossible, to tease apart from other factors affecting populations and it is important to note that we made large assumptions concerning both. Finer spatial scale quantitative information is critical to make informed management decisions regarding pinto abalone. However, there are general patterns that can be discussed. As a very general example, in areas like Prince of Wales, there are more otters and humans impacting populations than in other locations and this is associated with there being very few abalone and almost no large individuals (> 70mm).

Otter presence may also have some impact on abalone small scale distribution. In areas with otters, abalone are disproportionately found in refuge habitat and where otters have not established, abalone are more commonly found out of available refuge habitat. This type of pattern has been found in other species of abalone (Raimondi et al. 2015), and it is not known if this is a behavioral response or simply the result of predation.

Our ranking for human access effect has much less support than that for otter effect. This is because of the lack of information as to per area human take. Our ranking instead is based, as noted earlier, by a location’s proximity to towns, known access, collection accounts and expert opinion instead of actual reports for abalone harvest, which are not mandated in Alaska. In addition, the validity of these metrics decreases if used to assess historic take. Hence, our assessment cannot incorporate temporal human use or historic access as harvest differed significantly throughout locations, particularly during commercial harvest.

Conclusion

The pinto abalone surveys carried out in 2019, including some at done at sites in Southeast Alaska that had historic surveys, provided information where most basic data on populations (size frequencies and densities) were limited. Timed swim resurveys of historic sites in Prince of Wales highlighted an overall reduction in abalone density and decreased or no frequencies of large and legal size classes. Sites with the most historic surveys provided an idea of the progression of size frequency shifts. Interestingly, not all sites showed a shift towards smaller size classes. Continued, more robust surveys of these areas would better capture population dynamics. Comparisons of current or very recent surveys (2019, 2016) showed clear differences in densities at all spatial scales (regions, locations and sites). Locations in the Prince of Wales region had worrying densities; still juvenile abalone (≤ 40mm) persisted and Dixon Entrance had densities nearly four times higher than the critical threshold for collapse as determined by the California Abalone Recovery and Management Plan (CDFW 2005). Overall density was a better indicator than NND at these locations, however abalone densities and refuge use are likely influenced by larger ecological factors (i.e. environmental drivers, direct and indirect species interactions), Unfortunately, mainly due to the paucity of spatial and temporal data the effects of sea otter and human take can only be roughly estimated. Given the sensitivity of such data, a different approach could be designed around abalone surveys focusing on strategic temporal and spatial coverage in southeast Alaska. Such a program could reduce the need for estimation of the effects of otters and human take.

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Tables and Figures

Table 1a: Summary of 2019 abalone transect surveys by region, location, site, date and area surveyed (m^2). All dives were done by ADF&G dive researchers, who surveyed for abalone metrics including; size, neighbor distance, exposure (refuge use), and habitat associations and habitat metrics including: available substrate, biogenic habitat and exposure using point contact and photoplot methods.

Region	Location	Site Label	Date	Number of Transects	Area Surveyed m^2
Dixon Entrance	Bee Rocks	17	8/8/19	2	40
Dixon Entrance	Bee Rocks	23	8/8/19	2	31.2
Dixon Entrance	Duke	6	8/7/19	2	40
Dixon Entrance	Duke	15	8/7/19	2	40
Dixon Entrance	Duke	19	8/7/19	2	34
Dixon Entrance	Duke	35	8/7/19	2	40
Dixon Entrance	Duke	112	8/7/19	2	40
Dixon Entrance	Percy Islands	12	8/8/19	2	40
Dixon Entrance	Percy Islands	18	8/8/19	2	40
Prince of Wales	Gooseneck	95	7/13/19	2	40
Prince of Wales	Gooseneck	96	7/13/19	2	40
Prince of Wales	Gooseneck	97	7/13/19	2	40
Prince of Wales	Gooseneck	99	7/13/19	2	40
Prince of Wales	Port Bazan	2	7/12/19	2	40
Prince of Wales	Port Bazan	3	7/12/19	2	40
Prince of Wales	Port Bazan	4	7/12/19	2	40
Prince of Wales	Port Bazan	6	7/12/19	2	40

Table 1b. Overview of 2019 timed swims surveys by location, site, and date. All timed swims were done by the same diver, at historically surveyed sites in Prince of Wales. Abalone search time was fixed at 30 minutes per site. However, roving time varied as a function of in situ abalone measurement (i.e. a timing diver would stop the search "clock," while the survey diver measured abalone). This method attempts to account for historic methods, where abalone were collected during 30 minute timed swims and measured at the surface (Blankenbeckler and Larson, unpublished data, described in Donnellan and Hebert 2017). Note there are no corresponding transect surveys at site 100, due to poor counts and visibility and no timed swim survey at transect survey site 99 due to time constraints.

Location	Site	Date	Roving Time (min)	Roving Depth Range (ft)
Port Bazan	2	7/12/19	35	15 - 32
Port Bazan	3	7/12/19	33	3 - 32
Port Bazan	4	7/12/19	41	17 - 32
Port Bazan	5	7/12/19	31	9 - 42
Port Bazan	6	7/12/19	33	14 - 30
Cordova Bay	42	8/4/19	54	4 - 20
Cordova Bay	51	8/3/19	36	13 - 26
Cordova Bay	54	8/1/19	41	7 - 21
Cordova Bay	83	8/3/19	35	12 - 19
Cordova Bay	85	8/2/19	43	6 - 24
Gooseneck	95	7/13/19	42	25 - 33
Gooseneck	96	7/13/19	37	10 - 32
Gooseneck	97	7/13/19	40	10 - 23
Gooseneck	100	7/13/19	40	6 - 21

Table 2. Current v. historic timed swim size frequency comparison in Prince of Wales by site, location, and years surveyed. Specific focus on significant size frequency shifts from historically large size classes to smaller size classes using the non-parametric Kolmogorov–Smirnov (KS) test between pairs of years at each site (see Appendix C for all tests and size frequency bar charts).

Site ID	Location	Years Surveyed	Significant shift towards smaller size classes in more recent year
2	Port Bazan	1981, 1986, 2019	**Yes**
3	Port Bazan	1981, 1986, 2019	**Yes**
4	Port Bazan	1981, 1986, 2019	No
5	Port Bazan	1981, 1986, 2019	**Yes**
6	Port Bazan	1981, 1986, 2019	**Yes:** 1981 - 1986; 1981 - 2019 No: 1986 - 2019
42	Cordova Bay	1981, 2019	Size shift towards larger size classes
51	Cordova Bay	1981, 2019	Size shift towards larger size classes
54	Cordova Bay	1977, 1979, 1981, 1986, 2019	No 1977 - 1979 Size shift towards larger size classes: 1981- 1986 **Yes:** all other years
83	Cordova Bay	1979, 1983, 2019	No: 1979 - 2019, 1980 - 2019 **Yes:** 1970 - 1980
85	Cordova Bay	1979, 1980, 2019	**Yes**
95	Gooseneck	1980, 1986, 2019	No: 1986 - 2019 **Yes:** all other years
96	Gooseneck	1980, 1986, 2019	**Yes**
97	Gooseneck	1980, 1986, 2019	**Yes**
100	Gooseneck	1980, 2019	**Yes**

Table 3. Average abalone count, count per minute, and size (mm) in each location of historic timed swims (years combined) compared to current (2019) timed swims.

Location	Current Average CPM	Historic Average CPM	Current Average Count	Historic Average Count	Current Average Size	Historic Average Size
Gooseneck	0.4	3.4	12	354	44.4	78.77
Port Bazan	0.5734	4.46	17.2	203	42.52	74.74
Cordova Bay	0.56	4.18	16.8	351	53	87.14

Table 4. Analysis of variance of Abalone Count per Minute for current (2019) and historic (combined) timed swims. Site within location was a fixed effect and ≤ 40mm abalone were removed from analyses. Analysis on log transformed data to meet assumptions of normality.

Source	**Nparm**	**DFNum**	**DF Den**	**F Ratio**	**Prob > F**
Location	2	2	13.6	3.3357612	0.0663
Size Class	1	1	47.7	37.6721	< 0.0001*
Time Period	1	1	51.6	18.475664	< 0.0001*
Location*Size Class	2	2	47.7	0.8093896	0.4511
Time Period*Location	2	2	51.6	0.4526995	0.6384
Size Class*Time Period	1	1	48.0	15.383607	< 0.0003*
Size Class*Time Period* Location	2	2	48.0	0.9895142	0.3792

Table 5. A mixed model testing the difference between abalone densities as a function of depth and region.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Region	1.39142	1.39142	1	18.2630	0.0007*
Shallow/Deep	0.01898	0.01898	1	0.1734	0.6830
Shallow/Deep*Region	0.00283	0.00283	1	0.0258	0.8744

Table 6. Overview of Southern Southeast Alaska abalone transect surveys done in the summers of 2016 and 2019, including abalone count and average size (mm). Average size compared using ANOVA (p-value: < 0.0001, DF: 6, 977, F: 9.8727). Average density compared using ANOVA (p-value: < 0.0001, DF: 6,33, F: 6.7068)

Survey Year	Region	Location	Number of Sites	Abalone Count	Average Size (mm)
2016	Prince of Wales	Meares Pass	10	129	42
2016	Ketchikan	Gravina	15	461	49
2019	Prince of Wales	Port Bazan	4	9	51
2019	Prince of Wales	Gooseneck	4	19	51
2019	Dixon Entrance	Bee Rocks	2	115	57
2019	Dixon Entrance	Duke	5	183	55
2019	Dixon Entrance	Percy Islands	2	67	56

Table 7. Kolmogorov Smirnov (K-S) Tests comparing current abalone size frequency across locations surveyed in 2016 and 2019 in Southern Southeast Alaska. Meares Pass, Gooseneck, and Port Bazan locations are in the Prince of Wales region, Bee Rocks, Duke Island, and Percy Islands are in the Dixon Entrance region, and Gravina Island is in the Ketchikan region.

Location 1 (F1)	Location 2 (F2)	Count Location 1	Count Location 2	EDF Location 1	EDF Location 2	D=max |F1-F2|	Prob > D
Meares Pass	Port Bazan	19	9	0.566	0.333	0.2325581	0.7531
Meares Pass	Gooseneck	129	19	0.38	0.158	0.2219502	0.3883
Meares Pass	Bee Rocks	129	115	0.457	0.457	0.3964948	<.0001*
Meares Pass	Percy Islands	129	67	0.643	0.254	0.3896795	<.0001*
Meares Pass	Duke Island	129	183	0.457	0.038	0.419113	<.0001*
Meares Pass	Gravina	129	461	0.38	0.182	0.1976324	0.0008*
Port Bazan	Gooseneck	9	19	0.778	0.947	0.1695906	0.9947
Port Bazan	Bee Rocks	9	115	0.333	0.061	0.2724638	0.5652
Port Bazan	Percy Islands	9	67	0.667	0.254	0.4129353	0.1336
Port Bazan	Duke Island	9	183	0.333	0.038	0.295082	0.4439
Port Bazan	Gravina	9	461	0.333	0.607	0.2740419	0.5212
Gooseneck	Bee Rocks	19	115	0.368	0.13	0.2379863	0.3142
Gooseneck	Percy Islands	19	67	0.579	0.254	0.325216	0.0873
Gooseneck	Duke Island	19	183	0.421	0.131	0.2899051	0.1108
Gooseneck	Gravina	19	461	0.474	0.681	0.2074438	0.4121
Bee Rocks	Percy Islands	115	67	0.557	0.254	0.3027904	0.0009*
Bee Rocks	Duke Island	115	183	0.426	0.268	0.1583274	0.058
Bee Rocks	Gravina	115	461	0.296	0.549	0.2531548	<.0001*
Duke Island	Gravina	183	461	0.202	0.549	0.3466211	<.0001*
Percy Island	Duke Island	67	183	0.254	0.443	0.1888916	0.0604
Percy Island	Gravina	67	461	0.254	0.696	0.442581	<.0001*

Table 8. Results of non-linear regression (Michaelis Menten asymptotic function) for the relationship between adult abalone density and nearest neighbor distances in three regions: Prince of Wales, Dixon Entrance, and Sitka (included for robust analyses).

Parameter	Estimate	Std Error	Wald ChiSquare	Prob > ChiSquare	Lower 95%	Upper 95%
Max Reaction Rate	0.9958942	0.0644276	238.93662	<.0001*	0.8696185	1.12217
Inverse Affinity	0.993093	0.0407414	5.9416565	0.0148*	0.0194576	0.1791609
Model	**AICc**	**BIC**	**SSE**	**MSE**	**RMSE**	**R-Square**
Michealis Mentin	15.658693	20.726842	3.3979866	0.0738693	0.271789	0.1743552

Table 9. ANCOVA results for assessment of relationship between juvenile abalone (individuals <41mm) and the predictor variables adult density, percent of individuals within 1m of another individual, and region.

Parameter Estimates					
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob > |t|**	**VIF**
Intercept	19.930492	4.372681	4.56	<.0001*	.
Proportion within 1 meter of another abalone (> 40mm)	-24.68757	6.110314	-4.04	0.0003*	1.6723066
Mean (Abalone Density)	2.9816814	0.916764	3.25	0.0024*	1.2945784
Region (Dixon Entrance)	3.2742787	2.781412	1.18	0.2466	4.0661661
Region (Prince of Wales)	-13.44023	4.585146	-2.93	0.0058*	4.83436
Effects Tests					
Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Proportion within 1 meter of another abalone (> 40mm)	1	1	946.53269	16.3241	0.0003*
Mean (Abalone Density)	1	1	613.35676	10.5781	0.0024*
Region	2	2	843.76141	7.2758	0.0022*

Table 10. Overview table of location ranking in relation to other surveyed locations for otter occupation, human access, density, good habitat (lots of refuge), poor habitat (very little refuge), and nearest neighbor rank. In all cases, values ranked at “1” indicate the highest degree in the category, tied values indicate sameness in rank, and increasing values indicate lower rank in the category.

Region	Location	Otter Occupation Rank	Human Access Rank	Abalone Density Rank	Good “1” Habitat Rank	Poor “3” Habitat Rank	Neighbor Distance Rank
Prince of Wales	Meares Pass	1	1.5	5	2	7	7
Prince of Wales	Port Bazan	2.5	3.5	7	1	6	6
Prince of Wales	Gooseneck	2.5	3.5	6	3	5	5
Ketchikan	Gravina Island	5.5	1.5	3.5	5	4	3
Dixon Entrance	Percy Islands	5.5	6	3.5	4	2	4
Dixon Entrance	Duke Island	5.5	6	2	6	1	1
Dixon Entrance	Bee Rocks	5.5	6	1	7	3	2

Table 11. Results of log linear model assessing the relationship between exposure (or refuge based on an exposure index) and substrate and the relationship between observation type and specific substrate (i.e. boulder, cobble). Observation type incorporates the division of juvenile ≤ 40mm, mature abalone (≥41mm), and a substrate habitat available to both size groups. In the log-linear model the interaction terms are the key factors to consider.

Source	**DF**	**L-R ChiSquare**	**Prob>ChiSq**
Region	1	99.818219	<.0001*
Observation Type	2	792.46017	<.0001*
Exposure	2	473.5805	<.0001*
Substrate	4	515.30758	<.0001*
Exposure*Substrate	8	108.84886	<.0001*
Observation Type*Substrate	8	47.521088	<.0001*

Table 12. Results of log linear model assessing the relationship between biogenic habitat collected and exposure (or refuge amount) along with the relationship between observation type and biogenic habitat from point contact habitat methods. Observation type incorporates the division of juvenile ≤ 40mm, mature abalone (≥41mm), and biogenic habitat type available to both size groups. In the log-linear model the interaction terms are the key factors to consider.

Source	**DF**	**L-R ChiSquare**	**Prob>ChiSq**
Region	1	93.513297	<.0001*
Observation Type	2	209.10479	<.0001*
Exposure	2	36.071631	<.0001*
Biogenic Habitat	10	850.54611	<.0001*
Observation Type*Biogenic Habitat	20	218.89283	<.0001*
Exposure*Biogenic Habitat	20	359.30896	<.0001*

Table 13. Results of log linear model assessing the relationship between biogenic habitat and abalone use of available biogenic habitat collected from photoplot habitat methods. All sizes of abalone included in the Abalone/Habitat variable. In the log-linear model the interaction term is the key factors to consider.

Source	**DF**	**L-R ChiSquare**	**Prob>ChiSq**
Region	1	566.99275	<.0001*
Abalone/Habitat	1	0.0006983	0.9789
Biogenic Habitat	15	3606.99	<.0001*
Abalone/Habitat*Biogenic Habitat	15	138.92771	<.0001*

Table 14. Results of log linear model assessing the relationships between Exposure habitat type and Observation Type, Exposure habitat type and Region, and Region and Observation Type. Here exposure habitat type is based on the exposure index (1, 2, 3) and Observation Type incorporates the division of juvenile ≤ 40mm, mature abalone (≥41mm), and exposure habitat type available to both size groups. In the log-linear model the interaction term is the key factors to consider.

Source	**DF**	**L-R ChiSquare**	**Prob>ChiSq**
Region	1	21.910916	<.0001*
Observation Type	2	594.01908	<.0001*
Exposure	2	85.570161	<.0001*
Observation Type *Exposure	4	79.559898	<.0001*
Region*Exposure	2	739.76247	<.0001*
Region* Observation Type	2	203.6058	<.0001*

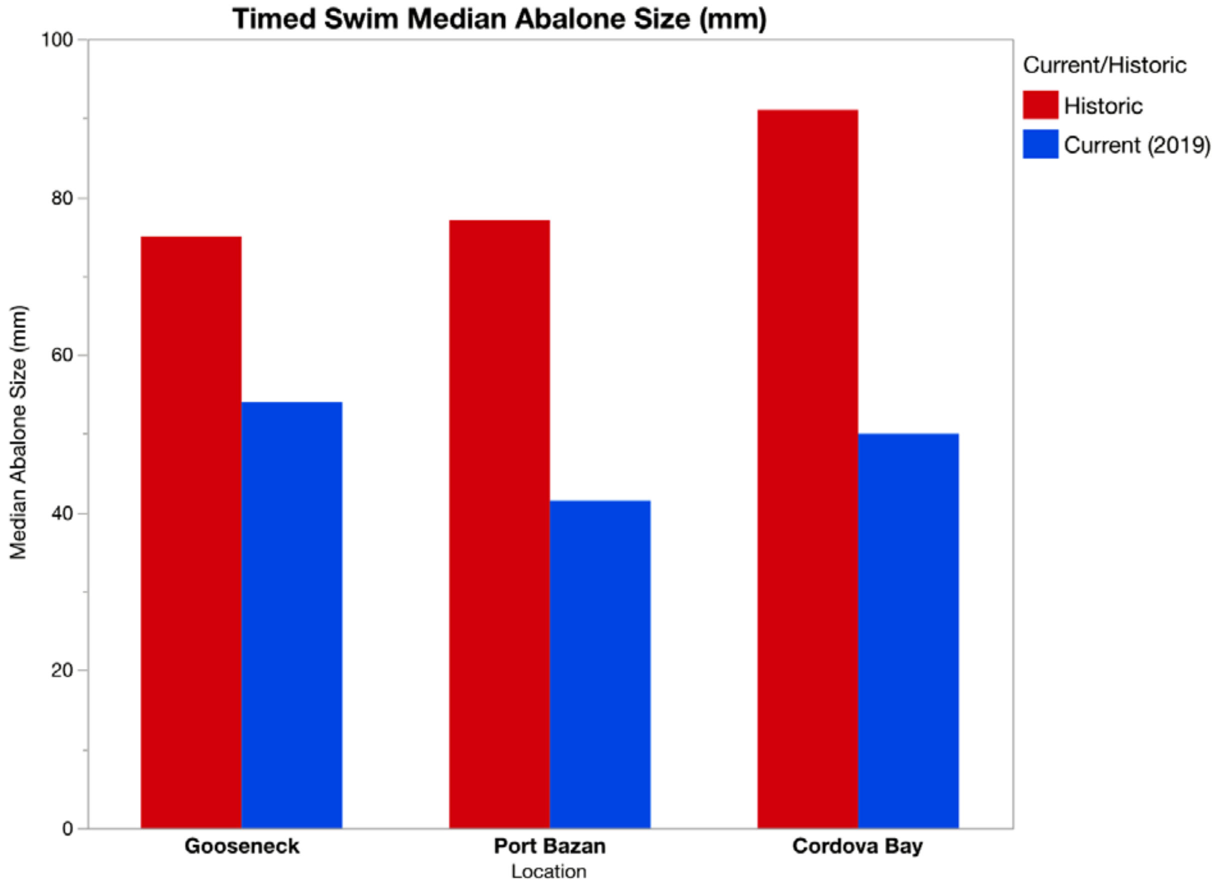

Figure 1. Median size of abalone counted during timed swims in Prince of Wales for combined historic (red) and current (blue) surveys. All abalone ≤ 40mm were excluded from this figure.

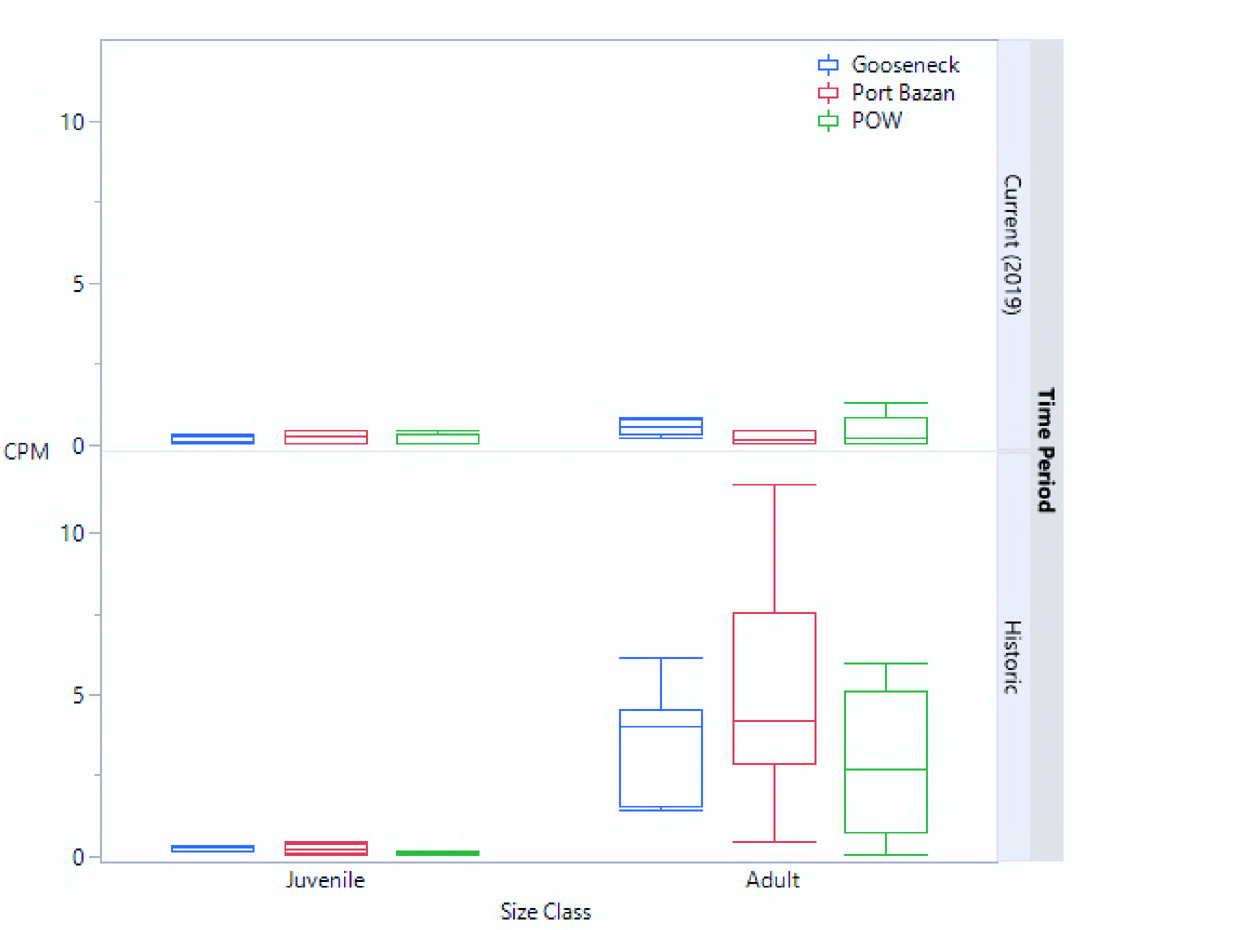

Figure 2. Box plots depicting the juvenile (>41mm) and adult (<41mm) abalone at all sites in locations: 2019 (upper) or historic (lower) surveys Gooseneck (blue), Port Bazan (red), and Cordova (aka POW in green). The top box plots indicate current surveys, while the bottom plots indicate the combination of historic surveys. The middle of each box plot represents the median catch per minute, which divides the first (lower box) and third (upper box) median quartiles. All historic data were taken from complied Blankenbeckler and Larson (unpublished data).

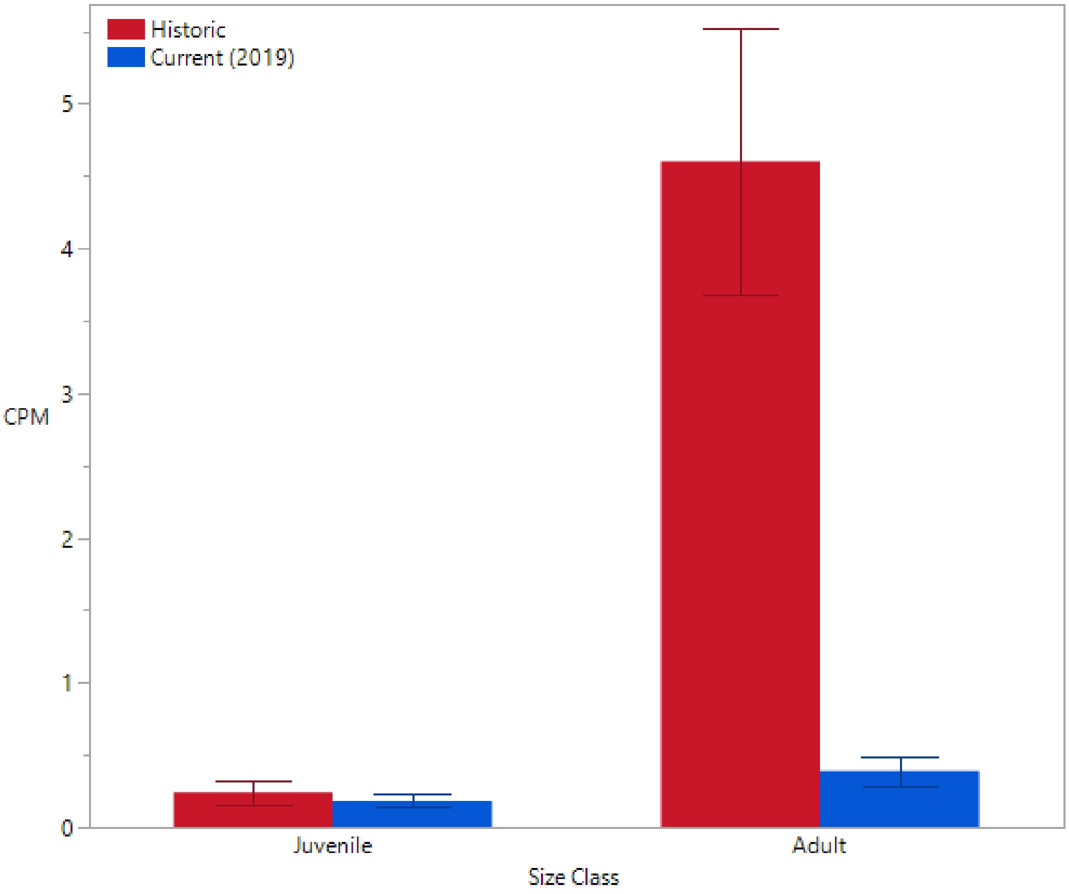

Figure 3. Abalone average count per minute (CPM) for juvenile (≤ 40mm) and adult (≥41mm) abalone during historic (red) and 2019 (blue) timed swims. All historic data were taken from complied Blankenbeckler and Larson (unpublished data). Historic sites were surveyed intermittently from 1971 – 1988 (Table 3).

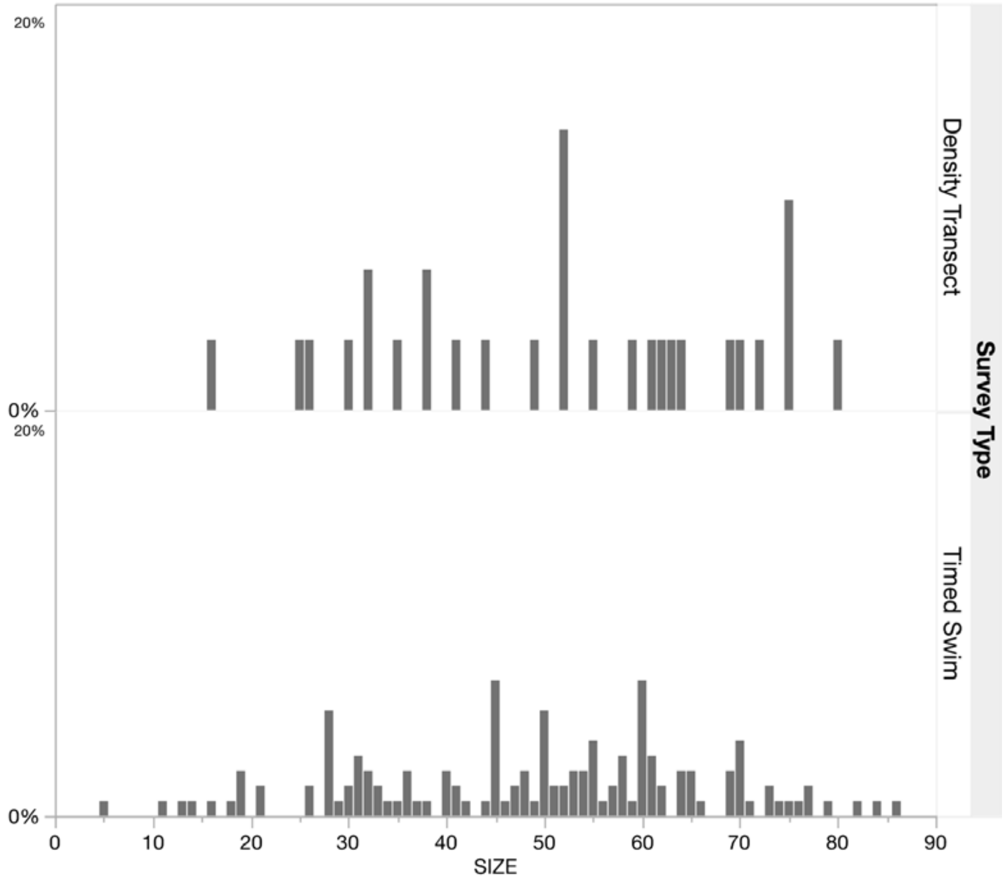

Figure 4. Comparison of abalone size proportions recorded during 2019 density transects (top) and 2019 timed swims (bottom) at the same monitoring sites in Prince of Wales. Both shallow and deep transects were included in bar charts. KS test p-value 0.4300.

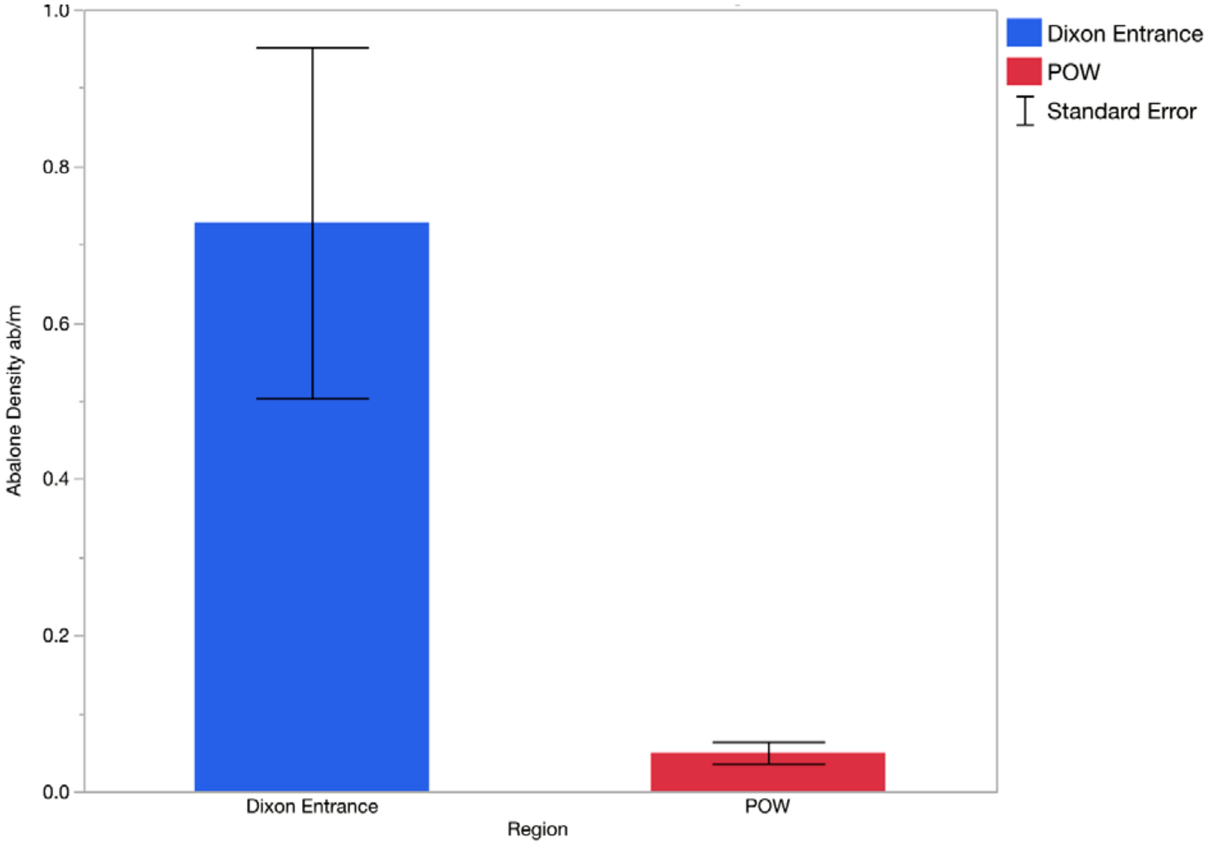

Figure 5. Mean abalone density between all transects on sites combined in Prince of Wales and Dixon Entrance regions with error bars delineating variation. Graphed with raw data. See Table 5.

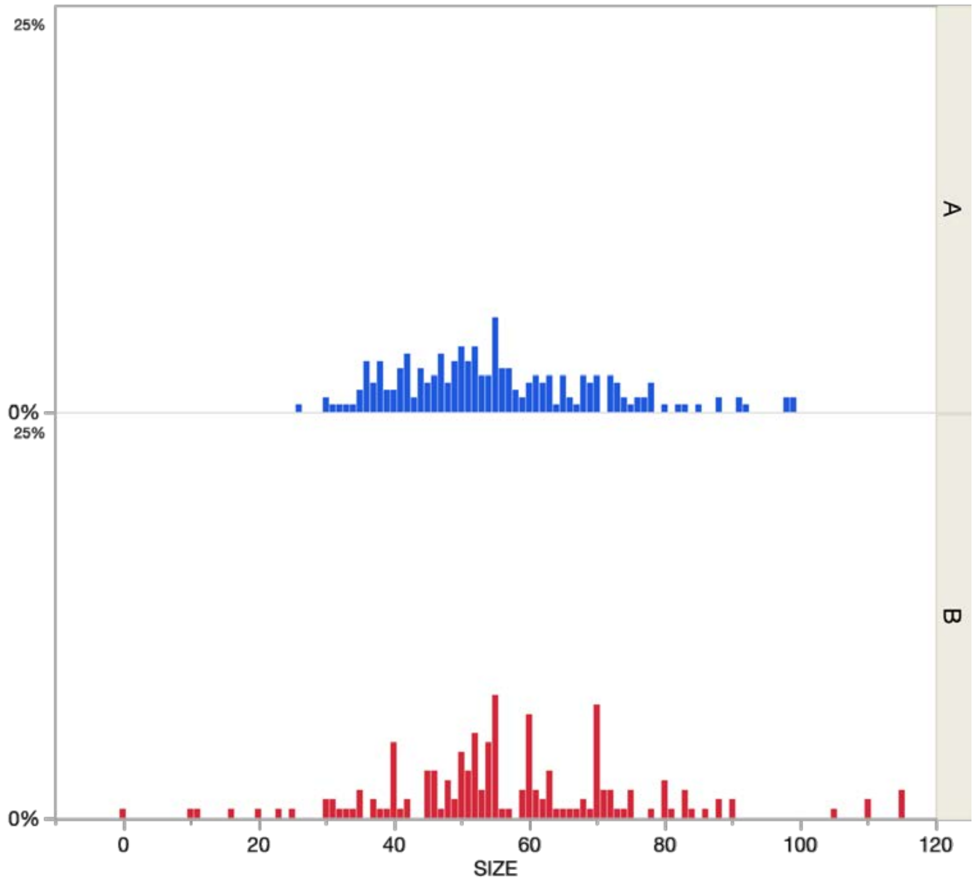

Figure 6. Percent of abalone size class recorded in 2019 on shallow "A" (blue top histogram) and deep "B" (red bottom) density transects. All sites and locations combined. Percent total size on y axis.

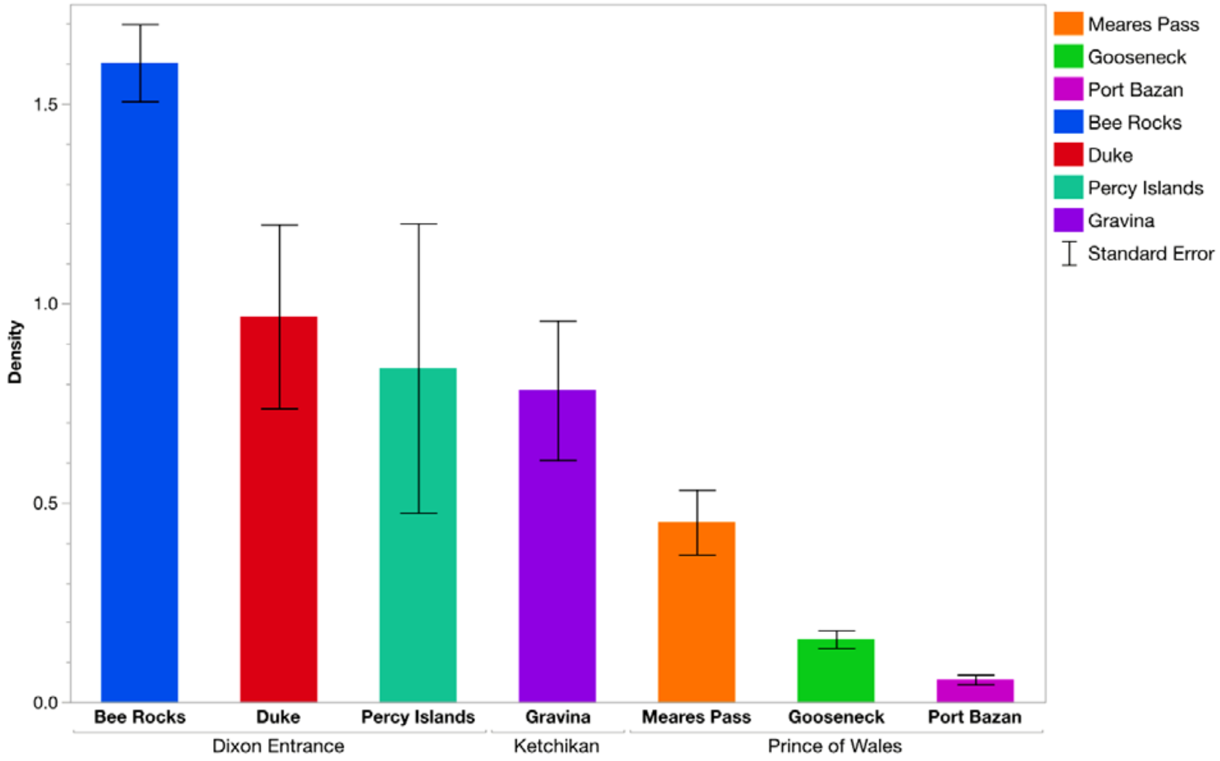

Figure 7. Mean abalone density per square meter of sites at locations and regions in southern Southeast Alaska during the summers of 2016 and 2019. See Table 6.

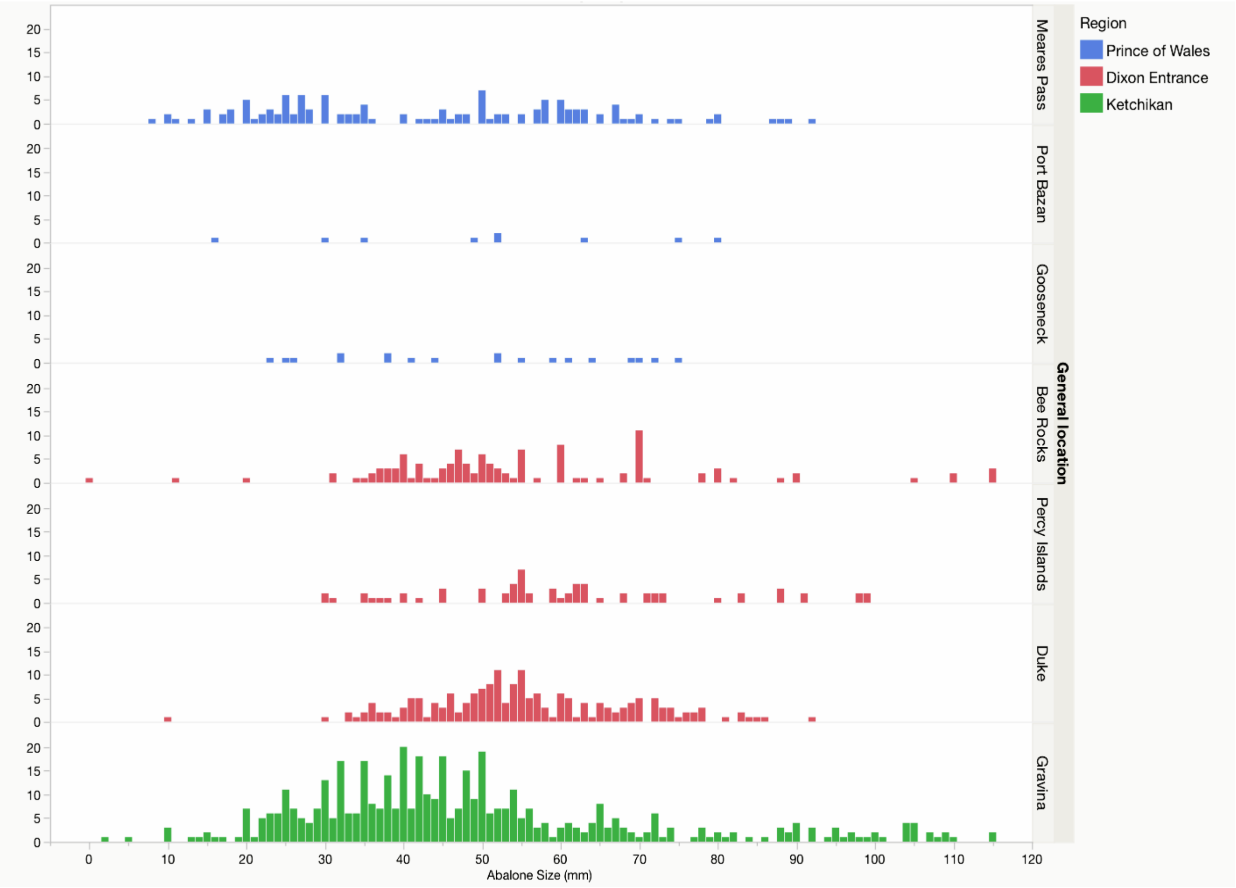

Figure 8: Size frequencies for survey locations in regions of southern Southeast Alaska. Prince of Wales (blue), Dixon Entrance (red), Ketchikan (green). KS tests compared locations to determine difference in current (2016, 2019) size structures. Raw data from Meares Pass and Gravina locations are from 2016 surveys (Donnellan and Hebert 2017). All other locations were surveyed in 2019. See Table 7.

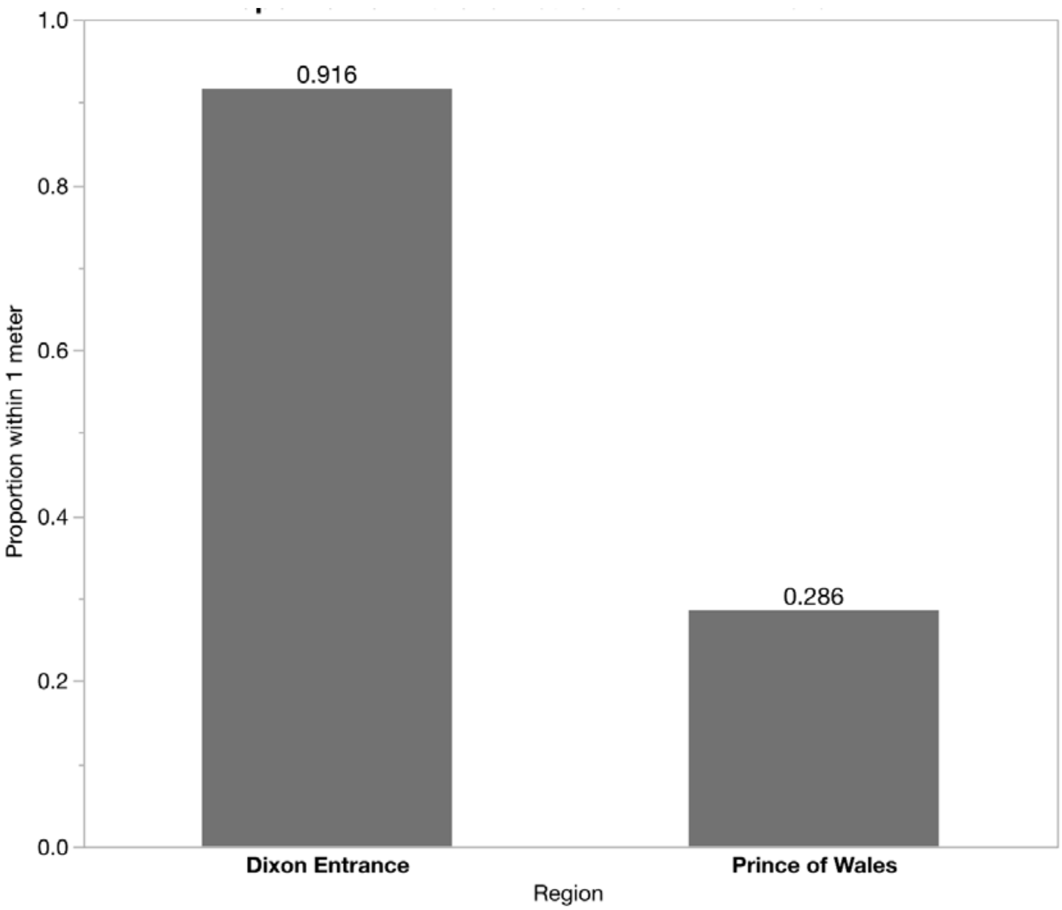

Figure 9. The percentage of total mature abalone within 1 meter of another mature abalone in Dixon Entrance (91.6%) and Prince of Wales (28.6 %). Both regions had recorded recruitment (defined here as counts of abalone ≤ 40mm). Only mature abalone were included in the calculation of nearest neighbor distances.

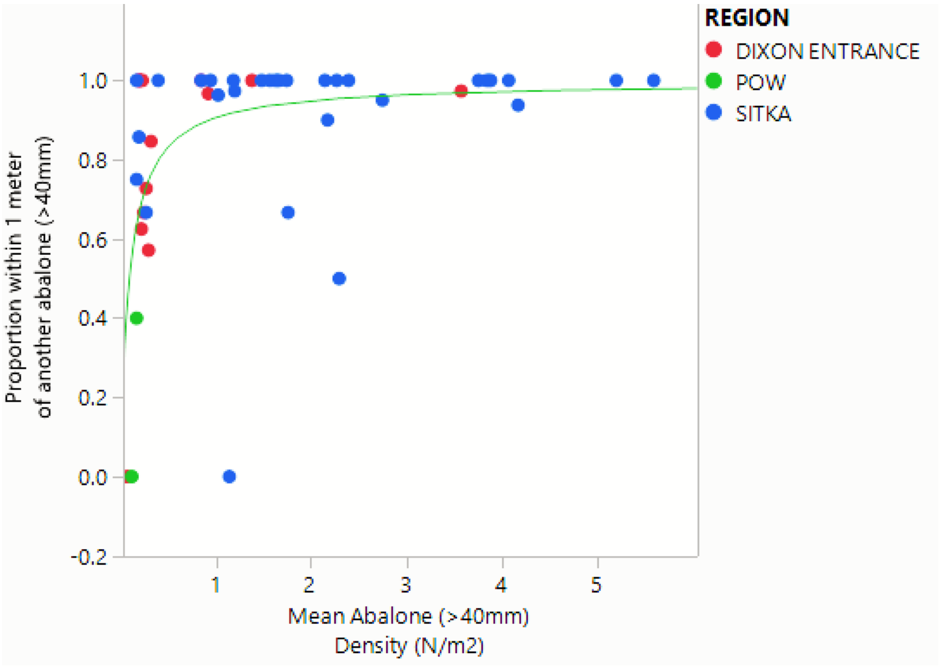

Figure 10. The proportion of mature abalone (> 40 mm) in relation to the mean abalone density at 2019 sites in Sitka (Blue), Prince of Wales (i.e. POW, Green), and Dixon Entrance (Red). (Chi-square p-value: <0.001).

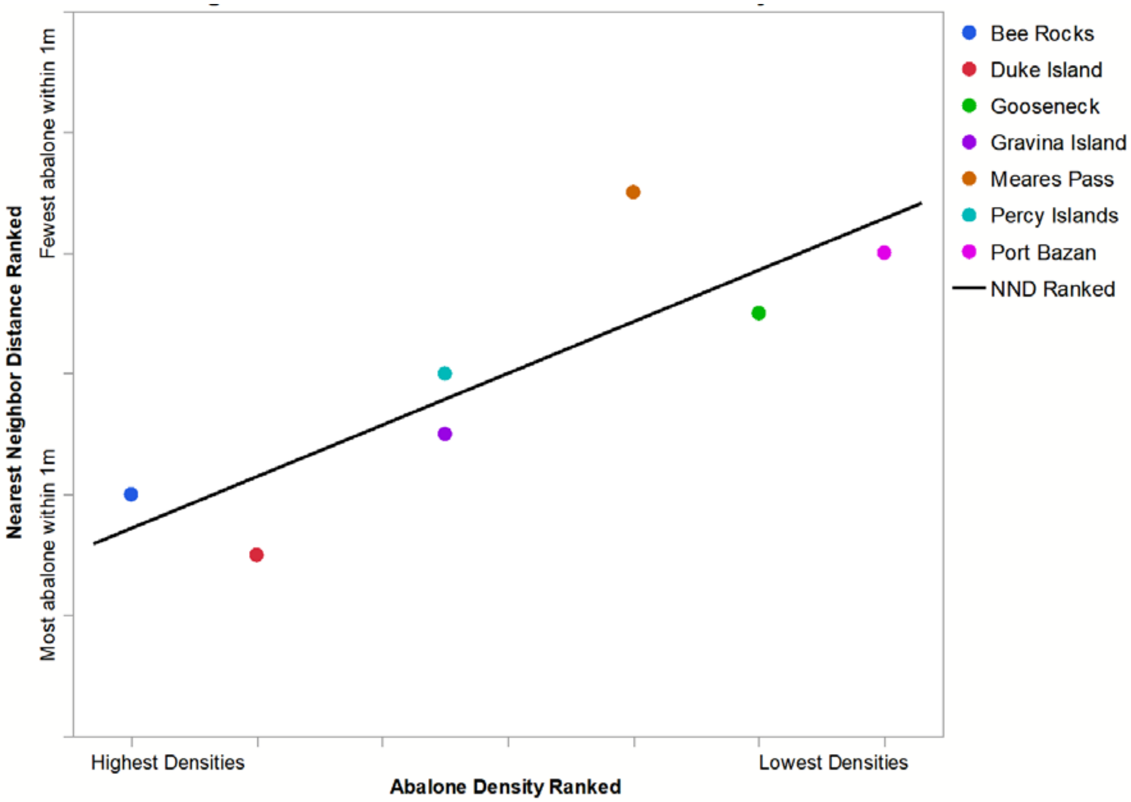

Figure 11. Relationship of abalone density and nearest neighbor based on ranking to other locations surveyed in Southeast Alaska (Table 10). Data from Gravina Island and Meares Pass were ranked based on 2016 surveys (Donnellan and Hebert 2017) all other locations are from 2019 surveys.

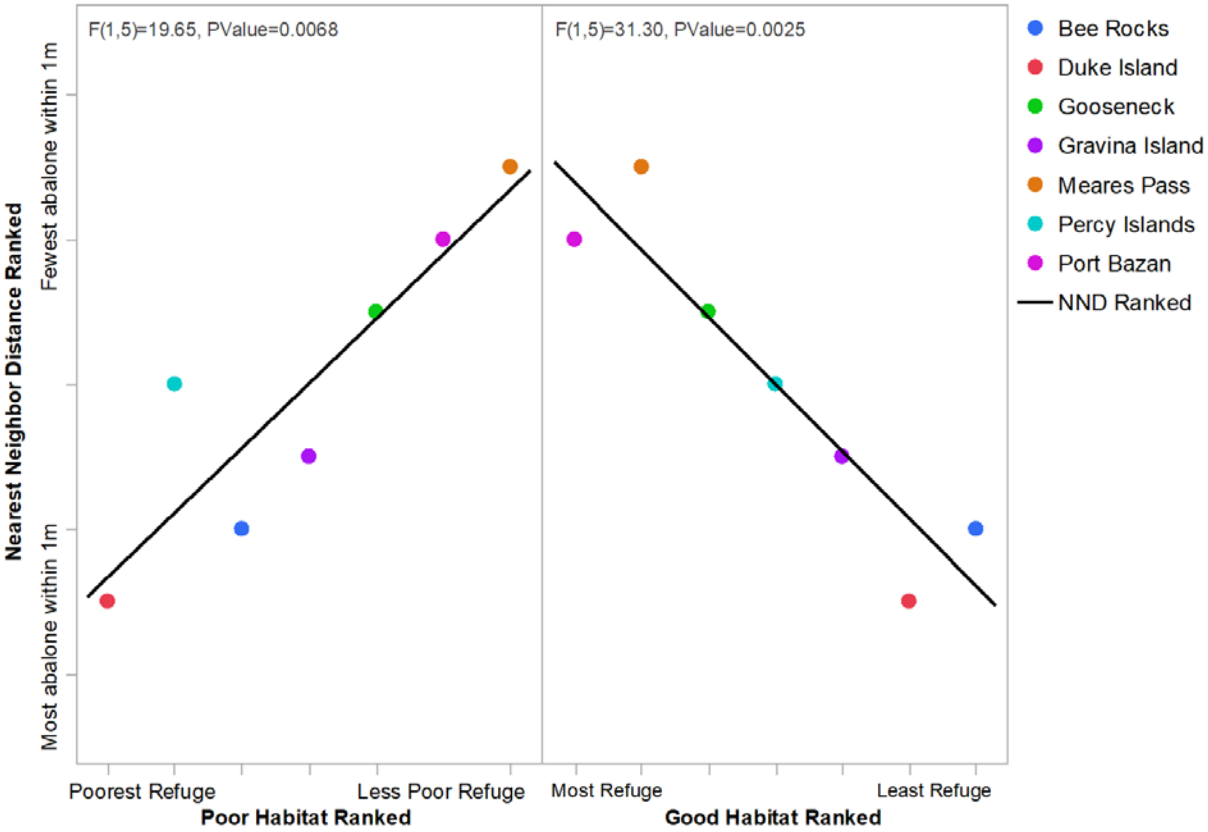

Figure 12. Relationship of nearest neighbor ranking to available poor and good habitat rankings across locations in Southeast Alaska (Table 10). Data from Gravina Island and Meares Pass locations were surveyed in 2016 (Donnellan and Hebert 2017) all other locations were surveyed in 2019.

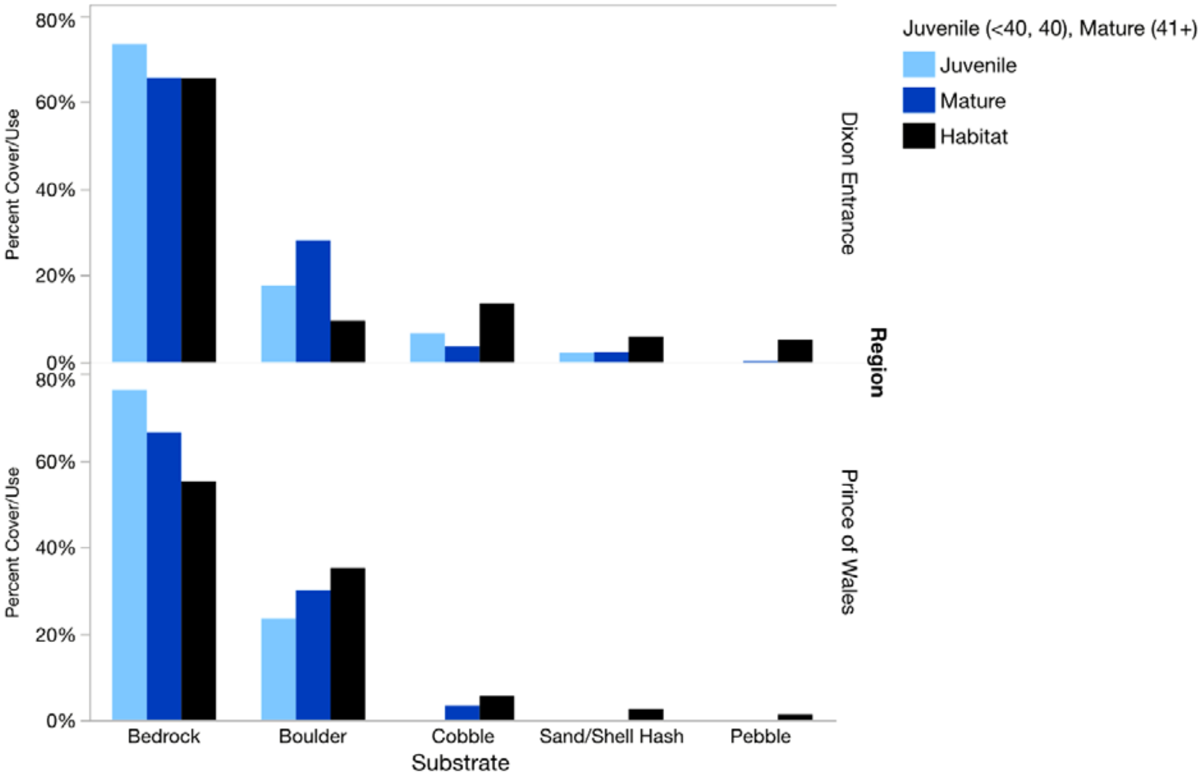

Figure 13. Comparison of observed abalone use of substrate (Juveniles, Adults) to available substrate (Habitat). See Table 11.

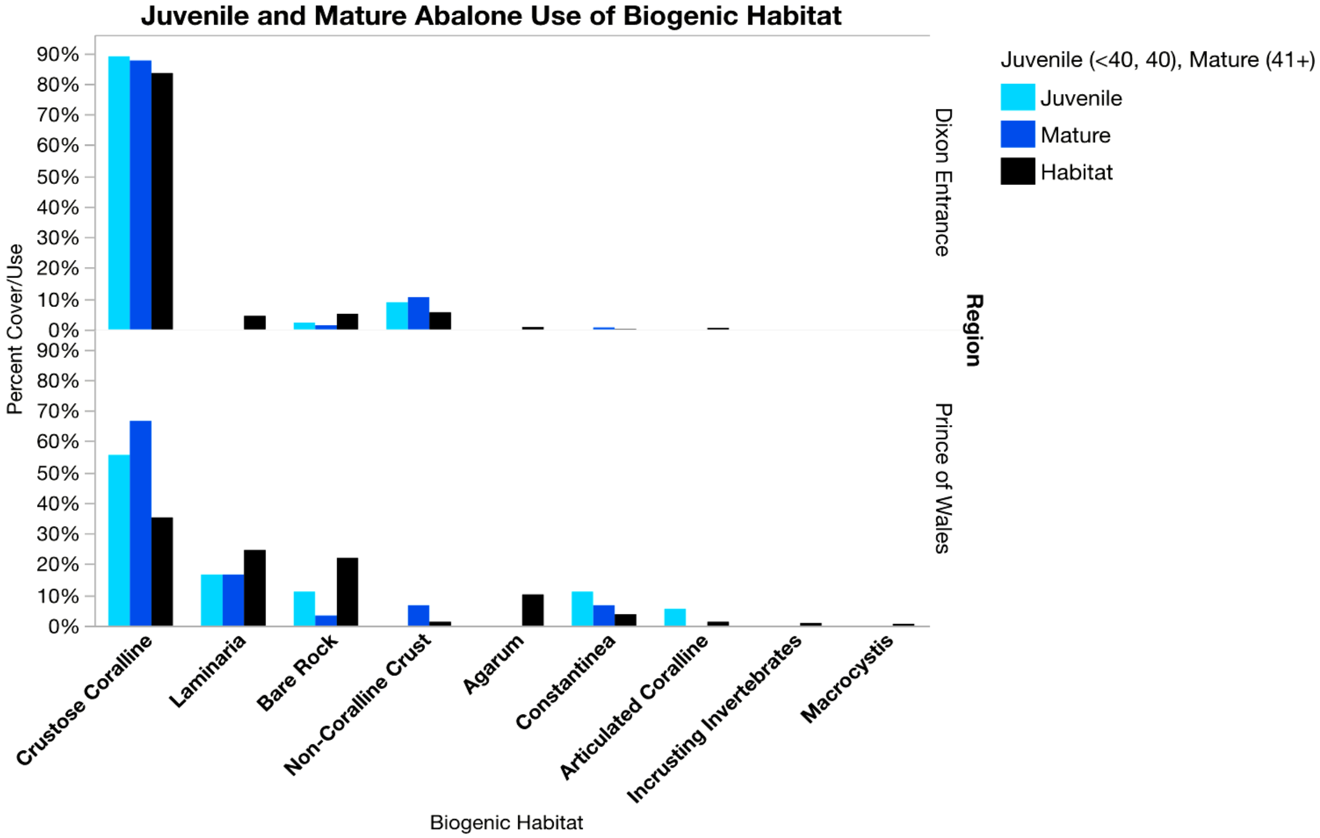

Figure 14. Comparison of observed use of biogenic habitat (juveniles, adults) to available biogenic habitat (habitat). Data were collected using point contact methods. See Table 12.

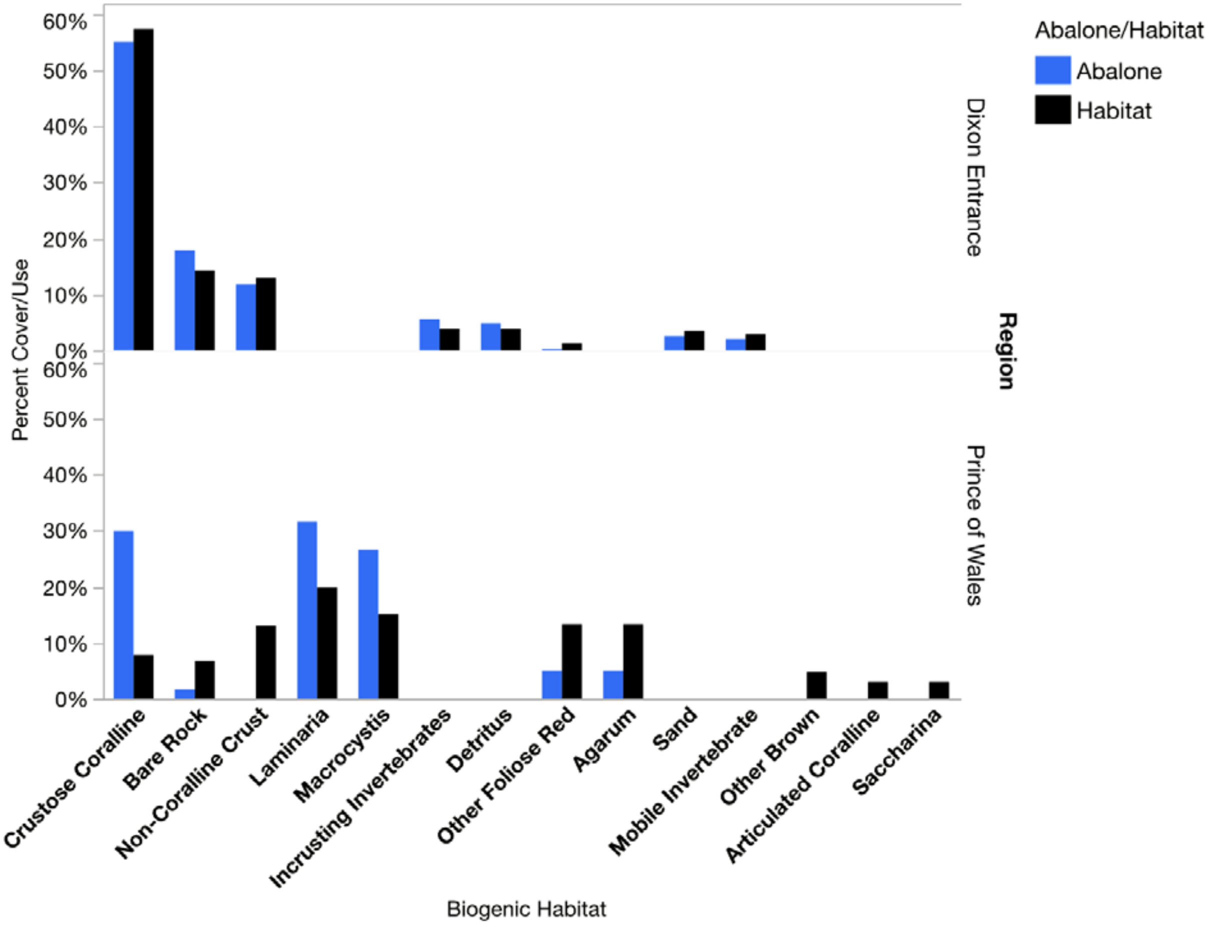

Figure 15. Comparison of observed use of biogenic habitat (juveniles, adults) to available biogenic habitat (habitat). Data used were collected from photoplots taken along transects. See Table 13.

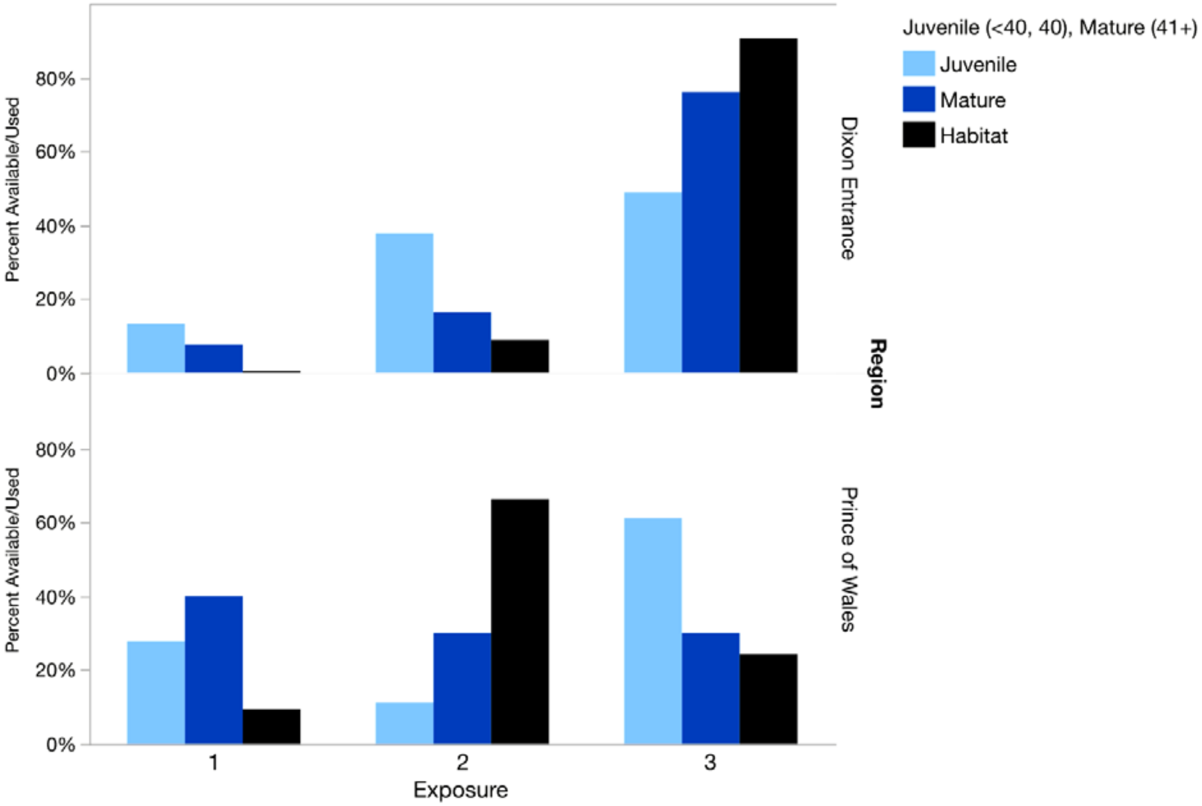

Figure 16. Comparison of observed abalone use of refuge (Juvenile, Adult) to available refuge in the habitat (Habitat). Exposure (x-axis) follows an index: 1: good refuge, 2: medium refuge, 3: poor refuge. See Table 14.

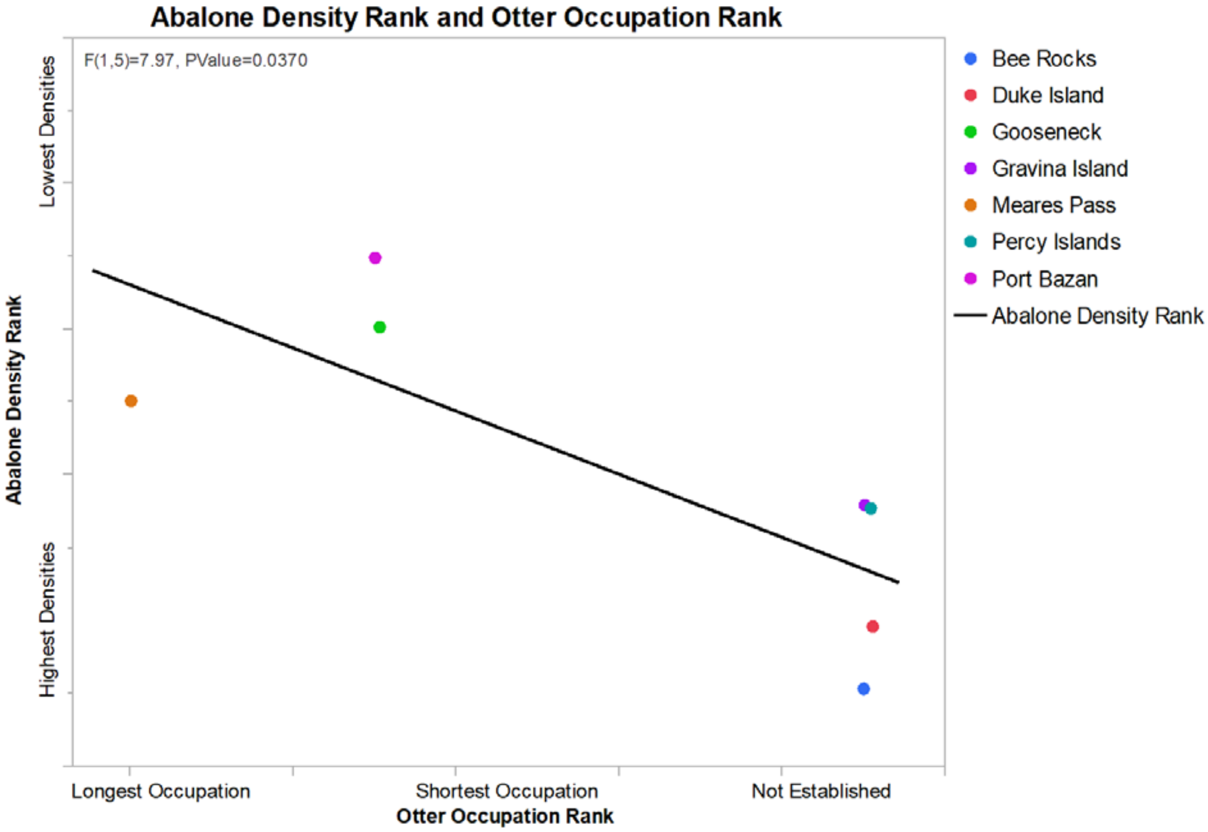

Figure 17. Comparison of Abalone Density Rank to Otter Occupation Rank at locations in Dixon Entrance (Bee Rocks, Duke Island, Percy Islands), Ketchikan (Gravina Island), and Prince of Wales (Meares Pass, Percy Islands, Port Bazan). Data from Gravina Island and Meares Pass were ranked based on 2016 surveys (Donnelllan and Hebert 2017) all other locations surveyed the summer of 2019.

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Appendix A – Monitoring Site Location

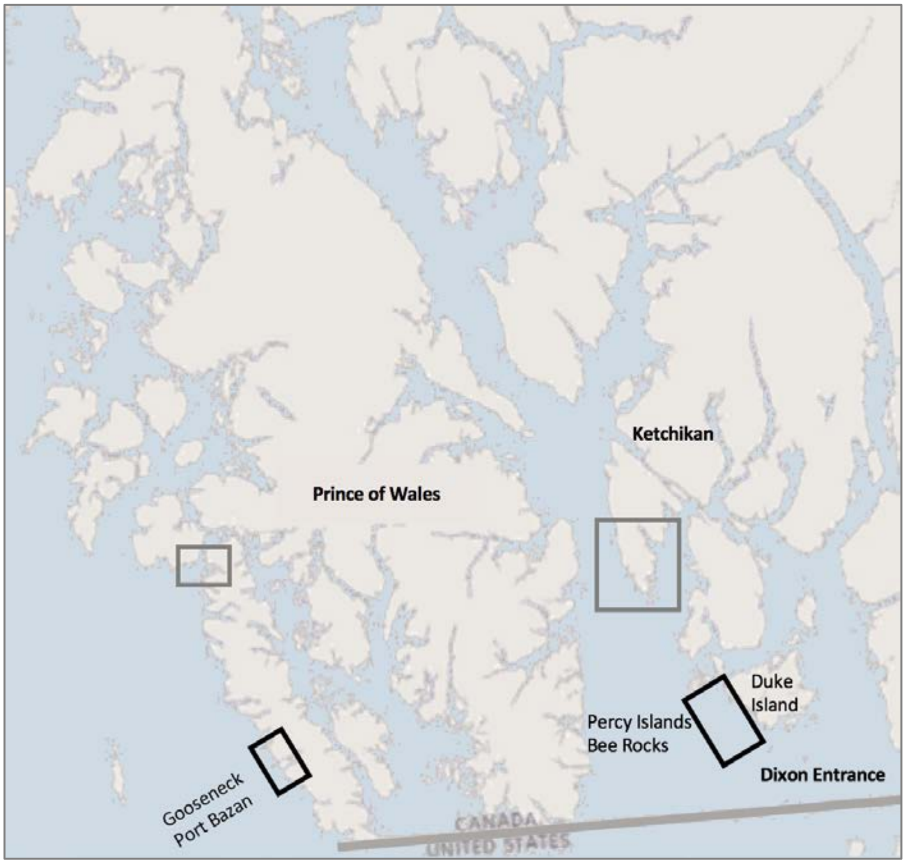
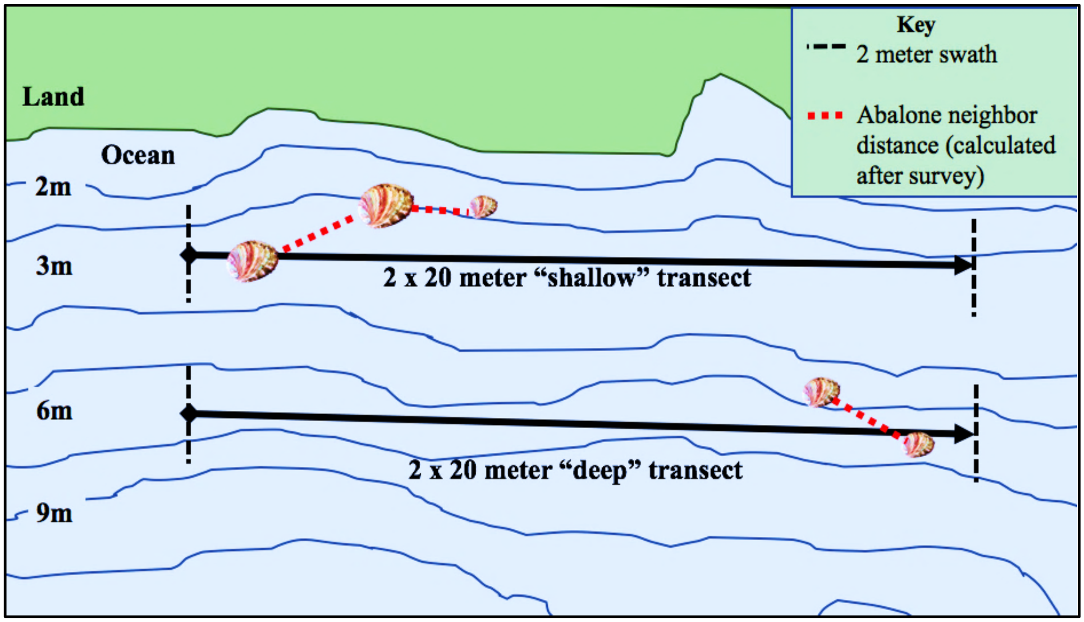


Figure 1. Overview map of study areas included in this report. Regions: Prince of Wales, Dixon Entrance, and Ketchikan are bolded Grey rectangles indicate 2016 survey location areas Meares Pass (Prince of Wales) and Gravina Island (Ketchikan). See Donnellan and Hebert 2017 for detailed reports on 2016 locations. Black rectangles indicate 2019 location areas: Gooseneck and Port Bazan (Prince of Wales); Percy Islands, Bee Rocks and Duke Island (Dixon Entrance). Map is oriented north, US Canada border is in grey. Basemap from Esri, HERE, Garmin ©, OpenStreetMap Contributers and the GIS user community.

Appendix B – Survey Protocol



Transect Layout Schematic. This schematic illustrates two permanent parallel abalone transects. Transects will be either shallow (~3m) or deep (~6m).

Abalone Surveyor Metrics

- Abalone distance away from, along transects (for Nearest Neighbor Distances)
- Abalone Shell Length (For size frequency, demographic analysis)
- Abalone Exposure Index (1 "hidden" – 3 "exposed") (for comparison of sites with and w/out sea otters)
- Sea Star #, size, species (sea star and abalone density associations)

Habitat Surveyor Metrics

- Algae & Substrate every 0.5m (2 layers)
- Available Refuge (1 "hidden", 2 a large crack, and 3 "exposed" habitat like bedrock)
- Urchin #, size, species (sea otter proxy – kelp abundance proxy)
- 0.5 x 0.5m photoplots (for habitat associations) of 5 abalone and 5 randomly selected habitat plots

Materials

- (1) 30 – 50 meter Transect Tape with weighted end (3-5 lbs)
- (1) GPS
- (2) Compass
- (2-3) Plastic Calipers
- (2) Dive Computer with time and depth gauge

- (1) Photoplot with GoPro and two lights
- (2) Pelican Float
- (2) Datasheets (2; 1 for abalone surveyor and 1 for habitat surveyor)
- (2) 1 meter transect rod with dive slate and pencil (aka "Sample T")

Specific Transect Methods

1) **Dive preparation**
    a) Fill out datasheet header information (Site number, Tide Correction, Target Depth (i.e. ~3 m deep for shallow and ~6 meters for deep transect), diver initials
    b) Divers should have 1 30m or 50m transect tape (with a weight to secure the end of the tape), datasheets for both abalone surveys and habitat surveys, 1 "sample T" with a pencil, 1 dive slate with a pencil, 2 calipers, 2 dive computers with depth gauges, 2 compasses, 1 photoplot (with 2 lights, 1 GoPro, 2 weights), 1 pelican float.
    c) Plan to dive transect sites at higher tides to reduce surge (during low tides and generally begin with the deep transect).

2) **Navigation**
    a) Navigate skiff to transect site using the GPS starting point (WAAS or differential correction is enabled)
    b) Drop off the dive team as close to given GPS as possible – have divers record their dive time start (24hr format).

3) **Transect Establishment**
    a) (Divers) descend to the target depth (~3m, 10' or ~6m, 20' corrected MLLW) and anchor one end of the transect tape with a weight. Divers should start with the deep transect at each site.
    b) Secure the photoplot (with lights and GoPro off) and other sample equipment (unless there is a strong surge) at the beginning of the transect
    c) Send up a pelican float to indicate the beginning of the transect
    d) Determine a heading to follow along the target depth.
    e) One diver should lay a transect out for 20m along the bottom, (doing their best to maintain the depth and compass heading), while the other should follow behind and secure the transect with rocks. **The transect should be secured to the bottom and not strung between rocks.**
    f) Habitat is variable and sites may have a variety of cracks, crevices, and boulders – the diver laying out the transect can allow for a corrected depth range of 9-12' (corrected) on shallow transects and 18 – 21' (corrected) for deep transects.
    g) If the diver runs out of "suitable" habitat along a transect (i.e. if the transect begins to run along sandy bottom or mudflats or the transect drops too deep), then the diver may change heading of the transect. The new heading and location of change along the transect (in meters) should be noted on a divers datasheet (in the comments section).

h) If it is difficult to establish a lower transect because no “suitable” habitat exists (i.e. regular stretches of sand), then a mid-transect (14-16’) should be established (and this should be noted on the datasheet)
i) Following transect establishment, divers should swim to the beginning of the transect 0.00m, pick up their sample T or dive slate and calipers and begin surveys

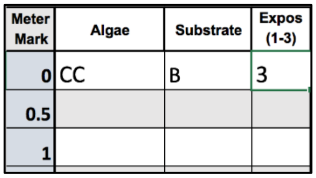
4) Transect Sampling (Habitat Surveys & Abalone Surveys)

Direction: The inshore 1m swath sections of the 20 meter transects should be surveyed first 0 to 20m (clockwise). Divers should turn at 20 meter and return to 0m surveying the offshore 1m swath of the transect – the exception being when the habitat diver records points directly beneath the transect tape and urchins within a 1 meter swath on **both** sides of the transect tape. Each side of each transect has an Inshore and Offshore area, these are indicated by + and – respectively (these terms and symbols will only be used during the photoplot portion of habitat surveys). Each transect surveyed could take around 45 - 60 minutes.

There are 2 types of transect surveys (Habitat and Abalone) and these will be staggered to start. The habitat diver will begin their survey of the 2x20m transect first:

Point Contact Habitat Surveys

a) Leave the photoplot (frame with GoPro off and lights off) at the established start of the transect
b) Mark your **sample start time** and the **bearing** (if you have not already) at the top of the habitat diver datasheet
c) Swim down the transect tape, and record the algae and substrate directly beneath the transect tape every 0.5 meters beginning at 0.00m (see left). Algae and substrate letter codes are found at the bottom of the habitat datasheet and below.



Meter Mark	Algae	Substrate	Expos (1-3)
0	CC	B	3
0.5			
1			

The above entry would indicate a Crustose Coralline Algae on a Boulder with Exposure “3”

M	Macrocystis	**C**	Constantinea spp.	**Algae + Substrate Key**	
S	Saccharina	**AC**	Articulated Coralline	**BR**	Bedrock
N	Nereocystis	**CC**	Crustose Coralline	**B**	Boulder (26cm-4m)
A	Agarum	**NC**	Non-Coralline Crust	**C**	Cobble (6-26cm)
L	Laminaria spp.	**OR**	Other Foliose Red	**P**	Pebble (0.4-6cm)
OB	Other Brown	**IN**	Incrusting Inverts	**S**	Shell/Sand

d) If there are more than one layer of algae (i.e. Macrocystis on coralline crust), use the first layer (i.e. Macrocystis, "M")

e) If there are more than one layer of substrate (i.e. sand on bedrock, use the lowest layer, i.e. bedrock, "BR") – record the largest size of substrate present (i.e. a boulder in a sand field is a "B" boulder)

f) If there is no algae layer (i.e. bare rock) then leave the corresponding algae field blank.

g) Measure the "Exposure Index" of the point directly under the transect tape (every 0.5m). The "Exposure Index" relates to abalone exposure. Picture an abalone directly under the meter mark you are surveying, would that abalone be completely exposed (i.e. on bare bedrock), then it would be an exposure "3", does the point land on lots of algae cover, with plenty of places for an abalone to hide?, then it is an exposure "2", does the point land directly in a crack that an abalone (of average size ~50mm) could fit into and be difficult to access by a predator? Then the point is a "1" on the index. A reminder of the Exposure Index is found at the top of the Habitat Datasheet (and bottom of the Ab Datasheet).

h) In addition to the algae, substrate, and exposure beneath each 0.5m along the transect tape, habitat divers will search and measure the first 20 green and first 20 red/purple urchins to the nearest mm within a 2-meter swath of the transect (1 meter on either side of the tape). When measuring urchins, measure the width of the test, excluding spines.

i) Once 20 of green urchins or 20 of red urchins are measured, record the meter mark (beneath the box titled "End urchin sample") and count, and tally the remaining green and red urchins (beneath boxes labeled "Green #" and "Red/Purp #").

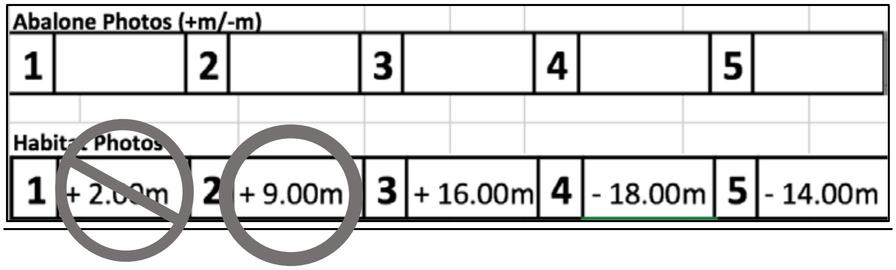
j) Once the 2x20m swath for urchins and point contact entries for algae, substrate, and exposure are complete (i.e. when the end of the transect is reached). The habitat diver will swim back to the beginning of the transect to take photos.

k) To begin photoplot surveys first turn on the photoplot's GoPro and 2 lights. (*leave the GoPro running for the duration of the survey*). (Note: "photos" from these photoplots are the best frame taken from the ongoing video)

l) Swimming clockwise (inshore + to offshore -) go to the first habitat photo location (indicated at the bottom of the sheet and shown below). For these surveys, the first habitat photo location at (inshore) + 2 meters.

m) Prior to "taking a photo" *do your best* to clear large blades of algae from the photoplot (Note: mesh added to the sides of the photoplots will assist in keeping large kelps out). Holdfasts of macro alga are fine to leave in the photoplot (no need to rip kelp out).

n) To "take a photo," align the side of the photoplot parallel with the transect tape and square the back corner on the photoplot with the predesignated inshore meter mark (+ 2.00, +9.00m, +16.00m) or predesignated offshore (-) mark (-18.00 and -14.00). (Note: the photoplot should be recording an area from +2.00m to +2.50m inshore etc. and -18.00m to -17.50m and -14.00m to -13.50m offshore).



Abalone Photos (+m/-m)

1		2		3		4		5	

Habitat Photos

1	+ 2.00m	2	+ 9.00m	3	+ 16.00m	4	- 18.00m	5	- 14.00m

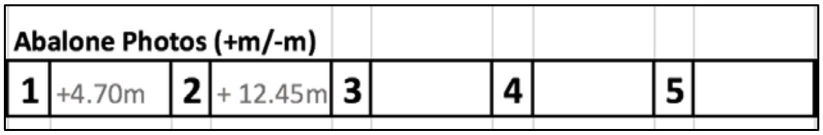
o) At the beginning of a "photo" circle the photo location on the datasheet (on your slate) and hold your datasheet in the photoplot frame (under the gopro) for at least 5 seconds. (This will help in determining the spatial location of a photo).

p) Finally, to officially "take a photo," hold the photoplot (with GoPro still running and lights on and facing down at the habitat) at it's predesignated meter mark for 10 – 15 seconds. Cross off the circled location and move to the next photo (abalone or habitat) (i.e**. in the photo above**, the diver has already taken a +2m photo and is now taking a +9m photo).

q) The habitat diver must also take 5 "photos" with abalone directly in the center of the "photo". Ideally these photos would be taken from +0 – 7, +8 – 14, and +15 – 20m inshore and -20 – -15m, and -14 – -7m. If the abalone diver finishes early, it is there job to help direct the habitat diver to abalone within these regions. (Note: take abalone photos during the same clockwise swim that habitat photos are taken)

r) To take abalone photos, first find an abalone on the 2x20m swath (if the abalone diver is done surveying they are encouraged to help and potentially mark abalone with flagging weighted with washers).

s) Record the meter mark along the transect where the abalone is found in the boxes labeled "abalone photos" at the bottom of the habitat datasheet (**see below**). There should be a plus or minus in front of the meter mark location, indicating whether the abalone is on the inshore or offshore side of the transect.



Abalone Photos (+m/-m)

1	+4.70m	2	+ 12.45m	3		4		5	

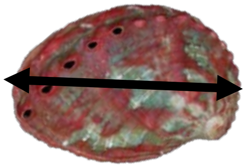
t) Center abalone in the photoplot, remove any marker for the abalone (aka flagging) and *do your best* to clear the photoplot of algae.

u) Prior to taking a photo, hold your datasheet (with the abalone photo meter mark recorded) in the photoplot frame (under the gopro) for at least 5 seconds. No need to circle the meter mark (feel free to – just **do not cross out the abalone meter mark**). (This will help in determining the location and type of photo taken)

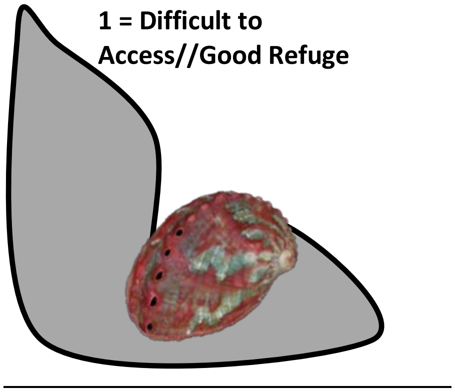
v) Following photos, record the sample time end, reel in transect tape, surface and record dive time end and turn off the GoPro and lights.

Abalone Surveys

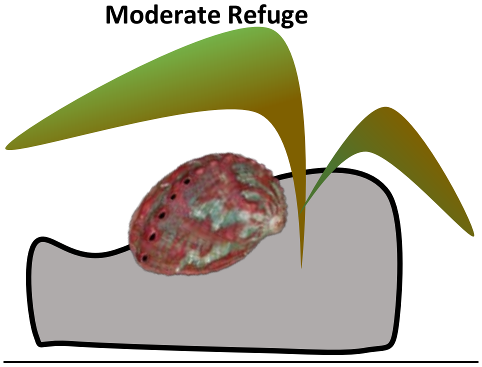
a) The abalone diver will wait for the habitat diver to survey 2 - 3 meters down the transect, then begin their clockwise survey of the 2x20m transect.
b) Mark sample time start (and bearing), then begin to survey the inshore 1m swath of the transect
c) With a "sample T" as a meter/measurement guide (i.e. the meter bar marked and labeled every 10 cm) search non-invasively (i.e. not moving rocks, lightly moving algae) in cracks and crevices for abalone and sea stars.
d) The goal is to record every abalone seen (with the knowledge that abalone, particularly small abalone, are cryptic). Those abalone <20mm do not need to be measured, only tallied at the bottom of the datasheet.



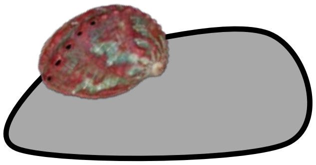
e) When an abalone is found, record its depth, the distance along the transect ("Meter Mark" on the datasheet), the distance from the transect **in cm** with the help of the sample T ("Dist. To Tape" on datasheet), the abalone length (the longest measurement from one end of the abalone to the next (**see left**), the algae and substrate the abalone is directly on top of (or that the mouth is directly over – if the abalone is on top of many types of algae), and the abalone's exposure "1, 2, or 3" (to predation – **see below**)



1 = Difficult to Access//Good Refuge

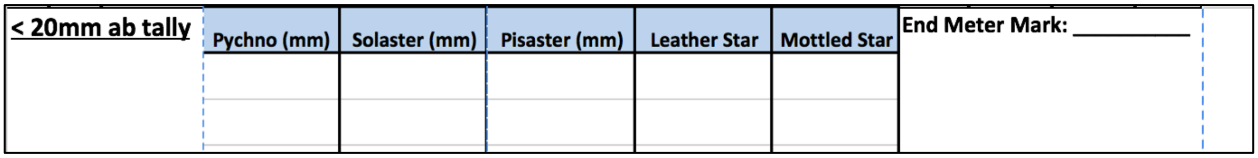


2 = Some Exposure// Moderate Refuge



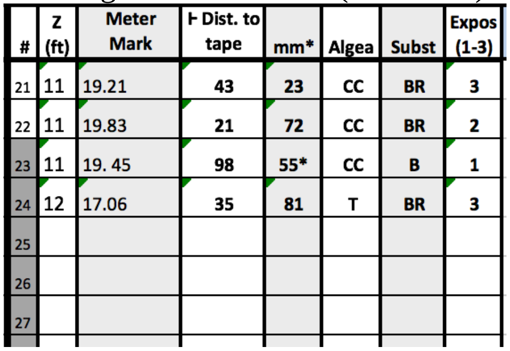
3 = Completely Exposed//Poor Refuge

f) If abalone is difficult to measure with calipers – estimate its size to the closest 5mm and put an * next to the measurement
g) In addition to abalone, search for sea stars within the 1 meter swath on either side of the transect. Measure each sea star in mm from its center to its longest ray. Record the mm in the species' corresponding box at the bottom of the datasheet (**below**). (Note: *only measure and record the species of stars listed on the datasheet*, **shown below**)



< 20mm ab tally	Pychno (mm)	Solaster (mm)	Pisaster (mm)	Leather Star	Mottled Star	End Meter Mark: __________

h) When the end of the inshore 1 x 20meter swath is completely surveyed, turn to the 1m offshore swath along the transect (sampling in the 20 – 0 m direction) and **shade in** the following abalone # boxes (see below)



#	Z (ft)	Meter Mark	⊢ Dist. to tape	mm*	Algea	Subst	Expos (1-3)
21	11	19.21	43	23	CC	BR	3
22	11	19.83	21	72	CC	BR	2
23	11	19. 45	98	55*	CC	B	1
24	12	17.06	35	81	T	BR	3
25							
26							
27							

i) If/when 40 abalone are recorded, write the sample "**End meter mark"** at the lower right corner of the datasheet and continue to complete the entire 2x20m surveying only sea stars.

j) Once back at the beginning of the transect (0.00) record sample stop time and assist the habitat diver in finding abalone for 5 abalone photoplot photos around 7, 14, and 20 meters inshore and 17, and 13 meters offshore

k) Ascend with the habitat diver and record dive time end

5) Wrap – up

a) Record the coordinates of the pelican float (indicating the transect start location) at the top of each datasheet, and retrieve float

b) Each Diver should make sure their datasheets are legible and complete

c) Determine next site and repeat

Habitat & Photoplot Datasheet

Site ___________ **Coordinates 5___.___________ N -13__. _____________ W Date: ____ / _____ /2019**

Recorder Initials: _____________________________________ **Buddy Initials:** ___________________________

Dive Time Start: _________ **Dive Time End:** ___________ **Tide Correction:** ______ **Bearing (°):** _______

Sample Time Start: ________ **Sample Time End:** ________ **Target Depth (un-corrected, ft):**______

Exposure Index 1: very hidden, **2:** slightly hidden, but collectable, **3:** exposed **Surge Index (High, Med, Low):** ______

Meter Mark	Algae	Substrate	Expos (1-3)	Meter Mark	Algae	Substrate	Expos (1-3)	Green Urch (mm)	Red/Purp Urchins
0	CC	B	3	10.5					
0.5				11					
1				11.5					
1.5				12					
2				12.5					
2.5				13					
3				13.5					
3.5				14					
4				14.5					
4.5				15					
5				15.5					
5.5				16					
6				16.5					
6.5				17					
7				17.5					
7.5				18					
8				18.5					
8.5				19					
9				19.5					
9.5				20					
10									

End Urchin Meter Mark

_______ m	_______ m
Green #	**Red/Purp #**

Abalone Photos (+m/-m)

1		**2**		**3**		**4**		**5**	

Habitat Photos

1	+ 2.00m	**2**	+ 9.00m	**3**	+ 16.00m	**4**	- 18.00m	**5**	- 14.00m

				Algae + Substrate Key	
M	Macrocystis	**C**	Constantinea spp.		
S	Saccharina	**AC**	Articulated Coralline	**BR**	Bedrock
N	Nereocystis	**CC**	Crustose Coralline	**B**	Boulder (26cm-4m)
A	Agarum	**NC**	Non-Coralline Crust	**C**	Cobble (6-26cm)
L	Laminaria spp.	**OR**	Other Foliose Red	**P**	Pebble (0.4-6cm)
OB	Other Brown	**IN**	Incrusting Inverts	**S**	Shell/Sand

Comments:

Abalone Transect (Index and Random)

Site ____________ **Start Coordinates 5___.________ N -13__. ___________ W Date: ____ / _____ /2019____**

Recorder Initials: _______________________________________ **Buddy Initials:** _____________________________

Dive Time Start: ____________ **Dive Time End:** ____________ **Tide Correct:** _______ **Bearing:** ________°

Sample Time Start: __________ **Sample Time End:** __________ **Target Depth (un-corrected, ft):**______

#	Z (ft)	Mark (m.##)	to tape (cm)	mm*	Algae	Subst	Expos (1-3)	#	Z (ft)	Mark (m.##)	to tape (cm)	mm*	Algae	Subst	Expos (1-3)
1								21							
2								22							
3								23							
4								24							
5								25							
6								26							
7								27							
8								28							
9								29							
10								30							
11								31							
12								32							
13								33							
14								34							
15								35							
16								36							
17								37							
18								38							
19								39							
20								40							

< 20mm ab tally

Pychno (mm)	Solaster (mm)	Pisaster (mm)	Leather Star	Mottled Star

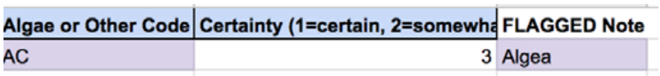
End Meter Mark: __________

M	Macrocystis	**C**	Constantinea spp.	**Algae + Substrate Key**	
S	Saccharina	**AC**	Articulated Coralline	**BR**	Bedrock
N	Nereocystis	**CC**	Crustose Coralline	**B**	Boulder (26cm-4m)
A	Agarum	**NC**	Non-Coralline Crust	**C**	Cobble (6-26cm)
L	Laminaria spp.	**OR**	Other Foliose Red	**P**	Pebble (0.4-6cm)
OB	Other Brown	**IN**	Incrusting Inverts	**S**	Shell/Sand

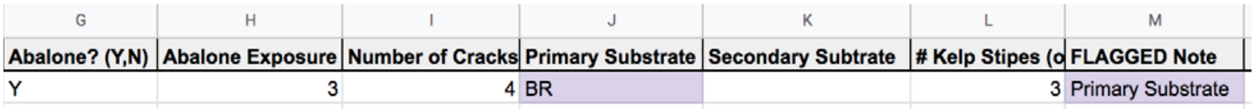
Exposure Index 1: very hidden
2: slightly hidden **3:** exposed

Photoplot Analysis Protocol

1. Make sure you have all the correct Image J macros
2. Download a picture from the “Photoplots for Processing” folder
3. RENAME your photo in the Photoplots for Processing folder by adding “DONE_” to the beginning of the original file name (i.e. DONE_PB2A.H.1.4) *NEW*
4. On your computer, open the photo in Image J
5. Overlay the proper Macro (for 1920 x 1080 or other pixel combination)
6. The goal is to sample 20 points within the quadrat - to start, find the first crosshair at the top left corner that is within the quadrat *and* has three crosshairs below it that are also in the quad (for a total of 4 vertical points//crosshairs). This top left hand crosshair should also have four crosshairs to the right that are within the quad (for a total of 5 horizontal points)
7. Start at the top left corner and work down, so the top left corner is crosshair #1 the crosshair below that is #2… #3… #4 and then go to the top of the next row and work down 5,6,7,8, and the third row working down 9,10,11,12, then the fourth row working down 13, 14, 15, 16 and the final and 5th row includes 17 (at the top working down) 18, 19, 20
8. The algae type or other ID (i.e. bare rock “B” or Detritus “D”) should be recorded next to # index of correct ID certainty.
9. Collect general photoplot data sheet: number of cracks and crevices (that any abalone might fit in), primary substrate (around 70% of what’s in the plot i.e. Bedrock or Boulder) and secondary substrate (around 30% or less of plot substrate), finally count the number of stipes of macro algae - or large kelps. Note: if there is no secondary substrate then leave the cell blank.
10. IF you have trouble identifying an algae, substrate or anything else – Flag it (return to footage or get assistance)
11. To Flag, Highlight (only) the cell that you’re struggling with and highlight the Flagged cell with a note on what was flagged and why.



Algae or Other Code	Certainty (1=certain, 2=somewha	FLAGGED Note
AC	3	Algea



G	H	I	J	K	L	M
Abalone? (Y,N)	Abalone Exposure	Number of Cracks	Primary Substrate	Secondary Subtrate	# Kelp Stipes (o	FLAGGED Note
Y	3	4	BR		3	Primary Substrate

Table 1. Photoplot Biogenic Habitat and Substrate Surveyed Codes and Clumping

Clumped Category (for analyses)	Photoplot Species	CODE	Includes
Agarum	Agarum spp	**A**	A.clathratum and A. fibriatum
Other Brown	Alaria marginata	**AM**	
Articulated Coralline	Articulated Corralline	**AC**	Calliarthron, Bossiella orbigniana, Bossiella schmittii
Non-Coralline Crust	Brown Crust	**BC**	Ralfsia fungiformis and other Ralfsia spps
Constantinea	Constantinea	**C**	
Other Brown	Costaria costata	**CC**	
Crustose coralline algae	Crustose coralline algae	**CCA**	
Other Brown	Cymathere triplicata	**TR**	
Other Brown	Desmarestia ligulata	**DL**	
Other Foliose Red	Filamentous Red	**FR**	(note this includes all other reds that are not Callophyllis or cryptopleura)
Fucus	Fucus spp.	**F**	
Non-Coralline Crust	Green Crust	**GC**	Codium setchellii
Non-Coralline Crust	Hildenbrandia rubra	**HR**	
Laminaria	Laminaria setchelii	**LS**	
Macrocystis	Macrocystis	**M**	
Other Brown	Nereocystis	**N**	
Other Foliose Red	Opuntiella	**O**	
Other Foliose Red	Osmundea	**OS**	
Other Foliose Red	Other Red	**OR**	Callophyllis, Cryptopleura
Non-Coralline Crust	Petrocelis phase	**PP**	
Other Brown	Pleurophycus gardeneri	**PG**	
Saccharina	Saccharina groenlandica	**SG**	
Saccharina	Saccharina latissima	**SA**	
Saccharina	Saccharina sessilis	**SS**	
Ulva	Ulva spps.	**U**	
	Other Photoplot IDs		
Mobile Inverts	Mobile Inverts	**MI**	
Detritus/Dead Material	Detritus/Dead Material	**D**	
Incrusting Invertebrates	Incrusting Invertebrates	**IN**	
Bare Rock	Bare Rock	**B**	
Sand	Sand	**S**	

Specific Macros for ImageJ Photoplot Processing

```
// "StartupMacros"
// The macros and tools in this file ("StartupMacros.txt") are
// automatically installed in the Plugins>Macros submenu and
// in the toolbar when ImageJ starts up.

// The "AutoRun" macro has been replaced by the Edit>Options>Startup command.

  macro "Command Finder Built-in Tool" {}
  macro "Developer Menu Built-in Tool" {}
  macro "Brush Built-in Tool" {}
  macro "Flood Filler Built-in Tool" {}
  macro "Arrow Built-in Tool" {}

  var pmCmds = newMenu("Popup Menu",
       newArray("Help...", "Rename...", "Duplicate...", "Original Scale",
       "Paste Control...", "-", "Record...", "Capture Screen ", "Monitor
Memory...",
       "List Commands...", "Control Panel...", "Startup Macros...",
"Search..."));

  macro "Popup Menu" {
      cmd = getArgument();
      if (cmd=="Help...")
           showMessage("About Popup Menu",
               "To customize this menu, edit the line that starts with\n\"var
pmCmds\" in ImageJ/macros/StartupMacros.txt.");
      else
          run(cmd);
  }

 macro "-" {} //menu divider

  macro "About Startup Macros..." {
      path = getDirectory("macros")+"About Startup Macros";
      if (!File.exists(path))
          exit("\"About Startup Macros\" not found in ImageJ/macros/.");
      open(path);
  }

  // This example macro demonstrates how to create a
  // custom command with a keyboard shortcut.
  //macro "Save As JPEG... [j]" {
  //   quality = call("ij.plugin.JpegWriter.getQuality");
  //   quality = getNumber("JPEG quality (0-100):", quality);
  //   run("Input/Output...", "jpeg="+quality);
  //   saveAs("Jpeg");
  //}

macro "(1920x1080) [1]" {
len = 40; // half size of the crosses
w = 3; // line width of the cross-lines
x =
newArray(496,496,496,496,496,496,640,640,640,640,640,640,784,784,784,784,784,
```

```
784,928,928,928,928,928,928,1072,1072,1072,1072,1072,1072,1216,1216,1216,1216
,1216,1216,1360,1360,1360,1360,1360,1360,1504,1504,1504,1504,1504,1504);
y =
newArray(76,276,476,676,876,1076,76,276,476,676,876,1076,76,276,476,676,876,1
076,76,276,476,676,876,1076,76,276,476,676,876,1076,76,276,476,676,876,1076,7
6,276,476,676,876,1076,76,276,476,676,876,1076);
for ( i=0; i<x.length; i++ ) {
   Overlay.drawLine(x[i]-len, y[i], x[i]+len, y[i]);
   Overlay.drawLine(x[i], y[i]-len, x[i], y[i]+len);
}
Overlay.show;}

macro "(1280x720) [2]" {
len = 20; // half size of the crosses
w = 3; // line width of the cross-lines
x =
newArray(98,98,98,98,98,98,98,98,98,196,196,196,196,196,196,196,196,196,294,2
94,294,294,294,294,294,294,294,392,392,392,392,392,392,392,392,392,490,490,49
0,490,490,490,490,490,490,588,588,588,588,588,588,588,588,588,686,686,686,686
,686,686,686,686,686,784,784,784,784,784,784,784,784,784,882,882,882,882,882,
882,882,882,882,980,980,980,980,980,980,980,980,980,1078,1078,1078,1078,1078,
1078,1078,1078,1078);
y =
newArray(140,210,280,350,420,490,560,630,700,140,210,280,350,420,490,560,630,
700,140,210,280,350,420,490,560,630,700,140,210,280,350,420,490,560,630,700,1
40,210,280,350,420,490,560,630,700,140,210,280,350,420,490,560,630,700,140,21
0,280,350,420,490,560,630,700,140,210,280,350,420,490,560,630,700,140,210,280
,350,420,490,560,630,700,140,210,280,350,420,490,560,630,700,140,210,280,350,
420,490,560,630,700,140,210,280,350,420,490,560,630,700);
for ( i=0; i<x.length; i++ ) {
   Overlay.drawLine(x[i]-len, y[i], x[i]+len, y[i]);
   Overlay.drawLine(x[i], y[i]-len, x[i], y[i]+len);
}
Overlay.show;}
```

Appendix C - Historic Comparisons

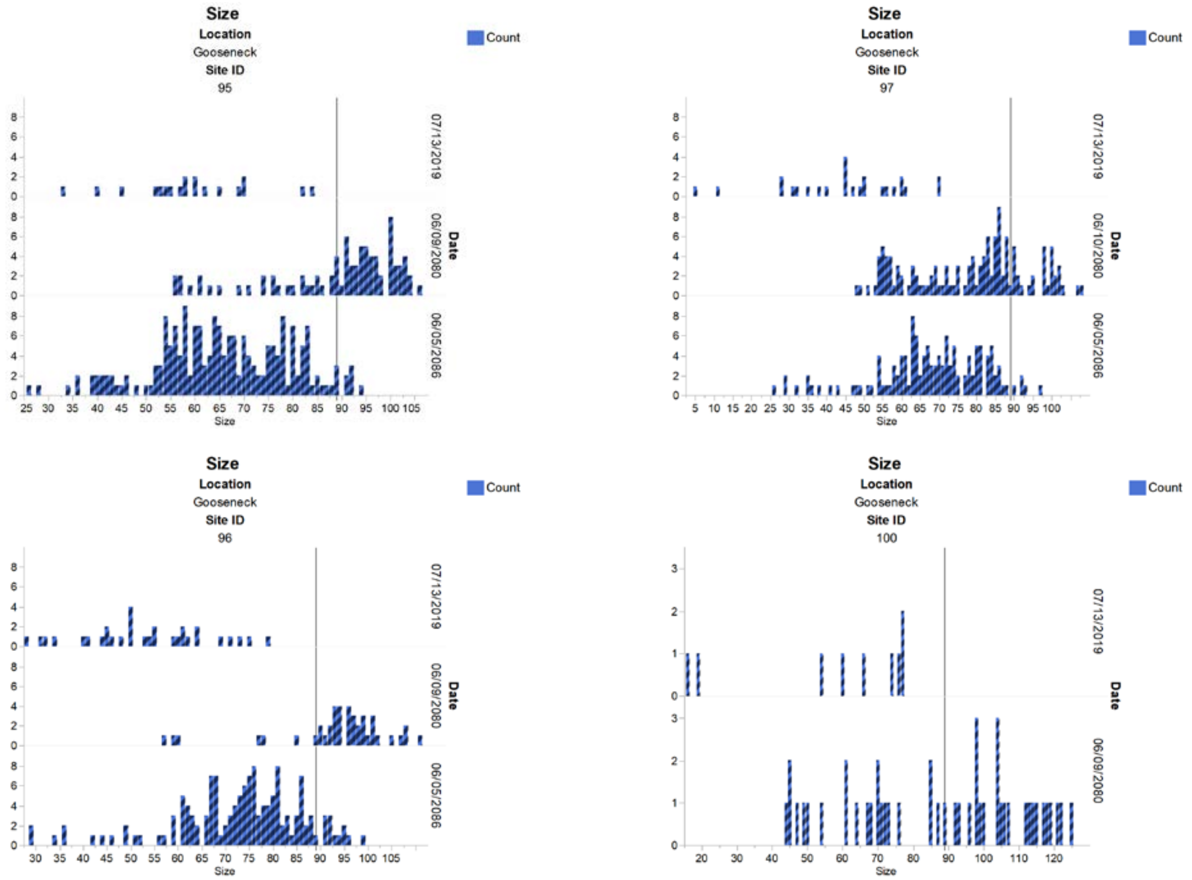
Table 1. Pairwise K-S Tests of size frequencies between timed swim site survey years. Pairwise tests are done in order from Year 1 to Year 2 (i.e. more historic year to successive recent years). Significant shifts in the opposite direction, from your 2 to year 1 (i.e. more recent surveys to successive are not shown here. Sites and years where the size frequency shifts significantly (0.0001) from small sizes historically to large sizes recently are highlighted in the table. All < 41mm abalone were removed from these tests.

Location	Site ID	Year 1 (F1)	Year 2 (F2)	D Value	P Value	Sig.
Port Bazan	2	1981	1986	0.4333624	0.0065	Yes
Port Bazan	3	1981	1986	0.1703174	0.0069	Yes
Port Bazan	3	1986	2019	0.622807	0.003	Yes
Port Bazan	3	1981	2019	0.7283237	0.0002	Yes
Port Bazan	4	1981	1986	0.1499658	0.1541	No
Port Bazan	4	1986	2019	0.754717	0.1113	No
Port Bazan	4	1981	2019	0.6217617	0.2164	No
Port Bazan	5	1981	1986	0.1858108	0.0132	No
Port Bazan	5	1986	2019	0.6904762	< 0.0001	Yes
Port Bazan	5	1981	2019	0.6138996	< 0.0001	Yes
Port Bazan	6	1981	1986	0.9297	< 0.0001	Yes
Port Bazan	6	1986	2019	0.4904762	0.1566	No
Port Bazan	6	1981	2019	0.7446809	0.013	No
Cordova Bay	42	1981	2019	0.9782609	0.1536	No
Cordova Bay	51	1981	2019	0.3076923	0.5187	No
Cordova Bay	54	1977	1979	0.0727794	0.4743	No
Cordova Bay	54	1977	1981	0.5548476	< 0.0001	Yes
Cordova Bay	54	1977	1986	0.4268144	< 0.0001	Yes
Cordova Bay	54	1977	2019	0.929558	< 0.0001	Yes
Cordova Bay	54	1979	1981	0.4730769	< 0.0001	Yes
Cordova Bay	54	1979	1986	0.4835544	< 0.0001	Yes
Cordova Bay	54	1979	2019	0.8717949	< 0.0001	Yes
Cordova Bay	54	1981	1986	0.1281609	0.248	No
Cordova Bay	54	1981	2019	0.4809524	0.055	No

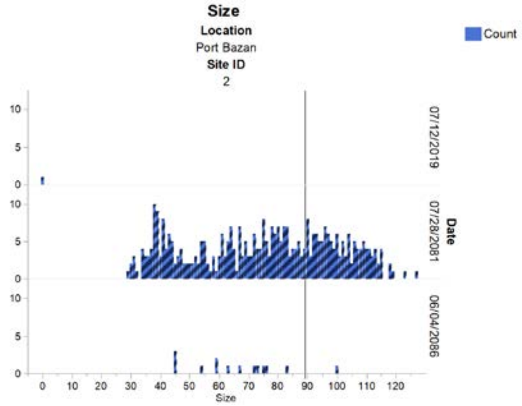
Cordova Bay	54	1986	2019	0.6502463	0.0035	Yes
Cordova Bay	83	1979	1980	0.3387097	< 0.0001	Yes
Cordova Bay	83	1979	2019	0.883333	0.2118	No
Cordova Bay	83	1980	2019	0.8924731	0.2068	No
Cordova Bay	85	1979	1980	0.5960784	0.0006	Yes
Cordova Bay	85	1979	2019	0.9647059	< 0.0001	Yes
Cordova Bay	85	1980	2019	0.9166667	0.0001	Yes
Gooseneck	95	1980	1986	0.6714194	< 0.0001	Yes
Gooseneck	95	1980	2019	0.7647059	< 0.0001	Yes
Gooseneck	95	1986	2019	0.2627877	0.1166	No
Gooseneck	96	1980	1986	0.7622523	< 0.0001	Yes
Gooseneck	96	1980	2019	0.8901099	< 0.0001	Yes
Gooseneck	96	1986	2019	0.6179113	< 0.0001	Yes
Gooseneck	97	1980	1986	0.3380742	< 0.0001	Yes
Gooseneck	97	1980	2019	0.6744186	< 0.0001	Yes
Gooseneck	97	1986	2019	0.6518595	< 0.0001	Yes
Gooseneck	100	1980	2019	0.6086957	0.0111	No

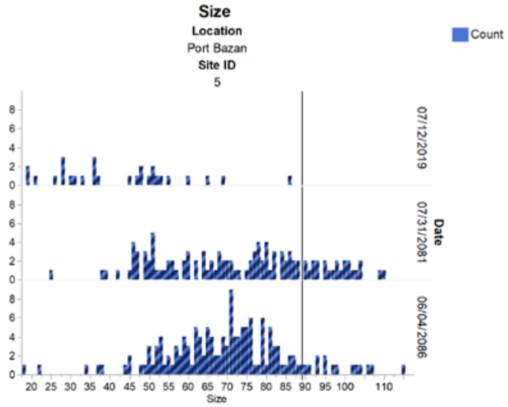
Figure 1. Size frequency histograms of timed swims organized by location and site and in order of most recent survey, 2019 (top) to most historic surveys (middle) The black line indicates pinto abalone legal size (89mm) for personal use harvest. All timed swims in 2019 surveys were done in Prince of Wales.

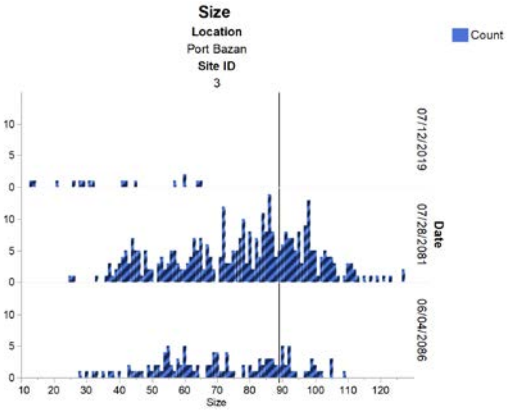
Location Gooseneck

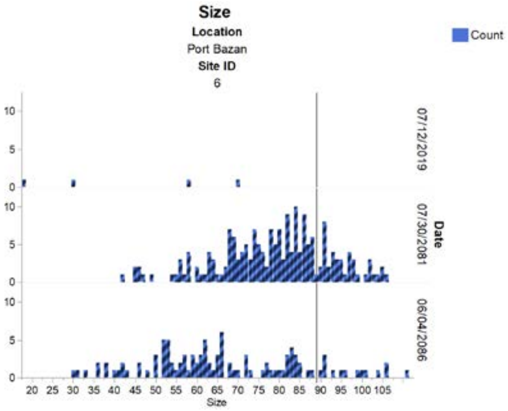


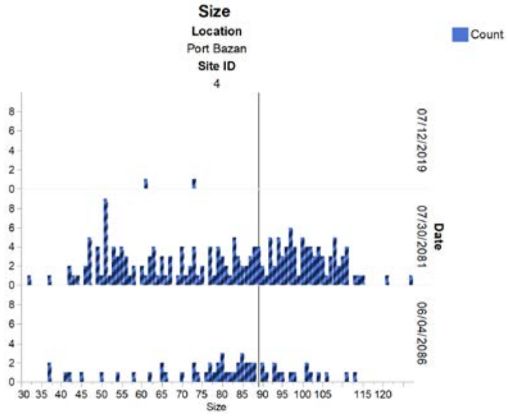
Location Port Bazan



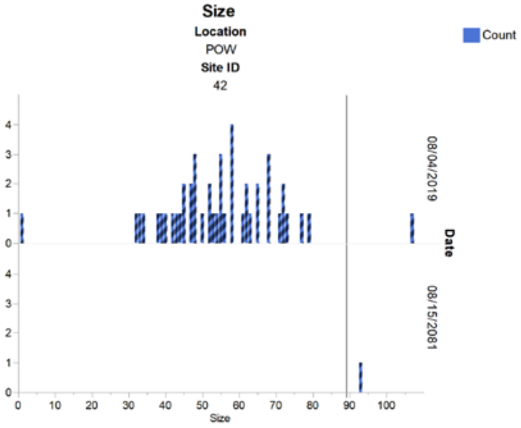


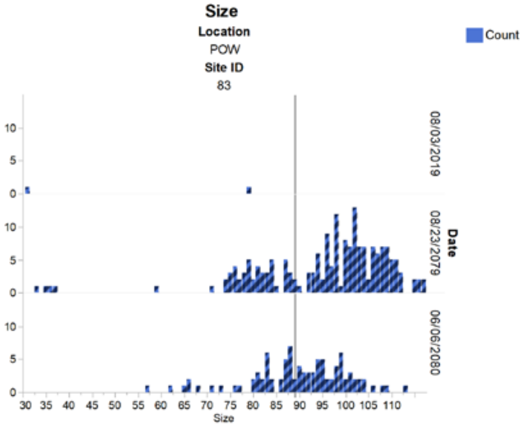


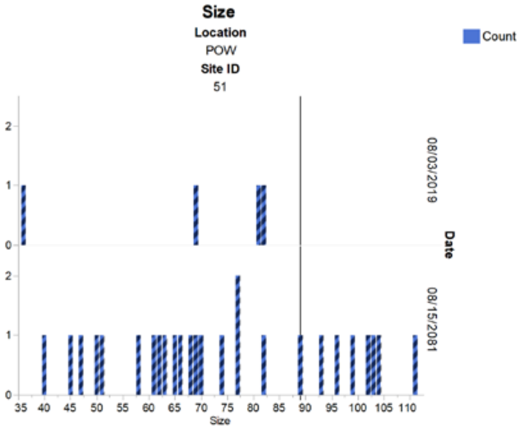


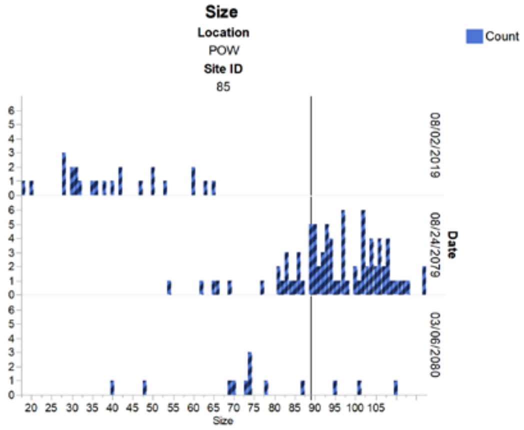


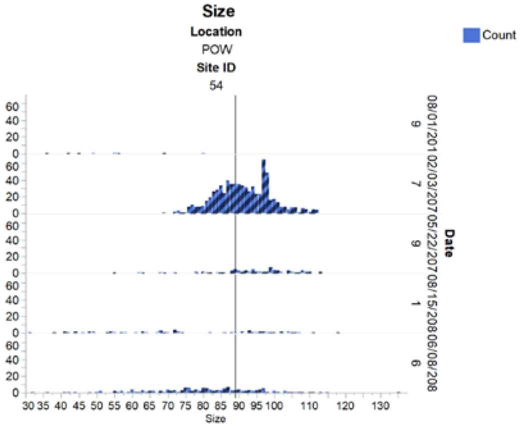
Location Cordova Bay (aka POW)











Appendix D - Ancillary Data

Table 1. 2019 Densities for each region and site, per transect (A: Shallow, B: Deep)

Region	Site location	Site Label	A/B	Abalone Density ab/m
Dixon Entrance	Bee Rocks	17	A	0.85
Dixon Entrance	Bee Rocks	17	B	0.85
Dixon Entrance	Bee Rocks	23	B	3.571428571
Dixon Entrance	Bee Rocks	23	A	0.2
Dixon Entrance	Duke	6	A	0.925
Dixon Entrance	Duke	6	B	0.225
Dixon Entrance	Duke	15	B	0.4
Dixon Entrance	Duke	15	A	0.075
Dixon Entrance	Duke	19	A	2.857142857
Dixon Entrance	Duke	19	B	0.475
Dixon Entrance	Duke	35	A	0.475
Dixon Entrance	Duke	35	B	0.075
Dixon Entrance	Duke	112	A	0.825
Dixon Entrance	Duke	112	B	0.15
POW	Gooseneck	95	A	0.075
POW	Gooseneck	95	B	0.05
POW	Gooseneck	96	A	0.125
POW	Gooseneck	96	B	0.025
POW	Gooseneck	97	A	0.175
POW	Gooseneck	97	B	0.125
POW	Gooseneck	99	A	0
POW	Gooseneck	99	B	0
POW	Port Bazan	2	A	0.1
POW	Port Bazan	2	B	0
POW	Port Bazan	3	A	0.025
POW	Port Bazan	3	B	0
POW	Port Bazan	4	B	0.075
POW	Port Bazan	4	A	0
POW	Port Bazan	6	A	0.025
POW	Port Bazan	6	B	0
Dixon Entrance	Percy Islands	18	A	0.3
Dixon Entrance	Percy Islands	18	B	0.25
Dixon Entrance	Percy Islands	12	B	0.325
Dixon Entrance	Percy Islands	12	A	0.275

Table 2. Mean abalone density per region

Region	**Year**	**Mean Density**
Ketchikan	2016	0.28
Meares Pass	2016	0.17
Dixon Entrance	2019	0.72797619
Prince of Wales	2019	0.05

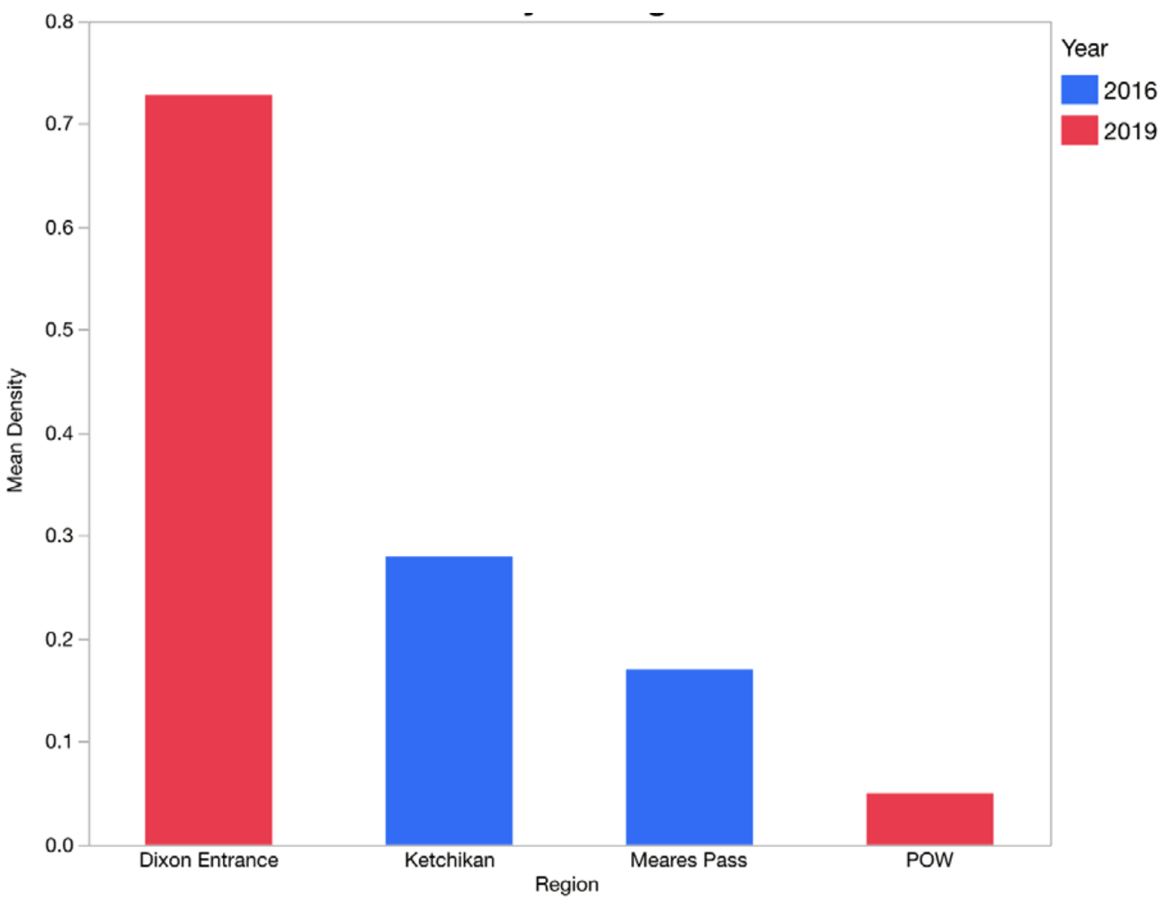


Figure 1. Average densities in Southeast Alaska regions. (Prince of Wales: POW)