Surveys for Olympia Oysters (Ostrea lurida Carpenter, 1864) at Six Index Sites in British Columbia - 2010 to 2021

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SURVEYS FOR OLYMPIA OYSTERS (*OSTREA LURIDA* CARPENTER, 1864) AT SIX INDEX SITES IN BRITISH COLUMBIA – 2010 to 2021

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ABSTRACT

Herder, E.C., Bureau, D., and Bigg, M.I. 2022. Surveys for Olympia oysters (*Ostrea lurida* Carpenter, 1864) at six index sites in British Columbia – 2010 to 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3477: viii + 90 p.

The Olympia Oyster (*Ostrea lurida* Carpenter, 1864) was designated a species of Special Concern under the Canadian *Species at Risk Act* in 2003 and a management plan was developed for the species in 2009. A primary objective of the plan was maintenance of the relative abundance of Olympia Oysters at index sites. Here, density is used as a proxy for abundance. Fourteen index sites were chosen in 2009 to monitor oyster density within their Canadian range. This number was reduced to six in 2018 so that annual surveys could be completed to better understand population dynamics and identify long-term trends. Observed densities at Port Eliza exhibited the highest density of oysters but showed a declining trend over time, density at index sites in Barkley Sound showed an increasing trend, and density in the Strait of Georgia remained relatively stable. Based on the observed trends, Olympia Oyster densities are being maintained at most index sites in British Columbia (BC). Variation in density estimates at sites over the survey years combined with a short time series provides the rationale for continued monitoring of Olympia Oyster at index sites. Data collected from future surveys will provide insight into trends in density and size and allow for continuing monitoring of Olympia Oyster populations in BC.

RÉSUMÉ

Herder, E.C., Bureau, D., and Bigg, M.I. 2022. Surveys for Olympia oysters (*Ostrea lurida* Carpenter, 1864) at six index sites in British Columbia – 2010 to 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3477: viii + 90 p.

En 2003, l'huître plate du Pacifique (*Ostrea lurida* Carpenter, 1864) a été désignée en tant qu'espèce préoccupante en vertu de la *Loi sur les espèces en péril* (LEP). En conséquence, on a élaboré un plan de gestion en 2009 pour cette espèce. Un des principaux objectifs du plan de gestion est d'assurer le maintien de l'abondance relative de l'espèce, et il a été déterminé qu'on utiliserait la densité comme indicateur de l'abondance. On a choisi quatorze sites témoins en 2009 pour surveiller la densité de l'espèce dans son aire de répartition dans les eaux canadiennes. En 2018, on a réduit le nombre de sites témoins à six, de sorte que chaque site puisse faire l'objet d'un relevé annuel pour mieux comprendre la dynamique de la population et déterminer les tendances à long terme. Les densités observées à Port Eliza présentaient la plus forte densité d'huîtres, mais ont montré une tendance à la baisse au fil du temps, la densité aux sites témoins dans la baie Barkley ont augmenté et la densité dans le détroit de Georgie est demeurée relativement stable. D'après les tendances observées, les densités d'huître plate du Pacifique se maintiennent dans la plupart des sites témoins en Colombie-Britannique. La variation des estimations de la densité dans les sites au cours des années de relevé, combinées à une courte série chronologique, justifient la poursuite de la surveillance de l'huître plate du Pacifique dans les sites témoins. Les données recueillies dans le cadre des relevés réalisés dans le futur donneront un aperçu des tendances potentielles en matière de densité et de la taille et permettront de poursuivre la surveillance de l'état de la population de l'huître plate du Pacifique en Colombie-Britannique.

INTRODUCTION

The Olympia Oyster, *Ostrea lurida* Carpenter, is one of four species of oysters established in British Columbia (BC), Canada, and the only naturally occurring oyster in BC (Bourne 1997; Gillespie 1999, 2009). *O. lurida* reaches the northern limit of its range in the Central Coast of BC at Gale Passage, Campbell Island, approximately 52°12'N, 128°24'W (Gillespie 2009).

First Nations historically utilized Olympia oysters for food and their shells for ornamentation (e.g., Ellis and Swan 1981; Harbo 1997). European settlers harvested Olympia oysters commercially from the early 1800s until the early 1930s when stocks became depleted and the industry moved towards other larger, introduced oyster species, mostly the Pacific Oyster (*Crassostrea gigas*) (Bourne 1997; Quayle 1988). Since that time, Olympia Oysters have likely maintained stable populations in BC, but have not recovered to abundance levels observed prior to the late 1800s (Gillespie 1999, 2009).

Olympia Oysters were designated a species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2000 and 2010 and listed on Schedule 1 under Canada's *Species at Risk Act* (SARA) in 2003 (DFO 2009; COSEWIC 2011). A management plan was developed and posted to the SARA Public Registry in 2009 (DFO 2009). One of the objectives of this plan was to ensure maintenance of the relative abundance of Olympia Oyster at index sites but it was determined that density would be used as proxy for abundance of Olmypia Oyster at these index sites. The plan also recommended development of a survey protocol for determining density estimates. In response, a Canadian Science Advisory Secretariat (CSAS) Research Document was completed recommending a survey method for Olympia Oysters (Norgard et al. 2010); a CSAS Science Advisory Report (DFO 2010) for selection of index sites was also completed. Olympia Oyster survey density is used as an index of abundance.

Thirteen index sites were selected in 2009 based on pre-exisiting survey information or by random selection. In 2014, a fourteenth site was added at Joes Bay in the Pacific Rim National Park Reserve in partnership with Parks Canada. Between 2009 and 2017, each site was surveyed a minimum of two times. In 2018, the number of index sites was scaled down to six, so that they could be monitored on an annual basis to better understand population dynamics and to more rapidly identify long-term trends. These sites include: Swy-a-lana Lagoon, Nanaimo; Transfer Beach, Ladysmith; Joes Bay, Barkley Sound; Hillier Island, Barkley Sound; Harris Point, Barkley Sound; and Port Eliza Beach #3, Nootka Sound (referred to as Port Eliza for the rest of this report). In 2020, no sites were surveyed due to the COVID-19 pandemic. The selected sites provide a representative sample of Olympia Oyster populations in key geographic zones on the BC coast where index sites have been established (Figure 1).

This report summarizes the results of all surveys that were completed at six index sites from 2010 to 2021. Assessment of Olympia Oysters at all index sites was previously summarized and reported in Norgard et al. (2018).

METHODS

During initial site investigations (2009-2011), oyster beds were identified from literature (e.g., Gillespie 2009; Stanton et al. 2011; Finney et al. 2012) and through reconnaissance to determine beaches that had Olympia Oysters present.

The rationale for the original index site selection followed DFO (2010). In 2009, ninety-eight beaches were visited throughout British Columbia to assess the distribution of Olympia Oysters (Stanton et al. 2011). From this survey, thirteen index sites were chosen within four zones: Northwest Vancouver Island (NWVI), Southwest Vancouver Island (SWVI), Strait of Juan de Fuca (JDF), and Strait of Georgia (SOG) as threats to Olympia Oyster vary by location (DFO 2009). For example, pollution, habitat alteration, and previous overharvesting are the primary threats to Olympia Oyster in the Strait of Georgia (SOG) while species competition and the introduction of invasive species is the primary threat to Olympia Oyster on the west coast of Vancouver Island (SWVI) (DFO 2010). Two sites from each zone were selected because either data already existed for a particular site, the oyster bed was easily accessible, or because an opportunity for future collaborations existed. Two additional sites from each zone were selected randomly using a random number generator (DFO 2010). No extra sites were randomly selected in JDF due to the limited number of Olympia Oyster beaches in this zone. This method of site selection balanced the need for a statistically rigorous random survey design while also accounting for the constraints associated with long-term field sampling (e.g., limited budget and accessibility) (DFO 2010).

The six index sites surveyed annually since 2018 (selected from the original 14 index sites) represent both randomly selected sites and opportunistic sites. Hillier Island and Transfer Beach were randomly selected, Harris Point was selected because previous survey information already existed for this site, and Swy-a-lana Lagoon was selected because previous survey information existed for this site and because it was easily accessible. Port Eliza Beach # 2 was originally identified as an index site in 2009 (DFO 2010) but this beach was eliminated in favour of Port Eliza (Beach #3) because more data were already available for this site. Joes Bay was selected because it provided a collaborative opportunity with Parks Canada.

DEFINING AND MAPPING SURVEY STRATA AND OYSTER BEDS

The entire Olympia Oyster bed at each site was mapped, in selected years when time was available to do so, by walking the perimeter of the bed starting at the low tide line and recording a track on a GPS unit. The outer boundaries of the beds were defined by the absence of Olympia Oysters. The GPS track was later imported into ArcGIS to estimate the surface area of each Olympia Oyster bed.

Survey strata were positioned to cover as much of the Olympia Oyster bed as possible while maximizing the area to be surveyed over one or two consecutive days at low tide. Survey strata were rectangular in shape to allow for ease of survey set-up. The long axis of a stratum typically runs parallel to shore and is defined as the Baseline, the perpendicular axis runs from shore towards the water and is defined as the Transect Length. The upper-left (when facing the water/back to shore) corner of a stratum is defined as the origin or 0-0 coordinate of the stratum. Multiple strata were used at four index sites where beds were large or discontinuous (Port Eliza, Joes Bay, Swy-a-lana Lagoon, Transfer Beach). Index sites at Harris Point and Hillier Island were each a single stratum. The goal was to survey the same strata, i.e., use the same strata corner points, on all surveys of a site; strata corner coordinates from prior survey years were used to locate strata corners on subsequent surveys. Refinements to strata boundaries have been made over time to exclude areas that are not able to be surveyed (e.g., subtidal portions) and slight increases to strata area have occurred to include more habitat if time allowed.

Between 2010-2013, a Panasonic U1 toughbook computer with integrated GPS was used to map corner points and the bed. GPS accuracy increased with use of the Trimble GPS Pathfinder Pro which was used to identify strata corner points from 2014 to 2019. From 2014 onward, coordinates for corner points were recorded for each survey that was completed. In 2021, an Arrow 100 GPS receiver coupled to a L1 G1 L-Band Antenna was used to identify the location of strata corner points and quadrat locations (see below).

Survey Design

Olympia Oyster index surveys followed a stratified two-stage (StTS) survey design (Gillespie and Kronlund 1999; Norgard et al. 2010); with transects used as first-stage units and quadrats along transects used as second-stage units. The StTS survey design stratifies the survey area by distributing the sampling over the large survey area. The first-stage units (transects) partition the strata into smaller sampling units and the second-stage units (quadrats) are randomly selected along each of the transects. Transects are of equal length and quadrats are square and of equal size (50 cm by 50 cm). This survey method is described by Gillespie and Kronlund (1999) and Kronlund et al. (1998).

Transect and quadrat positions were randomly selected in advance of the surveys using R code. For surveys between 2010-2019, first-stage units (transects) were randomly selected at positions along the baseline (long axis of the stratum, generally running parallel to shore). Minimum spacing between transects was greater than the quadrat width so that no quadrats overlap. The transect length was divided by the number of desired quadrats along each transect. The number of desired quadrats was based on the total number of quadrats sampled per stratum (See below, *Sampling Intensity*). The position of the first quadrat along the transect was randomly selected in the first portion of the transect. The remaining quadrats were then systematically positioned along the length of transect. The resulting output was a series of random cartesian X-Y quadrat coordinates (in meters) from the origin corner of the stratum.

In 2021, the random quadrat location R code was modified to read strata parameters (corner positions, baseline length, transect length, target number of quadrats) directly from the DFO Clam database. Random transect and quadrat locations were selected (random cartesian X-Y coordinates as in previous years). The cartesian random quadrat locations were then converted to latitude and longitude coordinates using bearing and distance of the quadrat from the stratum origin (high-left (with back to shore) corner) and the baseline bearing (bearing from upper-left to upper-right stratum corners) (Appendix 1). The R code was also modified to randomly select quadrats from which biological samples (i.e., measurements of individual Olympia Oyster shell length) should be collected. The new version of the R code still provides random X-Y cartesian quadrat locations as a backup in case of failure of the GPS equipment.

From 2010 to 2019, the location of first-stage units (transects) were established by placing a tape measure along the Baseline of the stratum on the beach between the high-left and high-right corners of the stratum (corner points of each stratum were located with GPS and marked with flags). Quadrat locations were located using a tape measure placed perpendicular to the baseline for each transect.

In 2021, the latitude and longitude coordinates of all quadrats and corner points were loaded into the AMIGO Cloud Application (v1.0) on a rugged Android tablet interfaced with Arrow 100 GPS receiver and mounted to a carbon fiber pole. This equipment allowed the surveyor to walk directly to each quadrat location on the beach. This method removed the need for using a tape measure to identify the location of transects and quadrats and provides precise location of each quadrat on the beach enabling spatial visualization of the data.

Sampling Intensity

Sampling intensity (number of quadrats) in each stratum was initially determined at the time of the survey and was dependent on the amount of time available to complete the survey and on the density of Olympia Oysters at the site. A sampling intensity of 50 quadrats was targeted for high density beaches and 100 quadrats for low density beaches as per Norgard et al. (2010). Refinements to sampling intensity have been made at numerous sites to address the objectives of narrowing confidence intervals (CIs) and improving survey precision (defined below). The sampling intensity is now pre-defined for each site but may be adjusted on a site by site basis in the future based on population trends.

Data Collection

Sites were surveyed at the lowest spring and summer tide cycles. Olympia Oysters are generally located in the low intertidal, so low tides of 0.1m or lower were selected when possible. Surveys utilized quadrats of area 0.25 m^2 (50 cm x 50 cm) as recommended in Norgard et al. (2010) with the exception of Transfer Beach in 2011 which was surveyed with quadrats covering 0.0625 m^2 (25 cm x 25 cm) in area. The number of live Olympia Oysters located on the surface layer of the quadrat including on and under rocks, shells and other substrate was counted and recorded in field datasheets.

Olympia Oyster shell lengths were measured, with calipers (to the nearest mm), in a randomly selected sub-set of survey quadrats. All Olympia oysters within each quadrat were measured. When a total of at least 50 Olympia Oysters were measured over all the randomly selected quadrats, no more quadrats were selected. Starting in 2021, all quadrats assigned for collecting measurements were measured. Shell length was measured from the umbo to the posterior shell margin (Quayle 1988). The number of oysters measured varied considerably between years and sites. Sample size was dependent on the amount of time available to complete all survey elements; if time permitted, more were measured.

Prior to 2011, Olympia Oysters were not separated into size categories and the densities for those years included all sizes of oysters (except Hillier Island which was separated by size category in 2011). A small size category (shell length $\leq$ 15 mm) was created to allow densities of small oysters to be presented separately. For beaches with both Olympia and Pacific Oysters, the small size category acknowledges the level of uncertainty inherent in distinguishing small oysters of the two species. This category also provides a general indication of recruitment events like those evident at Port Eliza (2012) and Hillier Island (2010, 2012) where densities of small oysters were much higher than in other years at those sites. However, overall recruitment success and mortality (of small oysters) has not been assessed as part of index site surveys.

All data collected were entered into DFOs intertidal clam database managed by the Fishery and Assessment Data Unit at the Pacific Biological Station, Nanaimo BC.

ANALYSIS

The Independent Sampling Design function (Svydesign) from the R software package *survey* (version 4.1-1) was used to estimate density. The Svydesign is a robust method to calculate density that can adjust for different lengths of transects within the two stage sampling design using a cluster analysis. Data in all surveys were standardized to 1 m^2 within the R code as part of the analysis. R software code was also used to produce all density and length frequency figures (Appendix 2).

For surveys with more than a single stratum, overall density estimates were calculated using the methods of Gillespie and Kronlund (1999). The population mean was estimated as:

$$\bar{y}_{StTS} = \frac{\sum_{h=1}^{H} N_h M_h \bar{y}_h}{\sum_{h=1}^{H} N_h M_h} = \sum_{h=1}^{H} W_h \bar{y}_h \qquad \text{Equation 1}$$

where

$$W_h = \frac{N_h M_h}{\sum_{h=1}^{H} N_h M_h} \qquad \text{Equation 2}$$

and

$$\bar{y}_h = \frac{1}{n_h m_h} \sum_{i=1}^{n_h} \sum_{j=1}^{m_h} y_{hij}$$

Equation 3

The variance of the population mean ($\hat{V}$) was estimated as:

$$\hat{V}(\bar{y}_{StTS}) = \sum_{h=1}^{H} W_h^2 \left[\frac{1 - {n_h}/{N_h}}{n_h} s_{1h}^2 + \frac{\left({n_h}/{N_h}\right)\left(1 - {m_h}/{M_h}\right)}{n_h m} s_{2h}^2 \right] \qquad \text{Equation 4}$$

where

$$s_{1h}^2 = \frac{\sum_{i=1}^{n_h} \left(\bar{y}_{hi\cdot} - \bar{y}_{h\cdot\cdot}\right)}{n_h - 1} \qquad \text{Equation 5}$$

and

$$s_{2h}^2 = \frac{\sum_{i=1}^{n_h} \sum_{i=1}^{m_h} \left(y_{hij} - \bar{y}_{hi\cdot}\right)}{n_h (m_h - 1)} \qquad \text{Equation 6}$$

and where h is the index for strata, i is the index for first stage units (transects), j is the index for second stage units (quadrats), N_h is the number of potential first stage units in the h^{th} stratum (i.e., baseline length/quadrat width), M_h is the number of potential second stage units per transect in the h^{th} stratum (i.e., transect length/quadrat width), W_h is the relative weight of stratum h in terms of potential second stage units, n_h is the number of first stage units selected from stratum h, m_h is the number of quadrats in each first stage unit in stratum h, y_{hij} is the count of Olympia Oysters in quadrat j of first stage unit i from stratum h, s^2_{1h} is the sample variance among first stage units in stratum h and s^2_{2h} is the sample variance between second stage units in stratum h.

The approximate 95% confidence interval (CI) for the population mean was estimated as:

$$\bar{y}_{StTS} \pm (1.96)\sqrt{\hat{V}(\bar{y}_{StTS})} \qquad \text{Equation 7}$$

Survey precision (Norgard et al. 2010) was calculated as:

$$\text{precision} = \left(\frac{\text{CI}}{\text{mean}}\right) \text{x } 100 \qquad \text{Equation 8}$$

where *mean* is the estimated mean density, *CI* is the 95% confidence interval of the mean estimate and precision is expressed as a percentage. Target precision for intertidal surveys was $\leq$ 30% (Allen and Davis, unpub. manuscript; Norgard et al. 2010). Precision was reviewed at the end of each survey and sampling intensity was increased for subsequent surveys if the precision value was high (i.e., indicating high variability). Sites with a large number of quadrats without oysters had an effect on confidence intervals.

Mean Olymipa Oyster shell length and 95% confidence intervals were also calculated for each site and year surveyed.

RESULTS AND DISCUSSION

The six Olympia Oyster index sites represent three zones: Northwest Vancouver Island (NWVI), Southwest Vancouver Island (SWVI), and Strait of Georgia (SOG). A fourth zone, Juan de Fuca Strait (JDF), contains sites selected as part of the original index site selection process (DFO 2010) (Figure 1). A total of 34 surveys were completed at six index sites between 2010 and 2021 (Table 1). Harris Point, Hillier Island, Joes Bay, Swy-a-lana Lagoon, and Transfer Beach were surveyed six times and Port Eliza was surveyed four times.

Figures 2 to 13 show site photos, location maps, the survey area dimensions, the current strata configuration, oyster bed and also the corresponding density graphs and length frequency histograms for each year sampled. Table 2 shows changes in Olympia Oyster bed area over time, and Table 3 summarizes density, 95% confidence intervals, and survey precision for each survey completed.

This report compares bed area, survey design, strata areas, densities, size frequencies, and other parameters for Olympia Oyster populations at each index site over multiple years.

NORTHWEST VANCOUVER ISLAND

Port Eliza

Location and Habitat Description

Port Eliza is located on the north side of Esperanza Inlet on northwest Vancouver Island. The index site beach is located about two thirds of the way up Port Eliza on the east side (Figure 2). This site is classified as beach code 25-12-005.

The beach is covered with small rocks and cobble, has a low slope, and has a creek that discharges through the middle of the oyster bed.

Survey Frequency and Design

This beach was surveyed in 2010, 2012, 2013 and 2021 (**Error! Reference source not found.**). The mapped Olympia Oyster bed area was 6,851 m^2 in 2012, 8,688 m^2 in 2013, and 9,257 m^2 in 2021 (Table 2). The Olympia Oyster bed at Port Eliza is split into two by a creek that runs through the middle of the bed. Only the side of the oyster bed containing the survey strata has been mapped. The oyster bed at Port Eliza is therefore much larger than the area mapped from year to year. In 2012, a portion of the bed to the southeast that was captured in 2013 and in 2021 was not mapped, leading to its smaller overall size.

In 2010, a single stratum (1,200 m^2) containing 14 quadrats was surveyed due to an insufficiently low tide. In 2012, the strata were changed from one smaller stratum to two larger strata. Strata 1 (1,850 m^2) had 45 quadrats surveyed and Strata 2 (1,600m^2) had 40 quadrats surveyed. In 2013, only stratum 1 (the re-defined strata from 2012) had 35 quadrats surveyed as additional time was required to count high numbers of oysters within the quadrats, most of which were small. Similar to 2012, in 2021 two strata were surveyed (45 and 40 quadrats, respectively), though a low tide in the early morning hours restricted survey time (Table 3).

Oyster Density

Changes to the number of strata and to the strata areas between years preclude meaningful comparison of overall density. Going forward, it is anticipated that two strata (85 quadrats total) will be surveyed to enable analysis of time series data at this site.

Density of Olympia Oysters oysters (all sizes) in stratum 1 was over 200 oysters m^{-2} in 2010 and 2013. In 2012, overall density (all sizes) of Olympia Oysters was also greater than 200 oysters m^{-2}. In 2021, overall density (all sizes) was the lowest observed in the time series at 90.1 ± 30.8 oysters m^{-2} (Table 3, Figure 3).

In stratum 1, density of oysters (all sizes) ranged from a low of 52.8 ± 28.4 oysters m^{-2} in 2021 to a high of 507.0 ± 74.1 oysters m^{-2} in 2013. In stratum 2, density of oysters (all sizes) was highest in 2013 (316.2 ± 55.7 oysters m^{-2}) and was less than half that density in 2021 at 133.3 ± 57.7 oysters m^{-2}. The density of the large oyster category for stratum 1 shows a decreasing trend from 2010 to 2021.

The small oyster size class (≤15 mm) had low densities in all years and both strata except in 2013 when a high density of small oysters (347.5 ± 115.8 oysters m^{-2}) was observed in stratum 1. In 2013, small oysters dominated the length frequency distribution and provided general evidence of a recent recruitment event (Figure 3). However, not all small oysters were able to be counted in several quadrats resulting in an underestimation of the density of small oysters. However, in 2013 only stratum 1 with 35 quadrats was surveyed; whereas in 2012 and 2021, 85 quadrats in two strata were surveyed, limiting meaningful comparison of densities and shell lengths between years. Low numbers of Pacific Oysters observed between 2010 and 2013 provide confidence that the recruitment event was Olympia Oysters and not small Pacific Oysters.

In 2012 and 2013, survey precision values were in the target range below 30% (See precision, pg.7). In 2021, survey precision was outside the target range (54% for stratum 1, 43% for stratum 2) (Table 3). In 2021, dead/opened empty shells were counted in five quadrats. Four quadrats contained between 17 and 53 dead/empty shells and the fifth quadrat contained 216 dead/empty shells. Between June 25 and July 1, 2021, BC experienced a heat dome and daily high temperatures ranged between 36 and 45°C in the town of Zeballos (June 25-28, 2021). This survey was conducted after the heat dome which may have contributed to the lower density estimates observed in 2021 and the large number of dead/empty shells in quadrats. However, this beach was surveyed for Olympia Oysters in 2009 (an exploratory survey to confirm historic records of Olympia oyster presence (Stanton et al. 2011), and dead/empty shells were recorded for all 67 quadrats sampled. During that survey, 19 quadrats had 0 dead shells, 56 quadrats had < 50 dead shells, and two quadrats had > 50 dead shells with one of those quadrats containing 144 dead shells. Based on these results, it may be common to find dead/ empty shells at this site.

Shell Length

Mean length of Olympia Oysters remained stable in 2010 and 2012. In 2010, mean length was 32.8 ± 0.7 mm in 2010 and in 2012 mean length was 33.3 ± 0.6 mm (Figure 3). For these years, the proportion of oysters (particularly those over 30 mm) was also maintained.

In 2013, a recruitment event was observed. Mean length was 7.9 ± 1.0 mm (Figure 3) with the largest proportion of oysters measured being small oysters ≤ 15 mm. In 2013, there was an insufficiently low tide and limited time available to measure oysters in quadrats that were selected for biological sampling (not all small oysters were counted and measured, but all large oysters were counted and measured), likely resulting in an underestimation of small oysters. In 2021, eight years after the 2013 recruitment event, mean length was 25.9 ± 0.7 mm and there was a cohort of oysters greater than 15 mm in length. The oysters measured in 2021 could include a proportion of those oysters that had grown since the 2013 recruitment event (Table 4, Figure 3).

SOUTHWEST VANCOUVER ISLAND

Index sites for SWVI are Harris Point, Hillier Island and Joes Bay, all located in Barkley Sound (Figure 1). These sites were all surveyed in May 2021, before the heat dome that occurred between June 25 and July 1, 2021. In Barkley Sound, air temperatures reached a high of 36°C (Ucluelet, BC) during the heat dome, however the lowest tide of the day occurred between 06:53 am and 11:26 am while highest tides each day occurred in the afternoon when the highest temperatures of the day would have been reached.

Harris Point

Location and Habitat Description

Harris Point is located in northeastern Barkley Sound at the mouth of Pipestem Inlet (Figure 4). This index site is a small saddle beach just south of Harris Point. This site is classified as beach code 23-10-005.

The beach has a low slope with a substrate of gravel, cobble and boulders. A creek flows from a lagoon in the upper beach and runs through the oyster bed.

This beach has a high abundance of Pacific Oysters which co-occur with the Olympia Oysters. Larger Pacific Oysters were easily distinguished from Olympia Oysters, however, difficulties in identifying small oysters may have resulted in over-estimation of small Olympia Oyster densities.

Survey Frequency and Design

Harris Point was surveyed in 2010, 2012, 2014, 2018, 2019, and 2021 (Table 1). Stratum size changed slightly from year to year at this site, ranging from 250 m^2 to 300 m^2 while the number of quadrats sampled ranged from 28 to 40. There is only one stratum at this site. This site has a large Pacific Oyster bed which complicated defining the Olympia Oyster bed boundary so changes in the stratum size and number of quadrats sampled occurred as a better understanding of this beach was gained.

The mapped Olympia Oyster bed area was 845 m^2 in 2010, 1,270 m^2 in 2012, 761 m^2 in 2014, 647 m^2 in 2018, and 1,554 m^2 in 2021 (Table 2). The least comparable bed area is from 2014 when only the area immediately around the stratum at this site was mapped. In 2010, 2012, and 2018 the bed area was narrower overall compared with 2021.

Oyster Density

The density of Olympia Oysters (all sizes and large categories) at Harris Point has been on an increasing trend from 47.0 ± 10.9 m^{-2} in 2010 to 258.9 ± 20.0 m^{-2} in 2021 (Table 3, Figure 5). Density of small Olympia Oysters (≤15 mm) was low in 2012, 2018, and 2019 (< 15.0 m^{-2}) but was high in 2014 (53.9 ± 21.1 m^{-2}) and 2021 (82.3 ± 32.2 m^{-2}), suggesting recruitment events in these years.

Survey precision was in the target range below 30% in most years, except for the small size category when all precision was outside the target range (Table 3).

Shell Length

Mean shell length of Olympia Oysters decreased from 31.3 ± 1.4 mm in 2010 to 18.5 ± 1.2 mm in 2014. In 2018, mean length slightly increased to 29.8 ± 0.6 mm but then decreased to 25.8 ± 0.9 mm in 2019 and 21.0 ± 1.0 mm in 2021 (Table 4, Figure 5). The low mean shell length values for 2014 and 2021 are likely attributed to recruitment events which show a larger proportion of ≤15 mm oysters (Figure 5). The larger mean shell length in 2018 of 29.8 ± 0.6 mm compared to 2014 at 18.5 ± 0.1 mm is likely in part due to growth of small oysters observed in 2014 and low densities of small oysters in 2018.

Hillier Island

Location and Habitat Description

Hillier Island is located in Toquart Bay in northeast Barkley Sound (Figure 6). This site is classified as beach code 23-10-002.

The large beach has a low slope, gravel substrate and a creek that runs adjacent to where strata were located. The beach has patchy distributions of both Olympia and large Pacific Oysters.

Survey Frequency and Design

The site was surveyed in 2010, 2012, 2014, 2018, 2019, and 2021 (**Error! Reference source not found.**). Stratum size has been consistent since 2014 with an area of 2,700 m^2. There were only slight differences in size in 2010 (+ 30 m^2) and 2012 (- 180 m^2). There is only one stratum at this site. Sampling intensity has varied among years from 120 quadrats (2010) to 40 quadrats (2012), and 74 quadrats (2014). Since 2018, 80 quadrats have been surveyed (79 quadrats in 2021 as one quadrat was incomplete due to tidal inundation).

The mapped Olympia Oyster bed area varied between years. Bed area was 4,065 m^2 in 2010, 8,673 m^2 in 2012, 6,760 m^2 in 2014, and 6,245 m^2 in 2018 (Table 2).

Oyster Density

Mean density of oysters (all sizes) varied from year to year at this site. In 2018, overall density was lowest at 19.9 ± 4.3 oysters m^{-2}. This was a decline from the start of the time series in 2010 when density was 62.4 ± 29.7 oysters m^{-2}. Density was highest in 2021 at 136.9 ± 28.0 oysters m^{-2} (Table 3, Figure 7). Both the mean densities in 2018 and 2019 show narrow confidence intervals indicating little variation in density within the quadrats in the stratum.

In 2012, 2018, and 2019, small oyster densities was relatively low and were below the mean for 2019 at 5.1 ± 2.4 oysters m^{-2}. Comparatively, density of small oysters (≤ 15 mm) was higher in 2010 (34.9 ± 24.4 oysters m^{-2}), 2014 (23.1 ± 9.4 oysters m^{-2}), and in 2021 (43.9 ± 14.9 oysters m^{-2}) suggesting recruitment events had occurred in these years (Table 3, Figure 7).

The density of large oysters in 2010 was lower than that of small oysters. In 2014 and 2021 the density of large oysters was roughly double that of small oysters. These data are consistent with a persistent adult population in addition to regular recruitment events in these years.

Survey precision was poor in 2010 and 2012. From 2014 onward, survey precision was below the target range of 30% except for the small size category which exceeded 30% every year.

Shell Length

Mean shell length was lowest in 2010 (10.3 ± 0.7 mm) increased to 23.3 ± 0.9 mm in 2012. In 2012, there was a higher proportion of large oysters > 15 mm, likely attributed to the cohort of small oysters observed in 2010, that grew over two years. Mean shell length was 23.5 ± 2.2 mm in 2014 and increased to 28.4 ± 1.2 mm in 2018 likely due to the recruitment of 2014 and increase in shell growth over four years. Mean shell length then decreased slightly in 2019 to 25.5 ± 1.1 mm. In 2021, mean shell length increased to 26.0 ± 1.4 mm (Table 4, Figure 7). Overall mean shell length has not varied greatly between 2012 and 2021.

Joes Bay

Location and Habitat Description

Joes Bay is located on the northeast side of Turtle Island in the Broken Group Islands of Pacific Rim National Park Reserve (Figure 8). This site is classified as beach code 23-08-002. Surveys at this site are led by Parks Canada Ecologists.

This index site includes a small stratum across a bedrock outcrop between two embayments (stratum 1) and a larger stratum in the small bay on north side (stratum 2). Stratum 2 has a moderate slope and its substrate is cobble and gravel.

Survey Frequency and Design

The site was surveyed in 2014, 2015, 2017, 2018, 2019, and 2021 (**Error! Reference source not found.**). This site was not part of the original set of index sites identified in DFO (2010). Parks Canada and DFO have worked in partnership since 2014 to conduct surveys and monitor Olympia Oysters at Joes Bay as part of the Parks Canada Shellfish Monitoring Program. Parks Canada utilizes the same survey methodology and design used by DFO at index sites.

In 2014 and 2015 both strata were surveyed. However, Olympia Oyster densities were very low in stratum 1. This stratum (33 m^2) was designed to include a narrow band on the southeastern portion of the bed across a bedrock outcrop. In 2015, the boundaries of stratum 2 were shifted seaward into high quality Olympia Oyster habitat. As of 2017, only stratum 2 has been surveyed.

In 2014, the bed area was 788 m^2 and encompassed both strata, however the bed area around stratum 1 was small with stratum 2 roughly 750 m^2. In 2018 the bed area around only stratum 2 was 635 m^2.

Oyster Density

Using the newly defined stratum 2 (as of 2015), the density of Olympia Oysters (all sizes and large category) increased between 2015 and 2017 and has remained stable through to 2021. Density was low in 2015 with 11.0 ± 8.8 oysters m^{-2} compared to 2021 with 37.1 ± 9.5 oysters m^{-2}. Density of small oysters fluctuated between 2015 and 2021 but remained low in all years surveyed. Density of small oysters was similar in both 2015 (4.6 ± 3.2 oysters m^{-2}) and in 2021 (5.3 ± 2.3 oysters m^{-2}) (Table 3, Figure 9). Based on these results, there is low recruitment at this site.

Survey precision was poorest for all size categories in 2014 and 2015 for stratum 2. In 2014, stratum 2 was located over poor oyster habitat and in 2015 stratum 2 was moved, but sampling intensity was low. Survey precision improved after 2015.

Shell Length

Mean length in 2014 was 35.8 ± 3.0 mm (includes measurements from stratum 1; sample size was small (n = 58)); between 2017 and 2019, mean length was approximately 30 mm, and in 2021 mean length declined to 26.9 ± 1.5 mm. Length measurements of oysters were not collected in 2015 (Table 4, Figure 9).

In 2021, the largest maximum shell length recorded for all 34 surveys done at these six index sites since 2010 was at Joes Bay with a length of 63 mm.

STRAIT OF GEORGIA

Olympia oyster index sites in the Strait of Georgia are Swy-a-Lana Lagoon in Nanaimo and Transfer Beach in Ladysmith (Figure 1).

Swy-a-Lana Lagoon

Location and Habitat Description

This index site is located in Maffeo Sutton Park in the City of Nanaimo (Figure 10). This site is classified as beach code 17-14-002.

Olympia Oysters do not form defined beds at this site; they are located within large concrete intertidal terraces that separate Nanaimo Harbour from Swy-a-lana Lagoon. Substrates within each terrace are comprised of boulders, cobble and gravel. All terraces form pools that remain flooded at low tide. Olympia Oyster aggregations have been observed on the subtidal terrace walls on the protected side of the lagoon where they co-occur with Pacific Oysters; Olympia Oysters are also present on the exposed, Nanaimo Harbour side where few Pacific Oysters are present.

Survey Frequency and Design

The site was surveyed in 2010, 2013, 2016, 2018, 2019, and 2021 (**Error! Reference source not found.**). The site is comprised of three strata, with strata 1 and 2 facing Nanaimo Harbour and stratum 3 positioned on the lagoon side toward the City of Nanaimo (Figure 10).

Stratum 1 is 20 m x 8 m and stratum 2 is 28 m x 10 m. These strata have varied slightly from year to year because the upper corner points of these two strata are located under a bridge, creating difficulty to acquire accurate GPS positions for these corners. Stratum 3 is 48 m x 6 m and has remained this size since 2010.

Oyster Density

Overall density of oysters (all sizes) has varied from year to year with a low of 33.6 ± 8.5 oysters m^{-2} in 2019 and a high of 83.9 ± 23.2 oysters m^{-2} in 2021. The 2021 survey occurred after the heat dome event that occurred between June 25 - July 1, 2021 when temperatures reached 40.5°C on June 28^{th}, 2021 (Nanaimo).

Density of oysters (all sizes) was low in strata 1 and 2 in 2010, 2013, and 2016 (< 13 oysters m^{-2}), but was higher between 2018 and 2021 where density of oysters (all sizes) reached a high of 24.5 ± 9.9 oysters m^{-2} in stratum 2 in 2021. Density of small oysters has remained low in all years and all strata except for 2018 in stratum 2 when 15.5 ± 4.1 oysters m^{-2} were observed. This density was roughly similar to the large oyster class in this stratum (17.5 ± 1.9 oysters m^{-2}), consistent with a recruitment event occurring (Table 3, Figure 11).

Stratum 3 has driven overall oyster density at this site with high densities occurring in this stratum ranging from 48.2 ± 16.7 oysters m^{-2} in 2019 to 165.1 ± 53.6 oysters m^{-2} in 2021 Table 3). Oyster densities (large and all sizes) in strata 2 and 3 fluctuated between 2010 and 2016, showed a decrease in 2018 and 2019 but increased again in 2021. A portion of quadrats surveyed in stratum 3 were done using SCUBA diving due to water depth and because a large number of the oysters in this stratum are attached to the walls of the terraces at depths of over a meter in a large portion of the stratum. Species identification of individuals located in deeper water and that are attached to the terraces is difficult and may have resulted in an over estimation of Olympia Oysters where mixed amongst Pacific oysters.

Survey precision was below the target range of 30% for 2013, 2019 and 2021 (for oysters of all sizes) and slightly greater than the target range for the other three years (Table 3).

Shell length

Mean shell length of Olympia Oysters has fluctuated among years sampled with no clear trend. The lowest mean length was observed in 2010 (25.2 ± 1.5 mm) and the highest mean length was observed in 2019 (36.3 ± 1.4 mm) (Table 4, Figure 11).

Transfer Beach

Location and Habitat Description

The Transfer Beach index site is located on the south side of Ladysmith Harbour (Figure 12). This site is classified as beach code 17-07-023.

The beach is adjacent to Transfer Beach Park and is used heavily by people year round. The substrate is comprised of boulder and cobble and the beach has a moderate slope. Large and small-sized Pacific Oyster and Olympia Oyster co-exist on this beach.

Survey Frequency and Design

This site was surveyed in 2011, 2012, 2016, 2018, 2019, and 2021 (Table 1). In 2011, only stratum 1 was surveyed and it was 420 m^2. Stratum 1 was made larger in 2012 and a second stratum was added in 2012. Both strata 1 (720 m^2) and 2 (480 m^2) were surveyed every year thereafter. In 2019 the transect length of stratum 2 was reduced from 8 m to 4 m (total stratum area 240 m^2) because the lower portion of this stratum could only be surveyed on extremely low tides, during a very short time period and therefore was often submerged and could not always be surveyed (Table 3).

The mapped oyster bed was 681 m^2 in 2011 and 1,896 m^2 in 2018 (Table 2). In 2011, the bed area was only mapped around the single stratum defined in 2011. The mapped bed area in 2018 encompassed both strata and extended to the low tide line.

Oyster Density

Overall density of oysters (all sizes) for both strata combined (overall) has remained relatively stable between 2012 and 2021, except in 2016 when densities of both small and large oysters were relatively high, though only stratum 1 was surveyed and variability was high (Figure 13). The reason for the high densities and high variability observed in 2016 is unkown due to a lack of data in the three years prior.

The density of small oysters (≤ 15 mm) remained low overall (< 6.2 ± 2.0 oysters m^{-2}; 2021) in all years sampled and showed an increasing trend from 2018 to 2021. Higher densities of small oysters were observed in stratum 1 in 2016 (14.8 ± 4.7 oysters m^{-2}) and in stratum 2 in 2021 (8.7 ± 4.1 oysters m^{-2}) (Table 3, Figure 13). Given that Olympia Oysters and Pacific Oysters co-exist on this beach, the densities calculated for the small oyster class likely include both species and may be an over-representation of the small size class of Olympia Oysters.

In 2011 and 2016, survey precison for the large size group was 51% and 56% but only stratum 1 was surveyed. In 2015, survey precision for the large size group was 32% and survey precision was below the target range of 30% between 2018 and 2021 (Table 3).

The 2021 survey occurred at low tide during the heat dome event (June 25-July 1, 2021) when daily temperatures soared to a high of 40.5°C on June 28th (Nanaimo).

Shell length

Mean shell length fluctuated over the time series. It increased between 2012 (16.7 ± 1.5 mm) and 2019 (35.0 ± 1.1 mm). In 2021 mean shell length declined to 25.9 ± 1.5 mm (Table 4; Figure 13). Mean shell length in 2021 was similar to 2011.

CONCLUSIONS

The primary objective of this report is to describe the results of surveys at six index sites between 2010 and 2021 to inform the next COSEWIC re-assessment of the status of Olympia Oyster in British Columbia. Results of surveys at eight other index sites (2009 - 2017) were presented in Norgard et al. (2018).

Refinement of the survey design for each site has been completed to optimize the time spent at each site and increase survey precision. Refinements include changes to survey strata boundaries and sampling intensity. Mean densities and shell length frequencies have been reported for each site and year.

Changes to Olympia Oyster bed size should be interpreted cautiously. The accuracy of different GPS devices used over the survey years may have affected the estimated bed size. Additionally, sampler bias was likely present as four different mappers have mapped the Olympia Oyster beds at index sites. Each mapper walked the edge of the bed by doing a visual assessment of where they no longer observed Olympia Oysters. This method is coarse and added uncertainty to bed area estimates. Rocks and Pacific Oysters were not flipped over and visually inspected for the presence of Olympia Oysters beyond where they were visually observed during a walk of the bed edge. Consequently, changes in estimated bed sizes between years should not be interpreted as the beds expanding or shrinking.

At all sites, Olympia Oysters were found on subsequent visits and recruitment events were observed at number of sites (Port Eliza 2013, Harris Point 2014 and 2021, and Hillier Island 2010, 2014, and 2021). Identification of small oysters to species is challenging; especially at sites which include large numbers of both Pacific and Olympia Oysters (e.g., Transfer Beach) so a "small" oyster size category was used to categorize all oysters ≤15 mm, without attempting to identify them to species which would be time consuming and in some cases not be possible. The small size category may therefore include some Pacific Oysters. Density of the small size category was used to provide a general indication of recruitment events.

For sites that initially showed high variability and poor precision in density estimates, the number of sampled quadrats was increased on subsequent surveys. In some cases this increased sampling improved survey precision.

The trends in relative density at Olympia Oyster index sites in BC between 2010 and 2021 vary between sites. On the west coast of Vancouver Island, density decreased at Port Eliza and was at the lowest point in the time-series in 2021; however density at Port Eliza in 2021 was still higher than at Joes Bay, Swy-a-Lana Lagoon and Transfer Beach. The reason for the decline in density at Port Eliza is unknown. Port Eliza was not surveyed between 2014 and 2019 as the other index sites were and this gap in data limits our understanding of the density trend over time at this site. Density was on an increasing trend at Harris Point and Hillier Island, while it increased at Joes Bay between 2015 and 2017 and has remained stable since this time. Hiller Island and Harris Point; located only two kilometers from each other at the mouth of Pipestem Inlet, both showed evidence of recruitment in 2014 and 2021 while no evidence of strong recruitment was observed in those years at Joes Bay, located eleven kilometers away. In the Strait of Georgia, density at Swy-a-lana Lagoon seems to show a slow increasing trend while densities at Transfer Beach appeared to be stable. Density was at the highest value in the time-series in 2021 at four of the six index sites, i.e., Harris Point, Hillier Island, Joes Bay and Swy-a-Lana Lagoon.

The heat dome of June 2021 may have affected Olympia Oyster survival, especially in the Strait of Georgia where some of the lowest tides of the year occurred in the afternoon during peak temperatures. Temperatures reached 37.5 to 40.5°C in Nanaimo between June 26-28th and these temperatures coincided with afternoon low tides of 0.1 – 0.6 m. This combination led to long exposures of oysters out of the water at the time of day when the heat was most intense. Harris Point, Hillier Island, and Joes Bay were surveyed before the heat dome, Transfer Beach was surveyed during the heat dome, and both Swy-a-lana Lagoon and Port Eliza were surveyed after the heat dome. Density at Port Eliza in 2021 was lower than previous years, while the density of oysters at Transfer Beach in 2021 was similar to previous years. Extreme heat and cold events, if they coincide with low tides, may cause mortality events of Olympia Oysters including young-of-the-year oysters (COSEWIC 2011). Olympia Oysters also cannot withstand freezing (COSEWIC 2011); a cold event coincided with a low tide cycle in January 2022 which may have also caused mortality.

Continued monitoring of Olympia Oyster index sites is necessary to meet the objectives of the SARA management plan and data collected will be essential to informing a new management plan. An increase in the number of individual shell length measurements (at least 100-150 per site) has allowed more robust estimates of size distributions at each site. Recording substrate and habitat information at each site could be valuable. Collection of data on the presence and abundance of invasive species (e.g., green crab (*Carcinus maenas*), Japanese and Atlantic oyster drills (*Ocinebrellus inornatus* and *Urosalpinx cinerea*)) could help determine their impacts to Olympia Oysters.

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Table 1. Dates of Olympia oyster index site surveys, 2010-2021.

	Northwest Vancouver Island	Southwest Vancouver Island			Strait of Georgia	
Year	Port Eliza	Harris Point	Hillier Island	Joes Bay	Swy-a-lana Lagoon	Transfer Beach
2010	June 2	June 14	June 15		Aug 24	
2011						July 5
2012	Aug1-2	July 4	July 3			May 9
2013	May 26				Sept 18	
2014		June 26	June 26	June 26		
2015				July 4		
2016					July 19	July 20
2017				May 26		
2018		Aug 13	Aug 11-12	Aug 14	July 11	July 13
2019		Aug 2	Aug 1	May 22	July 4	June 18
2020						
2021	July 22-23	May 28-30	May 27-28	May 28-29	Aug 9-10	June 24-25

Table 2. Mapped Olympia Oyster bed area (m^2), total area surveyed (m^2), and proportion (%) of the bed area surveyed for Olympia Oyster at index sites[1].

Index Site	Year	Mapped Bed Area[2,3] (m^2)	Total Strata Area Surveyed[4] (m^2)	% of Oyster Bed Surveyed
Northwest Vancouver Island				
Port Eliza [5]	2012	6,851	3,450	50%
	2013	8,688	1,850	21%
	2021	9,257	3,450	37%
Southwest Vancouver Island				
Harris Point	2010	834	250	30%
	2012	1,270	300	24%
	2014	761	260	34%
	2018	647	280	43%
	2021	1,554	260	17%
Hillier Island	2010	4,065	2,730	67%
	2012	8,673	2,520	29%
	2014	6,760	2,700	40%
	2018	6,245	2,700	43%
Joes Bay	2014	788	560	71%
	2018	635	525	83%
Strait of Georgia				
Swy-a-lana Lagoon[6]	-	-	-	-
Transfer Beach	2011	681	420	62%
	2018	1,896	1,200	63%

Notes:

- [1] Bed area was not mapped in all years that an index survey was completed.
- [2] Consideration should be made for differences in sampling protocol when comparing bed size from year to year. Different samplers measured bed area in different years which can introduce sampling bias. Different GPS technology was used from year to year which may have impacted the accuracy of the bed area measured.
- [3] Mapped bed area was calculated in ESRI ArcMap 10.8.1. Bed boundaries were determined by walking the beach with a GPS starting at the low tide line (or the lowest point on the beach where Olympia oysters were observed) and walking along the sides and upper part of the beach along a line in which Olympia Oysters were no longer observed.
- [4] Total strata area surveyed is the sum of the area of all strata surveyed for a given year (see Table 3 for individual Strata sizes).
- [5] The Port Eliza Olympia oyster bed is larger than what has been mapped. This bed is split in two by a freshwater outflow halfway across the bed. Bed area was only measured on the same side as the index survey, i.e., the South-East side.
- [6] Swy-a-lana Lagoon does not have a defined bed, therefore it is not included here.

Table 3. **Survey design, Olympia Oyster density (per m²) and 95% confidence intervals (CI) at index sites on Vancouver Island (2010-2021).**

							All Olympia Oysters (all sizes)				Large Olympia Oysters (> 15 mm)				Small Olympia Oysters (<=15 mm)			
Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quad-rat Size (m^2)	% Zero Oyster Count	Den-sity (# m^{-2})	95 % CI	Survey Pre-cision	% Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision	% Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision
		Northwest Vancouver Island																
Port Eliza	2010	1	20 x 60	1,200	14	0.25	0	278.9	73.5	26%	0	278.9	73.5	26%	100	0.0	-	-
	2012	1	50 x 37	1,850	45	0.25	11	170.6	40.7	24%	11	168.6	40.4	24%	73	2.0	0.9	47%
		2	50 x 32	1,600	40	0.25	0	316.2	55.7	18%	0	310.4	56.8	18%	78	5.8	4.8	83%
		Overall		3,450	85	0.25	6	238.1	33.8	14%	6	234.4	34.1	15%	75	3.7	2.3	62%
	2013	1	50 x 37	1,850	35	0.25	0	507.0	74.1	15%	17	159.4	61.4	39%	3	347.5	115.8	33%
	2021	1	50 x 37	1,850	45	0.25	44	52.8	28.4	54%	44	49.6	27.0	54%	76	3.2	1.6	50%
		2	50 x 32	1,600	40	0.25	5	133.3	57.7	43%	5	124.4	55.6	45%	53	8.9	5.1	57%
		Overall		3,450	85	0.25	26	90.1	30.8	34%	26	84.3	29.5	35%	65	5.8	2.5	43%
		Southwest Vancouver Island																
Harris Point	2010	1	25 x 10	250	40	0.25	8	47.0	10.9	23%	-	-	-	-	-	-	-	-
	2012	1	25 x 12	300	28	0.25	14	58.1	19.4	33%	18	52.7	18.4	35%	61	5.4	4.9	91%
	2014	1	26 x 10	260	38	0.25	0	136.1	33.8	25%	0	82.2	22.6	27%	13	53.9	21.1	39%
	2018	1	28 x 10	280	40	0.25	0	126.4	34.2	27%	0	120.2	31.2	26%	73	6.2	5.3	85%
	2019	1	28 x 10	280	40	0.25	0	130.8	45.0	34%	0	115.8	36.1	31%	40	15.0	9.5	63%
	2021	1	26 x 10	260	40	0.25	0	258.9	20.0	7%	0	176.6	28.9	16%	0	82.3	32.2	39%
Hillier Island	2010	1	70 x 39	2,730	120	0.25	21	62.4	29.7	48%	28	27.5	9.7	35%	73	34.9	24.4	70%
	2012	1	70 x 36	2,520	40	0.25	30	44.3	20.7	47%	30	43.7	20.5	47%	90	0.6	0.6	100%
	2014	1	75 x 36	2,700	74	0.25	4	64.1	17.7	28%	7	40.9	10.9	27%	27	23.1	9.4	41%
	2018	1	75 x 36	2,700	80	0.25	11	19.9	4.3	22%	14	16.9	3.9	23%	68	3.1	1.5	49%
	2019	1	75 x 36	2,700	80	0.25	4	31.3	4.4	14%	4	26.3	3.6	14%	64	5.1	2.4	48%
	2021	1	75 x 36	2,700	79	0.25	0	136.9	28.0	20%	3	93.0	17.6	19%	20	43.9	14.9	34%
Joes Bay	2014	1	11 x 3	33	15	0.25	53	3.2	3.7	114%	87	1.3	2.0	154%	60	1.9	1.8	95%
		2	35 x 16	560	60	0.25	70	4.0	2.6	64%	75	1.9	1.2	63%	78	2.1	1.7	83%
		Overall		593	75	0.25	67	4.0	2.4	61%	77	1.9	1.2	63%	75	2.1	1.6	79%
	2015	1	11 x 3	33	21	0.25	71	2.1	2.8	136%	90	1.0	1.5	150%	76	1.1	1.4	126%
		2	35 x 15	525	27	0.25	30	11.0	8.8	80%	48	6.4	6.8	106%	52	4.6	3.4	72%
		Overall		558	48	0.25	48	10.4	8.3	79%	67	6.0	6.4	107%	63	4.4	3.2	72%
	2017	2	35 x 15	525	60	0.25	20	33.0	12.3	37%	20	30.3	11.3	37%	70	2.7	1.6	60%
	2018	2	35 x 15	525	60	0.25	17	28.9	8.2	28%	20	26.6	8.4	32%	77	2.3	1.1	49%

							All Olympia Oysters (all sizes)				Large Olympia Oysters (> 15 mm)				Small Olympia Oysters (<=15 mm)			
Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quad-rat Size (m^2)	% Zero Oyster Count	Den-sity (# m^{-2})	95 % CI	Survey Pre-cision	% Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision	% Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision
	2019	2	35 x 15	525	60	0.25	17	28.6	12.2	43%	20	24.3	11.3	47%	52	4.3	1.6	37%
	2021	2	35 x 15	525	60	0.25	7	37.1	9.5	26%	7	31.8	9.0	28%	53	5.3	2.3	44%
Strait of Georgia																		
Swy-a-Lana Lagoon	2010	1	20 x 7.5	150	24	0.25	38	7.7	5.8	76%	-	-	-	-	-	-	-	-
		2	28 x 10	280	32	0.25	22	5.5	1.9	34%	-	-	-	-	-	-	-	-
		3	48 x 6	288	36	0.25		106.9	39.7	37%	-	-	-	-	-	-	-	-
		Overall		718	92	0.25	20	46.6	16.0	34%	-	-	-	-	-	-	-	-
	2013	1	20 x 7.5	150	24	0.25	54	3.7	2.0	53%	54	3.7	2.0	54%	100	0.0	-	-
		2	28 x 10	280	32	0.25	50	5.4	3.2	60%	50	5.1	2.9	57%	97	0.3	0.5	196%
		3	48 x 6	288	36	0.25	22	81.3	20.7	25%	22	81.2	20.7	25%	97	0.1	0.2	196%
		Overall		718	92	0.25	40	35.5	8.4	24%	40	35.3	8.4	24%	98	0.1	0.2	148%
	2016	1	20 x 7.5	150	29	0.25	28	12.3	6.2	51%	28	11.7	6.3	54%	90	0.6	0.6	100%
		2	28 x 10	280	30	0.25	30	10.9	5.3	48%	30	8.9	4.7	53%	77	2.0	1.2	60%
		3	48 x 6	288	35	0.25	0	145.6	52.4	36%	0	145.0	52.5	36%	94	0.6	0.9	158%
		Overall		718	94	0.25	18	65.2	21.2	32%	19	64.1	21.2	33%	87	1.1	0.6	55%
	2018	1	20 x 8	160	24	0.25	25	14.8	7.0	47%	25	10.7	4.6	43%	75	4.2	3.8	90%
		2	28 x 10	280	32	0.25	19	33.0	12.0	36%	41	17.5	1.9	11%	38	15.5	4.1	26%
		3	48 x 6	288	36	0.25	17	59.7	28.0	47%	17	58.7	27.4	47%	92	1.0	1.3	130%
		Overall		728	92	0.25	18	39.9	12.2	31%	27	32.6	11.9	37%	69	7.3	1.9	25%
	2019	1	20 x 8	160	24	0.25	25	23.5	17.0	72%	25	21.2	15.0	71%	75	2.3	2.2	95%
		2	28 x 10	280	32	0.25	31	23.9	9.7	41%	31	21.1	8.6	41%	63	2.8	1.3	46%
		3	48 x 6	288	36	0.25	19	48.2	16.7	35%	19	47.4	16.8	35%	89	0.8	0.9	113%
		Overall		728	92	0.25	24	33.6	8.5	25%	25	31.7	8.2	26%	76	1.9	0.8	41%
	2021	1	20 x 7	140	24	0.25	21	23.7	14.3	60%	21	22.0	13.8	63%	67	1.7	0.8	47%
		2	28 x 9	252	32	0.25	22	24.5	9.9	40%	28	21.1	8.9	42%	59	3.4	1.9	56%
		3	48 x 6	288	36	0.25	25	165.1	53.6	32%	25	164.3	53.3	32%	86	0.8	0.8	100%
		Overall		680	92	0.25	23	83.9	23.2	28%	25	82.0	23.0	28%	72	1.9	0.8	42%
Transfer Beach	2011	1	60 x 7	420	60	0.0625	55	14.9	6.1	41%	60	12.8	6.5	51%	92	2.1	2.7	127%
	2012	1	60 x 12	720	30	0.25	23	17.2	8.6	50%	23	17.2	8.6	50%	100	0.0	-	-
		2	60 x 8	480	47	0.25	23	26.1	10.6	41%	23	26.1	10.6	41%	100	0.0	-	-
		Overall		1,200	77	0.25	23	20.8	6.7	32%	23	20.8	6.7	32%	100	0.0	-	-

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quad-rat Size (m^2)	All Olympia Oysters (all sizes) % Zero Oyster Count	Den-sity (# m^{-2})	95 % CI	Survey Pre-cision	Large Olympia Oysters (> 15 mm) % Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision	Small Olympia Oysters (<=15 mm) % Zero Oyster Count	Den-sity (# m^{-2})	95% CI	Survey Pre-cision
	2016	1	60 x 12	720	44	0.25	5	60.5	27.6	46%	11	45.7	25.7	56%	18	14.8	4.7	32%
	2018	1	60 x 12	720	40	0.25	5	27.4	5.6	20%	8	25.4	5.5	22%	78	2.0	1.8	90%
		2	60 x 8	480	34	0.25	41	18.8	13.9	74%	41	16.2	11.4	70%	88	2.6	3.8	146%
		Overall		1,200	74	0.25	22	24.0	6.5	27%	23	21.7	5.6	26%	82	2.2	1.8	82%
	2019	1	60 x 12	720	52	0.25	12	27.1	5.2	19%	15	23.2	4.7	20%	67	3.8	1.9	50%
		2	60 x 4	240	40	0.25	15	47.6	25.6	54%	25	43.9	23.7	54%	65	3.7	2.8	76%
		Overall		960	92	0.25	14	32.2	7.5	23%	20	28.4	6.9	24%	66	3.8	1.6	41%
	2021	1	60 x 12	720	40	0.25	5	25.0	6.0	24%	5	19.7	5.8	29%	48	5.3	2.2	42%
		2	60 x 4	240	40	0.25	3	28.6	10.2	36%	8	19.9	7.7	39%	35	8.7	4.1	47%
		Overall		960	80	0.25	4	25.9	5.2	20%	6	19.8	4.7	24%	41	6.2	2.0	32%

Note: Small size class was not recorded separately at Harris Point or Swy-a-lana Lagoon in 2010.

Table 4. Olympia Oyster mean shell length (mm), 95% confidence intervals (CI) and range at index sites in British Columbia, 2010-2021.

Index Site	Year	n	Mean (mm)	± 95% CI	Min (mm)	Max (mm)
Northwest Vancouver Island						
Port Eliza	2010	976	32.8	0.7	3	58
	2012	658	33.3	0.6	6	54
	2013	175	7.9	1.0	2	44
	2021	455	25.9	0.7	5	48
Southwest Vancouver Island						
Harris Point	2010	75	31.3	1.4	10	44
	2012	87	27.3	1.6	11	48
	2014	205	18.5	1.1	3	42
	2018	186	29.8	0.6	19	42
	2019	218	25.8	0.9	5	44
	2021	321	21.0	1.0	4	43
Hillier Island	2010	621	10.3	0.7	1	50
	2012	195	23.3	0.9	8	39
	2014	89	23.5	2.2	2	41
	2018	201	28.4	1.2	7	55
	2019	186	25.5	1.1	6	43
	2021	155	26.0	1.4	8	47
Joes Bay	2014	58	35.8	3.0	4	56
	2017	460	29.2	0.9	3	57
	2018	212	30.3	1.8	3	56
	2019	427	29.9	1.1	4	55
	2021	214	26.9	1.5	3	63
Strait of Georgia						
Swy-A-Lana Lagoon	2010	135	25.2	1.5	4	49
	2013	130	34.6	1.1	17	51
	2016	149	31.3	1.4	3	55
	2018	124	32.1	1.7	11	54
	2019	169	36.3	1.4	18	60
	2021	403	32.9	1.0	6	61
Transfer Beach	2011	56	24.1	2.7	8	54
	2012	195	16.7	1.5	3	62
	2016	131	24.7	1.6	7	54
	2018	147	34.6	1.2	14	62
	2019	196	35.0	1.1	13	52
	2021	218	25.9	1.5	5	55

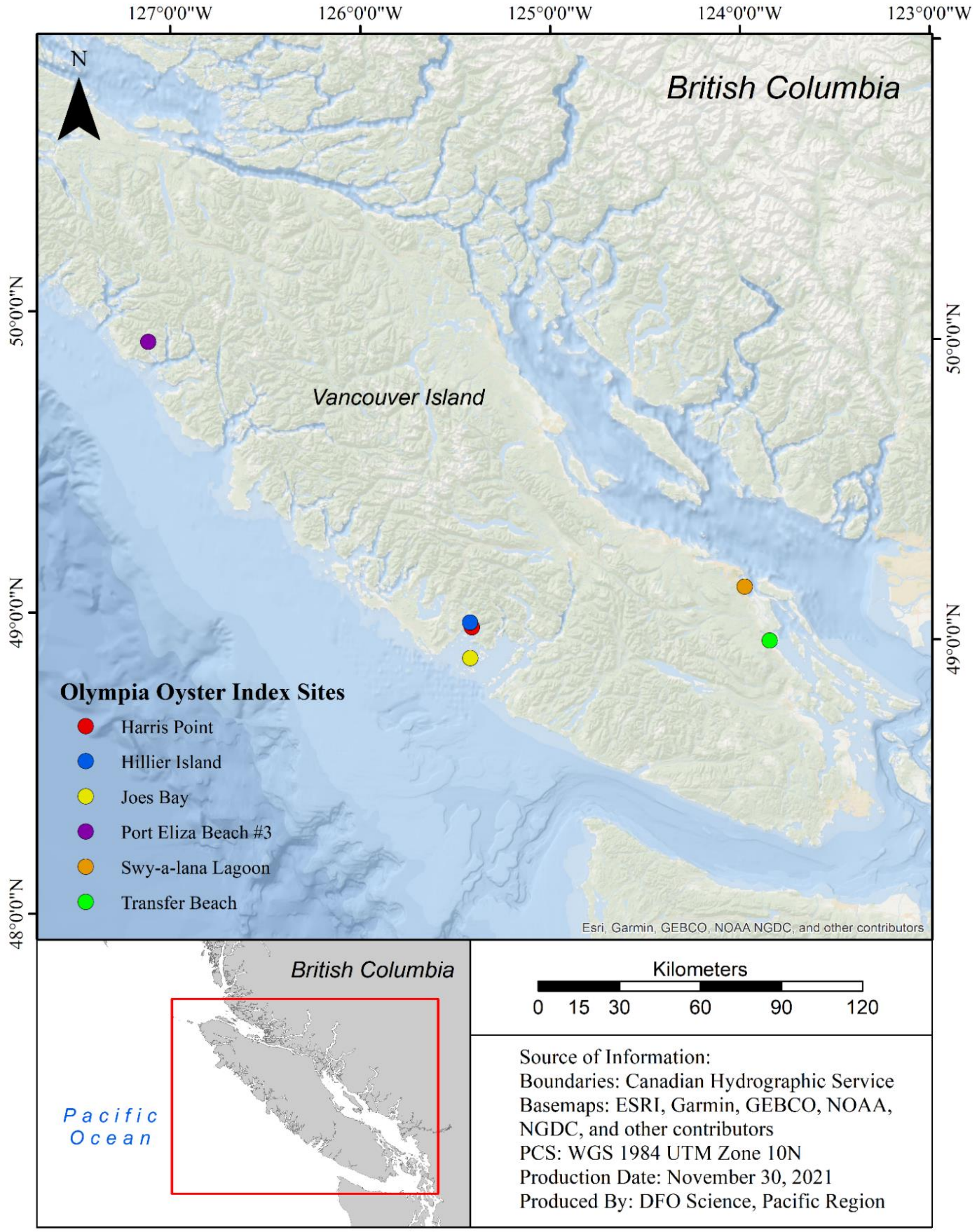


Figure 1. Olympia Oyster index sites surveyed in British Columbia, 2010-2021 (map only includes the six sites identified in 2018 for annual surveys).

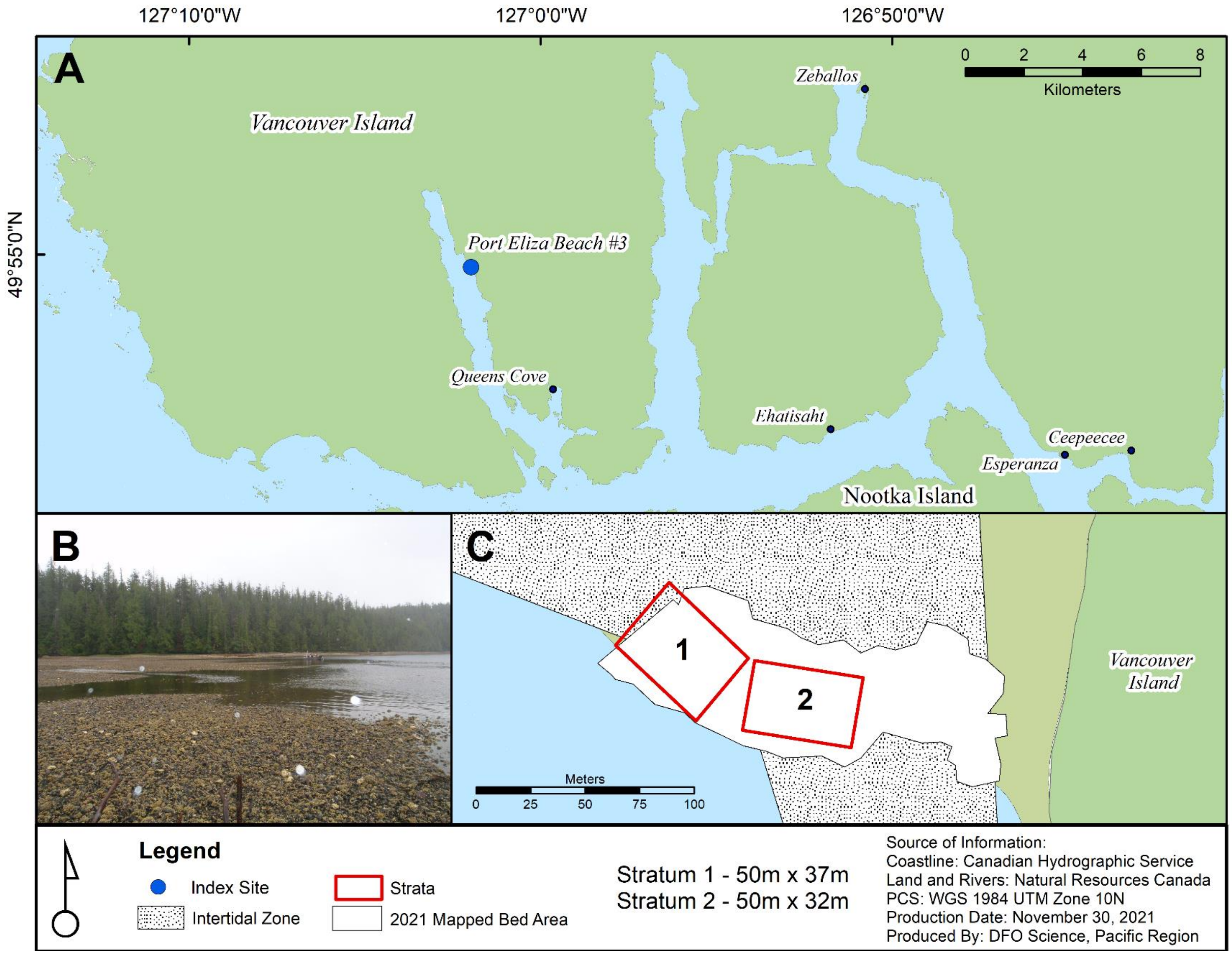


Figure 2. Location and strata layout for the Olympia Oyster index site at Port Eliza.

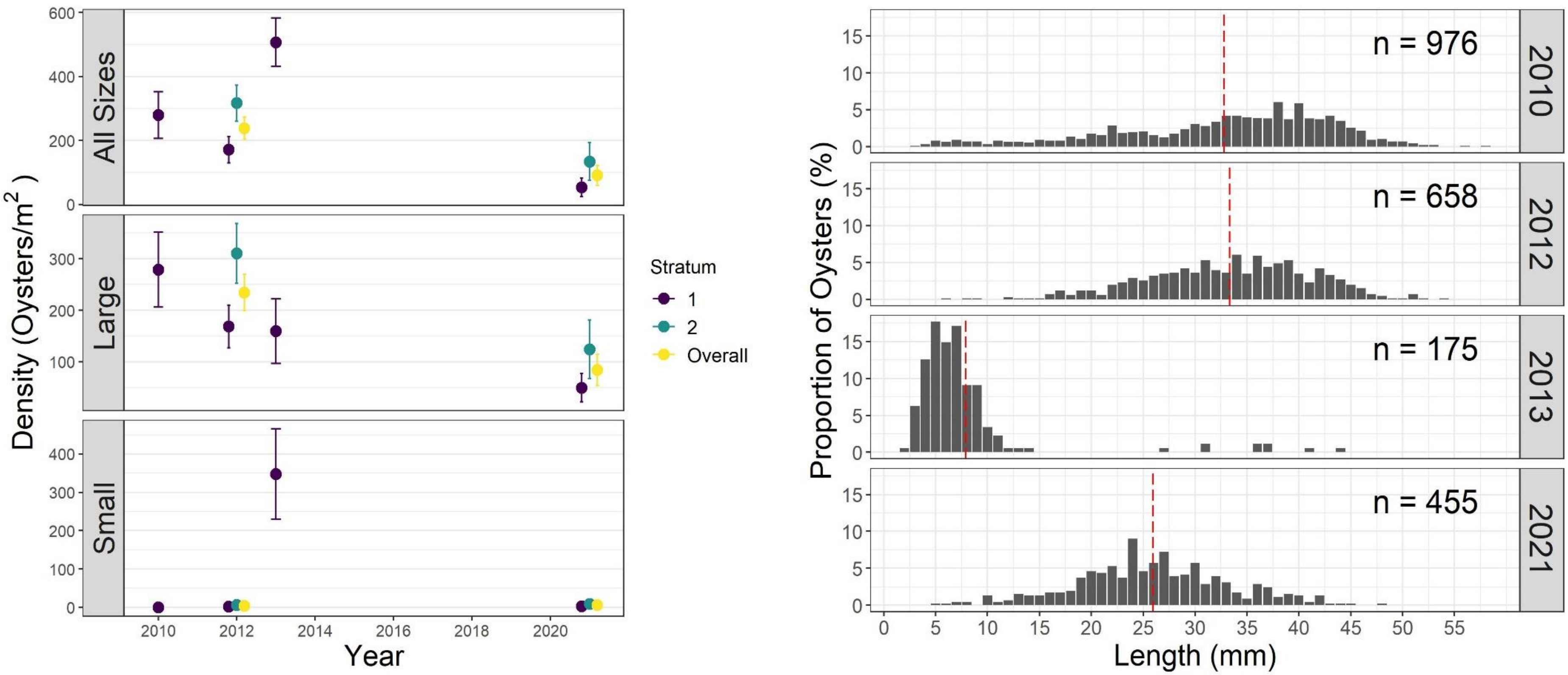


Figure 3. Port Eliza Olympia Oyster density (# m^{-2}) by stratum and year (left). Error bars represent 95% confidence intervals. The "Overall" category refers to the weighted average of Olympia Oyster density across all survey strata. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Port Eliza Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters.

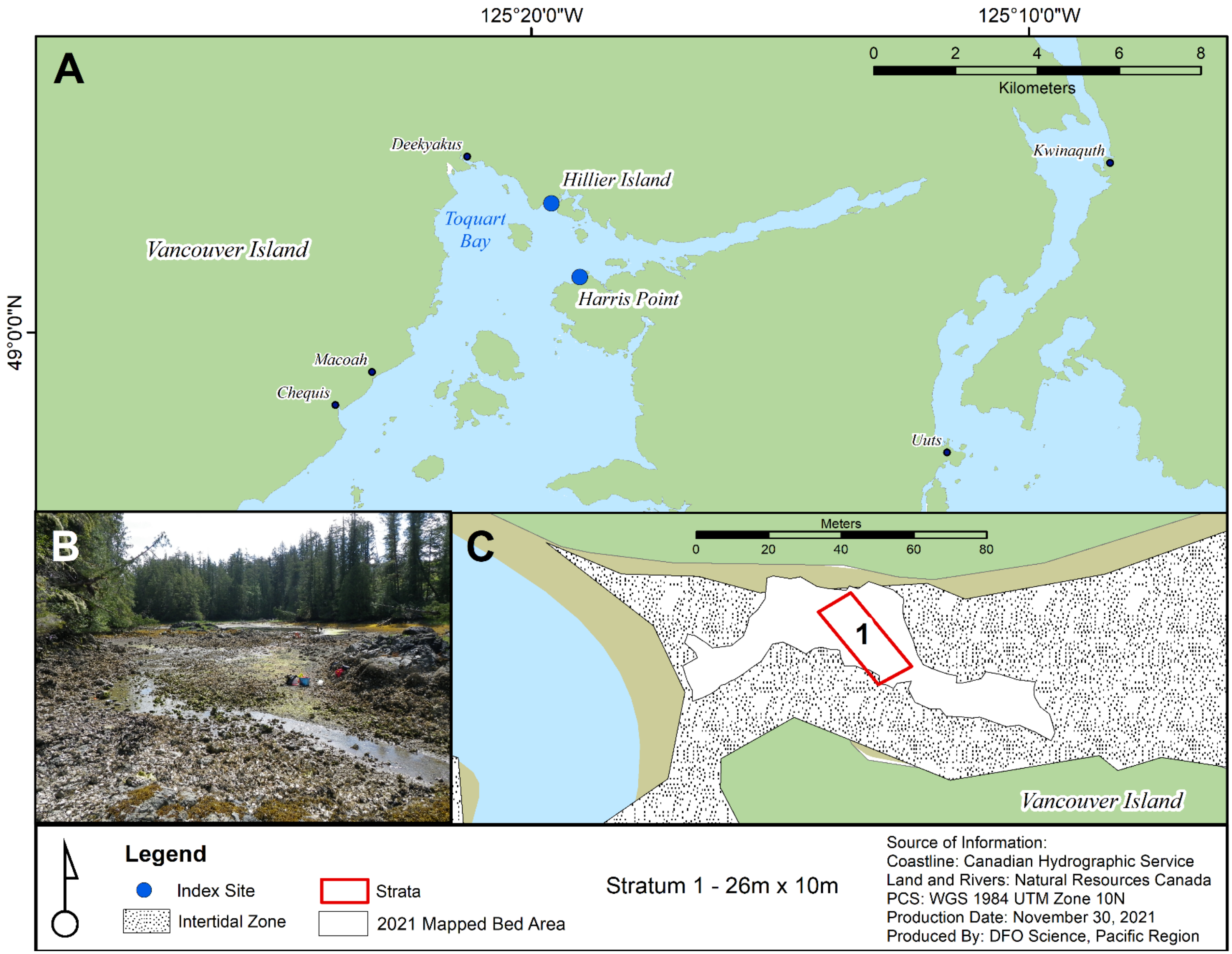


Figure 4. Location and stratum layout for the Olympia Oyster index site at Harris Point.

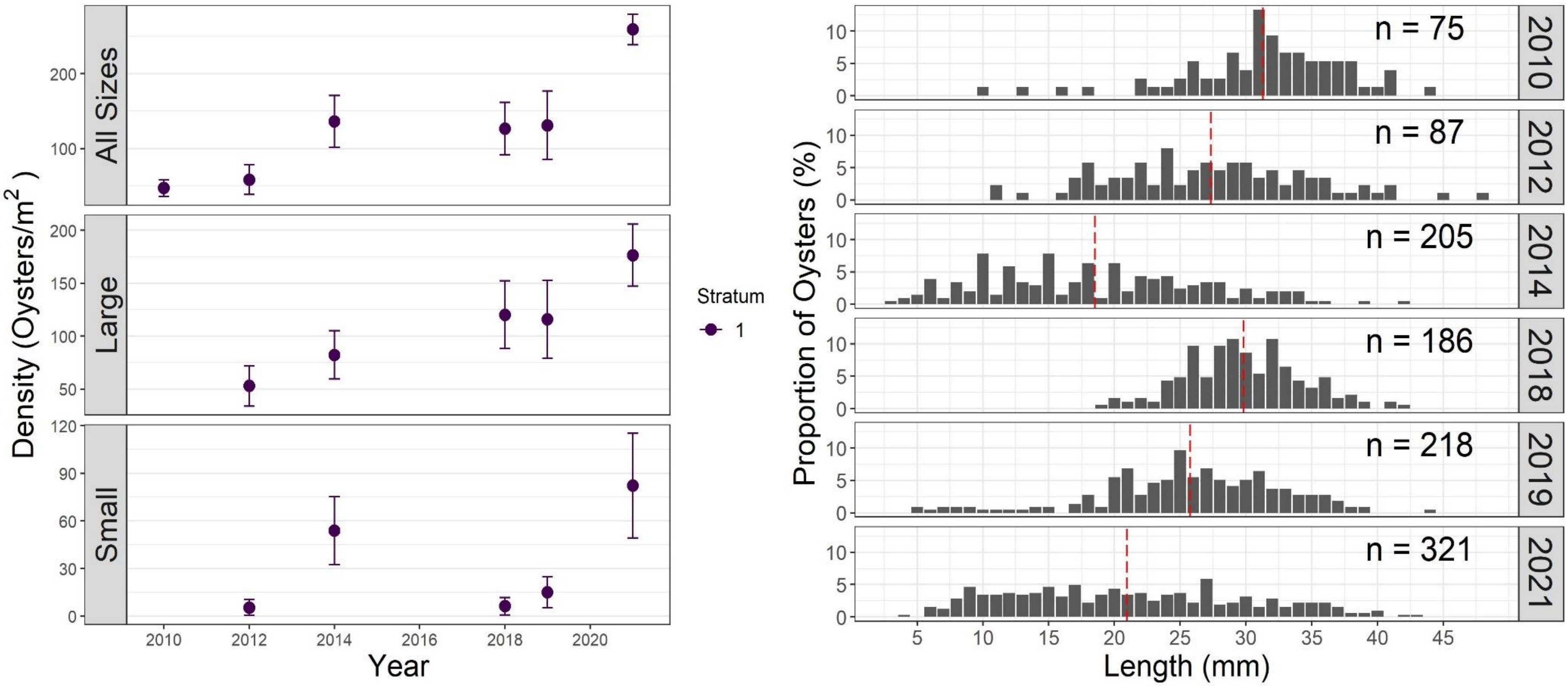


Figure 5. Harris Point Olympia Oyster density (# m^{-2}) by stratum and year (left). Error bars represent 95% confidence intervals. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Harris Point Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters.

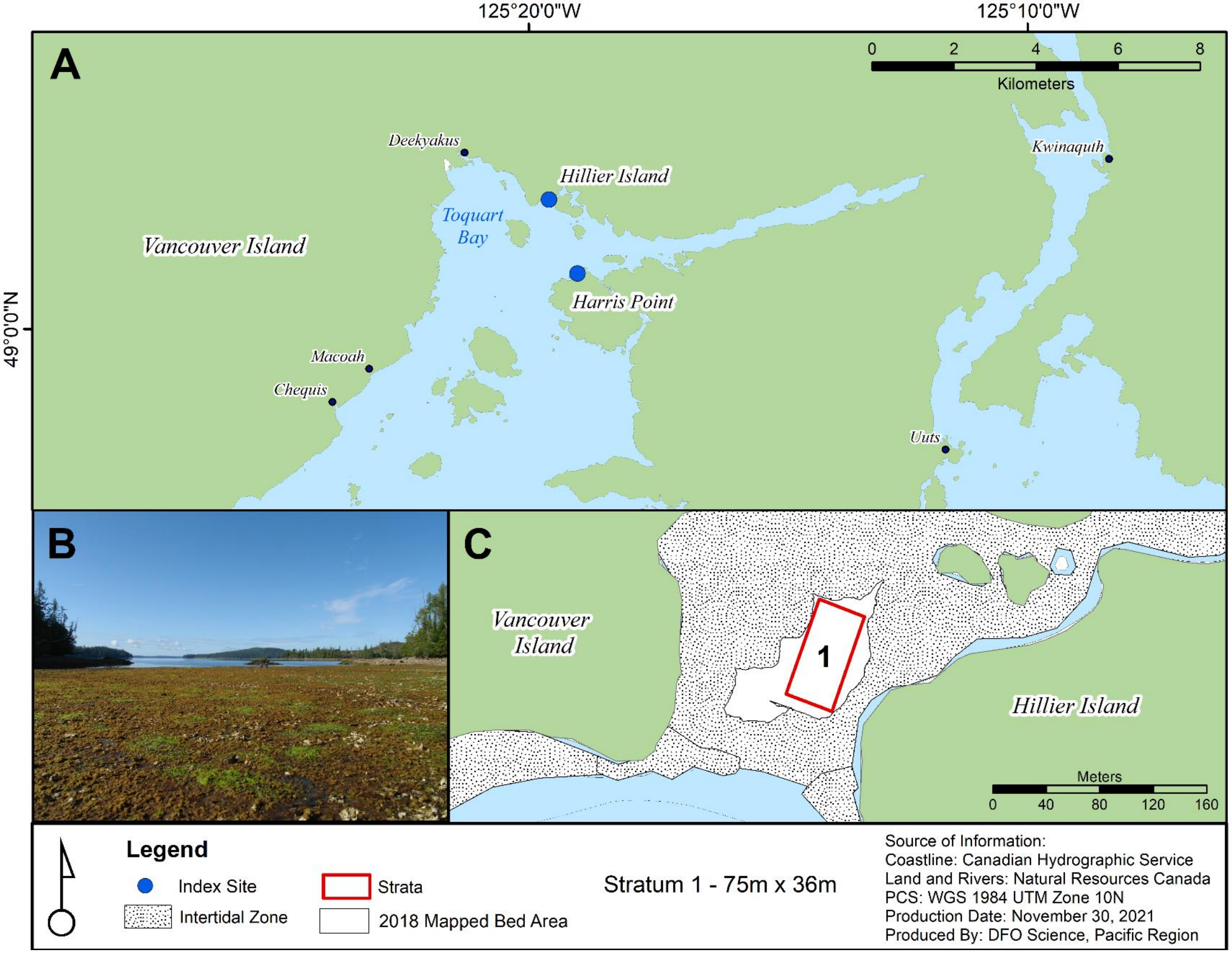


Figure 6. Location and stratum layout for the Olympia Oyster index site at Hillier Island.

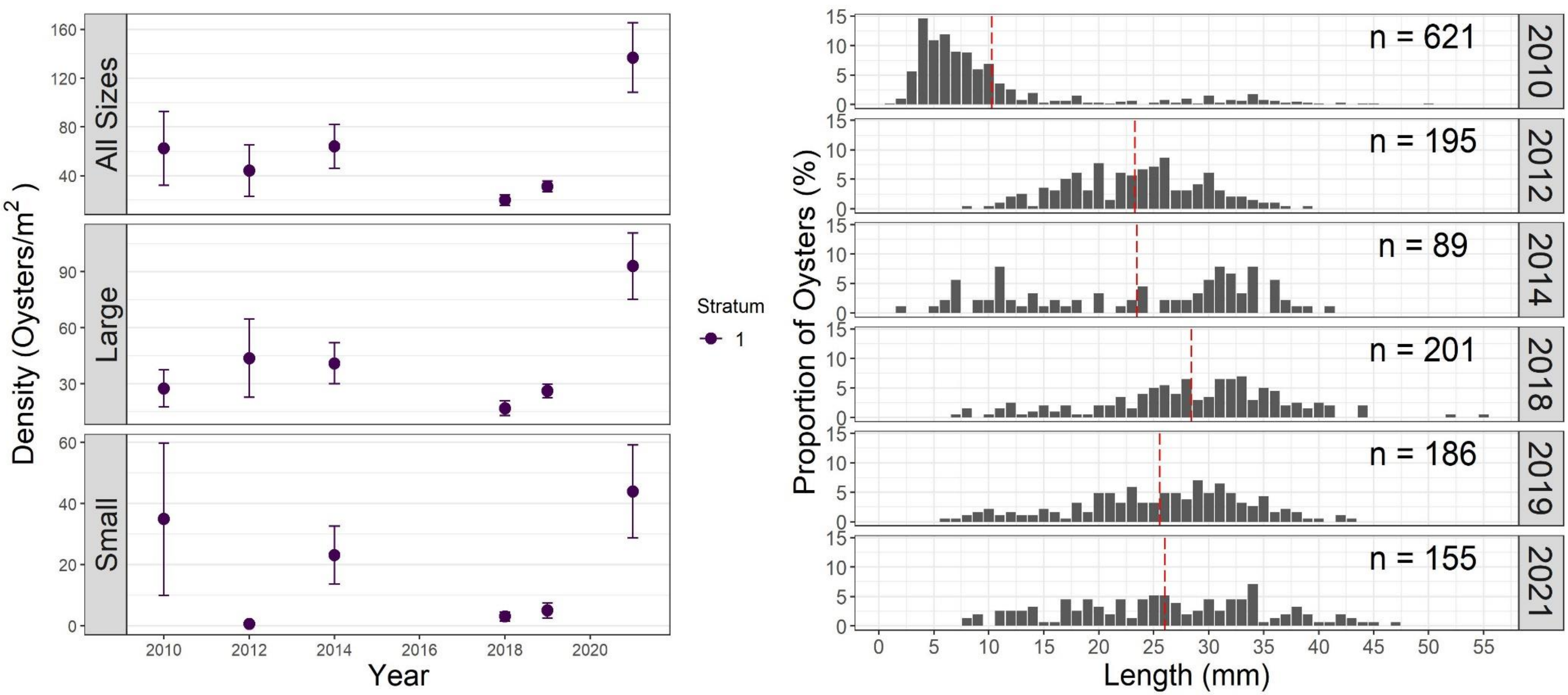


Figure 7. Hillier Island Olympia Oyster density (# m^{-2}) by stratum and year (left). Error bars represent 95% confidence intervals. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Hillier Island Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters.

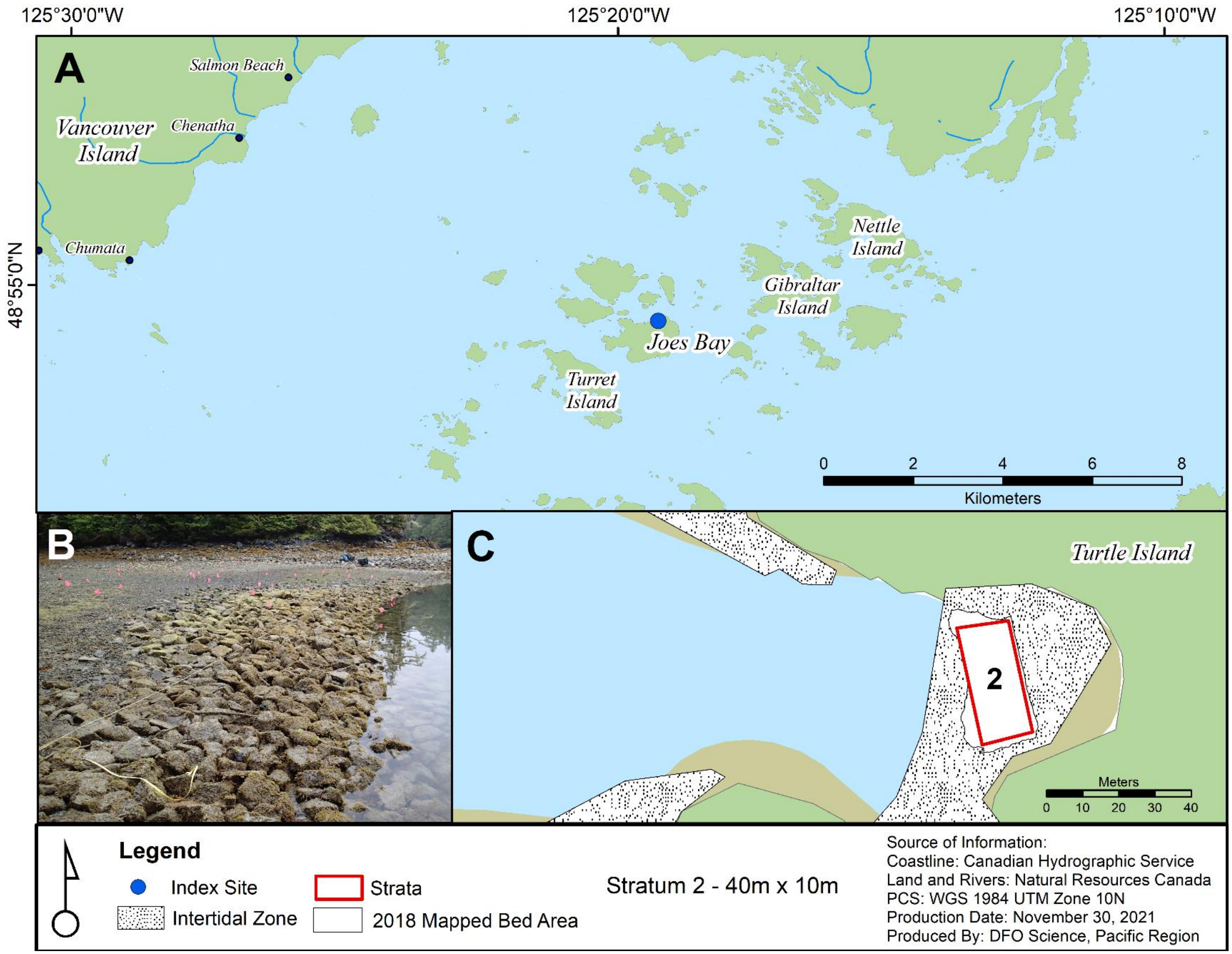


Figure 8. Location and strata layout for the Olympia Oyster index site in Joes Bay.

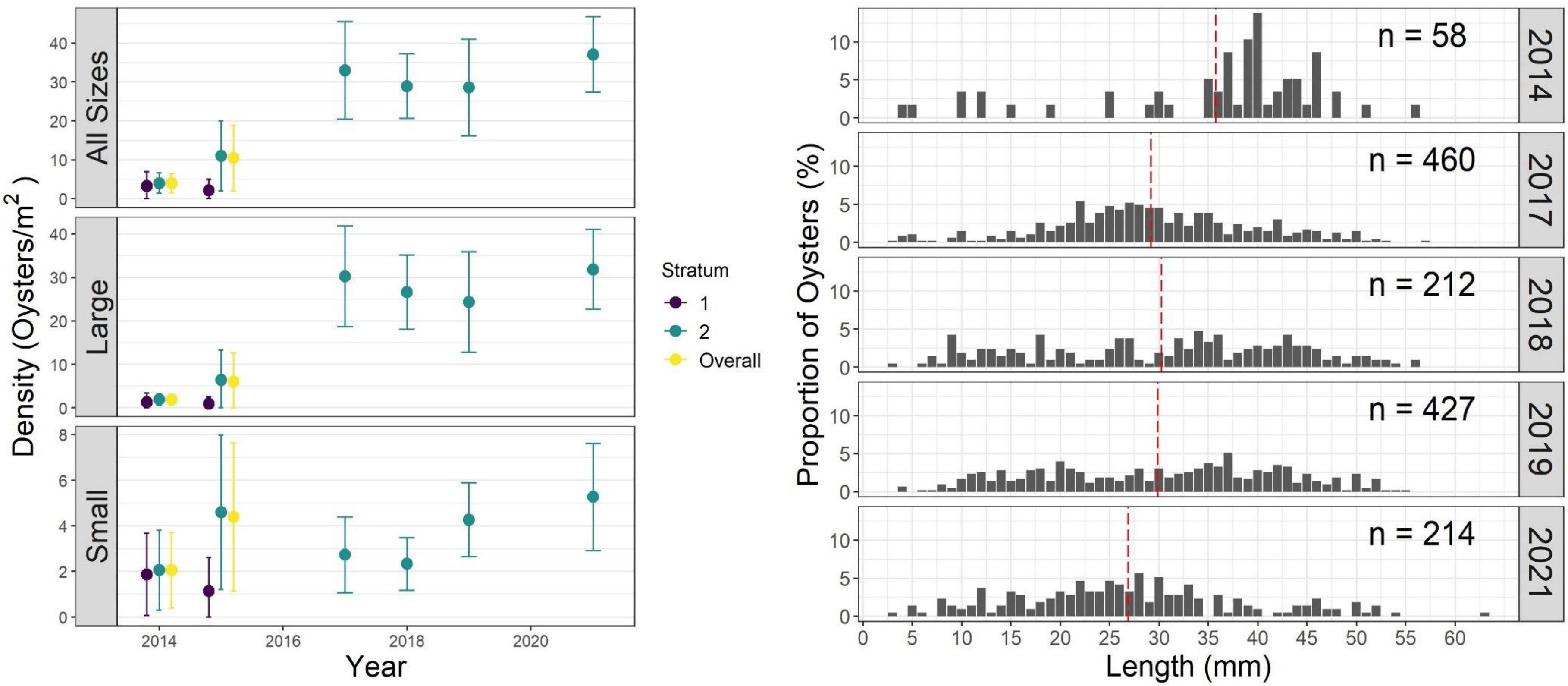


Figure 9. Joes Bay Olympia Oyster density (# m^{-2}) by stratum and year (left). The "Overall" category refers to the weighted average of Olympia Oyster density across all survey strata. Error bars represent 95% confidence intervals. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Joes Bay Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters. Histogram for 2015 is absent from the series given that length measurements of Olympia Oysters were not collected in during this survey year.

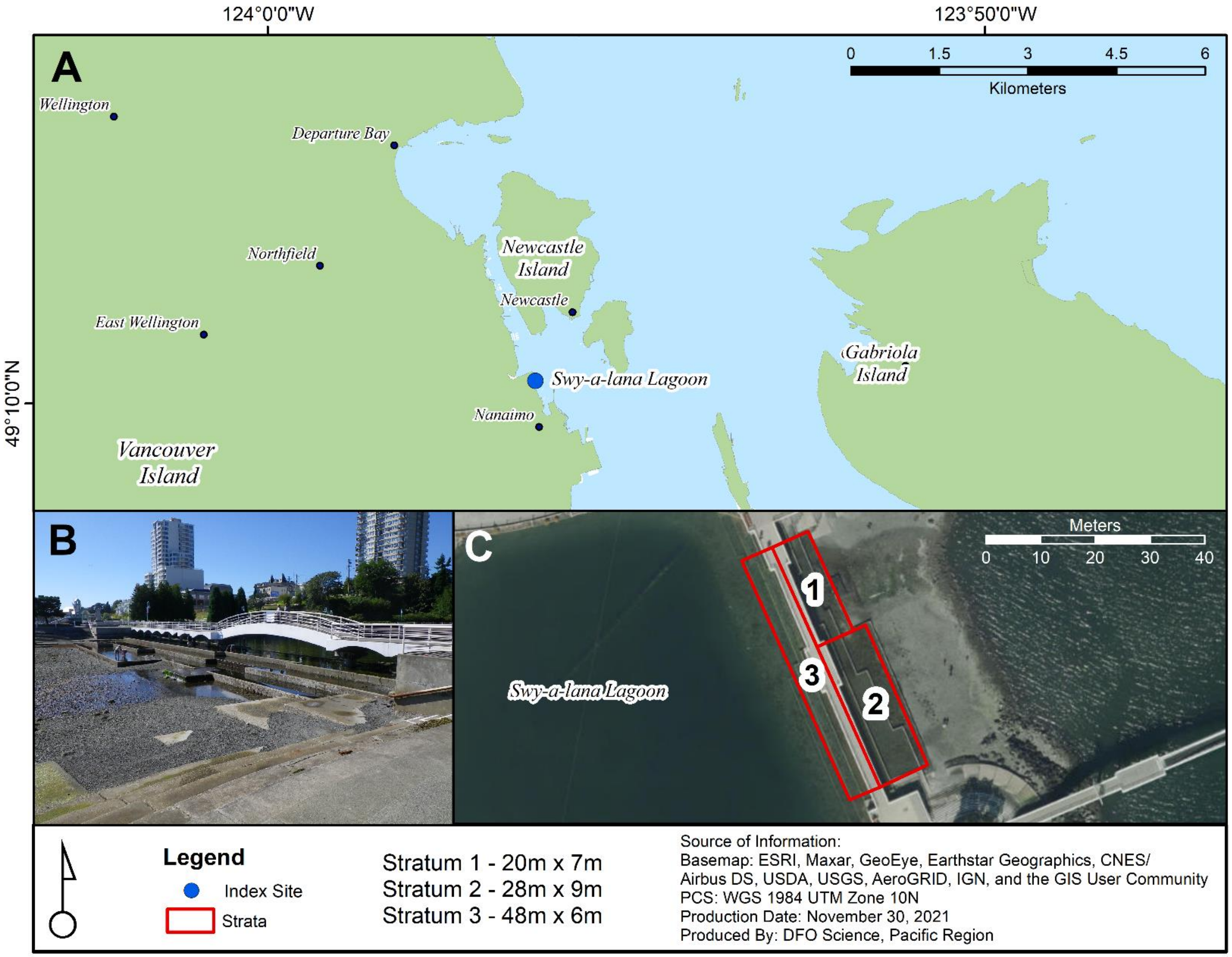
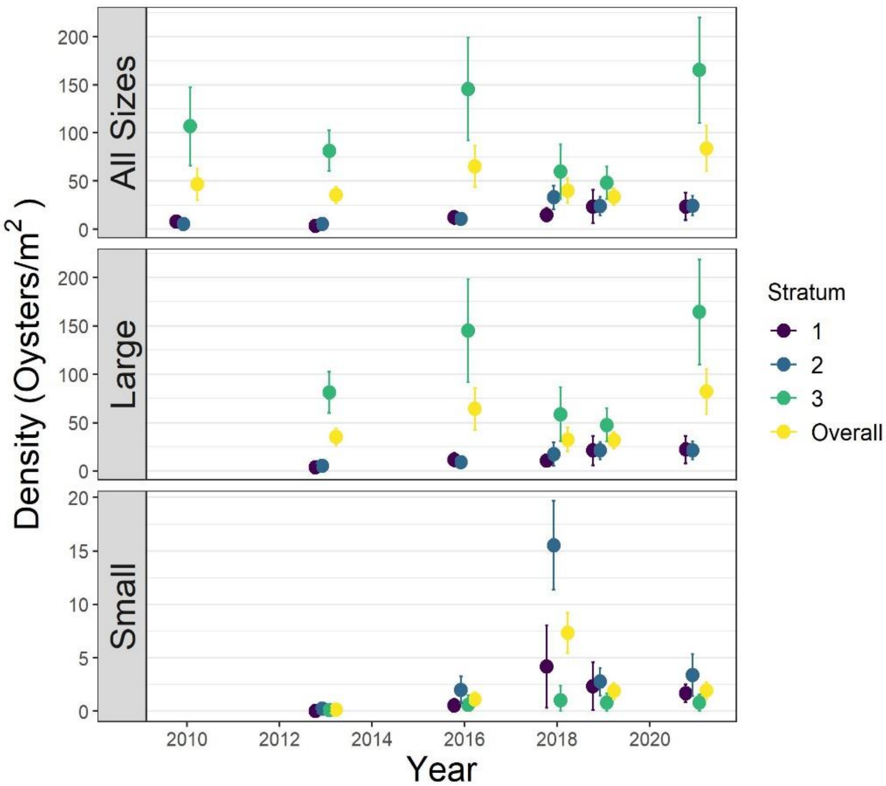


Figure 10. Location and strata layout for the Olympia Oyster index site in Swy-a-lana Lagoon.



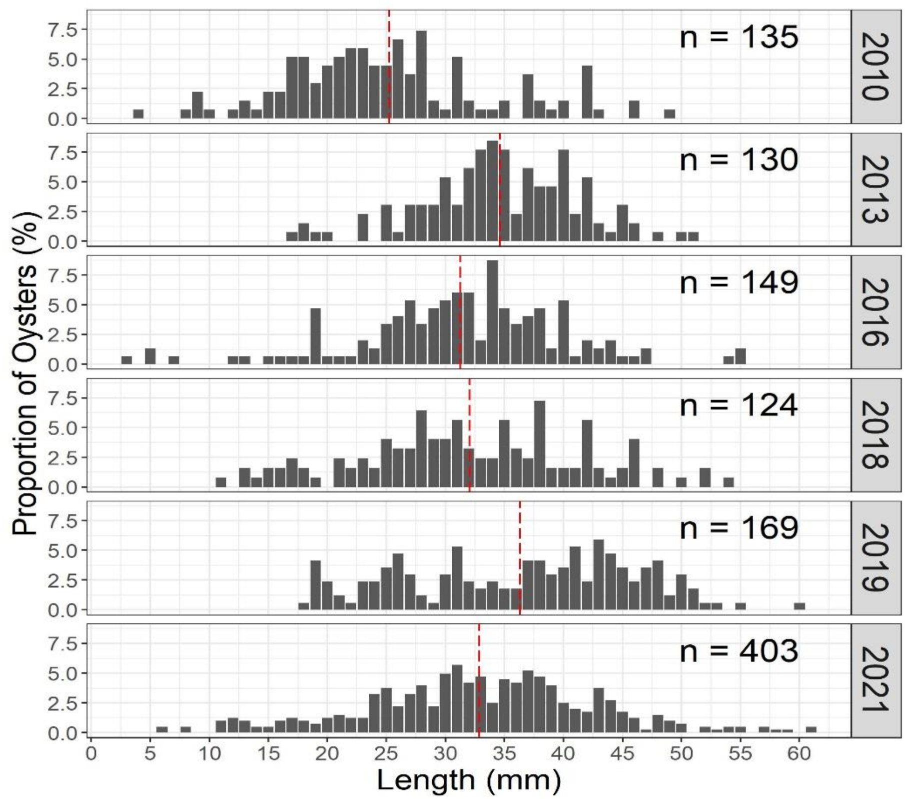


Figure 11. Swy-a-lana Lagoon Olympia Oyster density (# m^{-2}) by stratum and year (left). The "Overall" category refers to the weighted average of Olympia Oyster density across all survey strata. Error bars represent 95% confidence intervals. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Swy-a-lana Lagoon Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters.

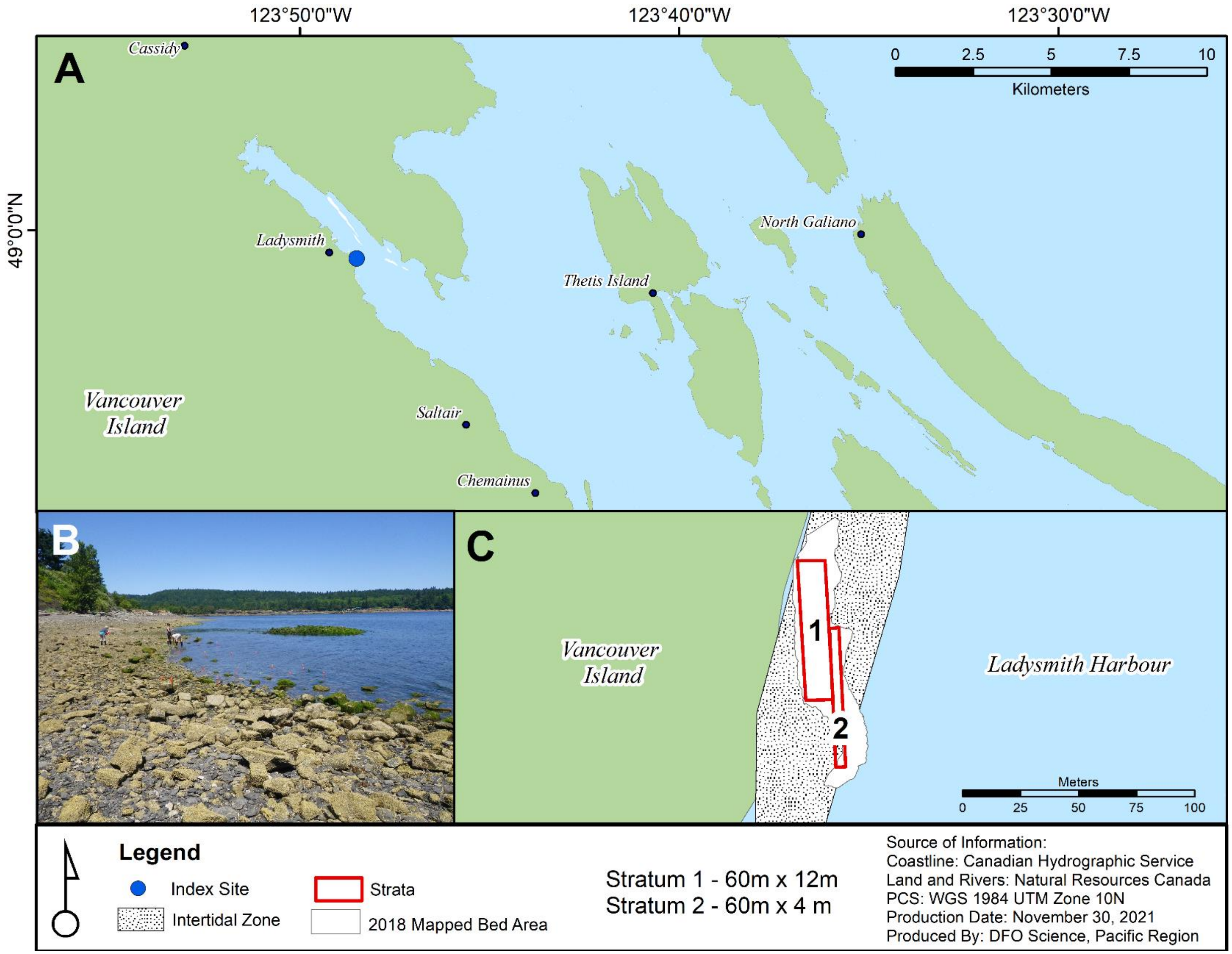


Figure 12. Location and strata layout for the Olympia Oyster index site at Transfer Beach.

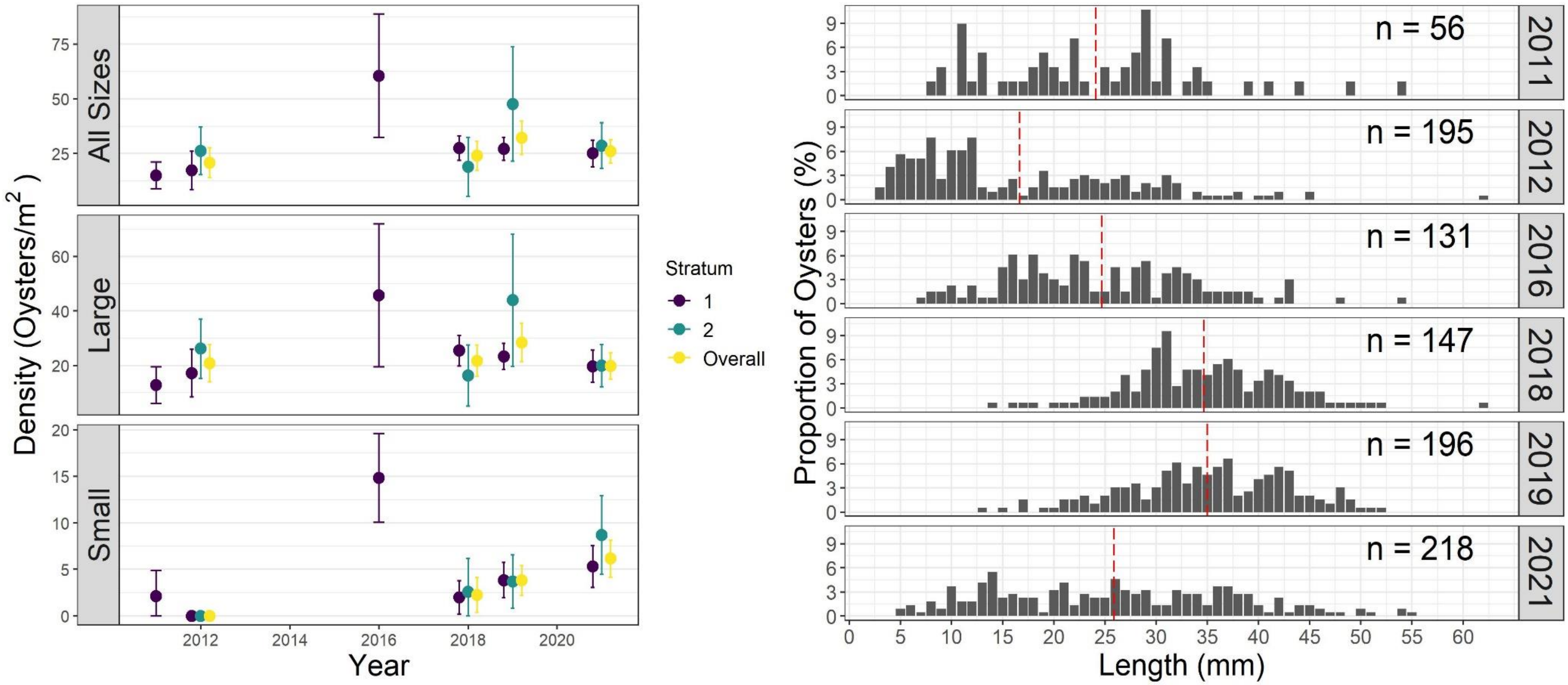


Figure 13. Transfer Beach Olympia Oyster density (# m^{-2}) by stratum and year (left). The "Overall" category refers to the weighted average of Olympia Oyster density across all survey strata. Error bars represent 95% confidence intervals. The *All sizes* category includes both the *Small* and *Large* size categories. The *Small* size category includes oysters ≤ 15 mm (which can include Pacific Oysters) while the *Large* size category includes Olympia Oysters > 15 mm. Transfer Beach Olympia Oyster length frequency histogram (right). Red dotted lines are mean shell length in millimeters.

Appendix 1. R code developed to randomly select transect and quadrat locations (updated to include GPS coordinates for 2021 surveys).

```
# Code to select transect and quadrat locations for a two-stage survey
# Update to convert cartesian XCoord,Y coordinates to geographic coordinates

# Written by:     Jessica Finney
# Last modified:  June 9 2014

# Edited by:      Alessandra Jones
# Last modified:  March 4 2021

# Reads from StrataMetadata table of clam database to get strata parameters
# For each strata, generates random cartesian x,y coordinates using a two stage
# stratified random design, then converts x,y coordinates to latitude and longitude
# using corner 1 lat and long, bearing from corner 1 to the point and x, y of point
# representing distance in meters

# Transect locations are all randomly selected along the baseline
# Quadrats are systematically placed along the transects after an initially randomly placed
quadrat
# This code automatically saves a csv file of quadrat coordinates and strata parameters
# Output contains all strata at all sites for a given year
# Text files are also produced with the layout of random points for each strata
# A text file for all strata and sites in a given year is generated to be entered
# into the HeaderSamples Access table

# Functions for establishing connections to databases and editing sql code
# Some based off of functions from gfdata in Utils.R
# db_connection() works with both 32bit and 64bit R

#Install packages

#install.packages("fossil")
#install.packages("Rmpfr")
#install.packages("geosphere")
#install.packages("DBI")
#install.packages("odbc")
#install.packages("reshape2")
#install.packages("dplyr")
require(dplyr)
require(reshape2)
require(DBI)
require(odbc)
require(geosphere)
```

```
require(Rmpfr)
require(fossil)

###Read .csv files and create dataframes###
# This will be replaced by DB lookup when ready.

#stratacoords<-read.csv("PriorityStrata.csv", header=TRUE)
#randompoints<-read.csv("randompoints2.csv", header=TRUE)

#Clam database connection
cl_db_connection <- function(server = "insert server name") {
  require(DBI)
  DBI::dbConnect(odbc::odbc(),
                 driver = "SQL Server",
                 server = server)
}

#SQL query

strataquery = "select
                b.BeachCode as BeachCode,
                b.Description as Description,
                p.Stratum as StrataNum,
                p.StrataKey as StrataKey,
                p.LatHiLeft as Latitude1,
                p.LonHiLeft as Longitude1,
                p.LatHiRight as Latitude2,
                p.LonHiRight as Longitude2,
                p.BaselineLengthm as BaselineL,
                p.TransectLengthm as TransectL,
                p.NumTransects as nTransects,
                p.QuadratSidem as QuadratSidem,
                p.NumQuadsPerT as nQuadrats,
                p.TargetNumBiosample as TargetBiosampleNum
               from Shellfish_Bio_Other.dbo.ClamStrataParameters p inner join
                Shellfish_Bio_Other.dbo.ClamBeaches b on p.BeachCode=b.BeachCode"

##Extract data from SQL Server

# Run query
stratacoords <- DBI::dbGetQuery( cl_db_connection(), strataquery )

#Generate 2 sample random quadrats
generateQuad <- function(BaselineL, QuadratSidem, nTransects, TransectL, nQuadrats) {
  BaselineMin = 0
  BaselineMax = BaselineL
```

```
    TransectLocations1 = seq(from = BaselineMin, to = BaselineMax, by =
QuadratSidem)
  TransectLocations  = sort(sample(TransectLocations1, nTransects, replace = FALSE))

  # Quadrat locations
  TransectMin = 0
  TransectMax = TransectL/nQuadrats

  QuadratStart1 = seq(from = TransectMin, to = (TransectMax-QuadratSidem), by =
QuadratSidem)
  QuadratStart  = sample(QuadratStart1, nTransects, replace = TRUE)

  # Make a dataframe with the quadrat and transect locations
  QuadratLocations = matrix(NA, nrow = nTransects, ncol = nQuadrats)
  QuadratLocations = as.data.frame(QuadratLocations)

  # Name the columns
  names(QuadratLocations) =  paste("Quad", 1:ncol(QuadratLocations), sep = "")

  # Enter the random start locations in the first column
  QuadratLocations[,1] = QuadratStart

  # Enter the location of the sequentially placed quadrats in the dataframe
  for( i in 1:nrow(QuadratLocations) ) {
    QuadStart1 = QuadratLocations[i,1]
    QSequence = seq(from = (QuadStart1 + TransectMax), by = TransectMax, length.out
= (nQuadrats -1))
    QuadratLocations[i,2:ncol(QuadratLocations)] = QSequence
  }
  # Append the transect start locations to the front of the dataframe
  Trans = TransectLocations
  QuadratLocations = cbind(Trans, QuadratLocations)
  return(QuadratLocations)
}

#Convert quadrat x,y locations to lat/long
#Uses mpfr function to maintain 64 bit precision
xytolatlong <- function(x,y,bearing,lati1,long1){
  lat = mpfr(lati1, 64)
  long = mpfr(long1,64)
#If the point is x,y 0,0, then return corner 1 lat long for the strata
  if(x == 0 && y==0) {
    return(c(lat,long))
  }
  #Convert metres to km
  x2 = mpfr(x/1000, 64)
```

```
  y2 = mpfr(y/1000, 64)

  R = mpfr("6378.1", 64) #Radius of the Earth
  brng = mpfr(bearing, 64)#Convert bearing to high precision data structure

  #If the random x value is 0, then the distance is y
  if(x==0){
   d = mpfr(y2, 64)
  }else{
   d = mpfr(sqrt((x2^2) + (y2^2)), 64)#Distance in km
  }

  #0,0 point cast to high precision 64bit
  lat = mpfr(lati1, 64)
  long = mpfr(long1,64)

  #Convert degrees to radians
  lat1 =  mpfr(lat*pi / 180,64)
  lon1 = mpfr(long*pi/180,64)

  #Calculate the latitude and longitude of the point in radians
  lat2 = mpfr(asin(sin(lat1)*cos(d/R)+cos(lat1)*sin(d/R)*cos(brng)), 64)
  lon2 = mpfr(lon1 + atan2(sin(brng)*sin(d/R)*cos(lat1), cos(d/R)-sin(lat1)*sin(lat2)), 64)

  #convert the latitude and longitude of the random point from radians back to
  #decimal degrees
  lat2 = mpfr(lat2*180/pi, 64)
  lon2 = mpfr(lon2*180/pi, 64)

  return(c(lat2,lon2))
}

#Calculate Year
Year = format(Sys.Date(),"%Y")

#Establish variable for prior beach code
priorbeachcode = 'NA'

#Last quadrat number
lastquadratnum = '1'

#Last transect number
lasttransectnum = '1'

# Make a data frame for the script output
RandomQuadrats = matrix(NA, nrow = 0, ncol = 14)
```

```
RandomQuadrats = as.data.frame(RandomQuadrats)
# Name the columns
names(RandomQuadrats) =
c("BeachCode","Description","Year","Stratum","StrataKey","FSU","QuadratNum","Qua
dratSidem","Latitude","Longitude","XCoord","YCoord","Biosample","BaselineBearing")

####outerloop
#loop through all strata from csv or db
for( i in 1:nrow(stratacoords) ) {

  long1 = stratacoords$Longitude1[i]
  lat1 = stratacoords$Latitude1[i]
  long2 = stratacoords$Longitude2[i]
  lat2 = stratacoords$Latitude2[i]

  #load baseline length etc...
  BaselineL = stratacoords$BaselineL[i]
  TransectL = stratacoords$TransectL[i]
  nTransects = stratacoords$nTransects[i]
  QuadratSidem = stratacoords$QuadratSidem[i]
  nQuadrats = stratacoords$nQuadrats[i]
  TargetBiosampleNum = stratacoords$TargetBiosampleNum[i]

  #Calculate random points using original code
  quadloc = generateQuad(BaselineL, QuadratSidem, nTransects, TransectL, nQuadrats)

  #Create a list to input the random geographic points
  latlonglist <- list()

  #Calculate bearing of baseline
  p1<-c(long1,lat1)
  p2<-c(long2,lat2)
  bearingofbaseline = bearingRhumb(p1,p2)
  #print(bearingofbaseline)
  bearingofbaseline = bearingofbaseline*pi/180 #bearing in radians

  #Transform dataframe from transect/quadrat matrix into list
  #of x,y coords
  randompoints <- melt(data = quadloc, id.vars = c("Trans"))

  randompoints <- melt(data = quadloc, id.vars = c("Trans")) %>%

    select(Trans, value)

  randompoints <- melt(data = quadloc, id.vars = c("Trans")) %>%
```

```
    select(Trans, value) %>%

    arrange(Trans) %>%
    rename(X = Trans, Y = value)

  ####Inner loop
  #Read random points and call xy to lat long conversion function
  for( m in 1:nrow(randompoints) ) {
    x = randompoints[m,"X"]
    y = randompoints[m,"Y"]

    #Calculate bearing for each point
    bearingofpoint = bearingofbaseline - atan(y/x)

    #Call xy to lat long conversion function
    latlonglist_temp<-xytolatlong(x,y,bearingofpoint,lat1,long1)

    #Extract latitude and longitude values from mpfr object, stored as strings
    #because no further calculations are needed
    output_lat <- capture.output(latlonglist_temp[1])[2]
    output_long <- capture.output(latlonglist_temp[2])[2]

    #Truncate non numerical characters from string and add to list
    latlonglist[[m]] = c(substr(output_lat,5,nchar(output_lat)),
                         substr(output_long,5,nchar(output_long)))
    #End inner loop
  }

  #Convert list to dataframe
  latlong<-do.call("rbind", latlonglist)

  # Make a data frame for the data for each strata
  StrataQuadrats = matrix(NA, nrow = (nQuadrats*nTransects), ncol = 14)
  StrataQuadrats = as.data.frame(StrataQuadrats)

  # Name the columns
  names(StrataQuadrats) =
c("BeachCode","Description","Year","Stratum","StrataKey","FSU","QuadratNum","Qua
dratSidem","Latitude","Longitude","XCoord","YCoord","Biosample","BaselineBearing")

  # Fill in dataframe with strata details
  StrataQuadrats$BeachCode    = rep(stratacoords$BeachCode[i],
length(nTransects*nQuadrats))
  StrataQuadrats$Description        = rep(stratacoords$Description[i],
length(nTransects*nQuadrats))
  StrataQuadrats$Year         = rep(Year, length(nTransects*nQuadrats))
```

```
  StrataQuadrats$Stratum      = rep(stratacoords$StrataNum[i],
length(nTransects*nQuadrats))
  StrataQuadrats$StrataKey    = rep(stratacoords$StrataKey[i],
length(nTransects*nQuadrats))

  #Check if new stratum on same beach. If so then continue quadrat numbers from
  #last stratum. Otherwise restart quadrat numbers at 1.
  if(priorbeachcode == stratacoords$BeachCode[i]){
    StrataQuadrats$QuadratNum = seq(from = lastquadratnum+1, to = (lastquadratnum
+(nTransects*nQuadrats)))
    StrataQuadrats$FSU = rep(lasttransectnum+1:nTransects, each = nQuadrats)

    }else{
    StrataQuadrats$QuadratNum = seq(from = 1, to = (nTransects*nQuadrats))
    StrataQuadrats$FSU = rep(1:nTransects, each = nQuadrats)
  }

  StrataQuadrats$QuadratSidem     = rep(stratacoords$QuadratSidem[i],
length(nTransects*nQuadrats))
  StrataQuadrats$Latitude     = latlong[,1]
  StrataQuadrats$Longitude    = latlong[,2]

  #Add x and y to the dataframe from the randompoints dataframe
  StrataQuadrats$XCoord = randompoints$X
  StrataQuadrats$YCoord = randompoints$Y

  #Generate a subset of the random quadrats for biosampling
  Biosample1 = seq(from = 1, to = nTransects*nQuadrats)
  StrataQuadrats$Biosample = rep('N', length(nTransects*nQuadrats))
  StrataQuadrats$Biosample[sample(Biosample1, TargetBiosampleNum)] = 'Y'

  #Populate baseline bearing
  StrataQuadrats$BaselineBearing = rep((bearingofbaseline*180/pi),
length(nTransects*nQuadrats))

  #Add strata to output dataframe
  RandomQuadrats <- rbind(RandomQuadrats, StrataQuadrats)

  #Write out cartesian coordinates for each strata as text
  #Function gsub used to remove single spaces. If other types of whitespace
  #present use regex to remove.
  Quadfile = paste(gsub(" ", "", stratacoords$Description[i], fixed=TRUE),
                 "Strata",
                 gsub(" ", "", stratacoords$StrataNum[i], fixed=TRUE),
                 "RandomQuadrats",Year, ".txt", sep = "")
```

```
  FolderName = "C:\\Users\\HERDERE\\Documents\\Aquatic Biologist II -
Nanaimo\\Olympia Oyster\\Olympia Oyster Site Index Report 2018-2021\\R Code -
Random Quadrat Selection for 2021"#Update file output path here
  write.table(format(quadloc, digits=2, nsmall=2), file = paste (FolderName,Quadfile, sep
= "/"),
            sep = "\t", row.names = F, col.names = T, quote = F)

  #Set prior row beach code to use to check if quadrat numbers should restart
  #at 1 or continue to increase
  priorbeachcode  = stratacoords$BeachCode[i]
  #Last quadrat number
  lastquadratnum = (nTransects*nQuadrats)
  #Last transect number
  lasttransectnum = nTransects

  #loop back to next strata
}

# Save as csv file
FolderName = "C:\\Users\\HERDERE\\Documents\\Aquatic Biologist II -
Nanaimo\\Olympia Oyster\\Olympia Oyster Site Index Report 2018-2021\\R Code -
Random Quadrat Selection for 2021"#Update file output path here
write.table(RandomQuadrats, file = paste (FolderName, paste("OlyQuadratFile", Year,
".csv", sep=""), sep = "/"),
          sep = ",", row.names = F, col.names = T, quote = F)

## Save a text file to enter into HeaderSamples table of Access

# Make a data frame for the data
AccessFile = matrix(NA, nrow = (length(RandomQuadrats$StrataKey)), ncol = 18)
AccessFile = as.data.frame(AccessFile)

# Name the columns
names(AccessFile) =  c("Stratum", "FSU", "QuadratNum", "Month", "Day", "Time",
    "LowTideHgt", "XCoord", "YCoord", "SqArea", "Screened", "Method",
"Comments","BeachCode","Description","StrataKey","Latitude","Longitude")

# Fill in data
AccessFile$Stratum      = RandomQuadrats$Stratum
AccessFile$FSU          = RandomQuadrats$FSU
AccessFile$QuadratNum   = RandomQuadrats$QuadratNum
AccessFile$Month        = NULL
AccessFile$Day          = NULL
AccessFile$Time         = NULL
AccessFile$LowTideHgt   = NULL
AccessFile$XCoord       = RandomQuadrats$XCoord
```

```
AccessFile$YCoord       = RandomQuadrats$YCoord
AccessFile$SqArea       = RandomQuadrats$QuadratSidem
AccessFile$Screened     = NULL
AccessFile$Method       = NULL
AccessFile$Comments     = NULL
AccessFile$BeachCode    = RandomQuadrats$BeachCode
AccessFile$Description  = RandomQuadrats$Description
AccessFile$StrataKey    = RandomQuadrats$StrataKey
AccessFile$Latitude     = RandomQuadrats$Latitude
AccessFile$Longitude    = RandomQuadrats$Longitude

# Save as text file
write.table(AccessFile, file = paste (FolderName, "OlyAccessFile.txt", sep = "/"),
    sep = "\t", row.names = F, col.names = T, quote = F)
```

Appendix 2. R code used for two-stage survey design and analysis.

```
##############################################################################

#                    Olympia Oyster Data Analysis                    #

##############################################################################

#Author: Erin Herder (See the three sections below for specific author contributions)

#Group: MIS, Stock Assessment and Research Division (StAR)

#Contact: erin.herder@dfo-mpo.gc.ca

#File: Olympia Oysters

#Code Name: OlyOyst_Dat_Analysis_Nov25_2021.R

#Version: 1.0

#Date Created: November 25, 2021

#Last Updated: November 25, 2021

##############################################################################

# Part 1: Acquires Olympia Oyster data from clam database and prepares it for density analysis.

# Part 2: Code to plot density estimates by beach, year and strata with error bars.

# Part 3: Code to make length frequency histograms from Olympia oyster index site bio sample data.

##############################################################################

# Set working directory before running code to ensure .csv files and folders with plots are saved in appropriate location.

################################

###      Part 1          ###

################################

# Authors: Erin Herder (New code added Nov 25, 2021), Original Code Authors? (Original Code).  See file: Cluster Analysis R Oly Final 17Oct03.R for original code.

#Updates:  The original code required queries of the clam database in Microsoft Access before bringing the data into RStudio for analysis. The original code also outputted three
```

.csv files that were later called back into other R scripts to produce density plots and length frequency plots. This new code calls the data directly from the back-end of the clam database directly into RStudio and prepares all data for density analysis. In this file, the original dataset has been cleaned up so older and unused bits of code have been removed. See the original file (listed above) for the original code.

####### Code: Part 1 ########

Note that on line 134 where new column "totalq" is being added and calculated, occasionally this column is not calculating appropriately. It appears to work when running the code line by line, but not when running this code as a whole. To check it is running correctly, verify in the "oyster" table that NumLegals and NumSublegals are totaled together into "totalq". If not, run this line of code again, verify it is working, then continue running the remaining code. If not correct, analysis will be wrong. Note that this data is also important at the bottom of this code for an additional piece of code that was written in 2022 to automate calculation of Zero Oyster counts.

Install and load required R packages:

#install.packages(c("DBI", "dplyr", "dbplyr", "odbc", "RODBC"))

library(DBI)

library(dplyr)

library(dbplyr)

library(odbc)

library(RODBC)

Connect to clam database:

channel <- dbConnect(odbc::odbc(), " insert server name") # THe odbc package connects to an oracle or SQL database

"Shellfish_Bio_Other" is the clam database -> "dbo" will show all tables in the database. The ones that start with "view" are likely what we are seen in Access (copies of queries). Use the tables in the database that start with "Clam.....". To view all tables available, look in the "connections" tab in the right top corner of the RStudio screen to view all.

For an unknown reason, cannot access the "HeaderSurvey" and "HeaderSamples" tables using the same code as "BioData" (see below). R will not pull the "date created" columns so a work around is supplied by selecting everything but those columns (see below).

###

Part 2: Creating a Density Graph Loop

###

#Authors: Erin Herder (Updates to code), Tammy Norgard (Original code) and Jessica Finney (Original code)

#Updates: The original and new code both produce .csv files. In the new code, a new RStudio script is not opened with the .csv files loaded. Instead, this entire script can be run from start to finish. As can be seen below, the new script immediately calls in the .csv files produced above to produce the density graphs.

##

Step 1: Load all necessary database tables:

ClamNumWgts <- dbGetQuery(channel,"SELECT * FROM [Shellfish_Bio_Other].[dbo].[ClamNumWgts]") # database query asking to select * (the * means to "select everything") from the specified database (first[]) then within the [dbo] folder and lastly [select the table to view].

ClamBeaches <- dbGetQuery(channel,"SELECT * FROM [Shellfish_Bio_Other].[dbo].[ClamBeaches]") # database query asking to select * (the * means to "select everything") from the specified database (first[]) then within the [dbo] folder and lastly [select the table to view].

ClamHeaderSurvey <- dbGetQuery(channel,"SELECT [Key],[Source],[SamplerCode],[BeachCode],[Year],[MonthStart],[DayStart],[MonthEnd],[DayEnd],[StatArea],[SubArea],[FileName],[TypeOfSample],[StateOfSample],[Technique],[NumStrata],[NumQuadrats],[SizeQuadrats],[TotalAreaDug],[TotalAreaStrata],[GotNumWgts],[GotBioData],[GotAges],[GotAnnulus],[GotObs],[AIS_Uploaded],[Location],[TimeOn],[TimeOff],[WaterTemp],[Salinity],[BeachSlope],[Substrate],[Cover],[NumScratches],[NumSamples],

[Comments] FROM [Shellfish_Bio_Other].[dbo].[ClamHeaderSurvey]") # This code specifies the columns from a particular table to select. The columns are specified here to deal with the fact that R will not pull the date created columns.

ClamHeaderSamples <- dbGetQuery(channel,"SELECT [H1_Key],[H2_Key],[Stratum],[FSU],[QuadratNum],[Month],[Day],[LowTideHgt],[XCoord],[YCoord],[SqArea],[Screened],[Method],[Lat],[Lon],[StrataKey] FROM [Shellfish_Bio_Other].[dbo].[ClamHeaderSamples]") # This code specifies the columns from a particular table to select. The columns are specified here to deal with the fact that R will not pull the date created column, LastDateModified column, or LastUserModified column. Other columns also removed include the Time and comments column.

ClamSurveyStrata <- dbGetQuery(channel,"SELECT * FROM [Shellfish_Bio_Other].[dbo].[ClamSurveyStrata]") # database query asking to select * (the * means to "select everything") from the specified database (first[]) then within the [dbo] folder and lastly [select the table to view].

ClamBioData <- dbGetQuery(channel,"SELECT * FROM [Shellfish_Bio_Other].[dbo].[ClamBioData]") # database query asking to select * (the * means to "select everything") from the specified database (first[]) then within the [dbo] folder and lastly [select the table to view].

#All of the columns in the tables listed above are not required for this analysis but are used to visualize the tables in the database. Below, a selection is made from each of the tables to subset only what is required to run the cluster analysis.

##

Step 2: Prepare first set of data such that it matches the originally produced allkeyloc.csv file (query from Microsoft Access) used in the density analysis.

View the four required tables:

ClamNumWgts

ClamBeaches

ClamHeaderSurvey

ClamHeaderSamples

Load additionally required packages:

library(tidyverse)

library(doBy)

library(survey)

library(plyr)

library(nlme)

library(pastecs)

library(ggplot2)

library(lmerTest)

library(lsmeans)

```
# Use the "select" tool from the pkg "tidyverse" to select columns from each of the three tables based on only the data wanted for the analysis:

ClamBeaches_Subset <- select(ClamBeaches, BeachCode, Description)

ClamHeaderSurvey_Subset <- select(ClamHeaderSurvey, Key, Source, BeachCode, Location, TypeOfSample, Year, MonthStart, DayStart)

ClamHeaderSamples_Subset <- select(ClamHeaderSamples, H1_Key, H2_Key, Stratum, FSU, SqArea, QuadratNum)

ClamNumWgts_Subset <- select(ClamNumWgts, H2_Key, Species, NumLegals, NumSubLegals)


# Merge the datasets together into a single dataframe:

Table_Join1 <- inner_join(ClamHeaderSurvey_Subset, ClamBeaches_Subset) # The order of the tables does not matter.  The inner_join looks for all matches on the column "BeachCode".

Table_Join2 <- inner_join(Table_Join1, ClamHeaderSamples_Subset, by = c('Key' = 'H1_Key')) # Joins by the "key" and "H1_Key"

Table_Join3 <- inner_join(Table_Join2, ClamNumWgts_Subset) # Joins by the "H2_Key"


# Filter the final Table Join by the selected criteria:

Allkeyloc <- filter(Table_Join3, Source == 'O') # Named this dataframe "Allkeyloc" to minimize changes to code below (this name was assigned in the original code from which the data was retrieved via Microsoft Access).

# Filter the dataframe further:

oyster <- filter(Allkeyloc, TypeOfSample == 'StTS', Species == '69H') # Filters out only the Type of Sample that = "StTS" and the Species "69H".


# Convert specified columns to numeric (from integer) to match the original code

oyster$NumSubLegals <- as.numeric(oyster$NumSubLegals)

oyster$NumLegals <- as.numeric(oyster$NumLegals)
```

oyster # view the changes from integer to numeric for the NumSubLegals and Num Legals columns

Load additionally required package:

library("imputeTS") # Packaged required to replace NAs with 0s

Replace NAs in the "NumSubLegals" column with 0s:

oyster <- na_replace(oyster, 0) # Replaces NAs showing up in the NumSubLegals column of "oyster" dataframe.

Test: The following three lines of code compare the original dataframe brought in from Microsoft Access with the new dataframe brought in through the database and filtered directly in R to ensure all data is the same. Use this code in the future if wanting to compare again to the original code for new data entered into the database.

test <- oyster$NumSubLegals # creates a dataframe with just the "NumSubLegals" column

unique(test) # gets unique values for the specified df

table(test) # creates a table with counts for each unique value in the column.

Add two columns to the new dataframe: the first new column calculates the total number of legal and sublegal oysters (adds the Num Legals and NumSubLegals columns together) in the quadrat and the second new column calculates the total number of legal and sublegal oysters per m2 (multiplies the total number legal and sublegal oysters by 4 or 16 based on the quadrat size used in the survey):

oyster$totalq <- oyster$NumLegals + oyster$NumSubLegals # Total number of legal and sublegal Oysters.

oyster$total <- oyster$totalq * (1 / oyster$SqArea) # Total number of legal and sublegal Oysters per m2.

oyster[1:5,] # Shows the appended two columns. [1:5,] means: show the first five rows and all the columns.

Add an additional new column that creates a unique name for each stratum of each survey so that they can be analyzed separately:

oyster$Surveyname = paste("key",oyster$Key, oyster$Location, oyster$Year, "Stratum", oyster$Stratum, sep = " ")

unique(oyster$Surveyname) # Displays all of the unique names in the newly created column

oyster[1:5,] # Can view the newly added column appended to the oyster dataframe.

Create a pivot table that summarizes the Olympia oyster data for each stratum by transect.

```
oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,

            Location = unique(Location),

            Key = max(Key),

            Year = max(Year),

            Stratum = max(Stratum),

            QuadratNum    = length(QuadratNum),

            total = sum(total),

            SqArea = max(SqArea),

            Diff = QuadratNum-total,

            SqAream2 = (1/SqArea),

            totalm2 = total*SqAream2)
```

oysterp # view the output

Weight each transect by the number of quadrats in the transect. A new column labeled "weight" is added to the oysterp dataframe:

oysterp$weight <- 1/oysterp$QuadratNum # creates a new column in the dataframe and puts a weight value based on the number of quadrats in the transect.

oysterp[1:5,] # view all columns and first five rows of the updated dataframe

##

```
# Step 3 - Prepare the second set of data as was previously done for the original file queried in Microsoft Access (allkeylocnames.csv file).


# Select the required columns from each dataset:

HeaderSurvey_Subset1 <- select(ClamHeaderSurvey, Source, Location, TypeOfSample, Year, TotalAreaStrata, SizeQuadrats, BeachCode, Key) %>%

  filter(Source == "O", TypeOfSample == "StTS") # In this case, filtered HeaderSurvey_Subset1 for specific criteria rather than after all the table joins were completed. This assisted in reporting the correct results based on the allkeylocnames.csv file outputted in Access.  the %>% command allows for chaining the first task (select) with the second task (filter) - This method simplifies the code (available in the tidyverse package)


HeaderSamples_Subset1 <- select(ClamHeaderSamples, H1_Key)

Beaches_Subset1 <- select(ClamBeaches, Description, BeachCode)

SurveyStrata_Subset1 <- select(ClamSurveyStrata, StrataArea, StrataNum, H_Key)

NumWgts_Subset1 <- select(ClamNumWgts, H2_Key)


# Merge the tables together:

Table_JoinA <- inner_join(Beaches_Subset1, HeaderSurvey_Subset1) # The order of the tables does not matter.  The inner_join looks for all matches on the column "BeachCode".

Table_JoinB <- inner_join(Table_JoinA, SurveyStrata_Subset1, by = c('Key' = 'H_Key'))

# Rename the dataframe to align with original R code (based on original Microsoft Access data file)

name.strat <- Table_JoinB

name.strat <- select(name.strat, 1, 3:11) # removed column that didn't match original file from Microsoft Access.

head(name.strat) # view a short clip of the dataframe


# Add a new column "Surveyname1" to the dataframe that gives each row in the dataframe a unique name.
```

```
name.strat$Surveyname1 = paste("key",name.strat$Key, name.strat$Location,
name.strat$Year,  "Stratum", name.strat$StrataNum,  sep = " ")


###########################################################################

# Step 4 - Create a blank table (dataframe) to store future calculated Olympia Oyster data.


# Display's the unique names for each row in name.strat

uNames <- unique( name.strat$Surveyname1 )


# Create a blank table with each row having a unique name (from uNames) and all the
columns are labeled as identified below and are based on the calculations assigned (e.g.
density, standard error, etc):

res <- data.frame( name=uNames,

          density=rep(NA, times=length(uNames)),

          stdErr=rep(NA, times=length(uNames)),

          SqArea=rep(NA, times=length(uNames)),

          #density.numby1meter=rep(NA, times=length(uNames)),

          #StdErrbymeter =rep(NA, times=length(uNames)),

          #quadnum =rep(NA, times=length(uNames)),

          Location =rep(NA, times=length(uNames)),

          Key=rep(NA, times=length(uNames)),

          Year=rep(NA, times=length(uNames)),

          Stratum=rep(NA, times=length(uNames)),

          SqArea.m2=rep(NA, times=length(uNames)),

          totalarea.m2=rep(NA, times=length(uNames)),

          StrataArea.m2=rep(NA, times=length(uNames)),

          #totalarea.quadsize=rep(NA, times=length(uNames)),

          #StrataArea.quadsize=rep(NA, times=length(uNames)),
```

```
#pop.mean =rep(NA, times=length(uNames)),
#pop.se =rep(NA, times=length(uNames)),
#prop.area=rep(NA, times=length(uNames)),
pop.est=rep(NA, times=length(uNames)),
pop.est.se=rep(NA, times=length(uNames)),
ratio.density=rep(NA, times=length(uNames)),
ratio.var=rep(NA, times=length(uNames)),
ratio.se=rep(NA, times=length(uNames)),
ratio.ci=rep(NA, times=length(uNames)),
Precision = NA,
VybarSTS = NA)
########################################################################
# Step 5 - Create a loop that selects all the data from the "oysterp" dataframe based on the
matching unique "uName". Each line of code is run 107 times - once for each unique
uName. Fill in the empty Res table with data.

for( i in 1:length(uNames) ) {

  iName <- as.character( uNames[i] ) # sets "uNames" as a character value for all unique
names (see "name" column in new table)

  oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight ) #
selects a subset of "oysterp" data for each unique uName (column labeled "name").

  oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight ) # Runs a
lm for each unique uName (name column).

 summary(oyster.fit) # Display's output of the lm for each unique location (name
column).
```

res$density [i] <- coef(oyster.fit)[1] # Get's lm of coefficient and fills this into the "density" column for the assigned unique row in the newly created blank table above.

res$stdErr[i] <- summary(oyster.fit)$coefficients[,2] # Take the standard error outputted from the lm and enters it into the "stdErr" column for each unique location (name column) in the newly create blank table above.

itotalarea <- (name.strat$TotalAreaStrata [i]) # Reports Total area of all Strata (combined) in the survey for each unique survey location (name column) in the new table.

istrataArea <- (name.strat$StrataArea [i]) # Reports Total area of the Strata for each unique location (name column) in the new table.

temp <- as.character(oysterSub$Location) # Designates the "Location" column as a character value

res$Location[i]<- unique(temp) # Assigns the "Location" column data in the new table based on the "Location" column from the oysterSub dataframe.

res$Key[i]<- unique(oysterSub$Key) # Assigns the "key" data to the new table from the oyster Sub dataframe.

res$Year [i] <- unique(oysterSub$Year) # Assigns the "year" data to the new table from the oyster Sub dataframe.

res$Stratum [i]   <- unique(oysterSub$Stratum) # Assigns the "Stratum" data to the new table from the oyster Sub dataframe.

res$SqArea [i] <- unique(oysterSub$SqArea) # Assigns the "SqArea" data to the new table from the oyster Sub dataframe.

res$SqArea.m2 [i] <- unique(oysterSub$SqAream2) # Assigns the "SqArea" data to the new table from the oyster Sub dataframe.

res$StrataArea.m2 [i]<- istrataArea # Display's the data in the StrataArea.m2 column of the res dataframe for the selected (i) row.

res$totalarea.m2 [i] <- itotalarea # Display's the data in the TotalArea.m2 column of the res dataframe for the selected (i) row.

res$Trannum [i] <- length(oysterSub$QuadratNum) # Fills Trannum (Transect Number) column with Qudrat Number (number of quadrats) from oysterSub dataframe.

res$quadcount [i] <- sum(oysterSub$QuadratNum) # Fills quadcount column by summing the number of quadrats for each transect from the oysterSub dataframe

Run survey analysis and add results to the "res" table:

oyster.design <- svydesign(data=oysterSub,

ids=~FSU,# clusters

variables=~total+QuadratNum,replace=T) # Survey sample analysis (svydesign)

est.ratio <- svyratio(numerator=~total,

denominator=~QuadratNum,oyster.design)

est.ratio.ci <- confint(est.ratio) # Calculates confidence interval of the est.ratio

est.ratio # Displays ratio estimation

```
  est.ratio.ci # Displays upper and lower confidence interval of ratio estimation


  pop <- predict(est.ratio, total=istrataArea) # Temporary dataframe to calculate population estimates for each unique row

  pop # Displays population total and standard error (for 1 of 107 unique rows)


  res$pop.est [i] <- pop$total  # Adds the estimated population to new dataframe "res" for each unique row

  res$pop.est.se [i]<- pop$se   # Adds the estimated population standard error to new dataframe "res" for each unique row


  res$ratio.density [i] <-as.numeric (est.ratio [1]) # Adds estimated density to new dataframe "res" for each unique row


  res$ratio.var [i] <- as.numeric(est.ratio [2]) # Adds estimated variation around density to new dataframe "res" for each unique row


}


res$ratio.se <- sqrt(res$ratio.var) # Calculate and adds ratio.se to the new dataframe "res" for each unique row


res$ratio.ci <- sqrt(res$ratio.var)*1.96 # Calculates and adds ratio.ci to the new dataframe "res" for each unique row


res$CI95 <- sqrt(res$ratio.var)*1.96 # Calculates and adds 95% confidence interval to new dataframe "res" for each unique row


########################################################################

# Step 6 - Create a table and outputs a .csv file for analysis of legal and small oysters
```

```
data <- res # renames the dataframe "res" and modifications are made to it below:


data["W"] <- NA # Creates a new column in dataframe "data" named "W" filled with "NA"

data$W <- data$StrataArea.m2 / data$totalarea.m2 # Calculates W for each unique row in "data"

data2 <- data # Renames the dataframe


data2["Wy"] <- NA # Creates a new column named "Wy" filled with "NA"

data2$Wy <- data2$W*data2$density # Calculates Wy for each unique row in "data"

data3 <- data2 # Renames the dataframe


data3["W2"] <- NA # Creates a new column named "W2" filled with "NA"

data3$W2 <- data3$ratio.var*data3$W*data3$W # Calculates W2 for each unique row in "data


rm(data) # Removes the dataframe "data"

rm(data2) # Removes the dataframe "data2"


# Using dataframe "data3", a pivot table is created next to summarize each stratum of each survey by transect to get the total number of quadrats and oysters. A number of the columns in the dataframe are left with NAs:


All <- ddply(data3, c("Location","Year"), summarise,

        name = NA,

        Year = unique(Year),

        Location = unique(Location),

        density = sum (Wy),

        VybarSTS = sum (W2),
```

```
stdErr = sqrt(VybarSTS),
CI95 = 1.96 * sqrt(VybarSTS),
Precision = (CI95/ density),
SqArea = "NA",
Key = "NA",
Stratum = "Overall",
SqArea.m2 = "NA",
totalarea.m2 = "NA",
StrataArea.m2 = "NA",
pop.est = "NA",
pop.est.se = "NA",
ratio.density = "NA",
ratio.var = "NA",
ratio.se = "NA",
ratio.ci = "NA",
Trannum = "NA",
quadcount = "NA")

rm(data3) # Removes the dataframe "data3"

res2 <- rbind(res,All) # Binds the "res" and "All" dataframes together

# Create and save .csv file:
csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2.csv",sep="")  #
Creates a file name title.
```

```
write.csv(res2, file=csvFileName,row.names=FALSE, na="") # creates a .csv file based
on the final dataframe and saves it in the working directory with the assigned file name
and date.


##########################################################################

# Step 7 - Re-run the above code to create another table and output a .csv file for analysis
of Large/Legal oysters only


# The original code cleared the dataframe and re-loaded a new file. If the dataframe is
cleared now, re-connection to the clam database would be required and would be very
repetitive.  By using the "oyster" dataframe again, we avoid having to reload the
database, tables, and filter the results for subsequent tables that are made. However, make
note that the results of "oyster" are over-written so caution should be taken re-running
different parts of the code in this file. In the future, it might be worth changing the name
of the dataframe for large+small oly, large only, small only to avoid this confusion.


oyster # dataframe from above (original Access database: "allkeyloc"). Filtered and with
unique names appended.


# Modify code and "oyster" dataframe from above to create a table with just Large/Legal
oysters

oyster$totalq <- oyster$NumLegals

oyster$total <- oyster$totalq * (1/oyster$SqArea)


# Create a pivot table that summarizes each stratum by each survey by transect to get the
total number of quadrats and oysters

oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,

          Location = unique(Location),

          Key = max(Key),

          Year = max(Year),

          Stratum = max(Stratum),

          QuadratNum    = length(QuadratNum),
```

```
        total = sum(total),
        SqArea = max(SqArea),
        Diff = QuadratNum-total,
        SqAream2 = (1/SqArea),
        totalm2 = total*SqAream2)

# Weigh each transect in the linear model:
oysterp$weight <- 1/oysterp$QuadratNum # Creates a new column labelled "weight"
oysterp[1:5,] # View first five rows of dataframe with the new column

# Create a loop (as above) but for only Large/Legal oysters:
uNames <- unique( name.strat$Surveyname1 ) # Get unique names (107 total)

res <- data.frame( name=uNames,
         density=rep(NA, times=length(uNames)),
         stdErr=rep(NA, times=length(uNames)),
         SqArea=rep(NA, times=length(uNames)),
         #density.numby1meter=rep(NA, times=length(uNames)),
         #StdErrbymeter =rep(NA, times=length(uNames)),
         #quadnum =rep(NA, times=length(uNames)),
         Location =rep(NA, times=length(uNames)),
         Key=rep(NA, times=length(uNames)),
         Year=rep(NA, times=length(uNames)),
         Stratum=rep(NA, times=length(uNames)),
         SqArea.m2=rep(NA, times=length(uNames)),
         totalarea.m2=rep(NA, times=length(uNames)),
         StrataArea.m2=rep(NA, times=length(uNames)),
```

```
#totalarea.quadsize=rep(NA, times=length(uNames)),
#StrataArea.quadsize=rep(NA, times=length(uNames)),
#pop.mean =rep(NA, times=length(uNames)),
#pop.se =rep(NA, times=length(uNames)),
#prop.area=rep(NA, times=length(uNames)),
pop.est=rep(NA, times=length(uNames)),
pop.est.se=rep(NA, times=length(uNames)),
ratio.density=rep(NA, times=length(uNames)),
ratio.var=rep(NA, times=length(uNames)),
ratio.se=rep(NA, times=length(uNames)),
ratio.ci=rep(NA, times=length(uNames)),
Precision = NA,
VybarSTS = NA) #Creates a blank table for which data will be calculated and
will fill in the table (below)
```

```
# Create a loop of calculations for each unique row with results fitting into the dataframe
"res". See above for description of what each line of code does:
```

```
for( i in 1:length(uNames) ) {
  iName <- as.character( uNames[i] )
  oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
  oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
  summary(oyster.fit)
  res$density [i] <- coef( oyster.fit )[1]
  res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]
  itotalarea<- (name.strat$TotalAreaStrata [i])
  istrataArea<- (name.strat$StrataArea [i])
  temp <- as.character(oysterSub$Location)
```

```
  res$Location[i]<- unique(temp)
  res$Key[i]<- unique(oysterSub$Key )
  res$Year [i] <- unique(oysterSub$Year )
  res$Stratum [i]   <- unique(oysterSub$Stratum )
  res$SqArea [i]  <- unique(oysterSub$SqArea )
  res$SqArea.m2 [i] <- unique(oysterSub$SqAream2)
  res$StrataArea.m2 [i]<- istrataArea
  res$totalarea.m2 [i] <- itotalarea
  res$Trannum [i] <- length(oysterSub$QuadratNum)
  res$quadcount [i] <- sum(oysterSub$QuadratNum)

  oyster.design <- svydesign(data=oysterSub,
                             ids=~FSU,# clusters
                             variables=~total+QuadratNum,replace=T)

  est.ratio <- svyratio(numerator=~total,
                        denominator=~QuadratNum,oyster.design)

  est.ratio.ci <- confint(est.ratio)
  est.ratio
  est.ratio.ci

  pop <- predict(est.ratio, total=istrataArea) # estimate total based on ratio
  pop

  res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in
dataframe
```

```
  res$pop.est.se [i]<- pop$se   #this takes the se from the ratio estimate puts in dataframe

  res$ratio.density [i] <-as.numeric (est.ratio [1])
  res$ratio.var [i] <- as.numeric(est.ratio [2])

}

res$ratio.se <- sqrt(res$ratio.var)
res$ratio.ci <- sqrt(res$ratio.var)*1.96
res$CI95 <- sqrt(res$ratio.var)*1.96

# Create a temporary dataframe to calculate further variables.
data <- res

data["W"] <- NA
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)
```

Create a pivot table that summarizes each stratum of each survey by transect to get total number of quadrats and oysters:

```
All <- ddply(data3, c("Location","Year"), summarise,
        name = NA,
        Year = unique(Year),
        Location = unique(Location),
        density = sum (Wy),
        VybarSTS = sum (W2),
        stdErr = sqrt(VybarSTS),
        CI95 = 1.96 * sqrt(VybarSTS),
        Precision = (CI95/ density),
        SqArea = "NA",
        Key = "NA",
        Stratum = "Overall",
        SqArea.m2 = "NA",
        totalarea.m2 = "NA",
        StrataArea.m2 = "NA",
        pop.est = "NA",
        pop.est.se = "NA",
        ratio.density = "NA",
        ratio.var = "NA",
        ratio.se = "NA",
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")
```

```
rm(data3)


res2 <- rbind(res,All) # Bind "res" and "All" dataframes together


# Write the new dataframe to a .csv file (will save and store in assigned working directory)

csvFileName <- paste("Olyclusteranalysislegals.csv",sep="")

write.csv(res2, file=csvFileName,row.names=FALSE, na="")


##########################################################################
#####

# Step 8 - Re-run this code again, this time for small/Juvenile oysters only:


# See comment in at start of Step 7 regarding re-running code.


oyster # Original dataframe from above

oyster$totalq <-   oyster$NumSubLegals # Small oysters only included in this analysis

oyster$total <- oyster$totalq * (1/ oyster$SqArea)


# Create a pivot table:

oysterp <- ddply(oyster, c("Surveyname","FSU"), summarise,

             Location = unique(Location),

             Key = max(Key),

             Year = max(Year),

             Stratum = max(Stratum),

             QuadratNum    = length(QuadratNum),

             total = sum(total),

             SqArea = max(SqArea),
```

```
        Diff = QuadratNum-total,
        SqAream2 = (1/SqArea),
        totalm2 = total*SqAream2)

#Weight each transect in the linear model:
oysterp$weight <- 1/oysterp$QuadratNum
oysterp[1:5,]

#Create a blank table to populate with calculated data:
res <- data.frame( name=uNames,
         density=rep(NA, times=length(uNames)),
         stdErr=rep(NA, times=length(uNames)),
         SqArea=rep(NA, times=length(uNames)),
         #density.numby1meter=rep(NA, times=length(uNames)),
         #StdErrbymeter =rep(NA, times=length(uNames)),
         #quadnum =rep(NA, times=length(uNames)),
         Location =rep(NA, times=length(uNames)),
         Key=rep(NA, times=length(uNames)),
         Year=rep(NA, times=length(uNames)),
         Stratum=rep(NA, times=length(uNames)),
         SqArea.m2=rep(NA, times=length(uNames)),
         totalarea.m2=rep(NA, times=length(uNames)),
         StrataArea.m2=rep(NA, times=length(uNames)),
         #totalarea.quadsize=rep(NA, times=length(uNames)),
         #StrataArea.quadsize=rep(NA, times=length(uNames)),
         #pop.mean =rep(NA, times=length(uNames)),
         #pop.se =rep(NA, times=length(uNames)),
```

```
            #prop.area=rep(NA, times=length(uNames)),
            pop.est=rep(NA, times=length(uNames)),
            pop.est.se=rep(NA, times=length(uNames)),
            ratio.density=rep(NA, times=length(uNames)),
            ratio.var=rep(NA, times=length(uNames)),
            ratio.se=rep(NA, times=length(uNames)),
            ratio.ci=rep(NA, times=length(uNames)),
            Precision = NA,
            VybarSTS = NA)
```

Create a loop to calculate and acquire data to fill in the empty dataframe for each unique row:

```
for( i in 1:length(uNames) ) {
  iName <- as.character( uNames[i] )
  oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
  oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
  summary(oyster.fit)
  res$density [i] <- coef( oyster.fit )[1]
  res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]
  itotalarea<- (name.strat$TotalAreaStrata [i])
  istrataArea<- (name.strat$StrataArea [i])
  temp <- as.character(oysterSub$Location)
  res$Location[i]<- unique(temp)
  res$Key[i]<- unique(oysterSub$Key )
  res$Year [i] <- unique(oysterSub$Year )
  res$Stratum [i]   <- unique(oysterSub$Stratum )
  res$SqArea [i]  <- unique(oysterSub$SqArea )
```

```
  res$SqArea.m2 [i] <- unique(oysterSub$SqAream2)
  res$StrataArea.m2 [i]<- istrataArea
  res$totalarea.m2 [i] <- itotalarea
  res$Trannum [i] <- length(oysterSub$QuadratNum)
  res$quadcount [i] <- sum(oysterSub$QuadratNum)

  oyster.design <- svydesign(data=oysterSub,
                             ids=~FSU,# clusters
                             variables=~total+QuadratNum,replace=T)

  est.ratio <- svyratio(numerator=~total,
                        denominator=~QuadratNum,oyster.design)

  est.ratio.ci <- confint(est.ratio)
  est.ratio
  est.ratio.ci

  pop <- predict(est.ratio, total=istrataArea) # estimate total based on ratio
  pop

  res$pop.est [i] <- pop$total
  res$pop.est.se [i]<- pop$se

  res$ratio.density [i] <-as.numeric (est.ratio [1])
  res$ratio.var [i] <- as.numeric(est.ratio [2])

}
```

```
res$ratio.se <- sqrt(res$ratio.var)
res$ratio.ci <- sqrt(res$ratio.var)*1.96
res$CI95 <- sqrt(res$ratio.var)*1.96

# Create a temporary dataframe to calculate more data to add to the "res" dataframe:
data <- res

data["W"] <- NA
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)

# Create a new blank pivot table to populate with data:
All <- ddply(data3, c("Location","Year"), summarise,
        name = NA,
        Year = unique(Year),
        Location = unique(Location),
```

```
        density = sum (Wy),
        VybarSTS = sum (W2),
        stdErr = sqrt(VybarSTS),
        CI95 = 1.96 * sqrt(VybarSTS),
        Precision = (CI95/ density),
        SqArea = "NA",
        Key = "NA",
        Stratum = "Overall",
        SqArea.m2 = "NA",
        totalarea.m2 = "NA",
        StrataArea.m2 = "NA",
        pop.est = "NA",
        pop.est.se = "NA",
        ratio.density = "NA",
        ratio.var = "NA",
        ratio.se = "NA",
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")

rm(data3)

res2 <- rbind(res,All) # Binds "res" and "All" dataframes together

# Create and save a .csv file for Small oysters (will save to working directory):
csvFileName <- paste("Olyclusteranalysissmalls.csv",sep="")
write.csv(res2, file=csvFileName,row.names=FALSE, na="")
```

#Changes to Density Graphs: The original graphs plotted a bar plot with 1, 2, or 3 strata and an "overall" strata that combined Strata 1-3 (but only plotted when more than 1 strata in a given year was surveyed). There was missing code in Norgard et al. 2010 that showed how this was plotted. The new code below includes an if/else statement that plots the "overall" category only when more than one strata was surveyed in a given year. The new density graphs are also plotted as a point plot instead of a bar plot for better visualization. The old graphs only plotted an "all sizes" category and the "smalls" category, the new graphs also plot a "large" category.

```
# Read in data for legal, legal and Small, and small only

# Legal and small
LegSmOyster <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2.csv",
                header=TRUE, as.is=TRUE, strip.white=TRUE)

# Small only
SmOyster <- read.csv("Olyclusteranalysissmalls.csv",
              header=TRUE, as.is=TRUE, strip.white=TRUE)

# Legal only
LegOyster <- read.csv("Olyclusteranalysislegals.csv",
              header=TRUE, as.is=TRUE, strip.white=TRUE)

# Add Size column to each data frame
LegSmOyster <- mutate(LegSmOyster, Size = "All Sizes")
SmOyster    <- mutate(SmOyster, Size = "Small")
LegOyster   <- mutate(LegOyster, Size = "Large")

# Merge Datasets
```

```
OysterDat <- rbind(LegSmOyster, SmOyster, LegOyster)


##############################################################################
#######

# New Line of Code Added Feb 23, 2022 to remove "Large" and "Small" Densities from 2010 for the two following sites:

  # Key 1511 Harris Point 2010 Stratum 1 (Large, Small) - overall not removed here because if statement below removes Overall fromt his site (because there is only 1 strata)

  # Key 1515 Swy-a-lana Lagoon 2010 Stratum 1,2,3 (Large, Small, Overall)

  # Removed because Large and Small oysters were not distinguished in these years and therefore, only the "all sizes" category should be plotting.  Automate this in the future? This is a Work around for now.

OysterDat <- OysterDat[-c(214, 239, 240, 241, 363, 401, 426, 427, 428, 550),]

# Be cautious when running code each year that the correct rows are being deleted.


##############################################################################


# Get unique locations

OysterLocations <- unique(OysterDat$Location)


# Create a Function for plotting density:

PlotDensity <- function(locations, dendata, directory) {


  for ( i in 1:length(locations) ) {


    # Subset data to specific location

    plot_data        <- subset(dendata, Location == locations[i])


    # Set year as integer so that spacing between years that weren't sampled is recognized
```

```
    plot_data$Year <- as.integer(plot_data$Year)


    # Create directory for plots to be saved
    mainDir<-getwd()
    subDir<- directory # folder name
    dir.create(file.path(mainDir, subDir), showWarnings = FALSE)
    results.dir<-file.path(mainDir, subDir)


    # Create file name for saved plot
    currentDate <- Sys.Date()
    jpegFileName <- paste(locations[i],currentDate, ".jpeg",sep="")


    # Set error bar limits
    limits <- aes(ymax = density + 2*stdErr, ymin= ifelse((density - 2*stdErr)<0, 0,
(density - 2*stdErr) ))


    # The bars and errorbars have different widths, need to specify how wide the objects
being dodged        are
    dodge <- position_dodge(width=0.6)


# Original Geom_Bar Plot (Left in just in case want to switch back in future)
   # plot <- ggplot(plot_data, aes(fill=Stratum, y=density, x=Year)) +
    # facet_grid(.~Size) +
    # geom_bar(position="dodge", stat="identity") +
    # scale_fill_grey(start = 0.3, end = 0.8) +
    # geom_errorbar(limits, position=dodge, width=0.25) +
    # ylab(bquote(.("Density" ~ "(Oysters/m"^2 ~ ")" ))) +
    # theme_bw() +
```

```
 # theme(panel.grid.minor.x=element_blank(),
      #  panel.grid.major.x=element_blank(),
      #  strip.text.x = element_text(size = 14),
      #  axis.title=element_text(size=8),
      #  axis.text=element_text(size=6))
  #ggsave(filename= paste(results.dir, jpegFileName, sep = "/"))


# Prep for new (2021) Geom_Point Plot:
  # Read in necessary package
  library(scales)


  # This section of code specifies when to plot the "overall" category on the figure (only
want this category to plot when more than 1 Stratum was sampled in a particular year)


  no_overall <- plot_data %>% filter(Stratum != "Overall") # removes all instances of
"overall"
  plot_list <- list() # creates a blank list
  Years <- unique(no_overall$Year) # creates a vector of unique Years
  for(i in 1:length(Years)){
    by_year <- no_overall %>% filter(Year == Years[i]) # filter no_overall for one
particular year
    if(length(unique(by_year$Stratum)) == 1){ # in that year, is there only one stratum?
      plot_list[[i]] <- by_year # if yes, then use "no_overall" for that year
    }else{
      plot_list[[i]] <- plot_data %>% filter(Year == Years[i]) # if no, then use original
data          (which includes "overall" for that year)
    }
  }
```

```
plot_data = do.call(rbind, plot_list)



# Read in packages needed for colour scheme

library(RColorBrewer)

library(viridis)


# New (2021) dot plot.  The if statement in the plot ensures that year doesn't get plotted as a         continuous variable when only 1 year was sampled (it plots as decimals otherwise)

  if(length(unique(plot_data$Year)) == 1){

  plot_data$Year <- as.character(plot_data$Year)

  plot <- ggplot(plot_data, aes(fill=Stratum, y=density, x=Year, colour=Stratum)) +

    facet_grid(rows = vars(Size), switch="y", scales="free") + # Note Size = "Large" plots only the Large size class, "Small" only plots small size class, etc. - change it here and in this spot and just below. When just "Size" is in brackets, all three plots plot in a facet grid.

    geom_point(size = 3, position = dodge) +

    scale_x_discrete()

}else{

  plot <- ggplot(plot_data, aes(fill=Stratum, y=density, x=Year, colour=Stratum)) +

    facet_grid(rows = vars(Size), switch="y", scales="free") +

    geom_point(size = 3, position = dodge) +

    scale_x_continuous(breaks = pretty_breaks())

}


  plot <- plot +

  scale_color_viridis(discrete = TRUE, option = "D") +

  geom_errorbar(limits, position=dodge, width=0.25) +
```

```
    ylab(bquote(.("Density" ~ "(Oysters/m"^2 ~ ")" ))) +
    theme_bw() +
    theme(panel.grid.minor.x=element_blank(),
          panel.grid.major.x=element_blank(),
          strip.text.y = element_text(size = 18),
          legend.title = element_text(size =12),
          legend.text = element_text(size = 12),
          axis.title=element_text(size=18),
          axis.text=element_text(size=10))



  print(plot)
  ggsave(filename= paste(results.dir, jpegFileName, sep = "/"))

 } # End location for loop

} # End Plot Density function

# Run the Function:
PlotDensity(locations = OysterLocations, dendata = OysterDat, directory =
"Density_Figs")

################################################################
## Part 3: Creating Length Frequency Graphs for each Site ##
################################################################
#Authors: Erin Herder (New Code), Jessica Finney (Original Code)
#Changes to Code: This section of code uses the original dataframes read in from the
database in Part 1 and subsets the necessary dataframes for required data to produce
```

length frequency plots. All other parts of this code are original. A new Function was written in order to have all the figures save into a specified folder in the working directory as was done in Part 2.

Load packages

library(moments)

library(plotrix)

library(dplyr)

View required tables for plotting Length Frequency Graphs:

ClamHeaderSurvey

ClamHeaderSamples

ClamBioData

Subset the tables to only the required columns from each table (to match original queries in Microsoft Access):

ClamHeaderSurvey_Subset1 <- select(ClamHeaderSurvey, Key, Source, Location, Year, MonthStart, DayStart)

ClamHeaderSamples_Subset1 <- select(ClamHeaderSamples, H1_Key, H2_Key)

ClamBioData_Subset1 <- select(ClamBioData, H2_Key, Species, Length)

Join the tables together

Table_JoinA <- inner_join(ClamHeaderSurvey_Subset1, ClamHeaderSamples_Subset1, by = c('Key' = 'H1_Key'))

Table_JoinB <- inner_join(Table_JoinA, ClamBioData_Subset1, by = (c('H2_Key' = 'H2_Key')))

#Filter for Source "O" and Species "69H". Dataframe name "dat" matches original .csv file (Biostats.csv) loaded into R and created in Microsoft Access.

dat <- filter(Table_JoinB, Source == 'O', Species == '69H')

```
# Remove columns with NAs in length
dat <- dat %>%
  filter(!is.na(Length))

# Calculate maximum and minimum lengths (for plotting purposes)
LengthMax = max(dat$Length, na.rm=T)
LengthMin = min(dat$Length, na.rm =T)

# Divide into locations and plot as histograms
# Create a list of the unique locations in the "dat" table
locations = unique (dat$Location)

# Group data by location and year
groupdat <- dat%>%
  group_by(Location, Year)

# Calculate statistics for each location and year grouping
biostats  <- dplyr::summarise(groupdat, n = n(),
                              Mean=mean(Length),
                              SE = std.error(Length),
                              Median = median(Length),
                              Kurtosis = kurtosis(Length),
                              Skewness = skewness(Length),
                              Min = min(Length),
                              Max = max(Length),
                              Range = max(Length)-min(Length),
                              CI95 = SE*1.96
```

```
                                )
biostats  <- as.data.frame(biostats)


# Make text file of "biostats" table
write.table(biostats, file = "Biostats.txt", row.names = FALSE, col.names = TRUE, sep =
",")
write.table(biostats, file = "Biostats.csv", row.names = FALSE, col.names = TRUE, sep =
",")


# Create a Function so that all figures are saved into a single identified folder
PlotLengthFreq <- function(beachi, beachdat, directory) {


# Create a loop to plot length frequency graphs for each beach and year
for( i in 1:length(locations) ) {


  # Subset data from beach i
  beachi <- locations[i]
  beachdat <- dat%>%
    filter(Location == beachi )


  beachmean <- biostats %>%
    filter(Location == beachi)


  mainDir<-getwd()
  subDir<- directory # folder name
  dir.create(file.path(mainDir, subDir), showWarnings = FALSE)
  results.dir<-file.path(mainDir, subDir)
  currentDate <- Sys.Date()
```

```
  jpegFileName1 <- paste(locations[i], "_Count_", currentDate, ".jpeg",sep="")

  jpegFileName2 <- paste(locations[i], "_Perc_", currentDate, ".jpeg", sep="")


  # Sets label location - for plots with count on y-axis.

  # For plots with Count on y-axis

  xloc <- 0.9 * max(beachdat$Length)

  ydat <- ddply(beachdat, .(Length, Year), summarise, Freq = length(Length))

  yloc <- 0.8 * max(ydat$Freq)


    #### This section of code added to that Length-Frequency plots plot as %/Proportion
on the Y-axis

  summary_beachdat <- beachdat %>% group_by(Year, Length) %>%

    dplyr::summarise(count = n())

  yearcounts <- list()

  perc_final  <- c()

  for(i in 1:length(beachmean$Year)){

    yearcounts[[i]] <- summary_beachdat[summary_beachdat$Year ==
beachmean$Year[i],]

yearcounts[[i]]$perc<- yearcounts[[i]]$count/beachmean$n[i]*100

if(sum(yearcounts[[i]]$perc) != "100"){stop("Error in Percentage outputs. Doesn't sum to
100")}

perc_final <- c(perc_final, yearcounts[[i]]$perc)

}

 summary_beachdat$perc <- perc_final


 # Sets label location - for plots with count on y-axis.

 # For plots with Perc on y-axis

 xloc2 <- 0.9 * max(beachdat$Length)
```

```
yloc2 <- 0.8 * max(perc_final)


#Plot with Count on y-axis
 locplot <- ggplot(beachdat, aes(Length)) +
   theme_bw( ) +
   facet_grid(Year~.) +
   #opts(strip.text.y = theme_text(size = 8)) +
   theme(strip.text.y = element_text(size = 20),
         axis.text = element_text(size = 12),
         axis.title=element_text(size= 18)) +
   geom_bar() +
   geom_vline(aes(xintercept = Mean), data = beachmean, linetype = "longdash", colour
= "red") +
   geom_text(data = beachmean, inherit.aes = FALSE, size = 7,
             aes(label = paste("n = ", n, sep = "")), x = xloc, y = yloc) +
   scale_x_continuous(breaks = seq(from = 0, to = max(beachdat$Length), by = 5)) +
   labs( x="Length (mm)", y="Number of Oysters" )
 ggsave(filename= paste(results.dir, jpegFileName1, sep = "/" ))


 # Plots of % on y-axis
 percplot <- ggplot(summary_beachdat, aes(x = Length, y = perc)) +
   theme_bw( ) +
   facet_grid(Year~.) +
   #opts(strip.text.y = theme_text(size = 8)) +
   theme(strip.text.y = element_text(size = 20),
         axis.text = element_text(size = 12),
         axis.title=element_text(size= 18)) +
```

```
  geom_bar(stat = "identity") +
  geom_vline(aes(xintercept = Mean), data = beachmean, linetype = "longdash", colour
= "red") +
  geom_text(data = beachmean, inherit.aes = FALSE, size = 7,
        aes(label = paste("n = ", n, sep = "")), x = xloc2, y = yloc2) +
  scale_x_continuous(breaks = seq(from = 0, to = max(beachdat$Length), by = 5)) +
  labs( x="Length (mm)", y="Proportion of Oysters (%)" )
 ggsave(filename= paste(results.dir, jpegFileName2, sep = "/" ))


} # Close locations loop
} # End of Function
# Run the Function:
PlotLengthFreq(beachi = location, beachdat = dat, directory = "LengthFreq_Plots")


###########################################################################
# Extract Zero Oyster Counts for each site for each year
###########################################################################


#Author: Erin Herder
#Date: January 8, 2022
## Added in 2022 during data analysis to update missing information for data report.
This code produces summary of proportion of quadrats that had no Olympia oysters in
them for each survey and strata and for All oysters, Legal only, and small only.
oyster
ZeroOysters <- oyster
ZeroOysters$UniqueLocbyYear <- paste("key", ZeroOysters$Key,
ZeroOysters$Location, ZeroOysters$Year)
ZeroOysters1 <- select(ZeroOysters, Surveyname, UniqueLocbyYear, QuadratNum,
totalq, NumLegals, NumSubLegals)
```

```
ZeroOystersFinal <- ddply(ZeroOysters1, c("Surveyname"), summarise,
        TotQuads = length(QuadratNum),
        All_TotQuadsZeros = sum(totalq==0),
        Legal_TotQuadsZeros = sum(NumLegals==0),
        SubLegal_TotQuadZeros = sum(NumSubLegals==0)
            )
ZeroOystersFinal$PropZerosAll <- (ZeroOystersFinal$All_TotQuadsZeros /
ZeroOystersFinal$TotQuads)*100
ZeroOystersFinal$PropZerosLegal <- (ZeroOystersFinal$Legal_TotQuadsZeros /
ZeroOystersFinal$TotQuads )*100
ZeroOystersFinal$PropZerosSubLegal <- (ZeroOystersFinal$SubLegal_TotQuadZeros /
ZeroOystersFinal$TotQuads)*100
ZeroOysters_Output <- ZeroOystersFinal
write.csv(ZeroOysters_Output, "ZeroOysters.csv", row.names=F)


### This code addresses the total numer of Zero Quadrats for the "overall" category
ZeroOystersOverall <- ddply(ZeroOysters1, c("UniqueLocbyYear"), summarise,
            TotQuads = length(QuadratNum),
            All_TotQuadsZeros = sum(totalq==0),
            Legal_TotQuadsZeros = sum(NumLegals==0),
            SubLegal_TotQuadZeros = sum(NumSubLegals==0)
)
ZeroOystersOverall$PropZerosAll <- (ZeroOystersOverall$All_TotQuadsZeros /
ZeroOystersOverall$TotQuads)*100
ZeroOystersOverall$PropZerosLegal <- (ZeroOystersOverall$Legal_TotQuadsZeros /
ZeroOystersOverall$TotQuads )*100
ZeroOystersOverall$PropZerosSubLegal <-
(ZeroOystersOverall$SubLegal_TotQuadZeros / ZeroOystersOverall$TotQuads)*100
ZeroOverall_Output <- ZeroOystersOverall
```

```
write.csv(ZeroOverall_Output, "ZeroOysters_Overall.csv", row.names=F)


############################################################################
#### Calculate Survey Precision
############################################################################


#Author: Erin Herder

#Date: January 8, 2022

## Added in 2022 during data analysis to update missing information for data report. This calculates survey precision (95 Confidence Interval/density for each unique site and for Large and Small oly's, Large only, and small only.

S1 <- select(LegSmOyster, name, density, CI95)

S1$LegSmallPrecision <- (S1$CI95 / S1$density)*100

S1 <- S1[-c(118:187),]

LegOyster

S2 <- select(LegOyster, name, density, CI95)

S2$LegPrecision <- (S2$CI95 / S2$density)*100

S2 <- S2[-c(118:187),]

S3 <- select(SmOyster, name, density, CI95)

S3$SmallPrecision <- (S3$CI95 / S3$density)*100

S3 <- S3[-c(118:187),]

Join1 <- inner_join(S1, S2, by = c('name' = 'name'))

Join2 <- right_join(Join1, S3, by = c('name'))

SurveyPrecision <- select(Join2, name, LegSmallPrecision, LegPrecision, SmallPrecision)

SurveyPrecision <- na_replace(SurveyPrecision, 0)

write.csv(SurveyPrecision, "SurveyPrecision.csv", row.names=F)
```