Index Site Surveys for Olympia Oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2009 to 2017

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INDEX SITE SURVEYS FOR OLYMPIA OYSTERS
(*OSTREA LURIDA* CARPENTER, 1864) IN BRITISH COLUMBIA – 2009 to 2017

by

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Abstract

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   The Olympia oyster (*Ostrea lurida* Carpenter, 1864) was designated a species of
Special Concern under the Canadian Species at Risk Act in 2003. A management plan
was developed in 2009, and a primary objective was maintenance of relative abundance
(density) at index sites. Fourteen index sites were chosen to monitor density within their
range in Canadian waters. Sites have been surveyed at least twice since 2009. Density,
length frequency, and bed area have been determined for sites. Densities varied across
sites and years, and ranged from $507 \pm 74.1 \text{ m}^{-2}$ at Port Eliza in 2013 to 0.6 ± 0.4 at
Bacchante Bay in 2012. The time series at most sites is short and precluded evaluation of
trends. However, baseline information from index site data and continued monitoring will
enable future analysis of variability and trends.

Résumé

En 2003, l'huître indigène du Pacifique (*Ostrea lurida* Carpenter, 1864) a été désignée comme espèce préoccupante en vertu de la *Loi sur les espèces en péril* du Canada. Un plan de gestion a été élaboré en 2009, et l'un des principaux objectifs de ce plan consistait à maintenir l'abondance relative (densité) de l'espèce à des sites repères. Quatorze sites repères ont été choisis pour surveiller la densité de l'espèce dans son aire de répartition dans les eaux canadiennes. Ces sites ont fait l'objet de relevés au moins deux fois depuis 2009. Des mesures relatives à la densité, à la fréquence de longueur et à la superficie du gisement ont été prises à chacun des sites. Les densités variaient d'un site à l'autre et d'une année à l'autre, de 507 ± 74.1 m^{-2} à Port Eliza en 2013 à $0,6 \pm 0,4$ m^{-2} à la baie Bacchante en 2012. Puisque la série chronologique de relevés à la plupart des sites était courte, elle n'a pas permis l'évaluation des tendances. Toutefois, les renseignements de base prélevés aux sites repères ainsi qu'une surveillance continue permettront l'analyse future de la variabilité des tendances.

Introduction

The Olympia oyster, *Ostrea lurida* Carpenter, 1864 (= *Ostrea conchaphila* Carpenter, 1857 [*partim*]), 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 (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 under the 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 (density) of Olympia oyster at 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.

Thirteen index sites were chosen from a mixture of previously surveyed sites, and by random site selection. In 2014, a fourteenth site was added at Joes Bay in the Broken Group area in partnership with Parks Canada. The selected sites provided a representative sample of Olympia oyster populations in different geographic zones in the Pacific region and span the much of the range of Olympia oysters in BC (Figure 1).

This report summarizes results from 43 surveys at 14 index sites from 2009 to 2017.

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 index site selection followed DFO (2010).

Defining and Mapping Survey Strata and Oyster Beds

Survey strata were positioned to cover as much of the oyster bed as possible while maximizing the area to be surveyed in one tide. Survey strata were rectangular in shape to allow for ease of survey set-up. Stratification was used at 10 index sites where beds were large or discontinuous. The remaining index sites had one stratum. Refinements to stratum boundaries have been made since 2009 to exclude areas that are not able to be surveyed (e.g., subtidal portions) and slight increases to stratum area have occurred to included more habitat if time allowed.

Coordinates of all Olympia oyster beds, strata and corner points were collected each survey year using Trimble GPS Pathfinder Pro. Mapping of Olympia oyster beds was focused on survey stratum when time did not permit mapping of the entire beach. The outer boundaries of the beds were defined by the absence of oysters. Strata coordinates from prior survey years were used to locate index sites.

Survey Design

All 43 surveys followed either two-stage (TS) or stratified two-stage (StTS) survey design (*fide* Gillespie and Kronlund 1999; Norgard et al. 2010); the rationale and methodology for use of two-stage designs for Olympia oyster index surveys was described in Norgard et al. (2010) . Transect and quadrat positions were chosen in advance of surveys using R software code (Appendix 1).

In this design the first stage units were established by placing a tape measure on the beach substrate to form a baseline along the length of the stratum. First stage units or transects were then randomly selected at positions along the baseline. The transect length was then divided by the number of desired quadrats and the first quadrat on these perpendicular transects randomly selected in the first portion of the transect. The remaining quadrats were then systematically positioned along the length of transect. Corner points of each stratum and quadrat were marked with flags.

Sampling Intensity

Sampling intensity (number of quadrats) surveyed in each stratum was determined at the time of survey and was dependent on the amount of time available to complete the survey and 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).

Data Collection

Sites were surveyed at the lowest spring and summer tide cycles. 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 2011, when four beaches were 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 rocks, shells and other substrate was counted and recorded in field notebooks.

Olympia oyster shell lengths were measured and collated to understand potential trends in growth and recruitment. Quadrats were randomly selected to conduct shell measurement. All oysters within the quadrats were measured until a minimum sample size of 50 oysters was attained. Shell length was measured by bisecting the shell vertically 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. 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 has the potential of documenting recruitment events like those evident at Port Eliza Beach 3 and Hillier Island where hundreds of small oysters were counted.

All data collected were entered into DFOs intertidal 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 was used to calculate density (Appendix 2). 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 graphs (Appendix 3).

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:

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

where

$$W_h = \frac{N_h M_h}{\sum_{h=1}^{H} N_h M_h}$$

and

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

The variance of the population mean was estimated as:

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

where

$$s_{1h}^2 = \frac{\sum_{i=1}^{n_h} (\bar{y}_{hi\cdot} - \bar{y}_{h\cdot\cdot})}{n_h - 1}$$

and

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

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 first stage units in the hth stratum, M_h is the number of second stage units in the hth stratum, W_h is the relative weight of stratum h in terms of 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, $yhij$ is the count in 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 first stage units in stratum h.

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

$$\bar{y}_{StTS} \pm (1.96)\sqrt{\hat{V}(\bar{y}_{StTS})} \ .$$

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

$$\text{precision} = \left(\frac{\text{CI}}{\text{mean}}\right) \times 100$$

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 values $\leq$ 30% (Allen and Davis, unpub. manuscript; Norgard et al. 2010). Precision was reviewed at the end of each survey; depending on results sampling intensity can be increased for subsequent surveys if precision is low. Statistics can be completed to estimate sample size. Also, sites with a large number quadrats without oysters will affect confidence intervals.

Length frequencies were collated and graphed using R code (Appendix 4).

Results and Discussion

Olympia oyster index sites were selected within four zones (Northwest Vancouver Island, Southwest Vancouver Island, Juan de Fuca Strait and Strait of Georgia) assigned as part of the index site selection process (DFO 2010)(Figure 1). A total of 43 surveys were completed at 14 index sites between 2009 and 2016. Eleven sites have been surveyed three times, two have been surveyed twice, and Gorge Site #9 and Klaskino have been surveyed four times since 2009 (Table 1). Index site maps (Figures 2-15) represent the most current strata configuration; quadrat densities are presented in Tables 2-10.

This report compares bed area, survey design, stratum area, densities, size frequencies, and other parameters for Olympia oyster populations at each beach over multiple survey years. Comparisons of these parameters between beaches have not been done. Index site beaches are not easily comparable for reasons such as beach areas, widely varying densities, and a wide range of habitat types that have not been fully assessed and quantified.

<u>Northwest Vancouver Island</u>

Index sites for Northwest Vancouver Island include Klaskino Inlet, Port Eliza Beach 3 and Amai Inlet (Figure 1).

Klaskino Inlet
<u>Location and Habitat Description</u>

This index site is located on the northern shore at the head of Klaskino Inlet (Figure 2). The beach was reported as Beach 1, head of Klaskino Inlet (Northeast) by Gillespie et al. (2004) and Northeast Klaskino by Gillespie and Bourne (2005); and it is classified as beach code 27-05-001.

The beach substrate is comprised of gravel, some larger rocks and shell. Flow from an upland creek discharges through the end of the third stratum. The beach slope is low

throughout most of the intertidal. However, the grade increases quickly at the low tide mark and delineates the most seaward edge of the Olympia oyster bed.

Survey Frequency and Design

All three strata at this site were surveyed in 2010, 2013, 2015 and 2017 (Table 1). The three strata covered 6,080 m^2 which represented 57% of the mapped Olympia oyster bed on the eastern end of the beach (Table 2). After the 2010 survey, stratum 1 was reduced in area from 1,750 m^2 to 1,680 m^2 to eliminate a subtidal portion (Table 3). The number of quadrats in stratum 3 was increased from 80 in 2013 to 99 in 2015 contributing to improved precision, lowering it from 60% in 2013 to 24% in 2015.

Oyster Density

Overall mean density at this site decreased from 9.4 ± 4.3 oysters m^{-2} in 2010 to 4.8 ± 2.0 in 2013, then increased to 10.3 ± 2.8 in 2015 (Table 3). This pattern was primarily due to decreased density in stratum 3 in 2013, as the other strata both showed increasing density trends over three surveys (Figure 3).

Stratum 1 densities increased during the last three surveys (2013-2017) from 0.5 ± 0.6 (2013) to 7.2 ± 3.1 m^{-2} (2017) (Table 3, Figure 3). Stratum 2 density increased over the four surveys and was considerably higher (29.7 ± 11.3) in 2017 than in previous years. Stratum 3 had the highest density over three survey years for 2010, 2013 and 2015 (Table 3, Figure 3).

The lowest densities occurred each year in stratum 1, where wide CIs and high numbers of quadrats with zero oyster counts resulted in low precision values of 131%, 108%, 81% and 43 % for each respective year (Table 3).

Few small oysters (≤ 15mm) were sampled at Klaskino Inlet; zero counts were at least 82% in all strata and all years (Table 4). The highest estimated density of small oysters (1.4 ± 2.2 m^{-2}) was Stratum 2 in 2017 (Table 4, Figure 3).

Shell Length

Mean length showed a decreasing trend from 2010 (46.4 ± 1.0 mm) to 2015 (31.8 ± 1.1 mm) (Table 5, Figure 3). Relatively low mean size and increased proportion of oysters ≤ 15 mm in 2015 (Figure 3) suggest a recent recruitment event.

Amai Inlet
Location and Habitat Description

Amai Inlet is located in Kyuquot Sound on the northwest coast of Vancouver Island (Figure 4). The index site is located on the south side of the head of Amai Inlet. This site was previously reported as Amai Inlet 2 by Gillespie and Bourne (2005) and it is currently classified as beach code 26-03-004. Although there are two suitable Olympia

oyster beds present, the distance between them precluded surveying both; the eastern side of the beach was chosen as the index site.

The beach has a moderate slope and is covered with small rocks and cobble. Although the edges of the oyster bed are not clearly delineated by steep gradients on the seaward side, the density of oysters is greatest in cobble substrate, and decreases substantially at the transition to sand and eelgrass habitat.

Survey Frequency and Design

This site was surveyed in 2010 and 2013 (Table 1). A single stratum (2,000 m^2) was surveyed in both years; the survey area represented 48% of the mapped Olympia oyster bed (Table 1).

Oyster Density

Estimated mean density decreased from 36.9 ± 12.8 oysters m^{-2} in 2010 to 6.6 ± 3.1 in 2013 (Table 3, Figure 5.). For 2013, 68% of all quadrats surveys had zero counts which contributed to the poor survey precision of 47%.

The density of small size class oysters was low in 2013 at 0.3 ± 0.4 oysters m^{-2} (Table 4); this size class was not counted separately in 2010.

Shell Length

Mean shell length decreased from 45.7 ± 0.9 mm in 2010 to 40.6 ± 3.4 mm in 2013. (Table 5, Figure 5). Higher CIs for shell length in 2013 are likely due to a combination of a wider range of sizes present and small sample size.

In 2010, there was a relatively even distribution of shell lengths above and below the mean value (Figure 5). The higher number of small oysters in 2013 may indicate a recruitment event.

Port Eliza Beach 3
Location and Habitat Description

Port Eliza is located on the north side of Esperanza Inlet on northwest Vancouver Island. Beach 3 is located about two thirds of the way up Port Eliza on the east side (Figure 6). This site is currently 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

The beach was surveyed in 2010, 2012 and 2013 (Table 1). In DFO (2010), Beach 2 was recommended as an index site. However, Beach 3 was assigned as the index site because this beach had a longer time series of surveys.

The mapped Olympia oyster bed area was 8,857 m^2. During 2010, a single stratum (14 quadrats) was surveyed due to an unfavourable low tide (Table 3). Similarly, in 2013, a single stratum (35 quadrats) was surveyed because additional time was required to count high numbers of oysters within the quadrats, most of which were small (Table 4).

Ideally, the 2012 survey design, which incorporated two strata covering 3,450 m^2 (39% of the mapped oyster bed, 45 and 40 quadrats, respectively) (Table 2, Table 3) should be replicated in the future.

Oyster Density

Changes to the number of strata and stratum areas between surveys preclude meaningful comparison of overall density; however, high densities of oysters have been observed each year at this site (Table 3, Figure 7). In stratum 1, the only stratum surveyed in all three years, densities ranged from 170.6 ± 40.7 m^{-2} in 2012 to 507.0 ± 74.1 in 2013. Low numbers of quadrats with zero counts (i.e., 5 in 2012 and 6 in 2013) contributed to narrow CIs and good survey precision values less than 30% (Table 3).

In 2013, a high density of small size class oysters was observed. High density of small size class oysters and the domination of the size frequency distribution by oysters ≤ 15 mm provide evidence of a recent recruitment event (Table 4, Figure 7). Not all small oysters were able to be counted in several quadrats resulting in an underestimation of the density of small oysters.

Low numbers of Pacific oysters observed between 2010 and 2013, provide confidence that the recruitment event was Olympia oysters and not small Pacific oysters.

Shell Length

Mean length is similar for the first two surveys; 32.8 ± 0.7 mm and 33.3 ± 0.6 mm in 2010 and 2012 respectively (Table 5, Figure 7). However, a lower mean length of 7.9 ± 1.0 mm occurred in 2013. Due to high numbers of small oysters and time constraints, not all small oysters in quadrats selected for biological sampling could be measured (all large oysters were measured).

Southwest Vancouver Island

Index sites for Southwest Vancouver Island include Darr Island, Bacchante Bay, Harris Point, Hillier Island and Joes Bay (Figure 1).

Darr Island

<u>Location and Habitat Description</u>

Darr Island is located in Stewardson Inlet in northern Clayoquot Sound (Figure 8). This site is currently classified as beach code 24-02-002.

The beach is large with a moderate slope, and a substrate comprised of gravel, cobble and boulders. Only the western edge of the beach was investigated for Olympia oyster. A small area was found with Olympia oyster densities suitable for surveying. Most oysters were attached to boulders and cobble. Olympia and Pacific oysters co-occur on this beach which made identification of small oysters difficult.

<u>Survey Frequency and Design</u>

The site was surveyed in 2010, 2012 and 2015 (Table 1). Stratum area was increased from 125 m^2 to 150 m^2 and the number of quadrats increased from 30 to 45 after the 2010 survey (Table 6) in an effort to increase survey precision. The 2015 surveyed area comprises 23% of the mapped bed size (Table 2).

<u>Oyster Density</u>

The highest density (18.9 ± 3.9 oysters m^{-2}) was observed in 2015 (Table 6). Survey precision improved each year, from 36% in 2010 to 21% in 2015, in part due to increased sampling intensity.

Density of small size class oysters increased each year, although CIs were relatively high in all years (Table 7, Figure 9).

<u>Shell Length</u>

Mean length was similar in the 2010 and 2012 surveys (33.1 ± 1.8 mm and 31.2 ± 2.0 mm respectively) and decreased to 26.3 ± 1.0 mm in 2015 (Table 5, Figure 9). Size frequency in 2015 had a much higher contribution from oysters ≤ 15 mm relative to previous surveys, possibly indicating successful recent recruitment.

Bacchante Bay

<u>Location and Habitat Description</u>

Bacchante Bay is located in northeastern Clayoquot Sound at the head of Shelter Inlet (Figure 10). This site is currently classified as beach code 24-13-004.

The bay has a large beach with low slope and cobble and gravel substrate. Distribution was patchy and large areas had only scattered single oysters. The survey area has lower elevation with shallow tide pools and relatively high concentration of Olympia oysters observed.

Survey Frequency and Design

In 2010, the survey area included one stratum and 60 quadrats (Table 6). However, in an effort to improve precision, the survey area was divided into three equal sized strata of 240 m^2 and an additional 40 quadrats were added in 2012. This design was also used in 2015. The total area surveyed in 2012 and 2015 was 720 m^2, which is larger than the 522 m^2 mapped bed area (Table 2).

<u>Oyster Density</u>

Density at this index site is low. Overall density increased slightly from 2012 to 2015, but low densities and poor precision do not allow meaningful comparisons. The maximum density observed was 1.7 ± 1.8 oysters m^{-2} in stratum 3 in 2015; the minimum was zero in stratum 1 in 2012 (Table 6, Figure 11).

The low density and patchiness at Bacchante Bay is evident by the high number of zero counts observed (Table 6). The high percentage of zero counts resulted in poor survey precision values for each survey year.

<u>Shell Length</u>

Mean size was highest in 2010 (42.9 ± 1.9 mm) and lowest in 2015 (35.6 ± 4.4 mm) (Table 5). Low sample sizes contributed to relatively high CIs for mean size frequency.

Harris Point

<u>Location and Habitat Description</u>

Harris Point is located in northeastern Barkley Sound at the mouth of Pipestem Inlet (Figure 12). The index site is a small saddle beach just south of Harris Point. This site is currently 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 overestimation small Olympia oyster densities.

Survey Frequency and Design

Harris Point was surveyed in 2010, 2012 and 2014 (Table 1). The mapped Olympia oyster bed is 761 m^2 in area (Table 2). In 2014, the stratum area was reduced from the 2012 are of 300 m^2 to 260 m^2 and a sampling intensity of 38 quadrats was chosen as the most appropriate to achieve survey precision ≤ 30%. This site has a large Pacific Oyster

bed which complicated defining the Olympia oyster bed boundary so the changes in the stratum occurred as we gained a more clear understanding of this beach.

<u>Oyster Density</u>

Density increased from 47 ± 10.9 oysters m^{-2} in 2010 to 58.1 ± 19.8 and 136.1 ± 33.9 in 2012 and 2014 respectively (Table 6, Figure 13). In each year there were low numbers of quadrats that had zero counts (8%, 18% and 0% respectively).

The lowest density of small size class oysters at 5.4 ± 4.9 oysters m^{-2} was observed in 2012 (size categories were not used in 2010). In 2014, the density of small oysters was considerably higher at 53.9 ± 21.6 oysters m^{-2} likely due to a recruitment event (Table 7, Figure 13).

<u>Shell Length</u>

Mean length of oysters dropped each survey year from 31.3 ± 1.4 mm in 2010 to 27.3 ± 1.6 mm in 2012 and 18.5 ± 1.2 mm in 2014 (Table 5, Figure 13). The 2014 mean length is lower than both means in the previous surveys. In 2014, 42% of oysters measured were in the small size class, providing evidence of recruitment. In comparison, the small size class comprised 2% in 2010 and 3% in 2012.

Hillier Island
<u>Location and Habitat Description</u>

Hillier Island is located in Toquart Bay in northeast Barkley Sound (Figure 14). This site is currently 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.

<u>Survey Frequency and Design</u>

The site was surveyed in 2010, 2012 and 2014 (Table 1). The mapped oyster bed is large, covering an area of 6,759 m^2 (Table 2). Stratum size was 2,700 m^{-2} in 2014 and varied little between years (Table 6). The most recent configuration encompasses 40% of the mapped oyster bed. Sampling intensity varied from 120 quadrats (2010), 40 (2012) and 74 (2014) and reflects the time available to complete surveys.

<u>Oyster Density</u>

Density ranged between 44.3 ± 20.7 oysters m^{-2} in 2012 and 64.1 ± 17.5 in 2014 (Table 6, Figure 15). Relatively wide CIs preclude discussion of differences or trends in density.

The highest densities of small oysters was 34.9 ± 24.4 oysters m^{-2} in 2010 and 23.1 ± 9.4 in 2014 both of which are considerably higher than the 2012 density of 0.6 ± 0.6 m^{-2} (Table 7, Figure 15).

Shell Length

Mean length was lowest in 2010 (10.3 ± 0.7 mm), compared to 23.3 ± 0.9 in 2012 and 23.5 ± 2.2 mm in 2014 (Table 5, Figure 15). In 2010, 84% of oysters measured were in the small size class indicating recent recruitment.

Joes Bay
Location and Habitat Description

Joes Bay is located on the northeast side of Turtle Island in the Broken Group Islands Unit of Pacific Rim National Park Reserve (Figure 16). This site is currently classified as beach code 23-08-002. Surveys at this site are led by Parks Canada Ecologists.

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

Survey Frequency and Design

The site was surveyed in 2014, 2015 and 2017 (Table 1). 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 all index sites.

The mapped Olympia oyster bed is 789 m^2 in area of which 593 m^2 (75%) was surveyed in 2014 (Table 2). The survey area includes one very small stratum (33 m^2) designed to include the narrow band on the southeastern portion across a bedrock outcrop. Stratum 2 is 560 m^2 and includes the main part of the beach. In 2015, the boundaries of stratum 2 were shifted seaward into higher quality Olympia oyster habitat.

Oyster Density

Density overall increased from 2014 to 2015 (4.0 ± 2.4 oysters m^{-2} and 10.4 ± 8.2 respectively)(Table 6, Figure 17). In all years, stratum 2 had the highest densities (4.0 ± 2.6 m^{-2}, 11.0 ± 8.7 and 33 ± 12.3 respectively). However, poor survey precision limits the utility of comparisons between strata or surveys (Table 6, Figure 17).

Low densities of small oysters were observed in all years. The lowest density was 1.1 ± 1.4 m^{-2} in stratum 1 and the highest was 4.6 ± 3.4 in stratum 2, both in 2015 (Table7, Figure 17).

Size frequency was measured in 2014 and 2017. In 2015, counts of small oysters were completed but individual measurements were not recorded. Size frequency decreased from 35.8 ± 3.0 mm in 2014 to 29.3 ± 0.4 mm in 2017 (Table 5, Figure 17).

Juan de Fuca Strait

Index sites in Juan de Fuca Strait include Gorge Site 9 and Ayum Creek (Figure 1).

Gorge Site 9
Location and Habitat Description

The index site is located on the south shore of the Gorge Waterway, approximately 800 m downstream of the Craigflower Bridge (Figure 18). This site is currently classified as beach code 19-01-003.

Olympia oysters were found on cobble, shell and sitting on hard packed and fine substrate areas. Pacific oysters were not observed at this site.

Gorge Site 9 has large subtidal population of Olympia oysters. Oyster distribution along the shore is continuous rather than in distinguishable beds. Oysters are present upstream and downstream of the index site and throughout the Gorge Waterway (Stanton et al. 2011).

Survey Frequency and Design

The index site was surveyed in 2009, 2010, 2011 and 2016 (Table 1). Since 2009 surveys have been conducted in partnership with the World Fisheries Trust (WFT). Survey methods at this site differ from other sites because much of stratum 2 is subtidal. For this reason, and due to the murkiness of the water and easily disturbed fine sediments, the most effective method to count and measure oysters is to collect the top layer of shell, strain to remove sediment and determine if oysters are alive or dead shell.

Survey layout varied due to the complexities of determining the best Olympia oyster habitat to survey within the subtidal. In 2009 and 2010, the survey was completed jointly by DFO and WFT. During these years, two strata (each 125 m^2 in area) were surveyed (Table 2, Table 8). Initial sampling intensity was 30 quadrats in 2009 and increased to 82 quadrats in 2010 to improve survey precision. In 2011, WFT completed the survey and used one stratum (375 m^2 in area). In 2016, strata 1 and 2 were 125 m^2 and 175 m^2 in area with sampling intensity of 15 and 20 quadrats respectively.

Oyster Density

Overall density estimates ranged between 43.0 ± 9.3 oysters m^{-2} in 2010 and 153.9 ± 35.9 in 2009 (Table 8, Figure 19), but differences in survey design preclude discussion of differences or trends between strata or years.

The highest densities occurred in stratum 2 for all surveys in which two strata were surveyed. Densities in stratum 2 decreased from 2009 (291.7 ± 70.4 oysters m^{-2}) to 2010 (76.8 ± 18.4), then increased in 2016 (143.8 ± 45.0).

Survey precision in stratum 2 was consistently good; 24%, 24% and 31% in 2009, 2010 and 2016 respectively. The lowest density observed for all years was 3.5 ± 2.4 oysters m^{-2} in 2016 within stratum 1.

In 2016, the density of small oysters was low (0.8 ± 0.6 oysters m^{-2} overall) (Table 9, Figure 19). No density data for the small size category of oysters were collected in 2009, 2010, or 2011.

Shell length

Mean size ranged from 32.9 ± 1.4 mm in 2016 to 38.5 ± 0.8 mm in 2010 (Table 5, Figure 19). Smaller sized oysters were more common in 2016 than 2010 or 2011.

Ayum Creek
Location and Habitat Description

Ayum Creek is located in Cooper Cove in Sooke Basin (Figure 20) and is currently classified as beach code 20-07-003.

The beach has a low slope and a mud and gravel substrate. A small creek originating from a mill pond flows through the middle of the beach.

Survey Frequency and Design

The site was surveyed in 2011, 2012 and 2013 (Table 1). The mapped Olympia oyster bed at this site is 2,567 m^2 (Table 2). The survey design included two strata with the smaller stratum 1 (168 m^2) directly beside the inflow from the mill pond and stratum 2 (480 m^2) located in the intertidal area of the beach. Stratum 1 supported a small patch of Olympia oysters, while stratum 2 contained single oysters scattered across the beach (Figure 20). To improve survey precision, sampling intensity was increased in stratum 1 from 28 quadrats (2011) to 112 (2013) (Table 8, Figure 21). In stratum 2, sampling intensity was increased from 28 (2011) to 32 quadrats (2013).

Oyster Density

Overall density was relatively similar in 2011 and 2012 (13.8 ± 9.8 oysters m^{-2} and 15.3 ± 11.5 respectively), then decreased in 2013 (9.5 ± 7.7)(Table 8, Figure 21). Densities were highest in stratum 1 and increased each survey (28.0 ± 32.3 oysters m^{-2} in 2011 to 36.1 ± 29.6 in 2013). However, densities did not vary considerably between years and low precision suggested that the differences were not significant.

An oyster density of 0.1 ± 0.2 oysters m^{-2} in stratum 2 in 2013 was the lowest encountered in both strata over all surveys (Table 8, Figure 21). Poor precision ($\pm 196\%$) was due to no Olympia oysters counted (zero counts) in the majority of quadrats surveyed (97%).

The density of small oysters in stratum 1 was low in 2011 (1.1 ± 2.2 oysters m^{-2}), zero in 2012 and increased in 2013 (10.0 ± 4.4)(Table 9, Figure 21). No small size class oysters were found in stratum 2 in any of the years.

<u>Shell length</u>

In 2011 and 2012 the mean length of oysters were similar (37 ± 2.8 mm and 39.6 ± 1.1 mm). However, in 2013 mean size was lower than previous years (25.3 ± 2.9 mm) due to increased frequency of oysters < 25 mm, suggesting a recruitment event (Table 5, Figure 21).

Strait of Georgia

Olympia oyster index sites in the Strait of Georgia include Jervis Inlet, Baker Bay, Swy-a-Lana Lagoon, and Transfer Beach (Figure 1).

Jervis Inlet 1
<u>Location and Habitat Description</u>

The Jervis Inlet index site is located on the eastern side of Dacres Point, near Goliath Bay and facing Prince of Wales Reach (Figure 22). This site is currently classified as beach code 16-13-006.

The beach has a moderate to high slope and is covered with boulders and cobble. Ideally, this site should be survey on the lowest available tide. Olympia oysters are sparse, hidden under rocks, and confined to the lower intertidal. Pacific oysters are present but not abundant and co-occur with Olympia oysters on the beach.

<u>Survey Frequency and Design</u>

The site was surveyed in 2011, 2013 and 2014 (Table 1). The mapped Olympia oyster bed is relatively small at this site (493 m^2) (Table 2). Survey design changed from a single stratum (180 m^2) in 2011 to two equal sized strata (180 m^2 each); totalling 360 m^2 in 2013 and 2014. The total surveyed area represented 73% of the mapped Olympia oyster bed.

Survey designs in 2013 and 2014 included a baseline that bisected the bed into two strata (Figure 22). Transects were laid perpendicular to the baseline in each stratum. Transects and quadrats were oriented down the beach from the mid to lower intertidal in stratum 1 and up the beach from the lower intertidal to mid intertidal in stratum 2. Sampling intensity increased from 90 quadrats in 2011 to a total of 106 and 101 quadrats in 2013 and 2014 respectively (Table 11).

Oyster Density

In 2011, the density was 4.8 ± 1.9 oysters m^{-2} (Table 10, Figure 22) and oysters were present in very few (10%) of quadrats surveyed (Table 10, Figure 23). Overall densities increased from 2013 to 2014 (4.2 ± 1.3 and 12.5 ± 3.0 oysters m^{-2} respectively).

Densities of small oysters were 3.2 ± 1.6 oysters m^{-2} in 2011 and 8.8 ± 3.4 overall in 2014; no small oysters were encountered in 2013 (Table 5, Table 11, Figure 23).

Shell length

Although mean length increased between 2011 and 2014, small sample sizes, particularly in the first two surveys, preclude discussion of trends (Table 5, Figure 23). Although densities of small size class oysters were relatively high in 2011 and 2014, indicating recruitment events, this is not reflected in the size frequencies for these surveys; in part an artifact of low sample size.

Baker Bay
Location and Habitat Description

Baker Bay is located at the northern end of Hotham Sound (Figure 24). This site is currently classified as beach code 16-12-007.

The beach has a low slope and is covered with cobble. Two creeks run across the beach; the larger creek crosses the west end of the beach and the smaller creek approximately bisects the beach. Olympia oysters were sparsely distributed and mostly found in the smaller creek and the lower intertidal between the two creeks. Large Pacific oysters were abundant at this site. The Olympia oyster bed is located in the lower intertidal and should ideally be surveyed on a tide < 0.5 m above chart datum.

Survey Frequency and Design

The site was surveyed in 2011, 2013 and 2014 (Table 1). The mapped Olympia oyster bed was small (457 m^2) of which 360 m^2 has been surveyed (Table 2). In 2011, 87 quadrats were surveyed in stratum 1. In 2013, the bed was divided into two strata and increased survey intensity of 112 quadrats to improve the precision of density estimates Table 10).

The survey design in 2013 and 2014 included placement of a baseline that bisects the bed into two strata (Figure 24). Transects were laid perpendicular to the baseline in each stratum. Stratum 1 was on the seaward side of the baseline and stratum 2 was on the shoreward side. Transects and quadrats were oriented down the beach from the baseline seaward for stratum 1 and up the beach from baseline shoreward for stratum 2.

Oyster Density

Overall densities increased from 8.8 ± 3.2 oysters m^{-2} in 2013 to 88.5 ± 31.8 in 2014 (Table 10, Figure 25). Stratum 1 had higher densities than stratum 2 in both 2013 and

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2014. Stratum 2 had the lowest density for all years (2.5 $\pm$ 2.0 oysters m^{-2}) in 2013 and the majority of quadrats surveyed had no Olympia oysters resulting in poor survey precision of 80% (Table 10).

Overall density of small oysters was high in 2014 (76.7 $\pm$ 29.4 oysters m^{-2}) relative to 2013 (0.7 $\pm$ 0.6) (Table 11, Figure 25). Every quadrat surveyed in stratum 1 in 2014 had small oysters.

<u>Shell length</u>

Mean shell length was lowest in 2011 (16.7 $\pm$ 1.1 mm) and lower than in 2013 (19.9 $\pm$ 1.0 mm) and 2014 (18.7 $\pm$ 2.0 mm)(Table 5, Figure 25). In 2011, 53% of oysters measured were $\leq$ 15 mm indicating a relatively strong recruitment event. Although small oyster densities were high in 2014 this was not reflected in the size frequency, likely due to small sample size (Table 5, Figure 25).

Swy-a-Lana Lagoon
<u>Location and Habitat Description</u>

The index site is located in Maffeo Sutton Park in Nanaimo (Figure 26). This site is currently classified as beach code 17-14-002.

Olympia oysters do not form defined beds; 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 are recessed and 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.

<u>Survey Frequency and Design</u>

The site was surveyed in 2010, 2013 and 2016 (Table 1). The site is comprised of three strata totalling 718 m^2, with stratum 1 and 2 facing Nanaimo Harbour and stratum 3 positioned on the lagoon side (Table 2, Figure 26).

<u>Oyster Density</u>

Overall densities ranged between 35.5 $\pm$ 8.4 oysters m^{-2} in 2013 and 65.2 $\pm$ 21.0 in 2016, with no clear trend (Table 10, Figure 27). Densities were highest in stratum 3 for all surveys and peaked at 145.6 $\pm$ 26.7 oysters m^{-2} in 2016.

Overall densities of small oysters increased from 0.1 $\pm$ 0.2 oysters m^{-2} in 2013 to 1.1 $\pm$ 0.6 in 2016. Small oysters were not recorded separately in 2010 (Table 1).
<u>Shell length</u>

Mean length was lowest in 2010 (25.2 $\pm$ 1.5 mm) (Table 5, Figure 27). Higher numbers of oysters < 25 mm in 2010 and 2016 suggest recruitment events (Table 5).

Transfer Beach

<u>Location and Habitat Description</u>

The Transfer Beach index site is located on the south side of Ladysmith Harbour (Figure 28). This site is currently classified as beach code 17-07-023.

The beach is adjacent to Transfer Beach Park and has heavy use 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. The Olympia oyster bed is located in the lower intertidal and should ideally be surveyed at a tide < 0.5 m above chart datum.

<u>Survey Frequency and Design</u>

The site was surveyed in 2011, 2012 and 2016. The mapped Olympia oyster bed at this site is 1811 m^2 of which 720 m^2 has been surveyed. Stratum area and placement has varied across surveys. Single strata were surveyed in 2011 and 2016; the 2012 survey was conducted on a much lower tide and stratum 1 was increased in area and a second stratum added (Table 1,Table 2, Figure 28).

<u>Oyster Density</u>

Estimated mean densities appear to have increased with each survey but differences in the size and number of strata preclude meaningful comparisons other than stratum 1 in the final two surveys (Table 10, Figure 29).

The highest density of small oysters was observed in 2016 (14.8 ± 4.7 oysters m^{-2}) (Table 11, Figure 29). However, recruitment of Pacific oysters in 2016 and potential identification error of oysters in the small size category reduces confidence that the recruitment event was exclusively Olympia oyster. This may have resulted in an overestimate of the density of small Olympia oyster.

<u>Shell length</u>

Mean shell lengths were similar in 2011 and 2016 (24.1 ± 2.7 mm and 24.7 ± 1.6 mm respectively) (Table 5, Figure 29).

Conclusions

Primary objectives of this report were to report results of index site surveys, inform evaluation of the SARA management plan, and inform refinement of future survey methods and data collection.

Refinement of the survey design at each site has been completed to optimize the time at each and increase survey precision. Refinements include changes from year to year to survey strata and sampling intensity. Densities and size frequencies have been

reported for each site and year. The time series at most sites is short and precluded evaluation of trends. However, baseline information from index site data and continued monitoring will enable future analysis of variability and trends.

At all sites Olympia oyster were found on subsequent visits and recruitment events were observed at number of sites (Port Eliza Beach #3 2013, Harris Point 2014, Hillier Island 2010, 2014 and Baker Bay 2014).   Identification of small oysters was challenging at sites which included larger number of both Pacific and Olympia oysters so a small oyster category (≤15mm) was used to categorize all oysters in which identification error may have occurred (Table 4Table 4Table 7, Table 9 and Table 11). This information was also used to provide evidence of recruitment events.

Low density sites tend to have increased number of 'zero' quadrats with no oysters found and therefore have survey poor precisions much greater than 30%. To increase precision the number of surveyed quadrats on subsequent visits was increased. In some cases this improved survey precision. However, increased survey effort may negatively impact oyster populations and habitat by increased survey traffic over the bed but individual oyster mortality is limited from survey handling because sampling is done on site. Sites will need to have time to recover between surveys, suggesting that surveys occur no more than every 3rd year at low density sites.

Continued monitoring is necessary to meet the objectives of the SARA management plan and data collected will be essential in informing a new management plan. If time allows, increased bio-sample measurements (at least 100 per site) will allow more robust estimates of size distributions at each site. Improvement of substrate and habitat information, including temperature and salinity, at each site would be valuable. Exploration of impacts of invasive species on Olympia oysters would benefit from continued collection of data on presence and abundance of these species.

Acknowledgements

References

Allen, B.L. and J.P. Davis. Unpubl. manuscr. Intertidal *Ostrea conchaphila* population assessment procedures; applications for surveying natural populations and restoration areas.

Bourne, N. 1997. Molluscan fisheries of British Columbia. NOAA Tech. Rep. NMFS 128: 115-130. Available online: http://spo.nmfs.noaa.gov/Technical%20Report/tr128.pdf.

COSEWIC. 2011. COSEWIC assessment and status report on the Olympia oyster *Ostrea conchaphila* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 56 pp. Available online: http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_olympia_oyster_0911_eng.pdf.

DFO. 2009. Management plan for the Olympia oyster (*Ostrea conchaphila*) in Canada. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, Ottawa. v + 31 p. Available online: https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/mp_olympia_oyster_0509_e.pdf.

DFO. 2010. Rationale for index site selection for Olympia Oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/053. 10 p. Available online: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2010/2010_053-eng.html.

Ellis, D.W. and L. Swan. 1981. Teachings of the tides: uses of marine invertebrates by the Manhousat people. Theytus Books, Nanaimo BC. 118 p.

Finney, J.L., T.C. Norgard, P.D.G. Boutillier, S.E.M. MacConnachie and G.E. Gillespie. 2012. Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia – 2010 and 2011. Can. Tech. Rep. Fish. Aquat. Sci. 3011: vii + 91 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/347603.pdf.

Gillespie, G.E. 1999. Status of the Olympia oyster, *Ostrea conchaphila*, in Canada. Can. Stock Assess. Secretar. Res. Doc. 99/150. 33 p. Available online: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/1999/pdf/99_150e.pdf.

Gillespie, G.E. 2009. Status of the Olympia oyster, *Ostrea lurida* Carpenter 1864, in British Columbia, Canada. J. Shellfish Res. 28(1): 59-68.

Gillespie, G.E. and N.F. Bourne. 2005. Exploratory intertidal bivalve surveys in British Columbia – 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2733. xi + 199 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/318598.pdf.

Gillespie, G.E. and A.R. Kronlund. 1999. A manual for intertidal clam surveys. Can. Tech. Rep. Fish. Aquat. Sci. 2270. x + 144 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/234406.pdf.

Gillespie, G.E., N.F. Bourne and B. Rusch. 2004. Exploratory intertidal bivalve surveys in British Columbia – 2000 and 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2681. ix + 120 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/280731.pdf.

Harbo, R.M. 1997. Shells and shellfish of the Pacific Northwest. Harbour Publishing, Madiera Park BC. 270 p.

Harbo, R., K. Marcus and T. Boxwell. 1997a. Intertidal clam resources (Manila, littleneck and butter clam). Vol. I: the west coast of Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2416. viii + 116 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/222293.pdf.

Harbo, R., K. Marcus and T. Boxwell. 1997b. Intertidal clam resources (Manila, littleneck and butter clam). Vol. II: the southern inside waters of Vancouver Island and the British Columbia mainland. Can. Manuscr. Rep. Fish. Aquat. Sci. 2417. viii + 245 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/226484.pdf.

Norgard, T., S. Davies, L. Stanton and G.E. Gillespie. 2010. Evaluation of survey methodologies for monitoring Olympia Oyster (*Ostrea lurida* Carpenter, 1864) populations in British Columbia. Can. Sci. Advis. Sec. Res. Doc. 2010/006. iv +56 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/340695.pdf.

Quayle, D.B. 1988. Pacific oyster culture in British Columbia. Can. Bull. Fish. Aquat. Sci. 218. 241 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/109165.pdf.

Stanton, L.M., T.C. Norgard, S.E.M. MacConnachie and G.E. Gillespie. 2011. Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia - 2009. Can. Tech. Rep. Fish. Aquat. Sci. 2940: vi + 115 p. Available online: http://waves-vagues.dfo-mpo.gc.ca/Library/344226.pdf.

Table 1. Survey dates for Olympia oyster index sites, 2009-2017.

Index Sites	2009	2010	2011	2012	2013	2014	2015	2016	2017
Northwest Vancouver Island									
Klaskino Inlet		May 30			May 24		Jun. 1		May 17
Amai Inlet		Jun 1			May 23				
Port Eliza Beach 3		Jun 2		Aug1-2	May 26				
Southwest Vancouver Island									
Darr Island		Jun 10		Jul 18			Jul 14		
Bacchante Bay		Jun 11		Jul 19			Jul 15		
Harris Point		Jun 14		Jul 4		Jun 28			
Hillier Island		Jun 15		Jul 3		Jun 27			
Joes Bay						Jun 25	Jul 4		May 26
Juan de Fuca Strait									
Ayum Creek			Jul 4	May 10	May 24				
Gorge Site 9	Jul 7	Jul 15	Jul 12					Jul 27	
Strait of Georgia									
Baker Bay			Jul 13		Jun 8	Jun 13			
Jervis Inlet 1			Jul 12		Jun 7	Jun 14			
Swy-a-lana Lagoon		Aug 24			Sep 18			Jul 19	
Transfer Beach			Jul 5	May 9				Jul 20	

Table 2. Calculated Oyster bed area (m^2) from GPS survey, total area surveyed (m^2) and percentage of the bed area surveyed for Olympia oyster index sites.

Index Site	Bed Area (m^2)	Total Area Surveyed (m^2)	% of Bed Surveyed
Northwest Vancouver Island			
Klaskino Inlet (2015)	10,601	6,080	57%
Amai Inlet (2013)	4,139	2,000	48%
Port Eliza Beach 3 (2012)	8,857	3,450	39%
Southwest Vancouver Island			
Darr Island (2015)	651	150	23%
Bacchante Bay (2015)	522	720	100%
Harris Point (2014)	761	260	34%
Hillier Island (2014)	6,759	2,700	40%
Joes Bay (2014)	789	593	75%
Juan de Fuca Strait			
Ayum Creek (2013)	2,567	648	25%
Gorge Waterway Site # 9 (2016)	-	300	-
Strait of Georgia			
Jervis Inlet 1 (2014)	493	360	73%
Baker Bay (2014)	457	360	79%
Swy-a-lana Lagoon (2016)	-	718	-
Transfer Beach (2016)	1811	720	40%

Notes:
- Bed Area comes from calculation of area from the GPS survey of the bed.
- Total Area is the sum of all strata areas at each site.
- Year in brackets () is the survey year that bed area was most recently calculated.
- Gorge Waterway and Swy-a-lana Lagoon sites do not have defined beds.

Table 3. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Northwest Vancouver Island 2010-2017.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Klaskino Inlet	2010	1	70x25	1,750	30	0.25	82%	0.5	0.7	131%
		2	80x30	2,400	48	0.25	75%	2.9	1.0	35%
		3	100x20	2,000	80	0.25	45%	24.8	13.1	53%
		Overall						9.4	4.3	46%
	2013	1	70x24	1,680	30	0.25	87%	0.5	0.6	108%
		2	80x30	2,400	40	0.25	55%	4.8	2.8	58%
		3	100x20	2,000	80	0.25	50%	8.4	5.0	60%
		Overall						4.8	2.0	42%
	2015	1	70x24	1,680	30	0.25	63%	3.1	2.5	81%
		2	80x30	2,400	35	0.25	34%	10.9	6.0	56%
		3	100x20	2,000	99	0.25	33%	15.8	3.7	24%
		Overall						10.3	2.8	27%
	2017	1	70x24	1,680	29	0.25	41%	7.2	3.1	43%
		2	80x30	2,400	14	0.25	0%	29.7	11.3	38%
		3	100x20	2,000	20	0.25	25%	20.8	9.0	45%
		Overall						20.6	5.4	26%
Amai Inlet	2010	1	100x20	2,000	80	0.25	31%	36.9	12.8	35%
	2013	1	100x20	2,000	80	0.25	68%	6.6	3.1	47%
Port Eliza Beach 3	2010	1	20x60	1,200	14	0.25	0%	278.9	73.5	26%
	2012	1	50x37	1,850	45	0.25	11%	170.6	40.7	24%
		2	50x32	1,600	40	0.25	0%	316.2	55.7	18%
		Overall						238.1	33.8	14%
	2013	1	37x50	1,850	35	0.25	17%	507.0	74.1	15%

Table 4. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Northwest Vancouver Island 2010-2017.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Klaskino	2010	-		-	-	-	-	-	-	
Inlet	2013	1	70x24	1,680	30	0.25	100%	0.0	-	-
		2	80x30	2,400	40	0.25	98%	0.1	0.2	196%
		3	100x20	2,400	80	0.25	100%	0.0	-	-
		Overall						0.0	0.1	196%
	2015	1	70x24	1,680	30	0.25	100%	0.0	-	-
		2	80x30	2,400	35	0.25	97%	0.1	0.2	200%
		3	100x20	2,000	99	0.25	82%	1.2	0.7	50%
		Overall						0.4	0.2	53%
	2017	1	70x24	1,680	29	0.25	100%	0.0	-	-
		2	80x30	2,400	14	0.25	98%	1.4	2.2	157%
		3	100x20	2,000	20	0.25	100%	0.0	-	-
		Overall						0.6	0.9	150%
Amai	2010	-		-	-	-	-	-	-	-
Inlet	2013	1	100x20	2,000	80	0.25	98%	0.3	0.4	143%
Port Eliza	2010	-		-	-	-	-	-	-	-
Beach 3	2012	1	50x37	1,850	45	0.25	73%	2.0	0.9	47%
		2	50x32	1,600	40	0.25	78%	5.8	4.8	83%
		Overall						3.7	2.3	62%
	2013	1	37x50	1,850	35	0.25	3%	347.5	15.8	33%

Note: Small size class was not recorded separately at Klaskino Inlet, Amai Inlet or Port Eliza Beach3 in 2010.

Table 5. Mean, variability and range of Olympia oyster shell length (mm) at index sites in British Columbia, 2009-2017.

Index Site	Year	n	Mean (mm)	± 95% CI	Min (mm)	Max (mm)
Klaskino Inlet	2010	172	46.4	1.0	15	66
	2013	63	40.9	2.1	20	55
	2015	478	31.8	1.1	7	65
	2017	155	33.8	1.7	8	61
Amai Inlet	2010	157	45.7	0.9	31	66
	2013	53	40.6	3.4	5	56
Port Eliza	2010	976	32.8	0.7	3	58
Beach #3	2012	658	33.3	0.6	6	54
	2013	175	7.9	1.0	2	44
Darr Island	2010	86	33.1	1.8	4	51
	2012	47	31.2	2.0	18	50
	2015	186	26.3	1.0	12	45
Bacchante	2010	50	42.9	1.9	23	58
Bay	2012	19	38.3	3.2	24	51
	2015	32	35.6	4.4	9	54
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
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
Joes Bay	2014	58	35.8	3.0	4	56
	2017	460	29.3	0.4	3	86
Gorge Site #9	2009	173	33.7	0.9	21	64
	2010	212	38.5	0.8	19	56
	2011	77	38.4	1.2	27	53
	2016	133	32.9	1.4	7	57
Ayum Creek	2011	39	37.0	2.8	12	58
	2012	136	39.6	1.1	14	61
	2013	82	25.3	2.9	7	56
Jervis Inlet	2011	27	12.1	2.9	3	30
	2013	52	16.5	1.3	9	30
	2014	102	21.8	1.2	10	43
Baker Bay	2011	159	16.7	1.1	5	37
	2013	122	19.9	1.0	8	42
	2014	81	18.7	2.0	6	43
Swy-A-Lana	2010	135	25.2	1.5	4	49
Lagoon	2013	130	34.6	1.1	17	51
	2016	149	31.3	1.4	3	55
Transfer	2011	56	24.1	2.7	8	54
Beach	2012	195	16.7	1.5	3	62
	2016	131	24.7	1.6	7	54

Table 6. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Southwest Vancouver Island 2010-2017.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Darr Island	2010	1	25x5	125	30	0.25	30%	14.4	5.3	36%
	2012	1	25x6	150	45	0.25	31%	8.8	3.0	35%
	2015	1	25x6	150	45	0.25	18%	18.9	3.9	21%
Bacchante Bay	2010	1	60x12	720	60	0.25	82%	1.1	0.6	56%
	2012	1	20x12	240	20	0.25	100%	0	-	-
		2	20x12	240	40	0.25	78%	1.6	1.0	61%
		3	20x12	240	40	0.25	95%	0.3	0.4	139%
		Overall						0.6	0.4	56%
	2015	1	20x12	240	20	0.25	95%	0.4	0.8	196%
		2	20x12	240	40	0.25	85%	1.3	1.2	90%
		3	20x12	240	40	0.25	85%	1.7	1.8	106%
		Overall						1.1	0.8	67%
Harris Point	2010	1	10x25	250	40	0.25	8%	47.0	10.9	23%
	2012	1	25x12	300	28	0.25	18%	58.1	19.4	33%
	2014	1	26x10	260	38	0.25	0%	136.1	33.9	25%
Hillier Island	2010	1	70x39	2,730	120	0.25	28%	62.4	29.7	48%
	2012	1	70x36	2,520	40	0.25	30%	44.3	20.7	47%
	2014	1	75x36	2,700	74	0.25	7%	64.1	17.5	27%
Joes Bay	2014	1	11x3	33	15	0.25	87%	3.2	3.7	114%
		2	35x16	560	60	0.25	75%	4.0	2.6	64%
		Overall						4.0	2.4	61%
	2015	1	11x3	33	21	0.25	90%	2.1	2.8	133%
		2	35x15	525	27	0.25	48%	11.0	8.7	79%
		Overall						10.4	8.2	79%
	2017	2	35x15	525	60	0.25	20%	33.0	12.3	37%

Table 7. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Southwest Vancouver Island 2010-2017.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Darr Island	2010	-		-	-	-	-	-	-	-
	2012	1	25x6	150	45	0.25	87%	0.6	0.5	81%
	2015	1	25x6	150	45	0.25	62%	2.4	1.1	48%
Bacchante Bay	2010	-		-	-	-	-	-	-	-
	2012	1	20x12	240	20	0.25	100%	0.0	-	-
		2	20x12	240	40	0.25	100%	0.0	-	-
		3	20x12	240	40	0.25	100%	0.0	-	-
		Overall						0.0	-	-
	2015	1	20x12	240	20	0.25	100%	0.0	-	-
		2	20x12	240	40	0.25	100%	0.0	-	-
		3	20x12	240	40	0.25	100%	0.0	-	-
		Overall						0.0	-	-
Harris Point	2010	1		-	-	-	-	-	-	-
	2012	1	25x12	300	28	0.25	61%	5.4	4.9	91%
	2014	1	26x10	260	40	0.25	13%	53.9	21.1	39%
Hillier Island	2010	1	70x39	2,730	120	0.25	73%	34.9	24.4	70%
	2012	1	70x36	2,520	40	0.25	90%	0.6	0.6	100%
	2014	1	75x36	2,700	74	0.25	27%	23.1	9.4	40%
Joes Bay	2014	1	11x3	33	15	0.25	60%	1.9	1.8	95%
		2	35x16	560	60	0.25	78%	2.1	1.7	83%
		Overall						2.1	1.6	79%
	2015	1	11x3	33	21	0.25	76%	1.1	1.4	126%
		2	35x15	525	27	0.25	52%	4.6	3.4	72%
		Overall						4.4	3.1	71%
	2017	2	35x15	525	60	0.25	70%	2.7	1.6	60%

Note: Small size class was not recorded separately at Darr Island, Bacchante Bay and Harris point in 2010.

Table 8. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in Juan de Fuca Strait 2009-2016.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m²)	# Quad-rats	Quadrat Size (m²)	Zero Oyster Count	Density (# m⁻²)	95% CI	Survey Pre-cision
Gorge Site # 9	2009	1	25x5	125	15	0.25	53%	16.0	13.8	86%
		2	25x5	125	15	0.25	0%	291.7	70.4	24%
		Overall						153.9	35.9	23%
	2010	1	25x5	125	50	0.25	66%	9.3	4.3	46%
		2	25x5	125	32	0.25	6%	76.8	18.1	24%
		Overall						43.0	9.3	22%
	2011	1	25x15	375	16	0.25	44%	23.5	11.8	50%
	2016	1	25x5	125	15	0.25	67%	3.5	2.4	69%
		2	25x7	175	20	0.25	6%	143.8	44.0	31%
		Overall						85.3	25.7	30%
Ayum Creek	2011	1	17x14	238	28	0.0625	68%	28.0	32.3	115%
		2	36x16	576	28	0.0625	61%	8.0	3.9	48%
		Overall						13.8	9.8	71%
	2012	1	12x14	168	109	0.25	50%	35.2	20.2	58%
		2	30x16	480	32	0.25	72%	8.4	13.8	165%
		Overall						15.3	11.5	75%
	2013	1	12x14	168	112	0.25	47%	36.1	29.6	82%
		2	30x16	480	32	0.25	97%	0.1	0.2	196%
		Overall						9.5	7.7	81%

Table 9. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in Juan de Fuca Strait 2009-2016.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Gorge Site #9	2009	-		-	-	-	-	-	-	-
	2010	-		-	-	-	-	-	-	-
	2011	-		-	-	-	-	-	-	-
	2016	1	25x5	125	15	0.25	93%	0.5	1.0	200%
		2	25x7	175	20	0.25	75%	1.0	0.6	60%
		Overall						0.8	0.6	70%
Ayum Creek	2011	1	17x14	238	28	0.0625	96%	1.1	2.2	196%
		2	36x16	576	28	0.0625	100%	0.0	-	-
		Overall						0.3	0.7	196%
	2012	1	12x14	168	109	0.25	100%	0.0	-	-
		2	30x16	480	32	0.25	100%	0.0	-	-
		Overall						0.0	-	-
	2013	1	12x14	168	112	0.25	58%	10.0	4.4	44%
		2	30x16	480	32	0.25	100%	0.0	-	-
		Overall						2.6	1.2	44%

Note: The small size class was not recorded separately at Gorge Site #9 in 2009-2011.

Table 10. Survey design, density and 95% CIs for all size classes of Olympia oysters at index sites in the Strait of Georgia 2010-2016.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Jervis Inlet	2011	1	60x3	180	90	0.0625	90%	4.8	1.9	40%
	2013	1	60x3	180	37	0.25	35%	5.4	2.2	41%
		2	60x3	180	69	0.25	59%	3.1	1.2	40%
		Overall						4.2	1.3	30%
	2014	1	60x3	180	59	0.25	44%	16.1	4.2	26%
		2	60x3	180	42	0.25	76%	8.9	4.3	48%
		Overall						12.5	3.0	24%
Baker Bay	2011	1	60x3	180	87	0.0625	59%	35.7	13.7	39%
	2013	1	60x3	180	52	0.25	38%	15.1	6.0	40%
		2	60x3	180	60	0.25	82%	2.5	2.0	77%
		Overall						8.8	3.2	36%
	2014	1	60x3	180	20	0.25	25%	153.6	61.9	40%
		2	60x3	180	30	0.25	63%	23.5	14.5	62%
		Overall						88.5	31.8	36%
Swy-a-Lana Lagoon	2010	1	20x7.5	150	24	0.25	38%	7.7	5.8	76%
		2	28x10	280	32	0.25	22%	5.5	1.9	34%
		3	48x6	288	36	0.25	6%	106.9	39.7	37%
		Overall						46.6	16.0	34%
	2013	1	20x7.5	150	24	0.25	54%	3.7	2.0	53%
		2	28x10	280	32	0.25	50%	5.4	3.2	60%
		3	48x6	288	36	0.25	22%	81.3	20.7	25%
		Overall						35.5	8.4	24%
	2016	1	20x7.5	150	29	0.25	28%	12.3	6.4	52%
		2	28x10	280	30	0.25	33%	10.9	5.4	50%
		3	48x6	288	35	0.25	0%	145.6	52.4	36%
		Overall						65.2	21.0	32%
Transfer Beach	2011	1	60x7	420	60	0.0625	60%	14.9	6.1	41%
	2012	1	60x12	720	30	0.25	23%	17.2	8.6	50%
		2	60x8	480	47	0.25	23%	26.1	10.6	41%
		Overall						20.8	6.7	32%
	2016	1	60x12	720	44	0.25	11%	60.5	27.6	46%

Table 11. Survey design, density and 95% CIs for small size class (≤ 15 mm) of oysters at index sites in the Strait of Georgia 2010-2016.

Index Site	Year	Stratum	Stratum Size (m)	Stratum Area (m^2)	# Quad-rats	Quadrat Size (m^2)	Zero Oyster Count	Density (# m^{-2})	95% CI	Survey Pre-cision
Jervis	2011	1	60x3	180	90	0.0625	84%	3.2	1.6	51%
Inlet	2013	1	60x3	180	37	0.25	100%	0.0	-	-
		2	60x3	180	69	0.25	100%	0.0	-	-
		Overall						0.0	-	-
	2014	1	60x3	180	59	0.25	46%	9.9	4.8	49%
		2	60x3	180	42	0.25	52%	7.7	4.7	61%
		Overall						8.8	3.4	39%
Baker	2011	1	60x3	180	87	0.0625	77%	8.8	4.9	56%
Bay	2013	1	60x3	180	52	0.25	88%	1.1	1.2	116%
		2	60x3	180	60	0.25	95%	0.3	0.4	112%
		Overall						0.7	0.6	87%
	2014	1	60x3	180	20	0.25	0%	135.6	63.6	47%
		2	60x3	180	30	0.25	57%	17.9	12.8	71%
		Overall						76.7	29.4	38%
Swy-a-	2010	-		-	-	-	-	-	-	-
Lana	2013	1	20x7.5	150	24	0.25	100%	0.0	-	-
Lagoon		2	28x10	280	32	0.25	97%	0.3	0.5	196%
		3	48x6	288	36	0.25	97%	0.1	0.2	196%
		Overall						0.1	0.2	148%
	2016	1	20x7.5	150	29	0.25	90%	0.6	0.6	100%
		2	28x10	280	30	0.25	77%	2.0	1.2	60%
		3	48x6	288	35	0.25	94%	0.6	0.9	158%
		Overall						1.1	0.6	54%
Transfer	2011	1	60x7	420	60	0.0625	92%	2.1	2.7	127%
Beach	2012	1	60x12	720	30	0.25	100%	0.0	-	-
		2	60x8	480	47	0.25	100%	0.0	-	-
		Overall						0.0	-	-
	2016	1	60x12	720	44	0.25	18%	14.8	4.7	32%

Note: The small size class was not recorded separately at Swy-a-lana Lagoon in 2010.
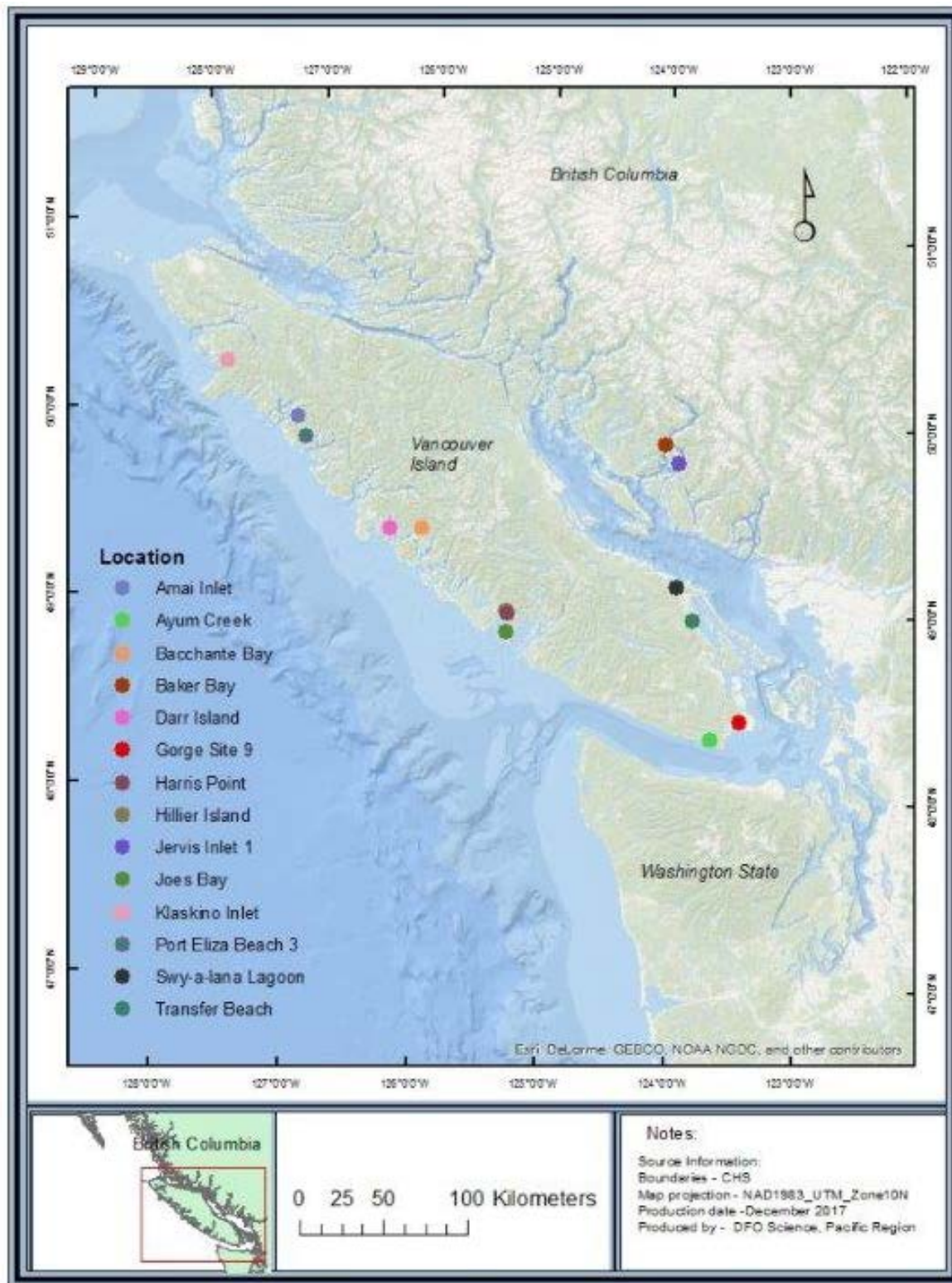
Figure 1. Olympia oyster index sites surveyed in British Columbia, 2009-2017.

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Figure 2. Location and strata layout for the Olympia oyster index site in Klaskino Inlet.

Figure 3. A) Klaskino Inlet Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Klaskino Inlet Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
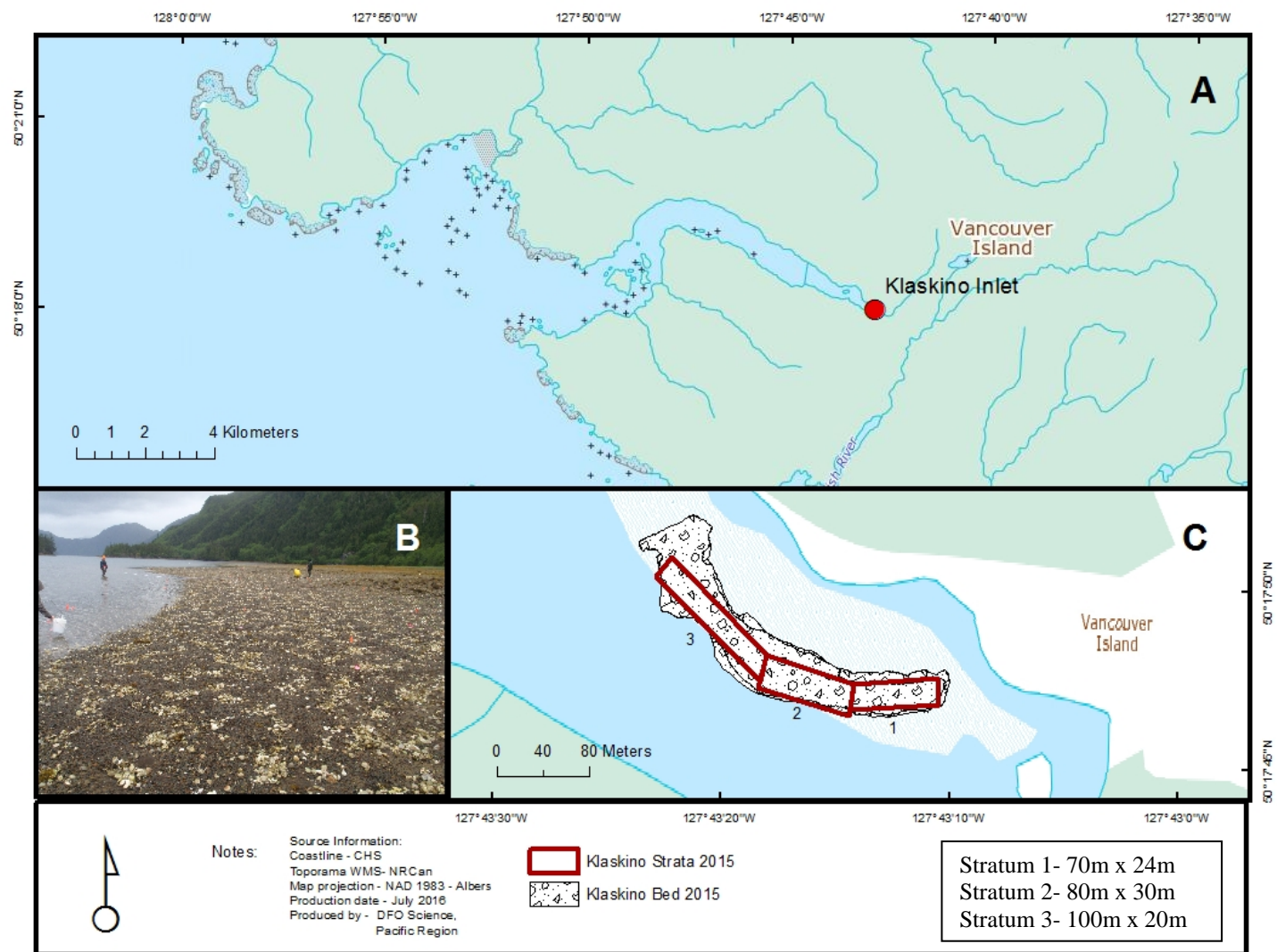
Figure 4. Location and stratum layout for the Olympia oyster index site in Amai Inlet.

Figure 5. A) Amai Inlet Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category.
The *Small* size category includes oysters ≤ 15 mm. B) Amai Inlet Olympia oyster size frequency (mm). Red dotted lines are mean
length (mm).

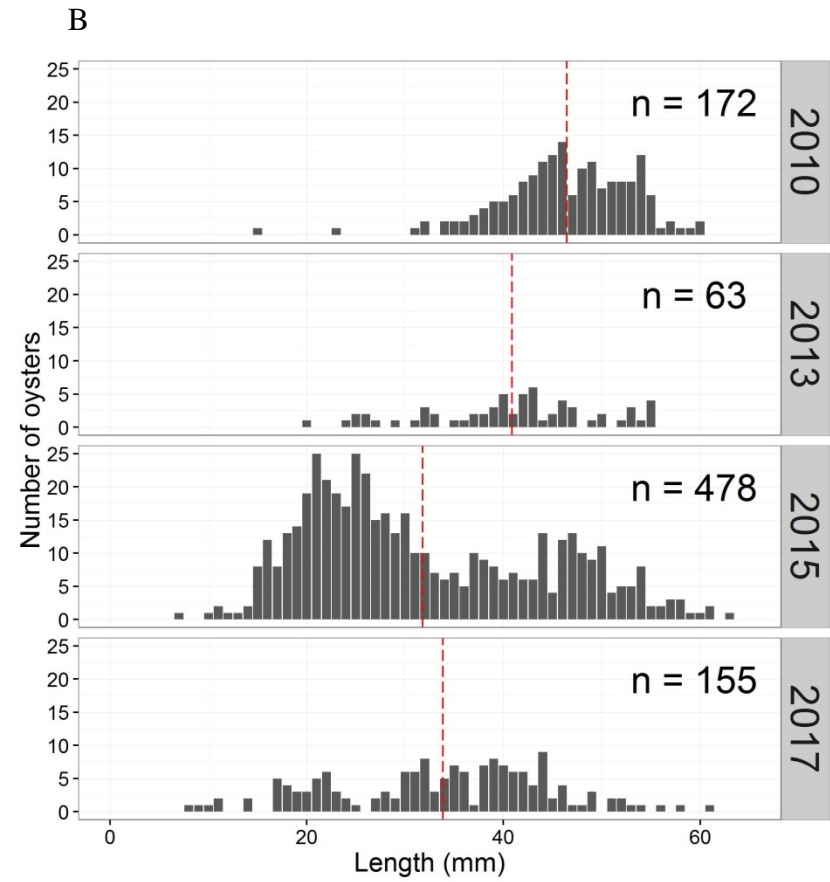Figure 6. Location and strata layout for the Olympia oyster index site at Port Eliza Beach 3.

Figure 7. A) Port Eliza Beach #3 Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Port Eliza Beach 3 Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

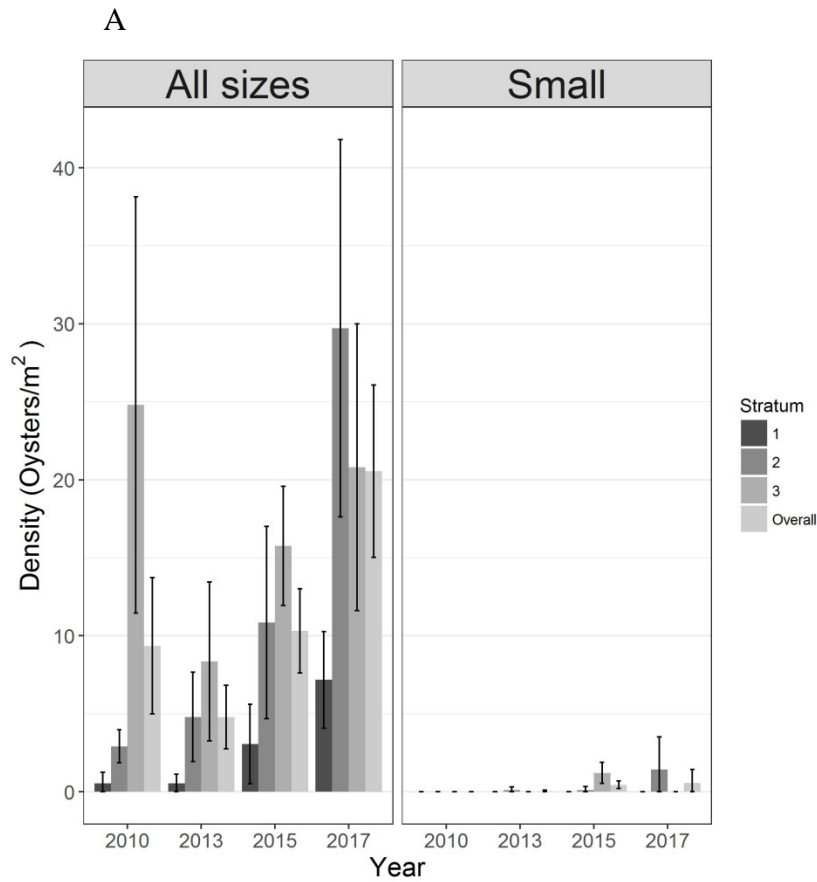Figure 8.   Location and stratum layout for the Olympia oyster index site in Darr Island.

Figure 9. A) Darr Island Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Darr Island Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

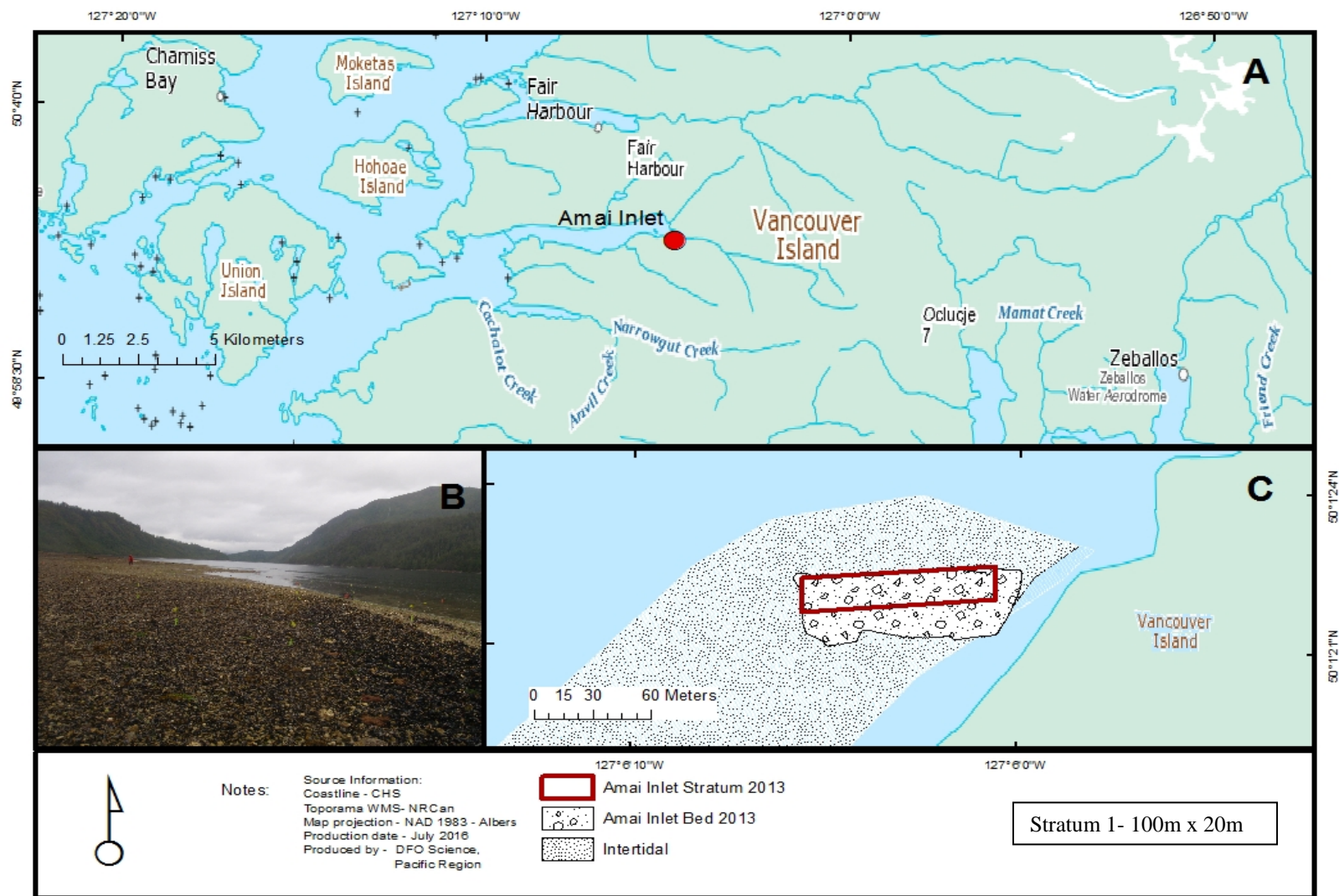Figure 10. Location and strata layout for the Olympia oyster index site in Bacchante Bay.

Figure 11. A) Bacchante Bay Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Bacchante Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

Figure 12. Location and stratum layout for the Olympia oyster index site at Harris Point.
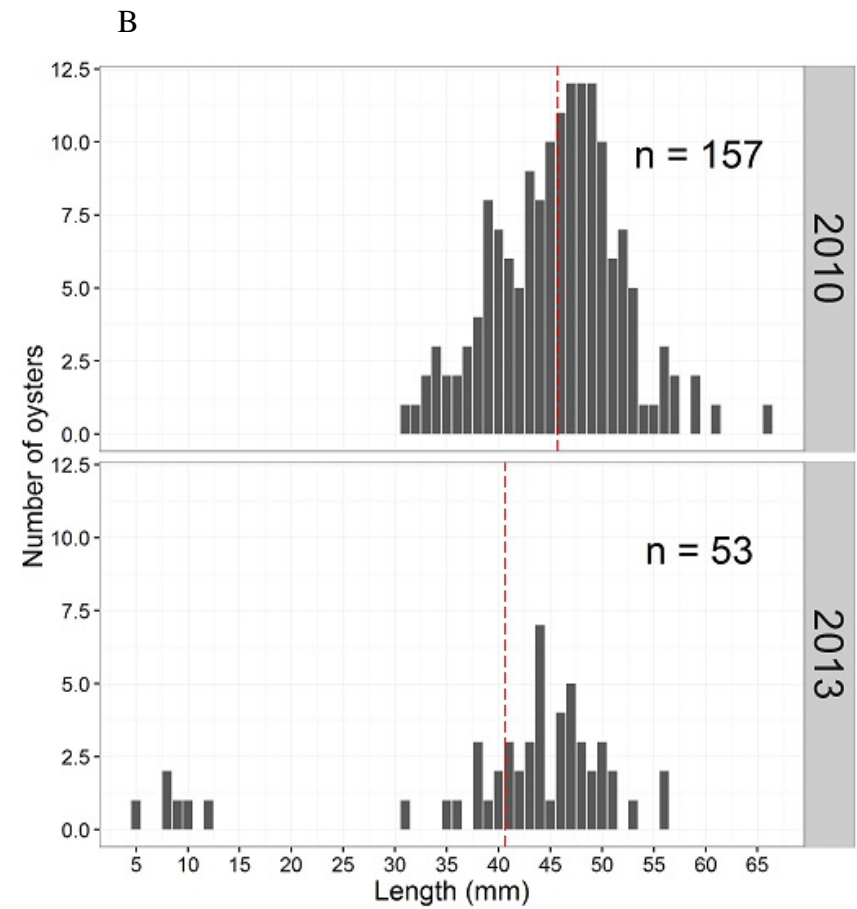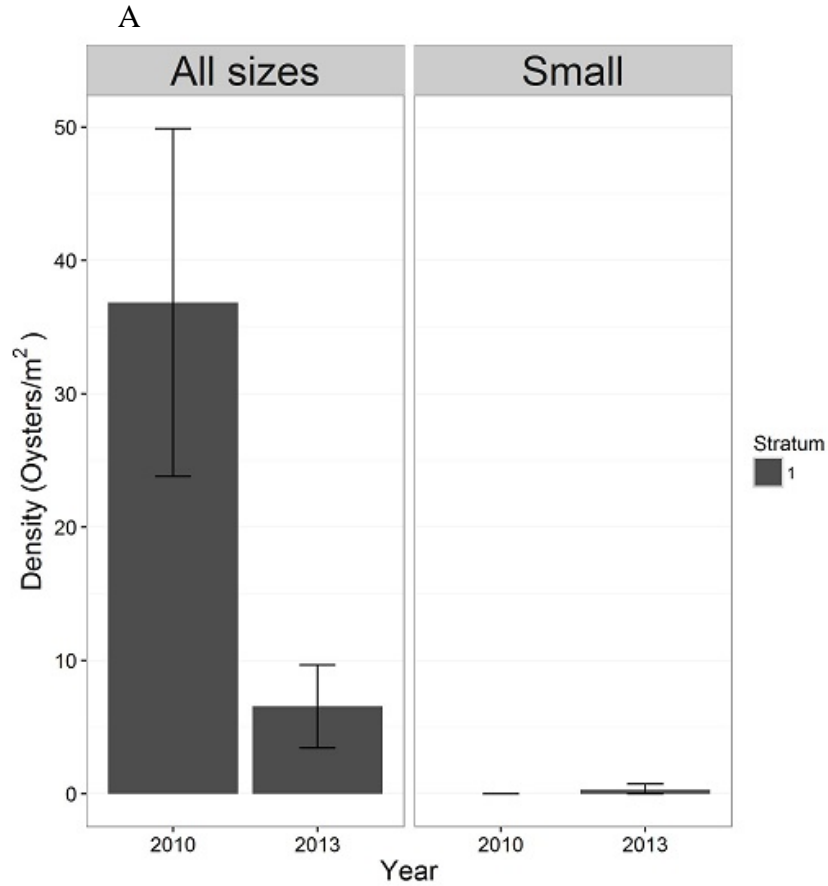
Figure 13. A) Harris Point Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B). Harris Point Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
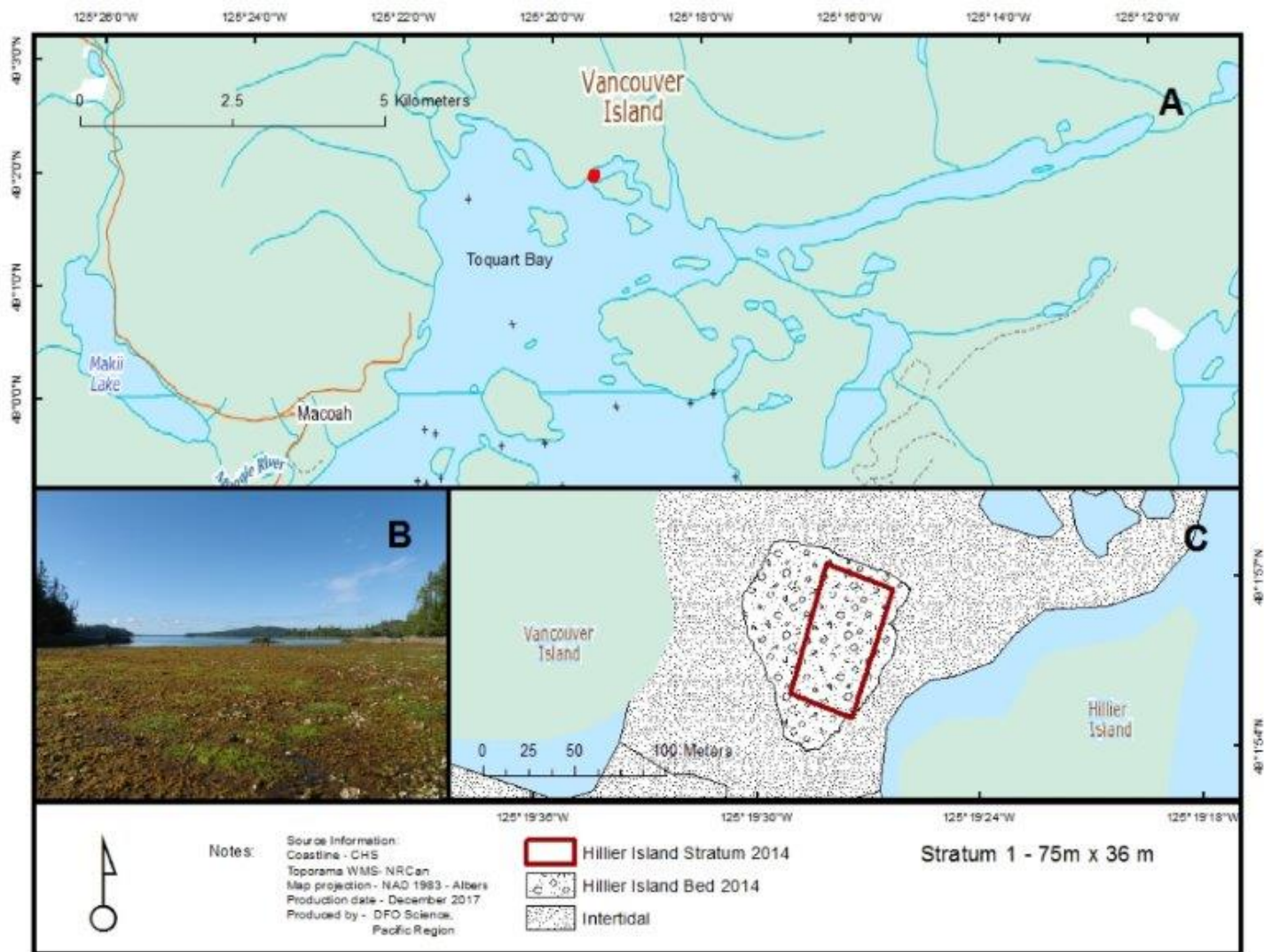
Figure 14. Location and stratum layout for the Olympia oyster index site at Hillier Island.
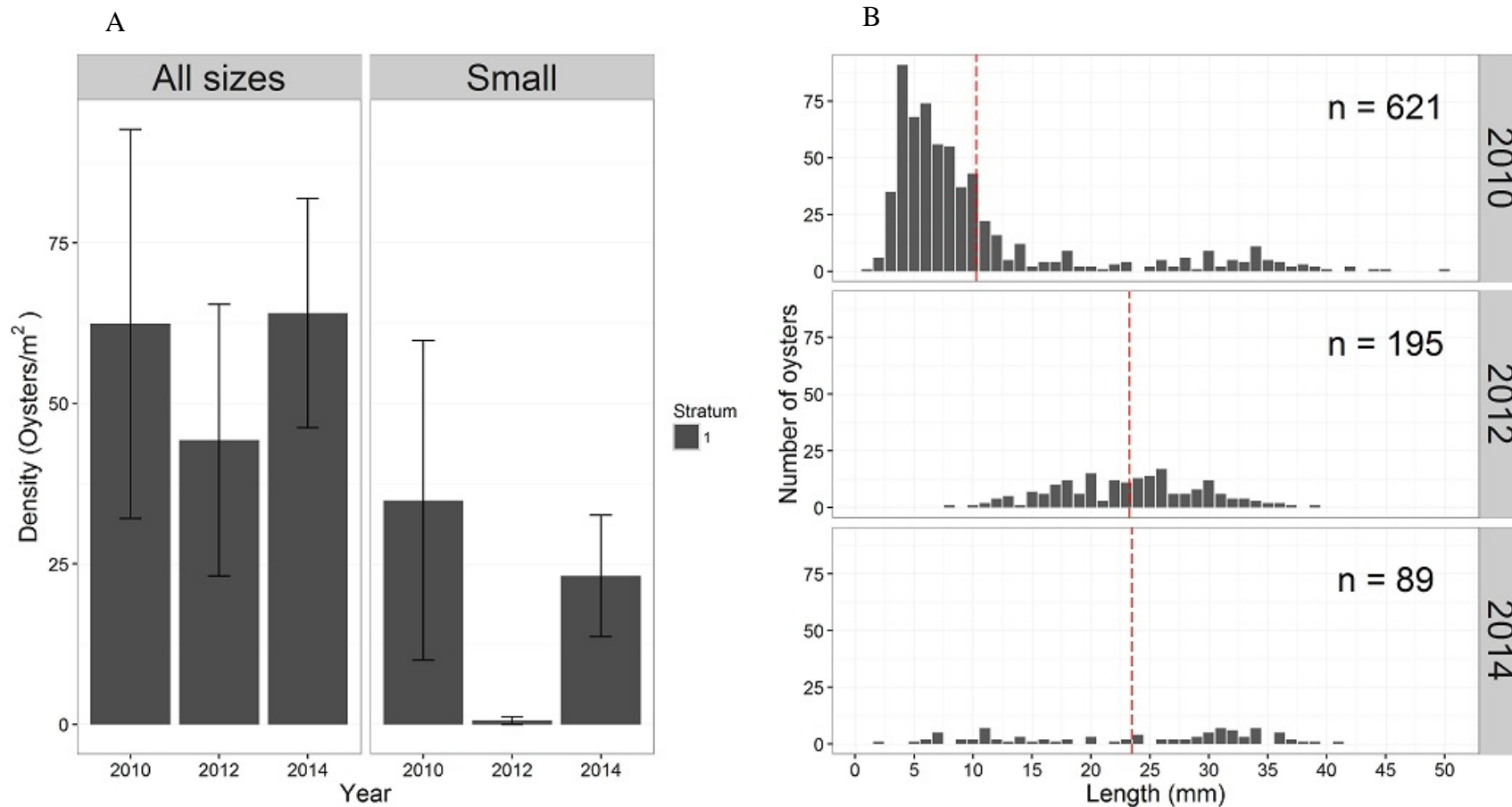
Figure 15. A) Hillier Island Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Hillier Island Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
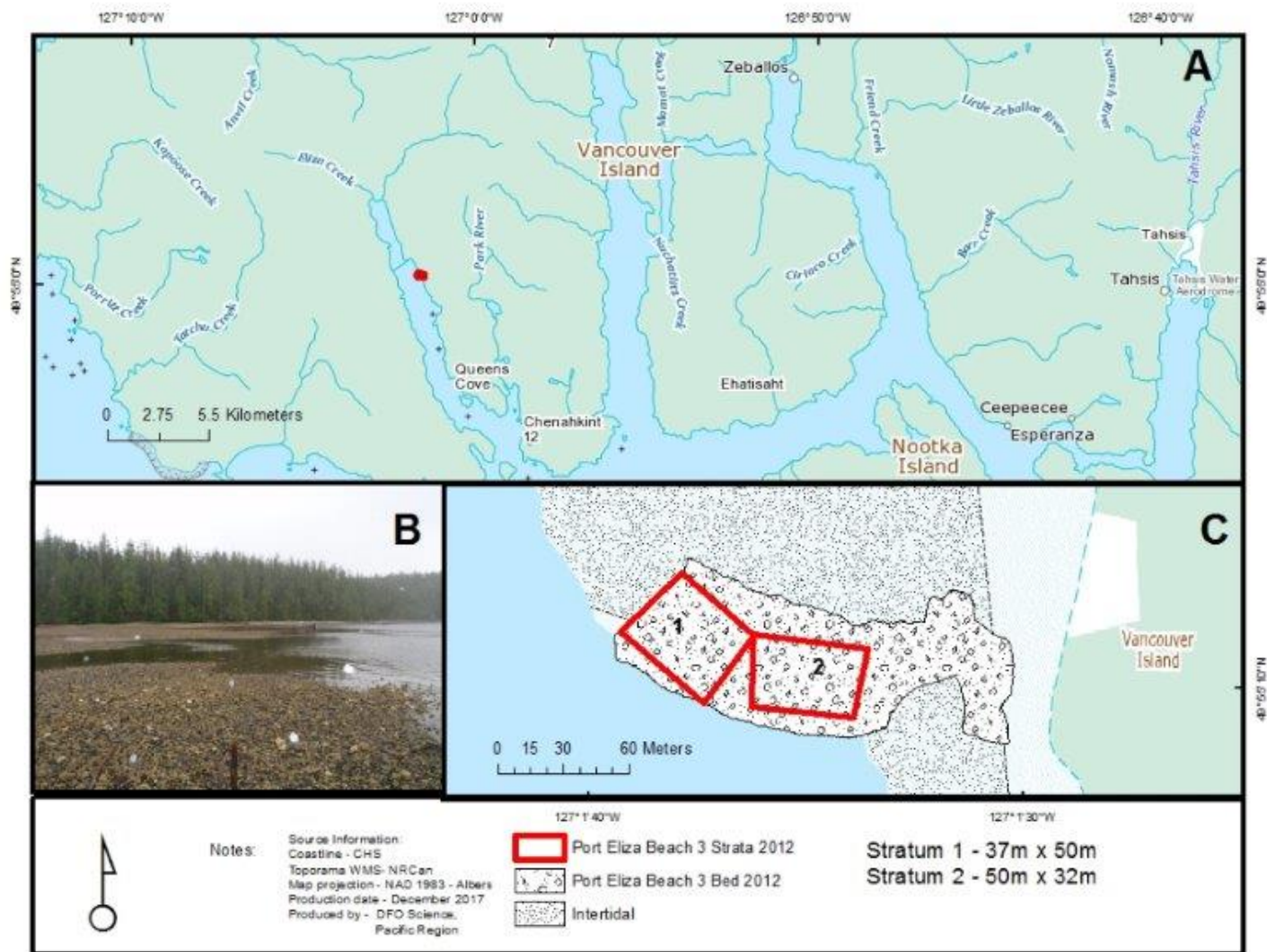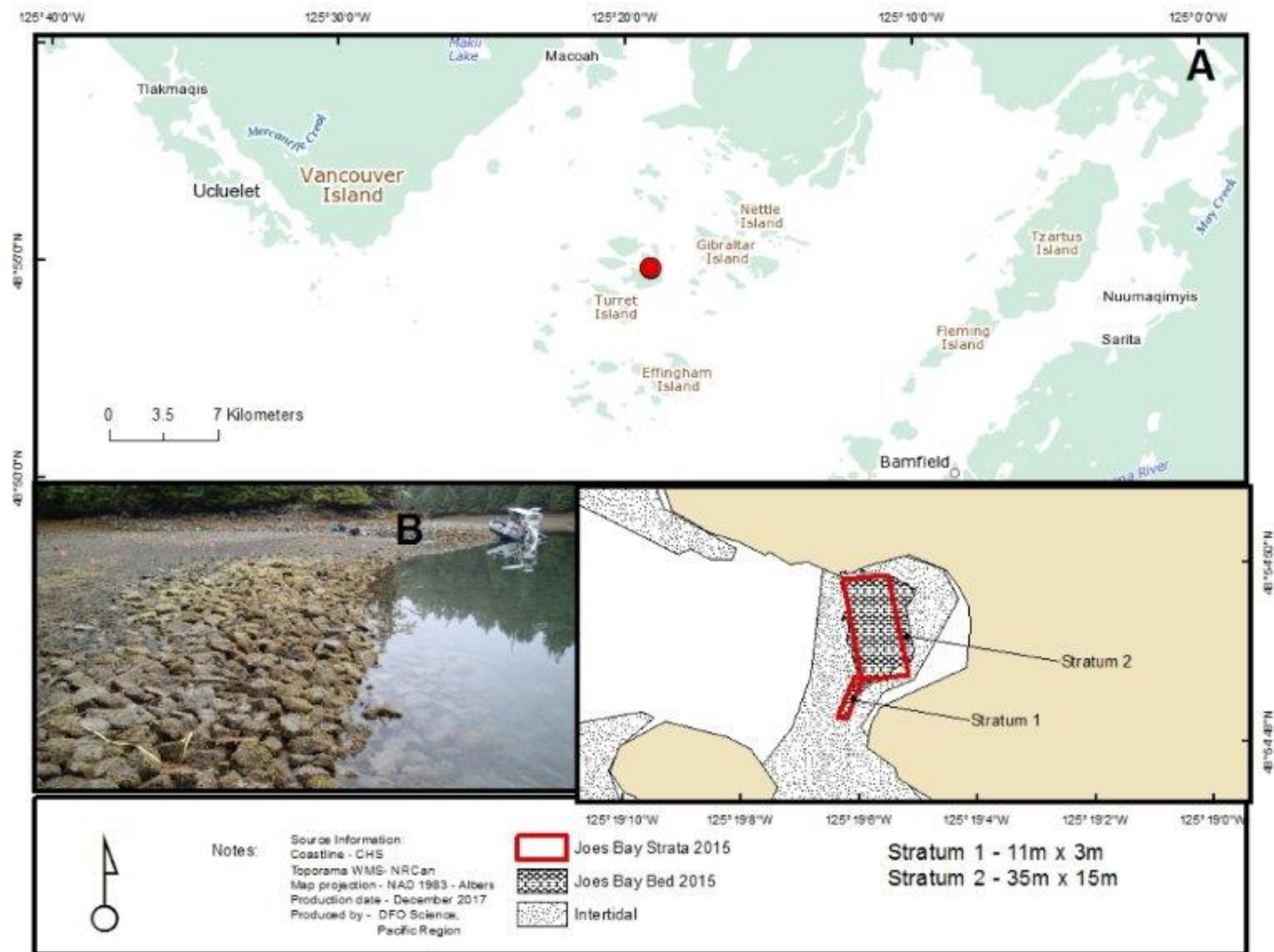
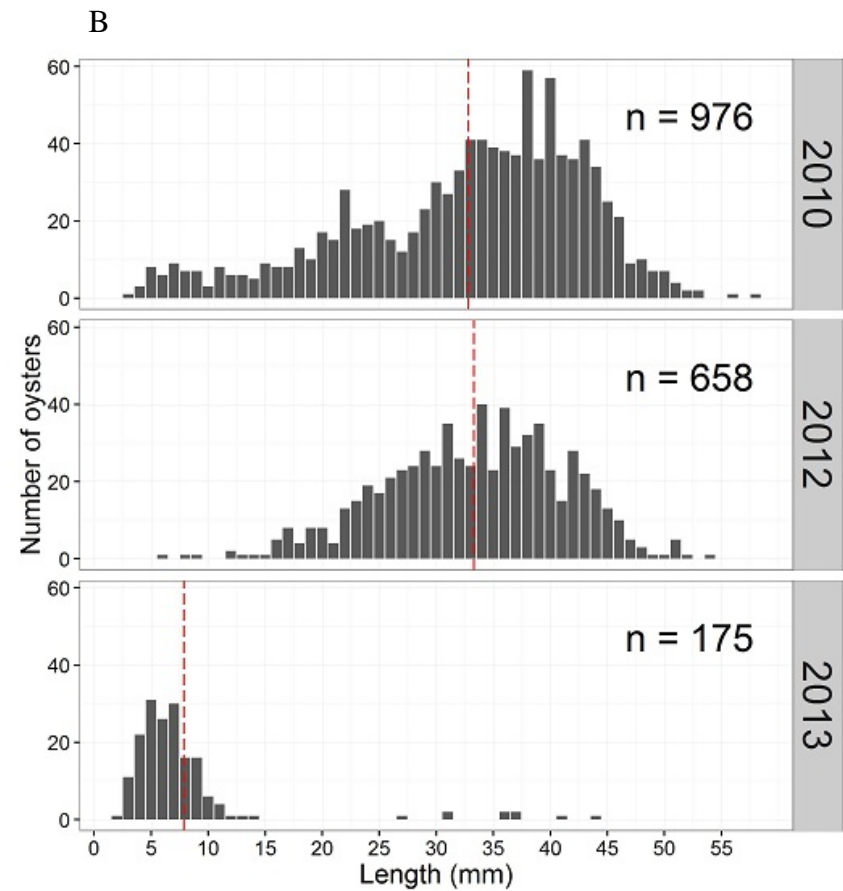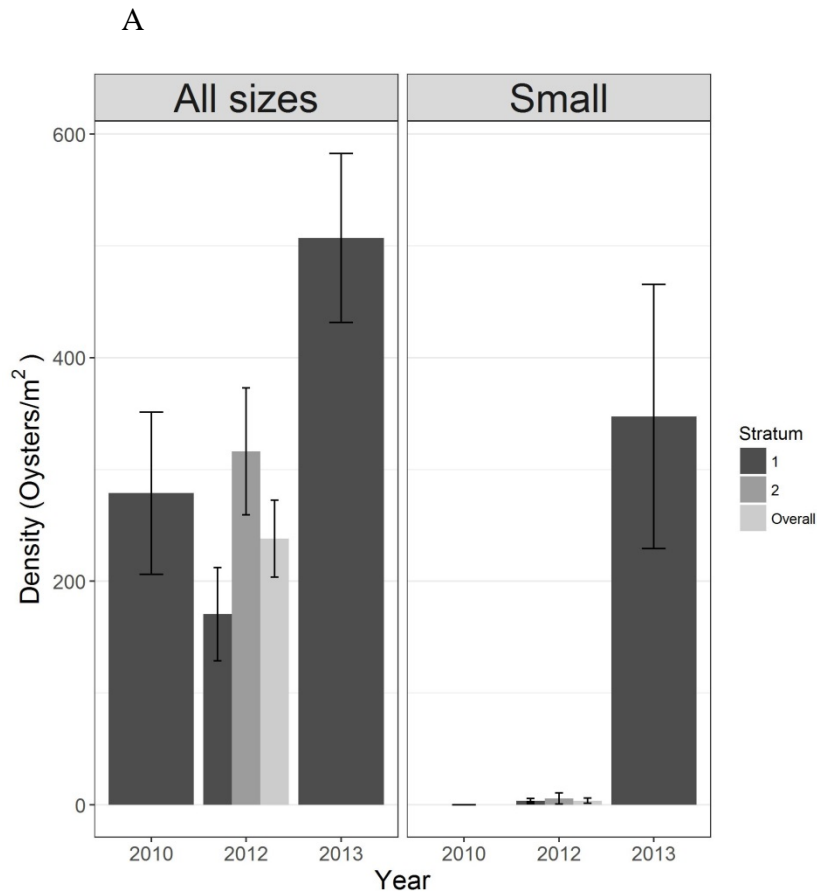Figure 16. Location and strata layout for the Olympia oyster index site in Joes Bay.
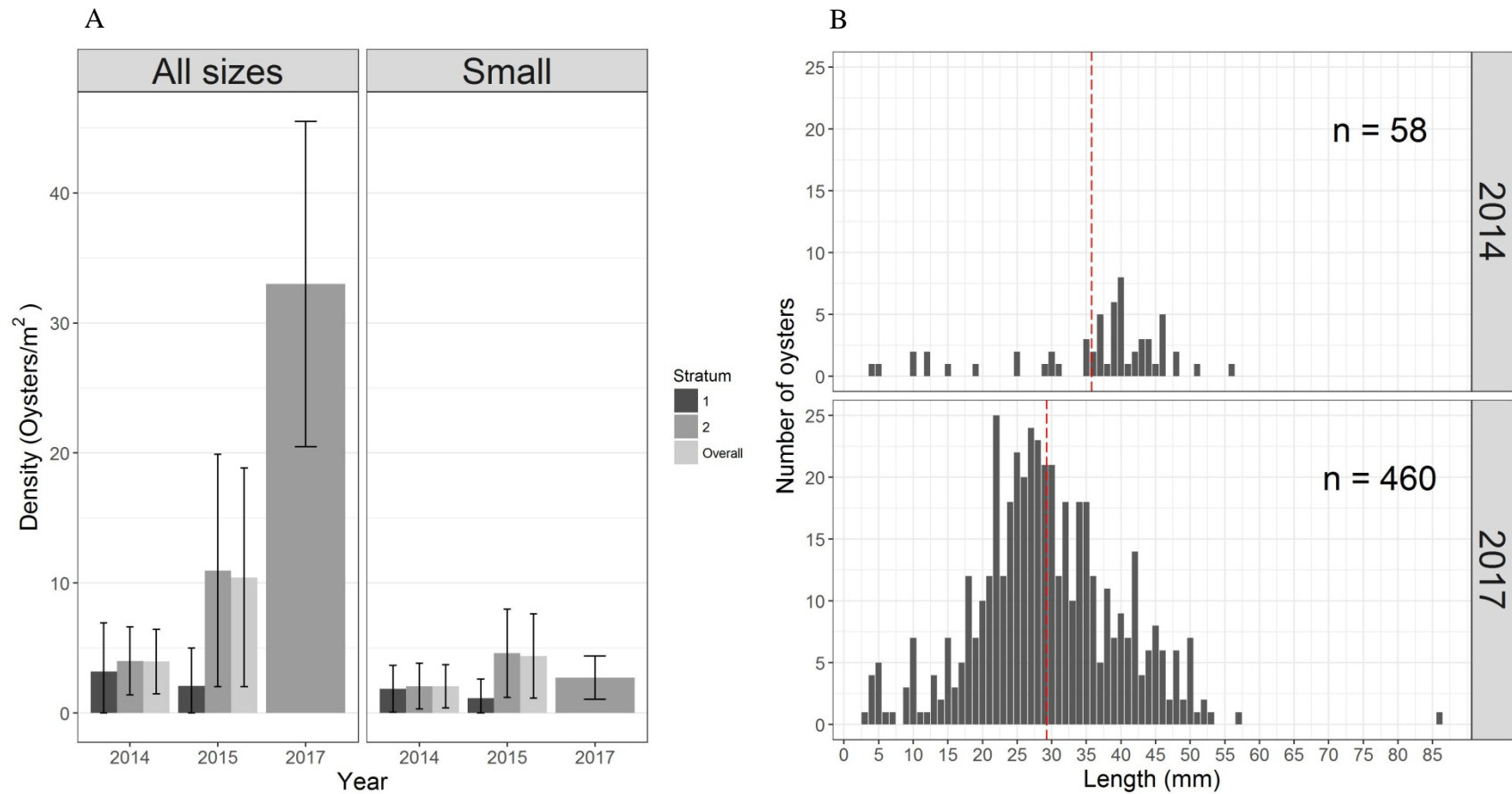
Figure 17. A) Joes Bay Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters $\leq$ 15 mm). B) Joes Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
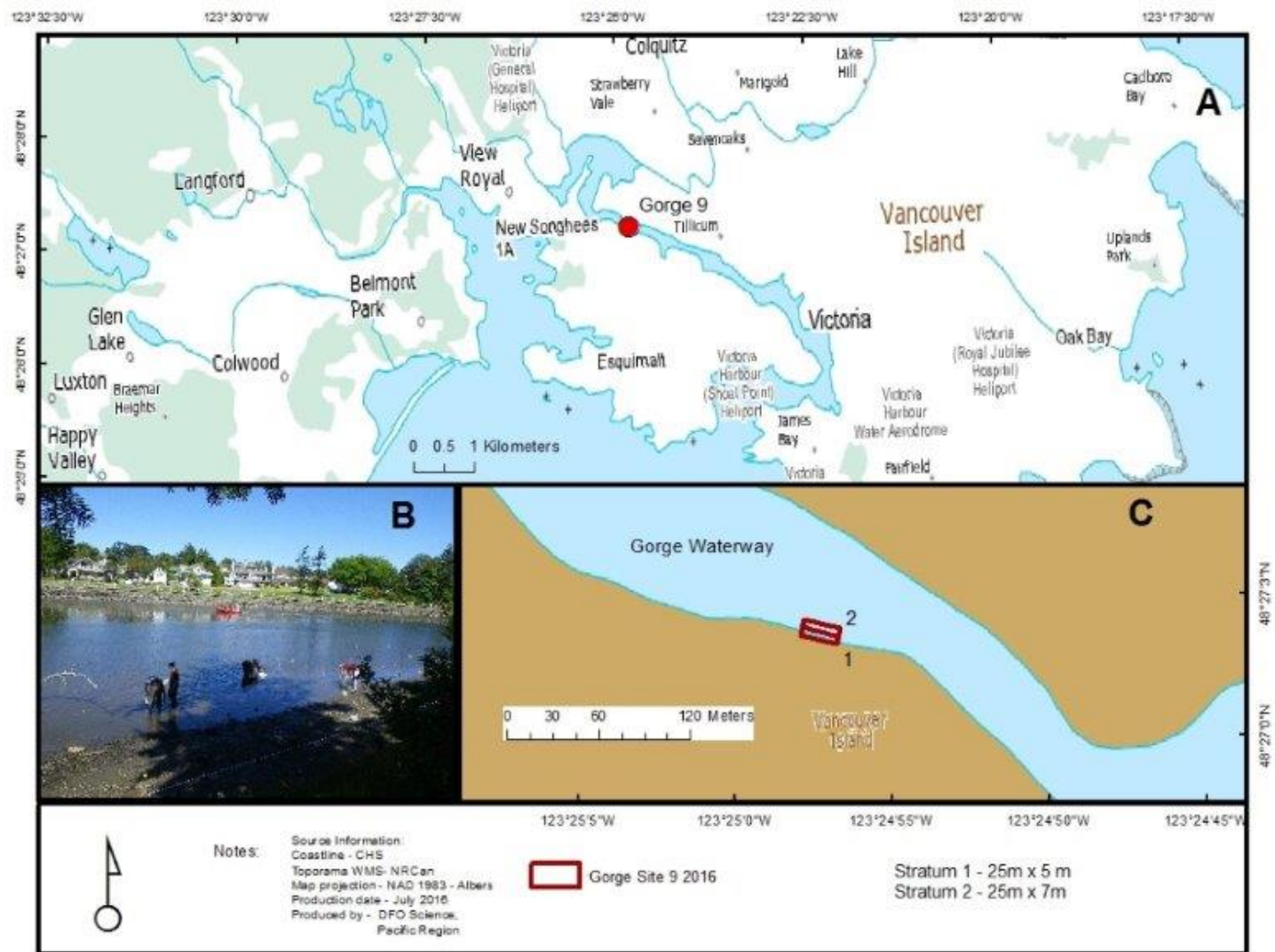
Figure 18. Location and strata layout for the Olympia oyster index site at Gorge Site 9.
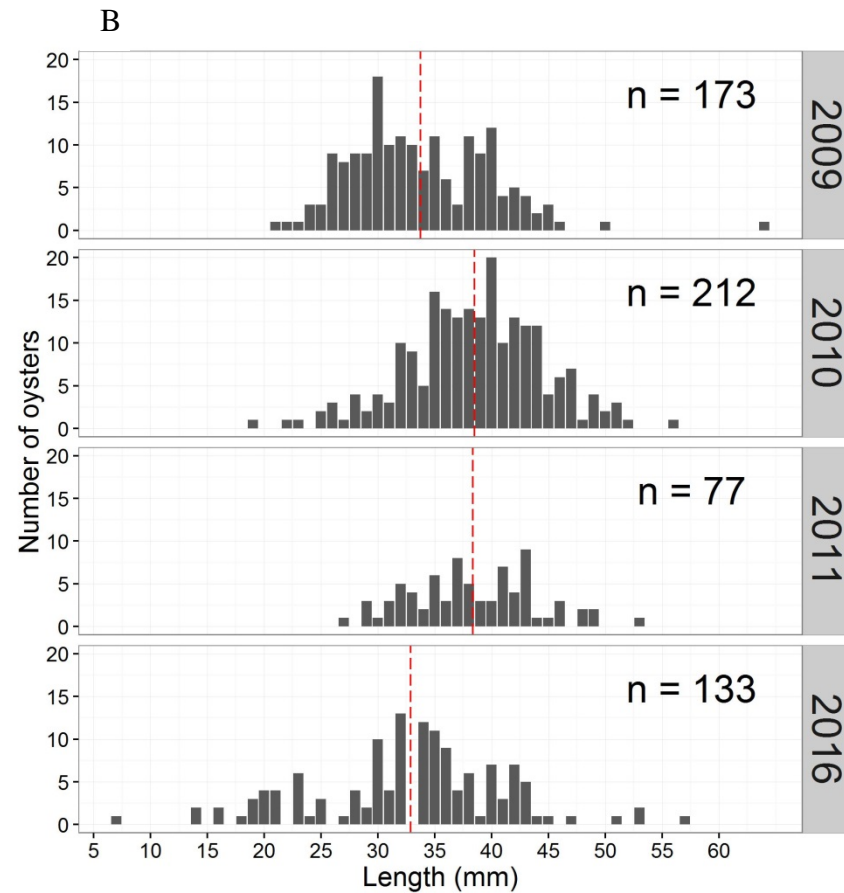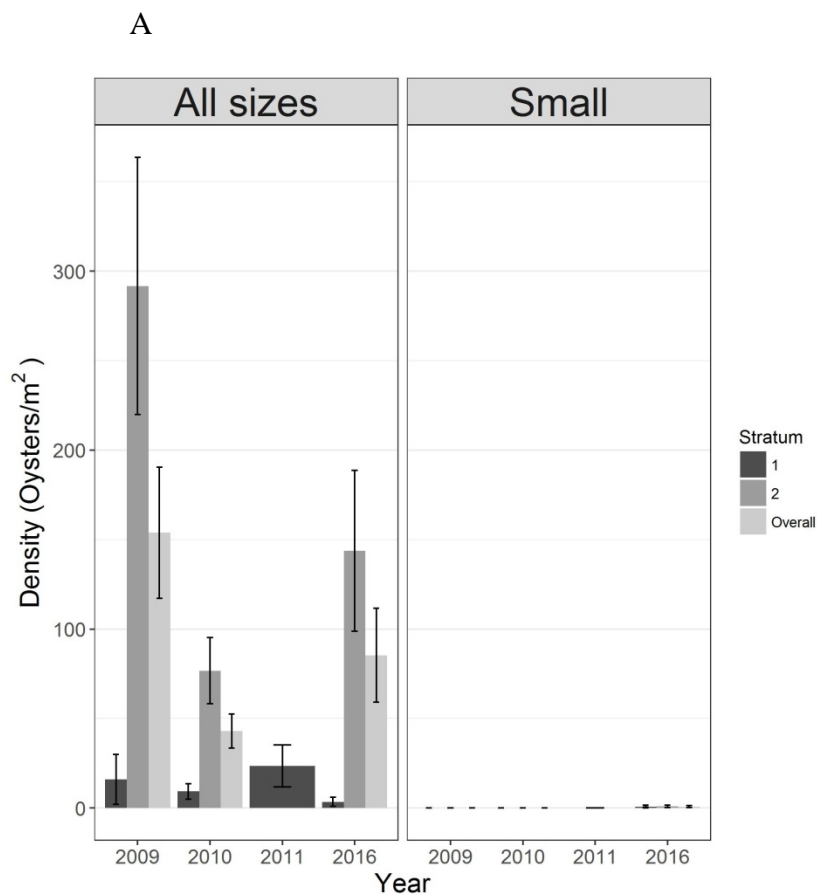
Figure 19. A) Gorge Waterway Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Gorge Waterway Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
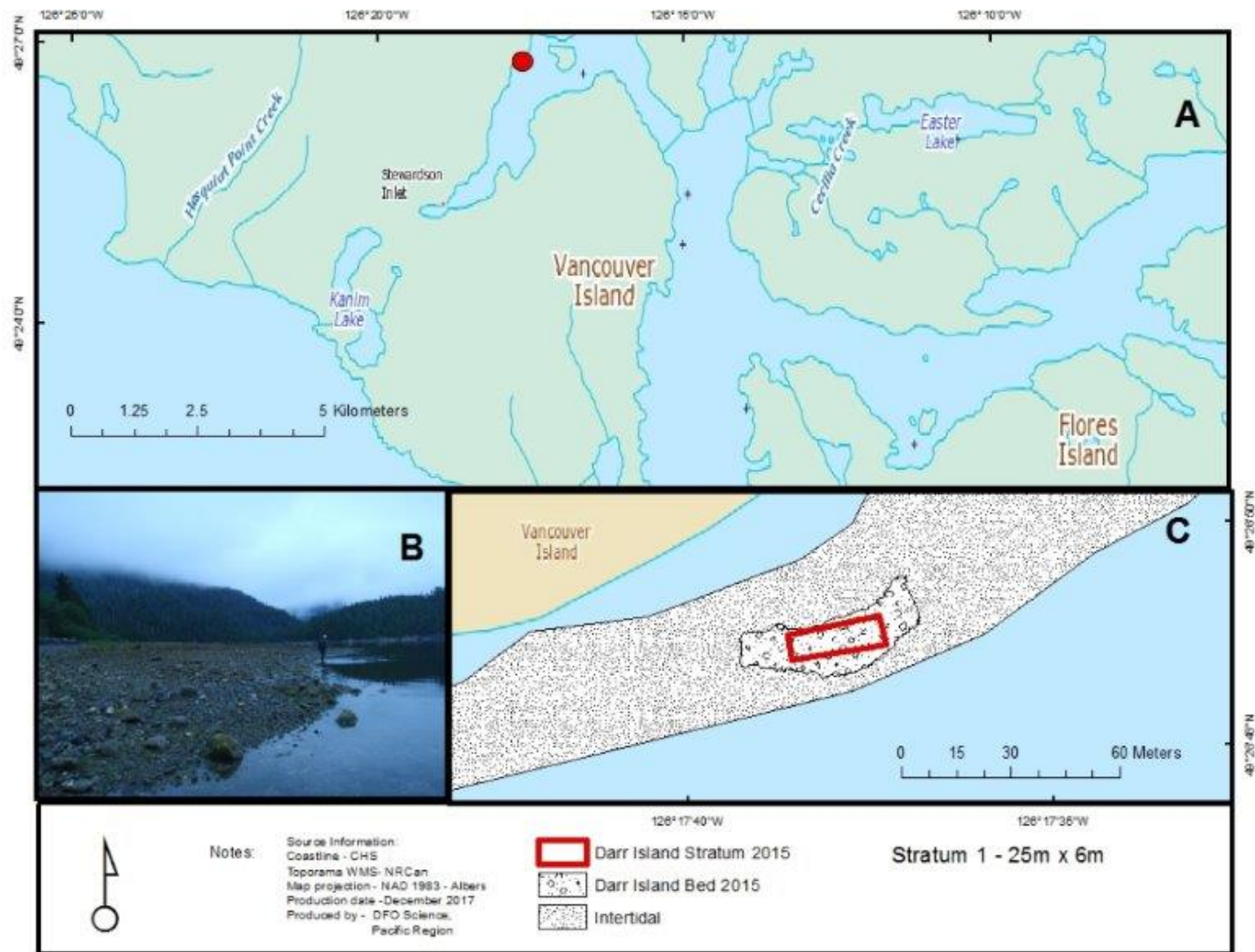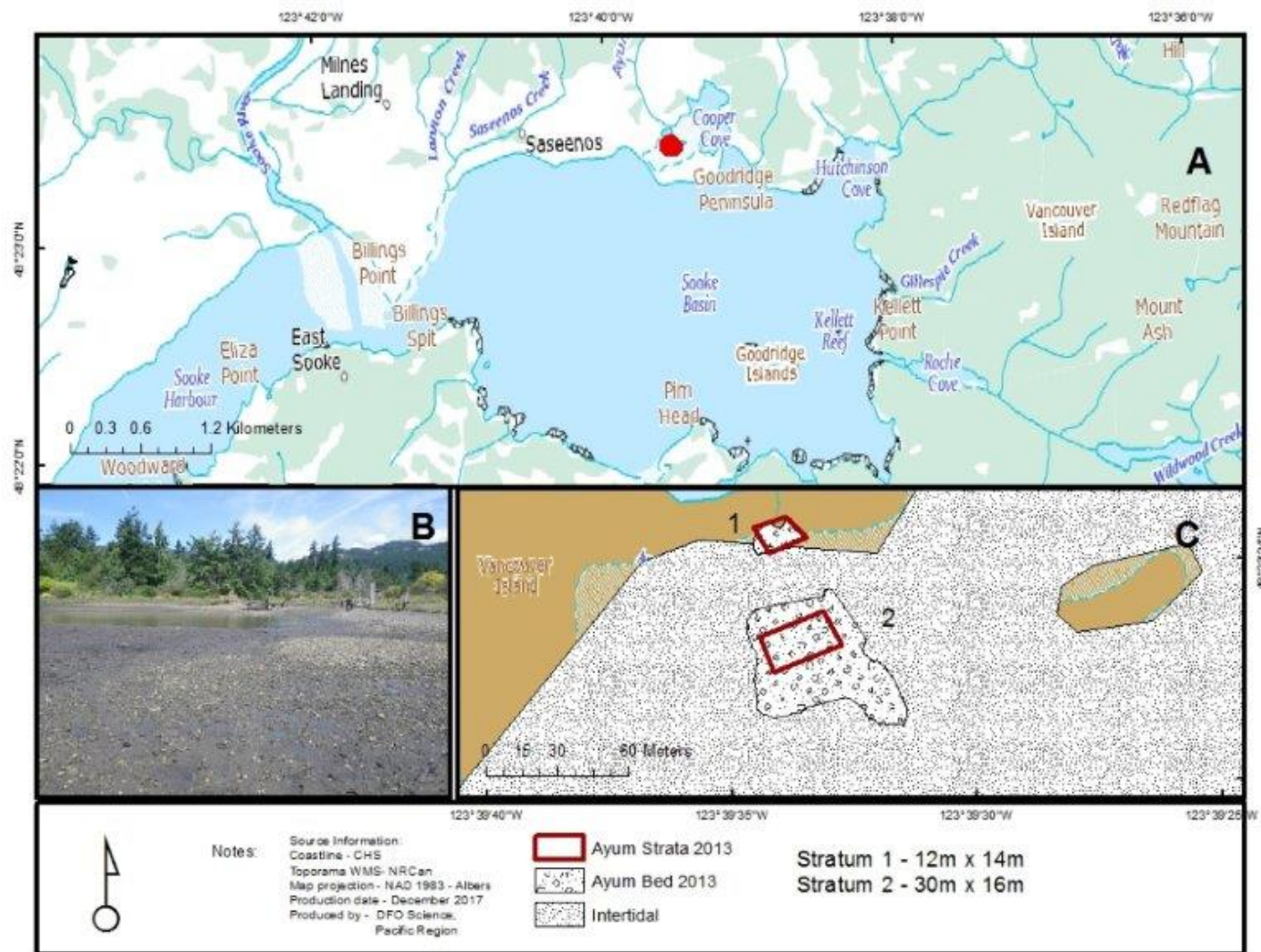
Figure 20. Location and strata layout for the Olympia oyster index site at Ayum Creek.
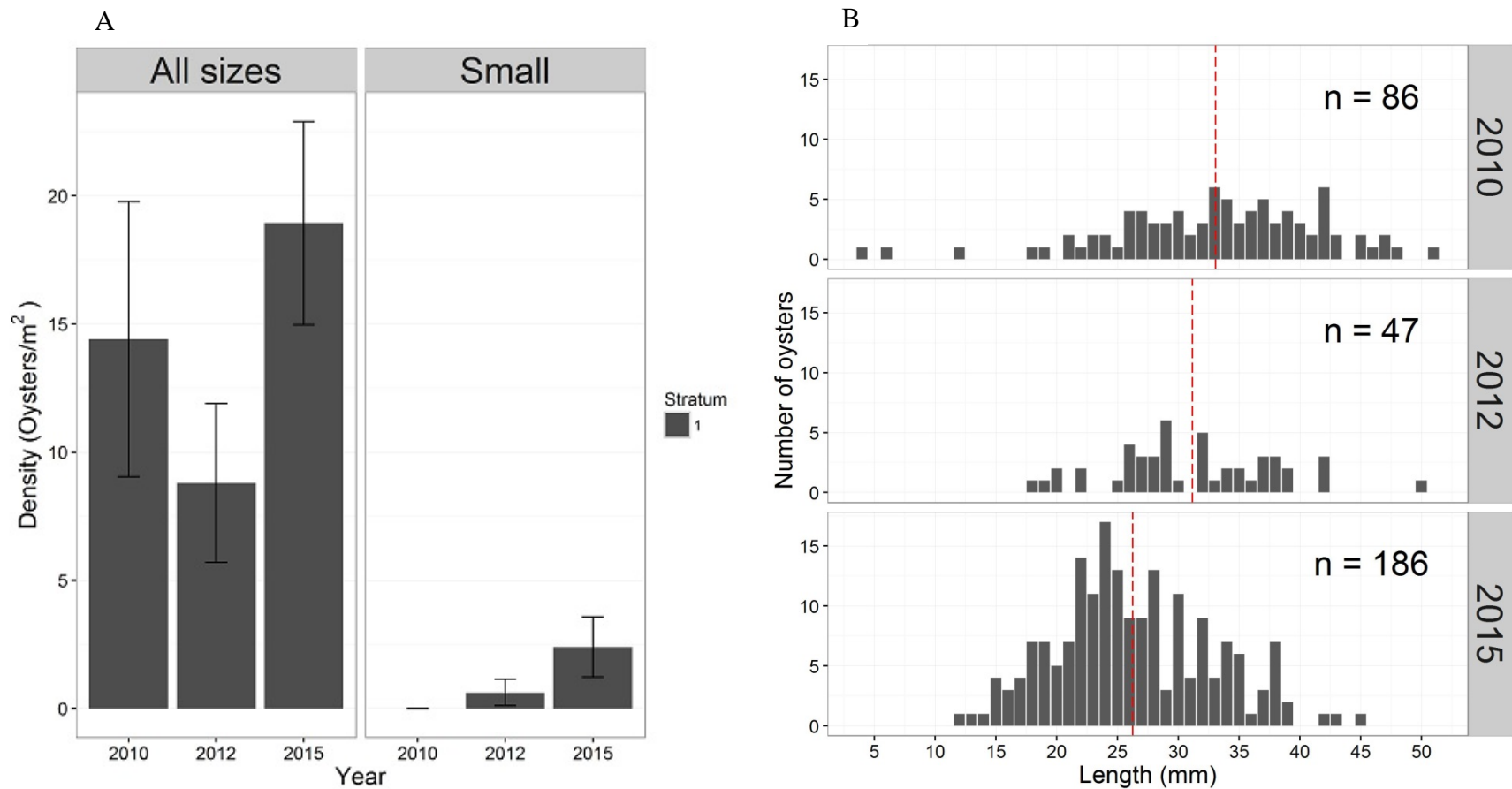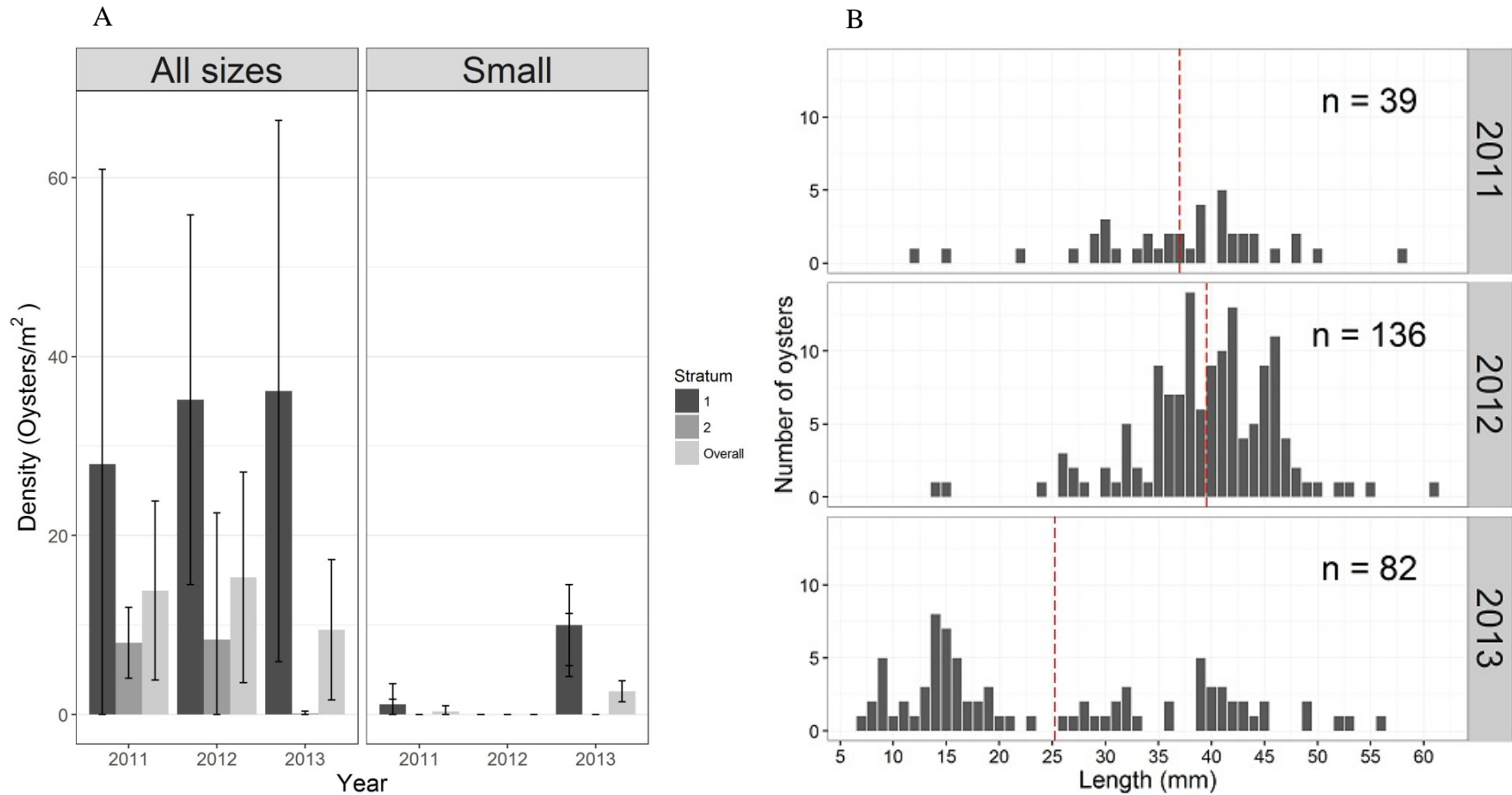
Figure 21. A) Ayum Creek Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters $\leq$ 15 mm. B) Ayum Creek Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
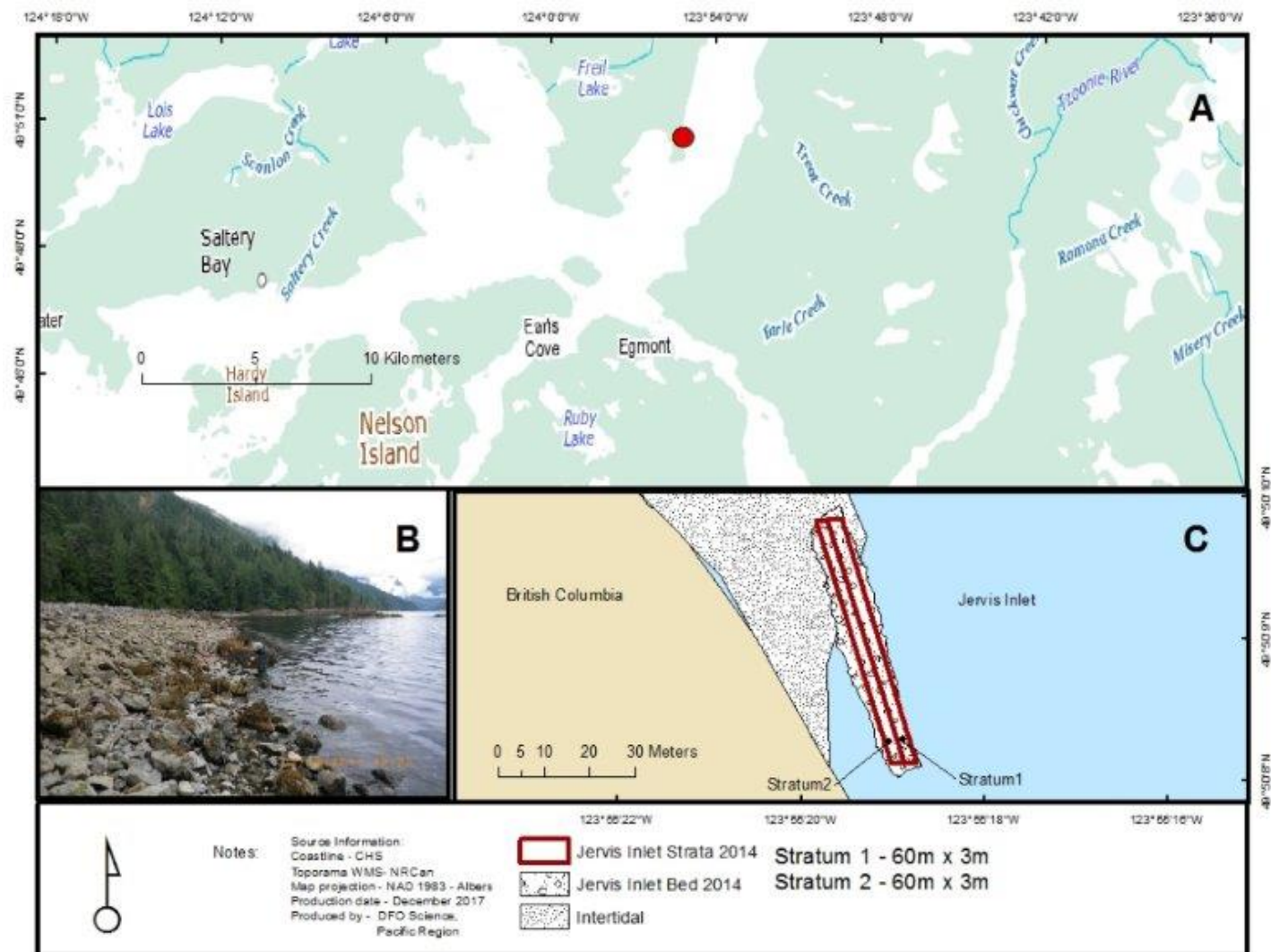
Figure 22. Location and strata layout for the Olympia oyster index site in Jervis Inlet.
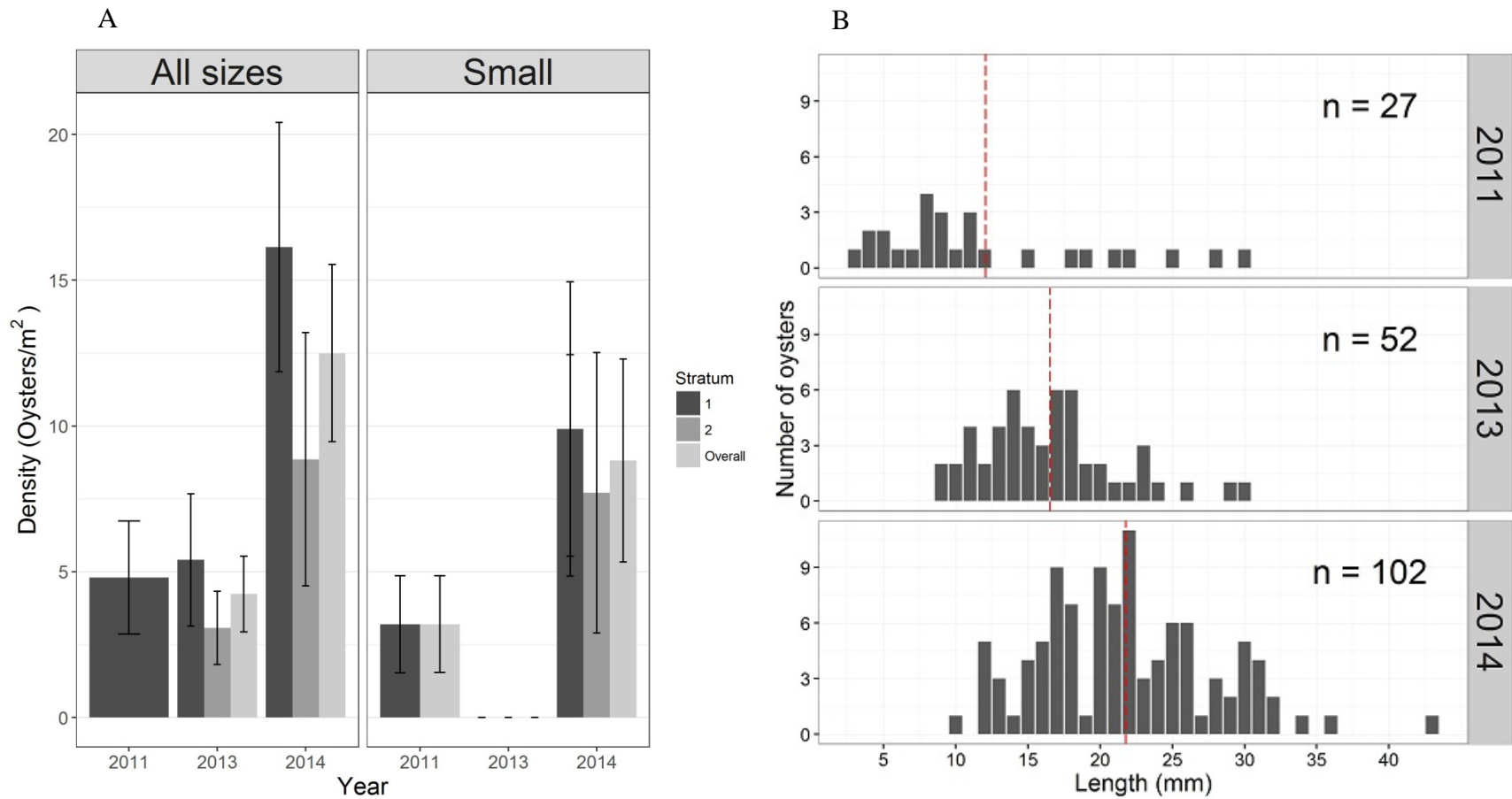
Figure 23. A) Jervis Inlet Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters $\leq$ 15 mm. B) Jervis Inlet Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
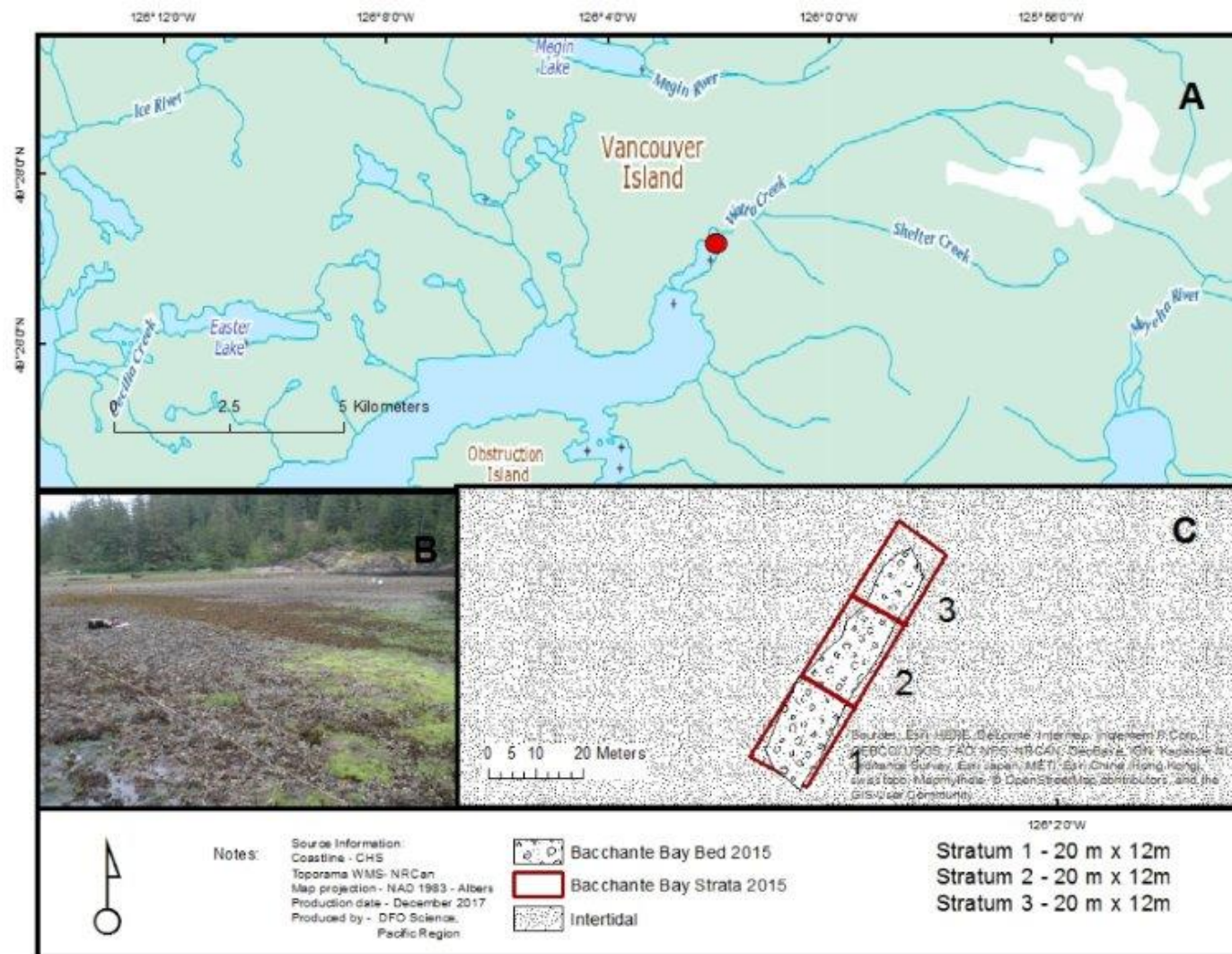
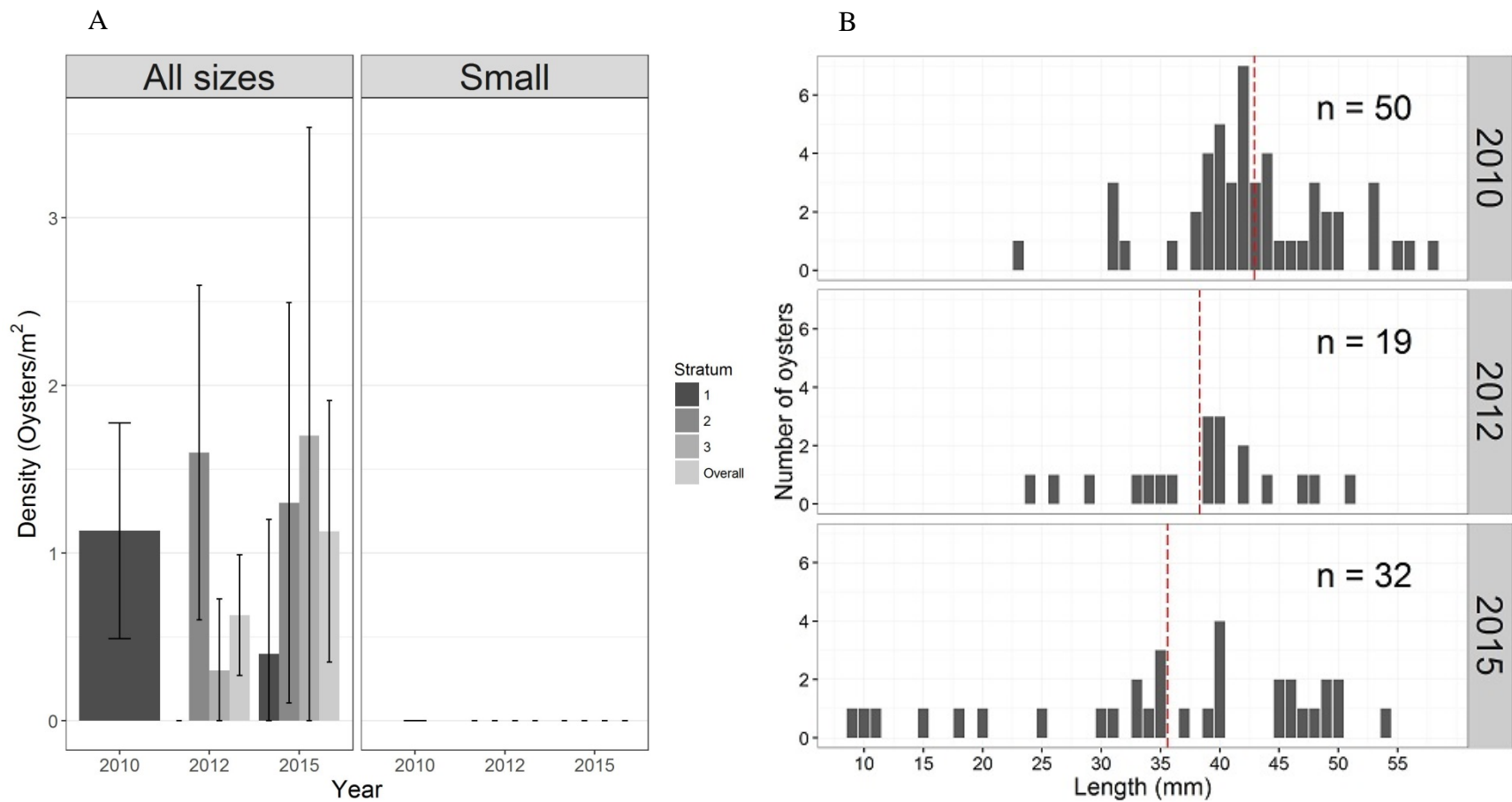Figure 24. Location and strata layout for the Olympia oyster index site in Baker Bay.
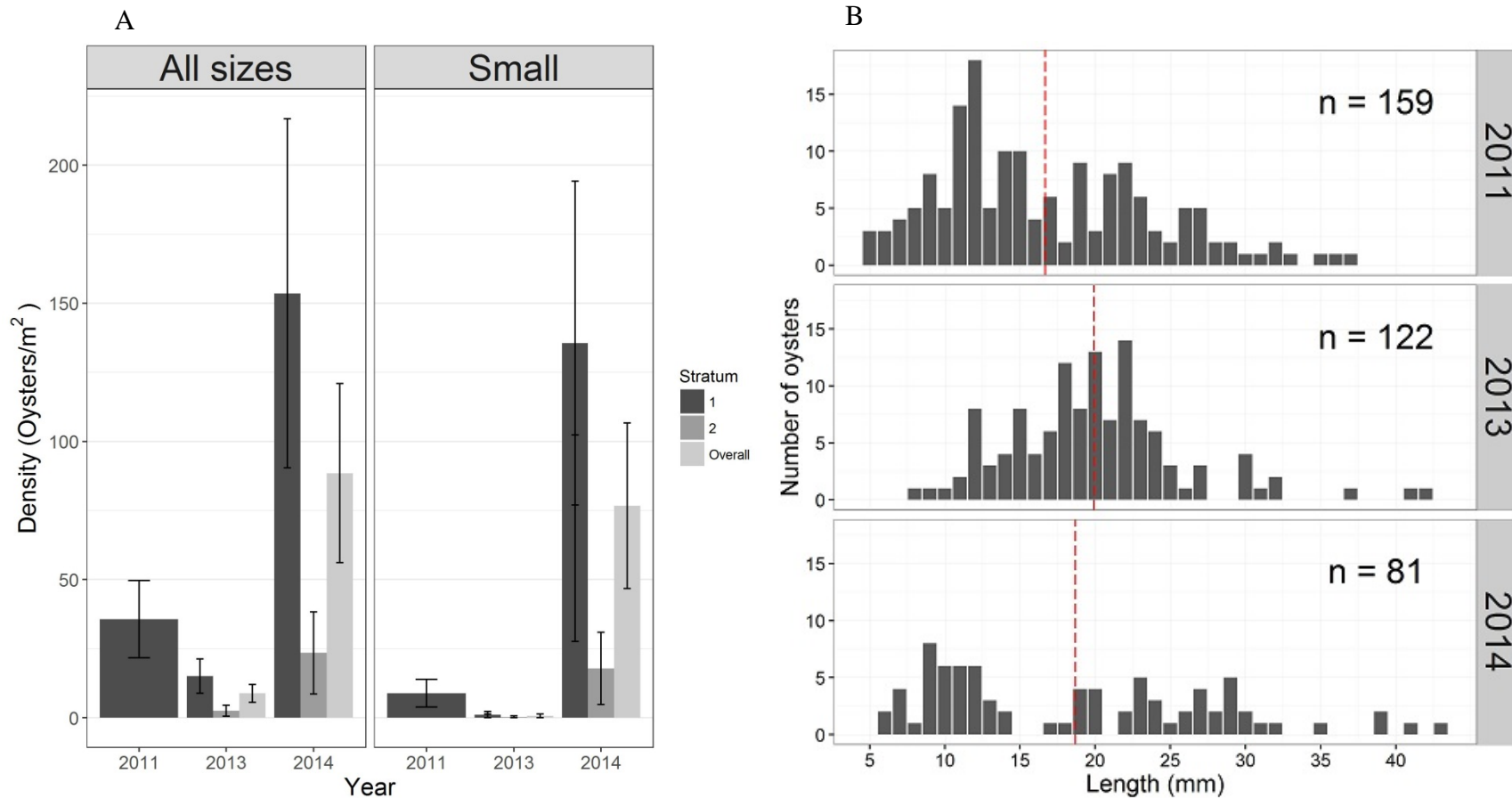
Figure 25. A) Baker Bay Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Baker Bay Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
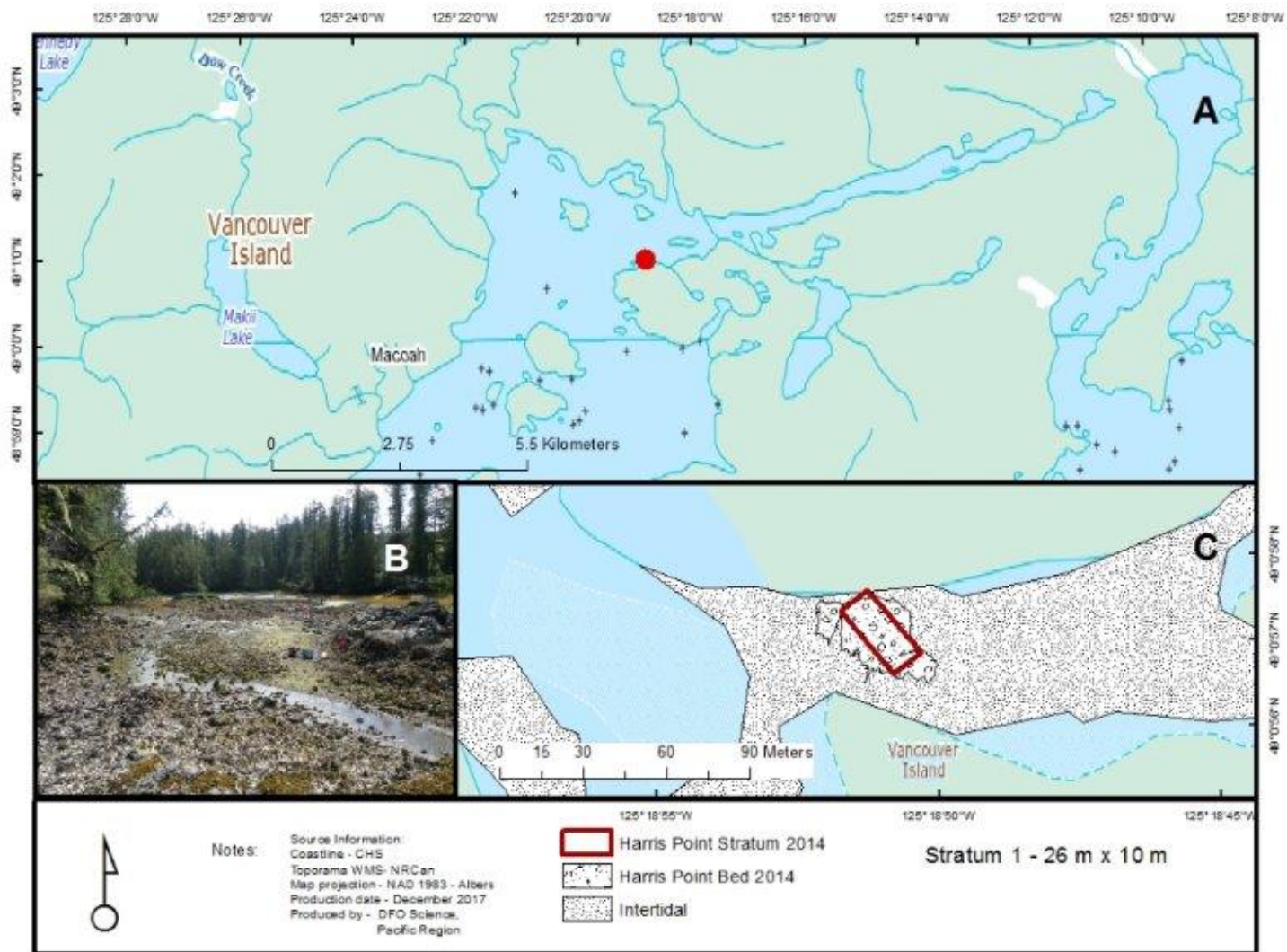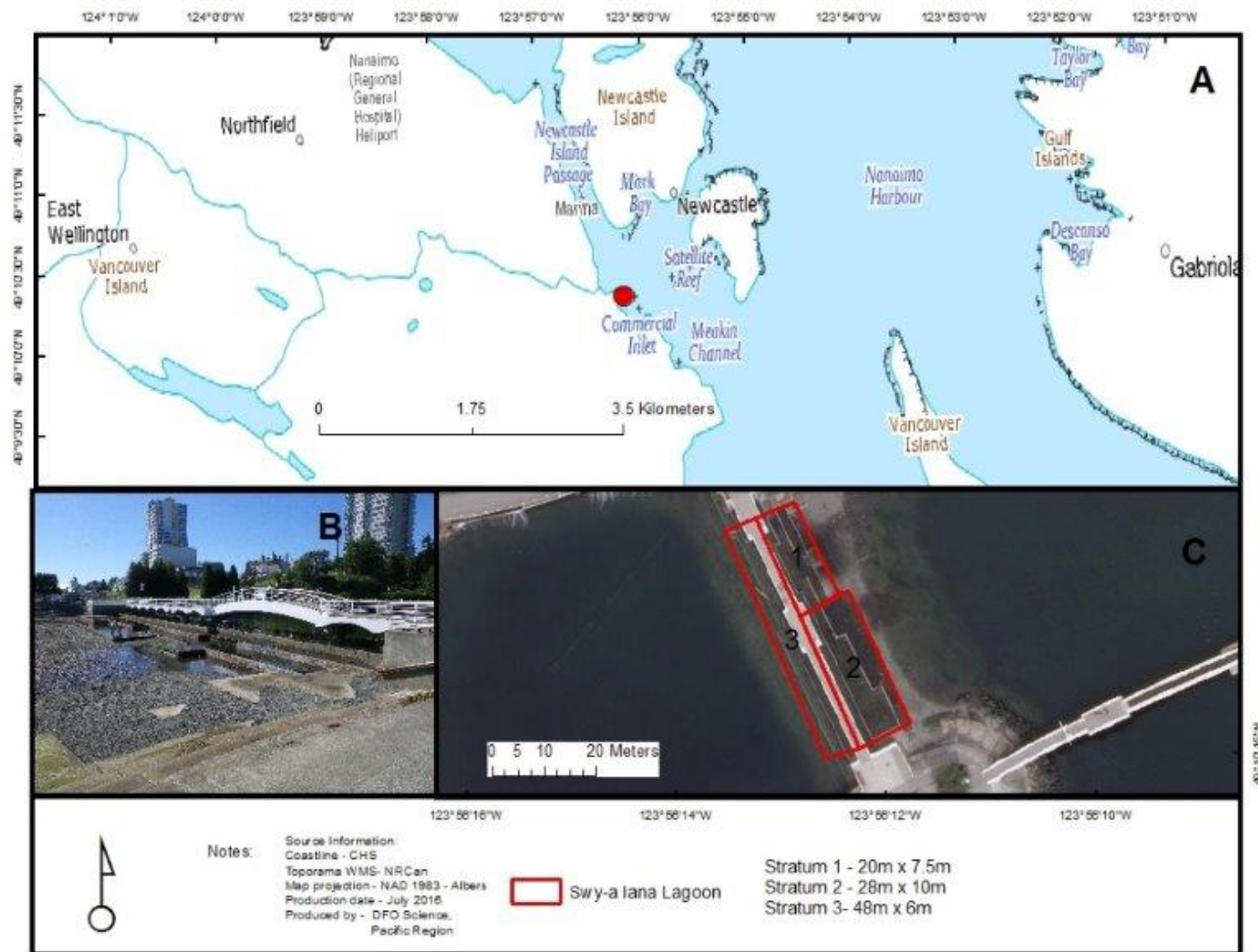
Figure 26. Location and strata layout for the Olympia oyster index site in Swy-a-lana Lagoon.
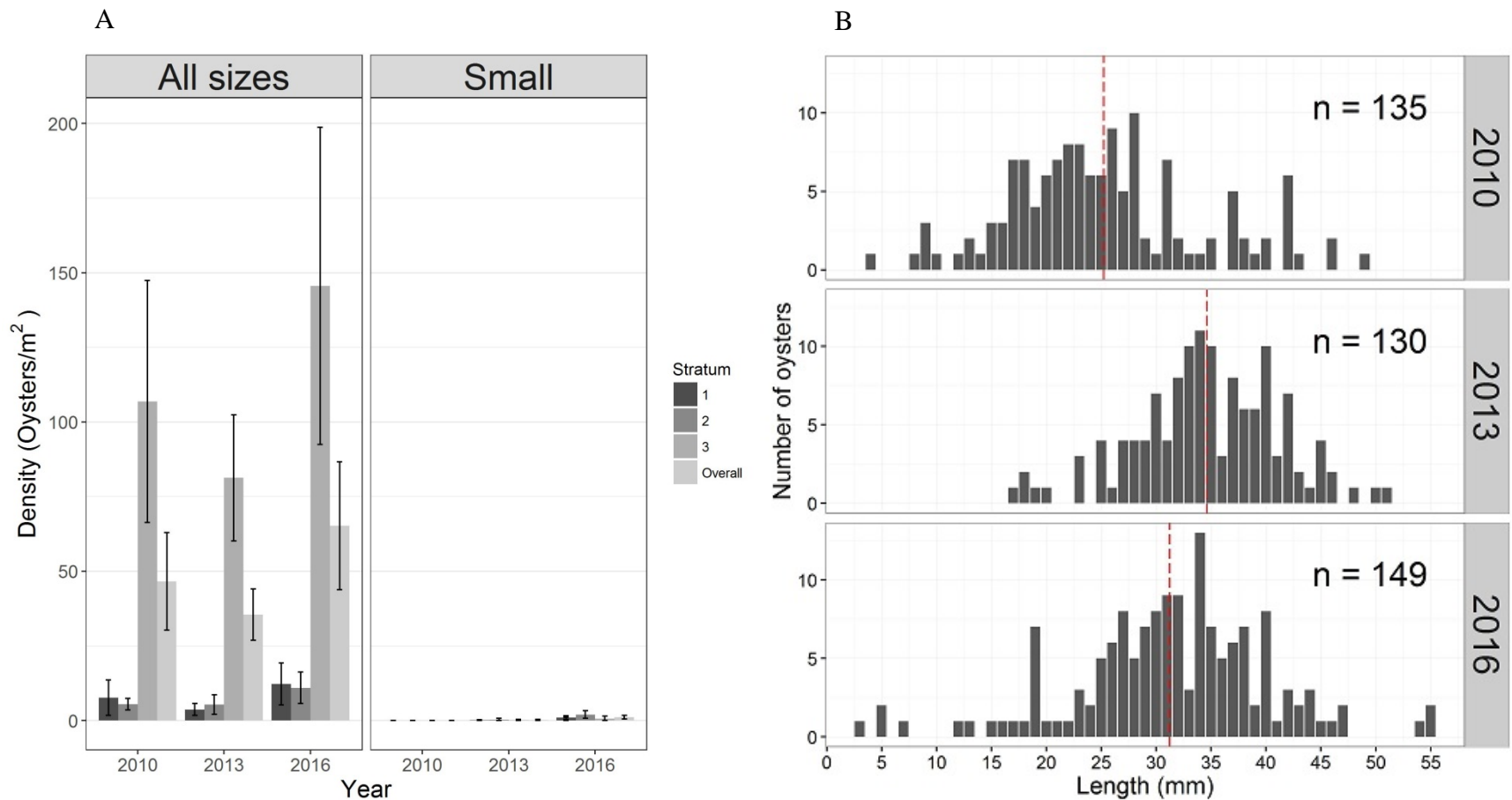
Figure 27. A) Swy-a-lana Lagoon Olympia oyster density(# m^{-2}) by stratum and year . The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Swy-a-lana Lagoon Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).
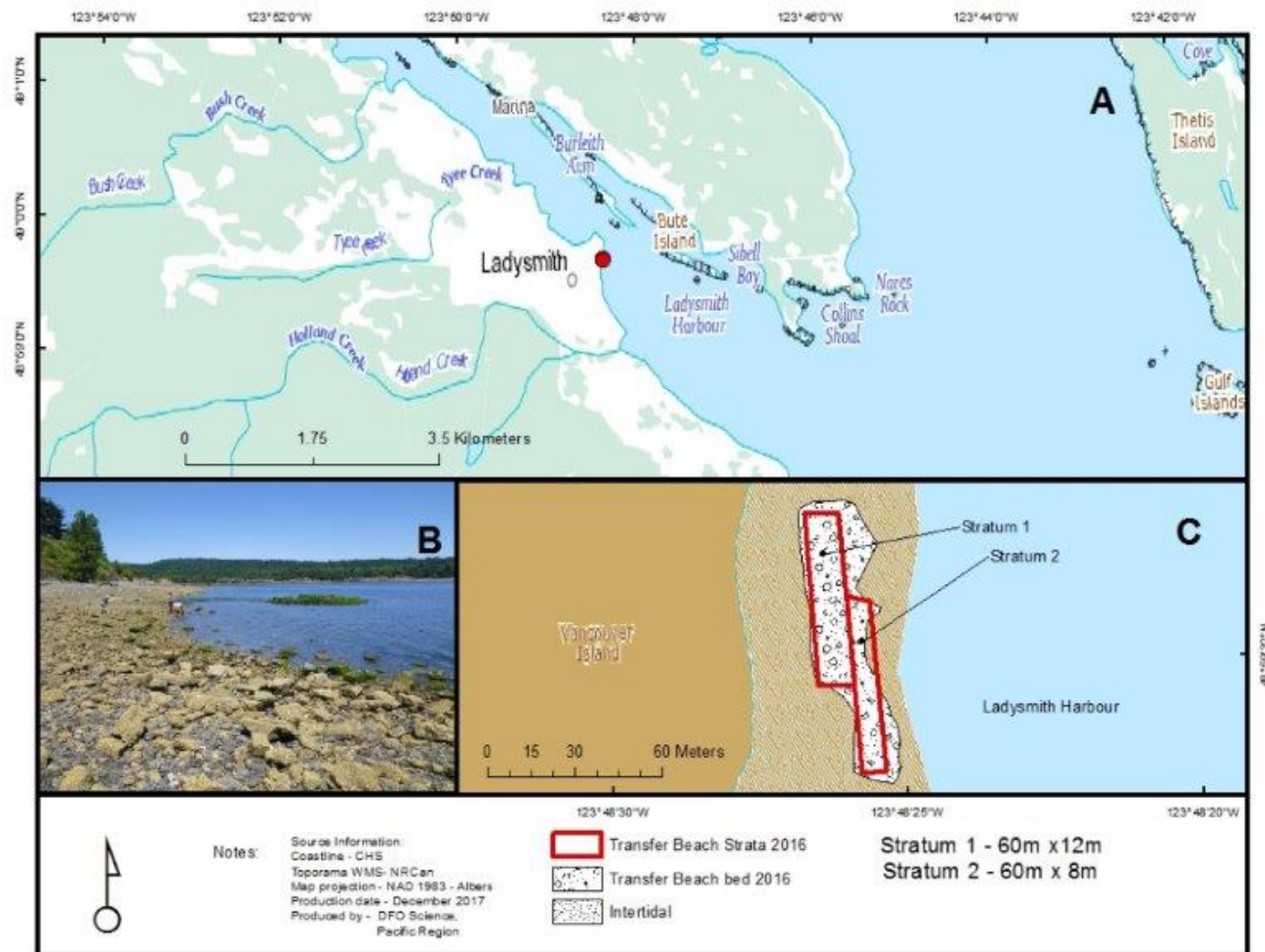
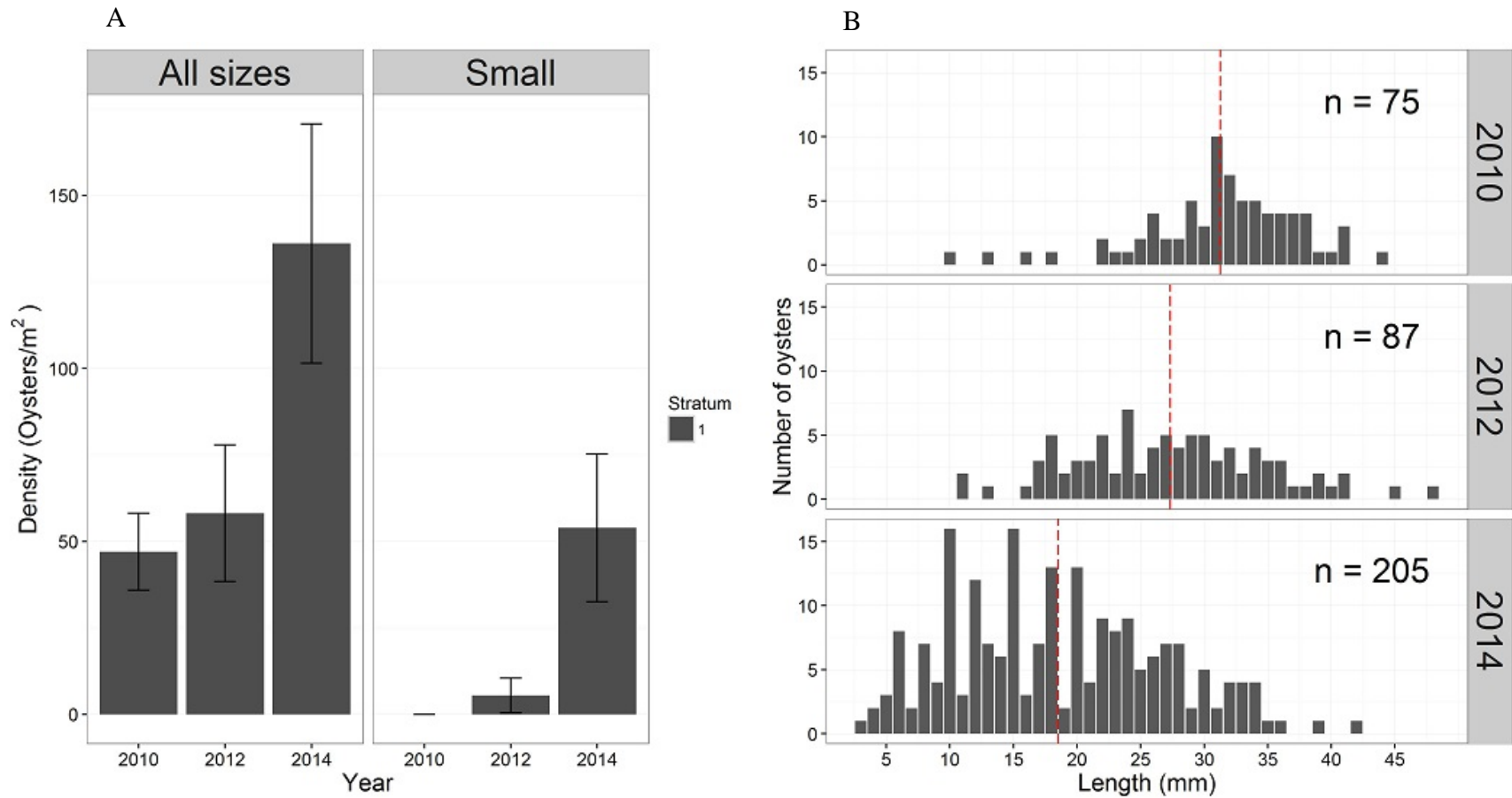Figure 28. Location and strata layout for the Olympia oyster index site at Transfer Beach.
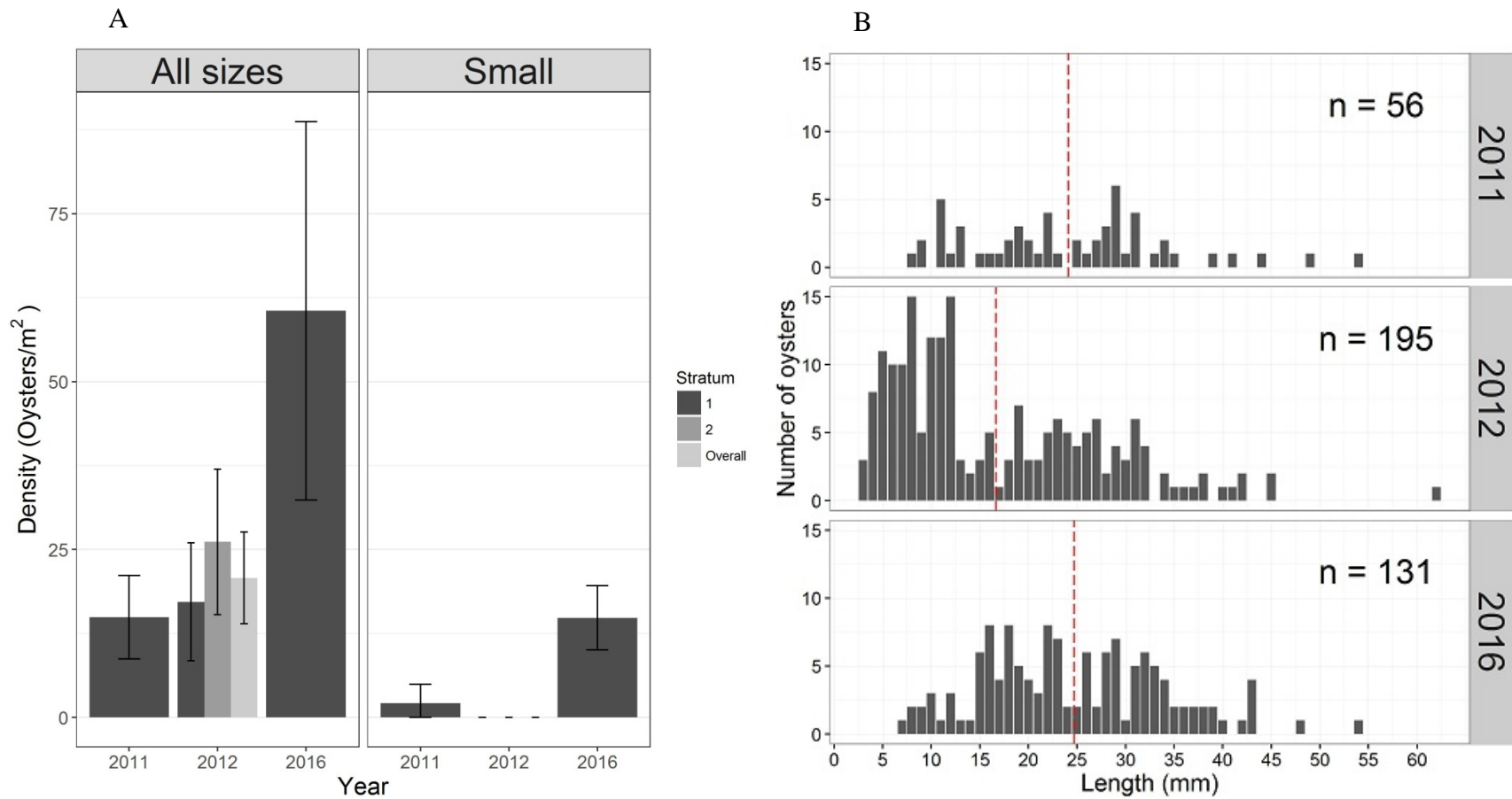
Figure 29. A) Transfer Beach Olympia oyster density (# m^{-2}) by stratum and year. The *All sizes* category includes the *Small* size category. The *Small* size category includes oysters ≤ 15 mm. B) Transfer Beach Olympia oyster size frequency (mm). Red dotted lines are mean length (mm).

Appendices

Appendix 1. R code used for setting Two-Stage survey designs.

Cluster_Analysis_R_Oly_Final_17Oct03.R

Biggm

Tue Dec 05 17:19:10 2017

#Important Note Jan 24, 2016
 # When the data is brought in for this code it is Transformed to m2, so the total number of oyster is multiplied but the number of quadrats either 4 or 16
 # Then when the population estimate is calculated it is the m2 estimate that is being used. This is different from the
 # code label est at quad size and that codes population estimate can just be multiplied by 4 or 16 to get pop estimate both codes
 # were done to for comparison so I could what the calculated error estimate were with each method.

Date Modified Jan 21, 2016
This code was created by Tammy Norgard from an initial code created by Carl Swartz and has a loop from Matte
This code takes the file extracted from the database query call allkeyloc and makes all changes in the code.
#So if there are changes to the database we can just rerun the code
#A second file is needed to be made in excel that has all the strata area and the survey names created in this code called allkeylocnames
#(this would be great if it could be made in this code)
#Run this hole file and it will produce 3 CSV files (Large&small oly analysis, large oly analysis, small oly analysis)

########## Initial cleanup ##########
```r
rm(list=ls(all=TRUE))
while("data.sub" %in% search()) detach(data.sub)   #if script has previsously crashed, data.sub will still be attached.
```

this r code will take the data file that come out of the database query called oyster_datacluster and reorganize it for cluster analysis.

```r
library(doBy)
```

Warning: package 'doBy' was built under R version 3.2.5

library(survey)

Loading required package: grid

Loading required package: Matrix

Loading required package: survival

Warning: package 'survival' was built under R version 3.2.5

##
Attaching package: 'survey'

The following object is masked from 'package:graphics':
##
dotchart

library(plyr)

Warning: package 'plyr' was built under R version 3.2.5

```
#library(nlme)
#library(pastecs)
#library(ggplot2)
#library(lmerTest)
#library(lsmeans)
#library(plyr)


##############################################################
#LARGE and Small Oly counts ##################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)
```

```
##   Source H1_Key                  Description
## 1    O   1506        Klaskino Inlet, Head of, N. Side
## 2    O   1506        Klaskino Inlet, Head of, N. Side
## 3    O   1506        Klaskino Inlet, Head of, N. Side
## 4    O   1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5    O   1508            Port Eliza (Beach 3)
## 6    O   1509               Darr Island
##       Location TypeOfSample Year TotalAreaStrata StrataNum StrataArea
## 1 Klaskino Inlet     StTS 2010         6150        1      1750
## 2 Klaskino Inlet     StTS 2010         6150        2      2400
## 3 Klaskino Inlet     StTS 2010         6150        3      2000
## 4    Amai Inlet     StTS 2010         2000        1      2000
## 5  Eliza Beach 3     StTS 2010         1200        1      1200
```

```
## 6    Darr Island        StTS 2010         125      1     125
##    SizeQuadrats
## 1        0.25
## 2        0.25
## 3        0.25
## 4        0.25
## 5        0.25
## 6        0.25
```

name.strat$Surveyname1 = **paste**("key",name.strat$H1_Key, name.strat$Location, name.strat$Year, "Stratum", name.strat$StrataNum, sep = " ")

oyster2 <- **read.csv**("allkeyloc.csv", header=TRUE)
oyster2[**is.na**(oyster2)] <- 0

 # subset to just STTS type of survey
oyster1 <- **subset**(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

 # subset to just species 69H
oyster <- **subset**(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
oyster$totalq <- oyster$NumLegals + oyster$NumSubLegals *# use to use both size*
oyster$total <- oyster$totalq * (1/ oyster$SqArea)

#oyster$total <- oyster$NumLegals   #use this to get large only
#oyster$total <- oyster$NumSubLegals   # use to get small only

oyster[1:5,]

```
##    Source BeachCode                Location H1_Key
## 1    O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2    O 24-13-004                  Bacchante  1558
## 3    O 24-13-004                  Bacchante  1558
## 4    O 24-13-004                  Bacchante  1558
## 5    O 24-13-004                  Bacchante  1558
##        Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)     StTS 2009      8      5     1  4
## 2     Bacchante Bay     StTS 2015      7     15     3  8
## 3     Bacchante Bay     StTS 2015      7     15     3  8
## 4     Bacchante Bay     StTS 2015      7     15     3  9
## 5     Bacchante Bay     StTS 2015      7     15     3  9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625      19    69H      5          0     5   80
```

```
## 2 0.2500     74   69H      0       0   0   0
## 3 0.2500     59   69H      0       0   0   0
## 4 0.2500    104   69H       0       0   0   0
## 5 0.2500     98   69H      0       0   0   0
```

#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = **paste**("key",oyster$H1_Key, oyster$Location, oyster$Year, "S
tratum", oyster$Stratum, sep = " ")
#unique(oyster$Surveyname)

 # this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- **ddply**(oyster, **c**("Surveyname","FSU"), summarise,
        Location = **unique**(Location),
        H1_Key = **max**(H1_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)

#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
oysterp[1:5,]

```
##                   Surveyname FSU      Location H1_Key Year
## 1 key 1506 Klaskino Inlet 2010 Stratum 1  1 Klaskino Inlet  1506 2010
## 2 key 1506 Klaskino Inlet 2010 Stratum 1  2 Klaskino Inlet  1506 2010
## 3 key 1506 Klaskino Inlet 2010 Stratum 1  3 Klaskino Inlet  1506 2010
## 4 key 1506 Klaskino Inlet 2010 Stratum 1  4 Klaskino Inlet  1506 2010
## 5 key 1506 Klaskino Inlet 2010 Stratum 1  5 Klaskino Inlet  1506 2010
##   Stratum QuadratNum total SqArea Diff SqAream2 totalm2    weight
## 1    1       3  8 0.25  -5    4     32 0.3333333
## 2    1       3  0 0.25   3    4      0 0.3333333
## 3    1       3  0 0.25   3    4      0 0.3333333
## 4    1       3  0 0.25   3    4      0 0.3333333
## 5    1       3  0 0.25   3    4      0 0.3333333
```

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

 #Loop

 # Get unique names
uNames <- **unique**(name.strat$Surveyname1)

```r
# Results - set up a table to store things
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)

# Start loop over names
for( i in 1:length(uNames) ) {
  # Get the ith name
  iName <- as.character( uNames[i] )

  # Get subset of oyster data for name i
  oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
  # Run the lm
  oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
  summary(oyster.fit)
  # Get lm coef
  res$density [i] <- coef( oyster.fit )[1]
  # Get std error of the estimate
  res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

  itotalarea<- (name.strat$TotalAreaStrata [i])
```

```r
istrataArea<- (name.strat$StrataArea [i])
temp <- as.character(oysterSub$Location)
# ilocation <- unique(temp)
# ilocation <- as.character(ilocation1)

res$Location[i]<- unique(temp)
res$Key[i]<- unique(oysterSub$H1_Key )
res$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)

##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterSub$SqAream2)) This line was wrong

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

#print(oyster.design)

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

#pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total based on ratio
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])
}
```

```
## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

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

 #brings in data
 # data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", header=TRUE)
 # head (data)
 data <- res

 data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
 data$W <- data$StrataArea.m2 / data$totalarea.m2
 data2 <- data

 data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
 data2$Wy <- data2$W*data2$density
 data3 <- data2



 data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
 data3$W2 <- data3$ratio.var*data3$W*data3$W

 rm(data)
 rm(data2)

 # this the R version of the pivot table it make a table that summarizes each stratum
 # of each survey by transect to get the total number of quadrats and oyster
 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 = "All",
          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)
 #res2 <- merge(res,All, by="Location")

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

currentDate <- Sys.Date()
csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDa
te,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

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

#write.csv(oysterSub, "data.csv", row.names=FALSE)

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

rm(list=ls(all=TRUE))
##############################################################
#LARGE Oly counts only ##################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)

##   Source H1_Key                 Description
## 1    O   1506        Klaskino Inlet, Head of, N. Side
## 2    O   1506        Klaskino Inlet, Head of, N. Side
## 3    O   1506        Klaskino Inlet, Head of, N. Side
## 4    O   1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5    O   1508              Port Eliza (Beach 3)
```

```
## 6      O  1509                       Darr Island
##       Location TypeOfSample Year TotalAreaStrata StrataNum StrataArea
## 1 Klaskino Inlet     StTS 2010          6150       1     1750
## 2 Klaskino Inlet     StTS 2010          6150       2     2400
## 3 Klaskino Inlet     StTS 2010          6150       3     2000
## 4    Amai Inlet     StTS 2010           2000       1     2000
## 5  Eliza Beach 3     StTS 2010          1200       1     1200
## 6    Darr Island     StTS 2010           125       1      125
##   SizeQuadrats
## 1        0.25
## 2        0.25
## 3        0.25
## 4        0.25
## 5        0.25
## 6        0.25
```

name.strat$Surveyname1 = **paste**("key",name.strat$H1_Key, name.strat$Location, name.strat$Year, "Stratum", name.strat$StrataNum, sep = " ")

oyster2 <- **read.csv**("allkeyloc.csv", header=TRUE)
oyster2[**is.na**(oyster2)] <- 0

 # subset to just STTS type of survey
oyster1 <- **subset**(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

 # subset to just species 69H
oyster <- **subset**(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
#oyster$total <- oyster$NumLegals + oyster$NumSubLegals # use to use both size
oyster$totalq <- oyster$NumLegals   *#use this to get large only*
oyster$total <- oyster$totalq * (1/ oyster$SqArea)
#oyster$total <- oyster$NumSubLegals   # use to get small only

oyster[1:5,]

```
##   Source BeachCode                  Location H1_Key
## 1     O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2     O 24-13-004                    Bacchante  1558
## 3     O 24-13-004                    Bacchante  1558
## 4     O 24-13-004                    Bacchante  1558
## 5     O 24-13-004                    Bacchante  1558
##         Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)     StTS 2009        8      5      1  4
## 2     Bacchante Bay      StTS 2015        7     15      3  8
```

```
## 3      Bacchante Bay    StTS 2015     7    15    3  8
## 4      Bacchante Bay    StTS 2015     7    15    3  9
## 5      Bacchante Bay    StTS 2015     7    15    3  9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625     19    69H     5        0     5  80
## 2 0.2500     74    69H     0        0     0  0
## 3 0.2500     59    69H     0        0     0  0
## 4 0.2500    104    69H      0        0     0   0
## 5 0.2500     98    69H     0        0     0  0
```

#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = **paste**("key",oyster$H1_Key, oyster$Location, oyster$Year, "S
tratum", oyster$Stratum, sep = " ")
#unique(oyster$Surveyname)

 # this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- **ddply**(oyster, **c**("Surveyname","FSU"), summarise,
        Location = **unique**(Location),
        H1_Key = **max**(H1_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)

#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
#oysterp[1:5,]

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

#Loop
 # Get unique names
uNames <- **unique**(name.strat$Surveyname1)

 # Results - set up a table to store things
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)),

```

```r
                #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)

# Start loop over names
for( i in 1:length(uNames) ) {
 # Get the ith name
 iName <- as.character( uNames[i] )

 # Get subset of oyster data for name i
 oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
 # Run the lm
 oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
 summary(oyster.fit)
 # Get lm coef
 res$density [i] <- coef( oyster.fit )[1]
 # Get std error of the estimate
 res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

 itotalarea<- (name.strat$TotalAreaStrata [i])
 istrataArea<- (name.strat$StrataArea [i])
 temp <- as.character(oysterSub$Location)
 # ilocation <- unique(temp)
 # ilocation <- as.character(ilocation1)

 res$Location[i]<- unique(temp)
 res$Key[i]<- unique(oysterSub$H1_Key )
 res$Year [i] <- unique(oysterSub$Year )
```

```r
  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)

  ##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterS
ub$SqAream2)) This line was wrong

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

  #print(oyster.design)

  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

  #pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total bas
ed on ratio
  res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in data
frame
  res$pop.est.se [i]<- pop$se   #this takes the se from the ratio estimate puts in datafra
me

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

}

## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

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

```r
#brings in data
# data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", header=TRUE)
# head (data)
data <- res

data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled with "NA"
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
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 = "All",
      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",
```

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```
        ratio.ci = "NA",
        Trannum = "NA",
        quadcount = "NA")


rm(data3)

res2 <- rbind(res,All)
#res2 <- merge(res,All, by="Location")

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

currentDate <- Sys.Date()
#csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDate
,".csv",sep="")
csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

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

#write.csv(oysterSub, "data.csv", row.names=FALSE)

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

rm(list=ls(all=TRUE))
##############################################################
#Small Oly counts only  ##################################

#brings in data
name.strat <- read.csv("allkeylocnames.csv", header=TRUE)
head (name.strat)

##   Source H1_Key                 Description
## 1    O  1506        Klaskino Inlet, Head of, N. Side
## 2    O  1506        Klaskino Inlet, Head of, N. Side
## 3    O  1506        Klaskino Inlet, Head of, N. Side
## 4    O  1507 Amai Inlet, S. Side, across from Soatwoon Cr.
## 5    O  1508             Port Eliza (Beach 3)
## 6    O  1509                Darr Island
##      Location TypeOfSample Year TotalAreaStrata StrataNum StrataArea
## 1 Klaskino Inlet     StTS 2010      6150      1     1750
## 2 Klaskino Inlet     StTS 2010      6150      2     2400
## 3 Klaskino Inlet     StTS 2010      6150      3     2000
## 4    Amai Inlet     StTS 2010      2000      1     2000
## 5  Eliza Beach 3     StTS 2010      1200      1     1200
## 6   Darr Island     StTS 2010       125      1      125
```

```
##   SizeQuadrats
## 1      0.25
## 2      0.25
## 3      0.25
## 4      0.25
## 5      0.25
## 6      0.25
```

name.strat$Surveyname1 = **paste**("key",name.strat$H1_Key, name.strat$Location, name.strat$Year, "Stratum", name.strat$StrataNum, sep = " ")

oyster2 <- **read.csv**("allkeyloc.csv", header=TRUE)
oyster2[**is.na**(oyster2)] <- 0

 # subset to just STTS type of survey
oyster1 <- **subset**(oyster2, oyster2$TypeOfSample == "StTS", drop = TRUE)

 # subset to just species 69H
oyster <- **subset**(oyster1, oyster1$Species == "69H", drop = TRUE)
rm(oyster1)
rm(oyster2)
#####BElow is where you change the counts for large or small or both
#oyster$total <- oyster$NumLegals + oyster$NumSubLegals # use to use both size
#oyster$total <- oyster$NumLegals   #use this to get large only
oyster$totalq <- oyster$NumSubLegals   *# use to get small only*
oyster$total <- oyster$totalq * (1/ oyster$SqArea)

oyster[1:5,]

```
##   Source BeachCode               Location H1_Key
## 1     O 25-12-005 Port Eliza beach 3 2009 not index survey   1548
## 2     O 24-13-004                  Bacchante  1558
## 3     O 24-13-004                  Bacchante  1558
## 4     O 24-13-004                  Bacchante  1558
## 5     O 24-13-004                  Bacchante  1558
##          Description TypeOfSample Year MonthStart DayStart Stratum FSU
## 1 Port Eliza (Beach 3)     StTS 2009        8      5     1  4
## 2     Bacchante Bay      StTS 2015        7     15     3  8
## 3     Bacchante Bay      StTS 2015        7     15     3  8
## 4     Bacchante Bay      StTS 2015        7     15     3  9
## 5     Bacchante Bay      StTS 2015        7     15     3  9
##   SqArea QuadratNum Species NumLegals NumSubLegals totalq total
## 1 0.0625      19   69H      5         0     0   0
## 2 0.2500      74   69H      0         0     0   0
## 3 0.2500      59   69H      0         0     0   0
```

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```
## 4 0.2500      104    69H     0        0    0    0
## 5 0.2500       98    69H     0        0    0    0
```

#makes a unique name for each stratum of each survey to be analyzed sepreatly
oyster$Surveyname = **paste**("key",oyster$H1_Key, oyster$Location, oyster$Year, "S
tratum", oyster$Stratum, sep = " ")
#unique(oyster$Surveyname)

 # this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
oysterp <- **ddply**(oyster, **c**("Surveyname","FSU"), summarise,
        Location = **unique**(Location),
        H1_Key = **max**(H1_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)

#below us used to weight each transect in teh linear model
oysterp$weight <- 1/oysterp$QuadratNum
#oysterp[1:5,]

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

#Loop

 # Get unique names
uNames <- **unique**(name.strat$Surveyname1)

 # Results - set up a table to store things
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)),

```r
            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)


# Start loop over names
for( i in 1:length(uNames) ) {
 # Get the ith name
 iName <- as.character( uNames[i] )

 # Get subset of oyster data for name i
 oysterSub <- subset( oysterp, Surveyname==iName, select=Surveyname:weight )
 # Run the lm
 oyster.fit <- lm( total ~ 0 + QuadratNum, data=oysterSub, weights=weight )
 summary(oyster.fit)
 # Get lm coef
 res$density [i] <- coef( oyster.fit )[1]
 # Get std error of the estimate
 res$stdErr[i] <- summary(oyster.fit)$coefficients[,2]

 itotalarea<- (name.strat$TotalAreaStrata [i])
 istrataArea<- (name.strat$StrataArea [i])
 temp <- as.character(oysterSub$Location)
 # ilocation <- unique(temp)
 # ilocation <- as.character(ilocation1)

 res$Location[i]<- unique(temp)
 res$Key[i]<- unique(oysterSub$H1_Key )
 res$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)


  ##iStrataArea.quadsizecalculated <-  (name.strat$StrataArea [i]) * (unique(oysterSub$SqAream2)) This line was wrong

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

  #print(oyster.design)

  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

  #pop <- predict(est.ratio, total=iStrataArea.quadsizecalculated ) # estimate total based on ratio
  res$pop.est [i] <- pop$total  #this takes the total from the ratio estimate puts in data frame
  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])

}
## Warning in svydesign.default(data = oysterSub, ids = ~FSU, variables =
## ~total + : No weights or probabilities supplied, assuming equal probability

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

#brings in data
# data <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-10-03.csv", header=TRUE)
```

```r
# head (data)
data <- res

data["W"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled wit
h "NA"
data$W <- data$StrataArea.m2 / data$totalarea.m2
data2 <- data

data2["Wy"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data2$Wy <- data2$W*data2$density
data3 <- data2

data3["W2"] <- NA # That creates the new column named "MY_NEW_COLUMN" filled
with "NA"
data3$W2 <- data3$ratio.var*data3$W*data3$W

rm(data)
rm(data2)

# this the R version of the pivot table it make a table that summarizes each stratum
# of each survey by transect to get the total number of quadrats and oyster
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 = "All",
        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")
```

```r
rm(data3)

res2 <- rbind(res,All)
#res2 <- merge(res,All, by="Location")


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

currentDate <- Sys.Date()
#csvFileName <- paste("Olyclusteranalysislegalsandssmalls_pop_est_m2_",currentDate
,".csv",sep="")
#csvFileName <- paste("Olyclusteranalysislegals",currentDate,".csv",sep="")
csvFileName <- paste("Olyclusteranalysissmalls",currentDate,".csv",sep="")

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

#write.csv(oysterSub, "data.csv", row.names=FALSE)
```

Appendix 2. R code used for calculating density of Olympia oysters at each site in 3 different size category formats ("Only small oysters (≤15mm)", "Large (>15mm) and small oysters (≤15mm)", and "Large oysters (>15mm) only").

DensityGraphsLoopFinal17Oct03.R

BiggM

Wed Dec 13 17:16:05 2017

```
################# Olympia Oyster Density Graphs ##################

            # Author:      Tammy Norgard and Jessica Finney
        # Affiliation:  Pacific Biological Station, Fisheries and Oceans Canada (DFO)
            # Group:        Shellfish, Marine Ecosystems and Aquaculture Division
            # Address:      3190 Hammond Bay Road, Nanaimo, BC, Canada, V9T 6N7
            # Contact:      e-mail: jessica.finney@dfo-mpo.gc.ca | tel: 250.756.7023
                    # Project:     Olympia oysters
                    # Code name:   DensityGraphsLoop.R
                        # Version:      1.0
                    # Date started: Nov 2, 2015
                        # Date edited:


                        # Overview:
        # Plots density estimates by beach, year and strata with error bard

        # Requirements: Olympia oyster data on density in each strata for each location


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


                        # Clear workspace
                        rm(list=ls(all=TRUE))
while("data.sub" %in% search()) detach(data.sub)   #if script has previsously
                        crashed, data.sub will still be attached.


                        # Load packages
                    #install.packages("ggplot2")
                        library(ggplot2)
```

Warning: package 'ggplot2' was built under R version 3.2.5

```
library(dplyr)
```

Warning: package 'dplyr' was built under R version 3.2.5

```
##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union


####################################
# Read in data
####################################

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

# Legal and small
LegSmOyster <- read.csv("Olyclusteranalysislegalsandssmalls_pop_est_m2_2017-11
-23.csv",
                header=TRUE, as.is=TRUE, strip.white=TRUE)

# Small only
SmOyster <- read.csv("Olyclusteranalysissmalls2017-11-23.csv",
            header=TRUE, as.is=TRUE, strip.white=TRUE)


####################################
# Merge datasets
####################################

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

# Merge
OysterDat <- rbind(LegSmOyster, SmOyster)


####################################
# Get unique locations
####################################

OysterLocations <- unique(OysterDat$Location)


####################################
# Function for plotting density
####################################
```

```r
# Note: the directory parameter must be in brackets,
# e.g. "Results-Legal", "Results-Legal and Small", or "Results-Small"

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

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

  # Subset data to specific location
  plot_data       <- subset(dendata, Location == locations[i])

  # Make year and stratum into factors for easier plotting
  plot_data$Year   <- as.factor(plot_data$Year)
  #plot_data$Stratum <-as.factor(plot_data$Stratum)

  # 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.numbyqsize + 2*stdErr, ymin=max((density.numbyqsiz
e - 2*stdErr), 0))

  limits <- aes(ymax = density + 2*stdErr, ymin= ifelse((density - 2*stdErr)<0, 0, (d
ensity - 2*stdErr) ))

  # Because the bars and errorbars have different widths
  # we need to specify how wide the objects we are dodging are
  dodge <- position_dodge(width=0.9)

  # Plot density in each stratum
  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 = 24),
```

```
        axis.title=element_text(size=16),
        axis.text=element_text(size=12))
  ggsave(filename= paste(results.dir, jpegFileName, sep = "/"))


  } # End location for loop

} # End PlotDensity function



####################################
# Run function
####################################

PlotDensity(locations = OysterLocations, dendata = OysterDat, directory = "All")
```

Appendix 3. R code for Olympia oyster density graphs

LengthFrequencyDist_JFedits.r

BiggM

Wed Dec 13 17:18:18 2017

```r
########## Initial cleanup ##########
rm(list=ls(all=TRUE))
# Code to make length frequency histograms of Olympia oyster index site bio samples

# Written by:    Jessica Finney
# Last modified:  May 11, 2016


# This code requires an input table from Access that can be obtained using the XXXXX
query in the Clams database.  Use the query to select the locations and years you want.

# Load packages
#install.packages(c("moments", "plotrix", "dplyr"))
library(plyr)
```

Warning: package 'plyr' was built under R version 3.2.5

```r
library(moments)
```

Warning: package 'moments' was built under R version 3.2.5

```r
library(plotrix)
library(dplyr)
```

Warning: package 'dplyr' was built under R version 3.2.5

```
##
## Attaching package: 'dplyr'
```

```
## The following objects are masked from 'package:plyr':
##
##     arrange, count, desc, failwith, id, mutate, rename, summarise,
##     summarize
```

```
## The following objects are masked from 'package:stats':
##
##     filter, lag
```

```
## The following objects are masked from 'package:base':
##
##    intersect, setdiff, setequal, union

library(ggplot2)

## Warning: package 'ggplot2' was built under R version 3.2.5

# Read in table from Access
# file name from the Access XXX quer
dat <- read.csv("qselBioSamplesTable.csv", header=TRUE)

# Remove columns with NA 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  <- summarise(groupdat, n = n(), Mean=mean(Length), SE = std.error(Len
gth),
          Median = median(Length), Kurtosis = kurtosis(Length), Skewness = ske
wness(Length),
          Min = min(Length), Max = max(Length), Range = max(Length)-min(Len
gth))
biostats  <- as.data.frame(biostats)

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

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

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

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

# Set label location
xloc <- 0.9 * max(beachdat$Length) # 80% of maximum length value
ydat <- ddply(beachdat, .(Length, Year), summarise, Freq = length(Length))
yloc <- 0.8 * max(ydat$Freq)


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 = 24),
      axis.text = element_text(size = 12),
      axis.title=element_text(size=16)) +
  geom_bar() +
  geom_vline(aes(xintercept = Mean), data = beachmean, linetype = "longdash", col
our = "red") +
  geom_text(data = beachmean, inherit.aes = FALSE, size = 8,
        aes(label = paste("n = ", n, sep = "")), x = xloc, y = yloc) +
  scale_x_continuous(breaks = seq(from = 0, to = max(beachdat$Length), by = 5))
+
  xlim(0,65)+
  #5g scale_x_continuous(, by = 5)) +
  labs( x="Length (mm)", y="Number of oysters" )
ggsave( file= paste(locations[i], "jpg", sep = "." ))

} # Close locations loop
```