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Restoration of the Olympia Oyster, *Ostrea lurida*, in Fidalgo Bay

Year Twenty-One Report

Skagit County Marine Resources Committee

Prepared by Paul Dinnel

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Abstract

The Olympia oyster, *Ostrea lurida,* is native to the Pacific Coast of North America ranging from Sitka, Alaska to Baja California and is the only oyster species native to the U.S and Canadian west coasts. Populations declined rapidly after the arrival of European settlers and overharvest was apparent in the late 1800's. In the early 20th century, severe pollution from pulp and paper mills heavily impacted Pacific oyster (*Crassostrea gigas*) cultivation and may have had significant adverse effects on Olympia oyster populations, especially in South Puget Sound. In Anacortes, WA, a restoration project began in Fidalgo Bay in 2002, a cooperative project between Skagit County Marine Resources Committee (Skagit MRC), Puget Sound Restoration Fund, Washington Department of Fish and Wildlife and other partners to establish several Olympia oyster beds. Subsequent to successful planting of seed oysters in 2002 and again in 2003, 2004 and 2006, survival rate, growth and natural recruitment have been deemed high, and natural recruitment was seen in Fidalgo Bay at areas outside the seed planting sites, with exceptionally high recruitment in 2015 and very high recruitment in 2019 and 2021. In 2012 and 2013, "wide area" surveys of Fidalgo Bay were undertaken at nine areas in addition to yearly monitoring of the original trestle seeding site. In 2012-2013, the trestle area around the original seeding plots was extensively surveyed beyond the normal yearly monitoring efforts and an additional eight sites in Fidalgo Bay were examined for Olympia oysters and substrate composition. An additional two sites outside of Fidalgo Bay were also surveyed in 2014: 1) The southeast shore of Guemes Island (just north of Fidalgo Bay) was surveyed for the presence/absence of Olympia oysters that may have originated from spawning in Fidalgo Bay; none were found. In 2018, 19 areas were part of an updated "wide area" survey to assess increased/decreased oyster densities since 2012-14. Shell cultch bags to monitor natural post-larval recruitment were deployed at 19 sites around Fidalgo Bay from 2011 through 2017 and at 3-4 sites from 2018 through 2023. Results of sampling the recruitment bags indicate that annual recruitment is highly variable and that most recruitment takes place on the eastern side of the bay, likely due to local summer current patterns. In an effort to improve recruitment on the western side of the bay, Skagit MRC planted seed oysters in the northwestern corner of the bay (Cap Sante Marina area) in 2016. Subsequent monitoring showed that survival was zero in this area. In 2013, Skagit MRC worked with Puget Sound Restoration Fund to deploy a total of 2.5 acres of new Pacific oyster substrate in four plots on the eastern shore of Fidalgo Bay. Monitoring from 2014 to 2018 showed that Olympia oyster recruitment was exceptionally high in these new plots. Since 2002, the estimated abundance of Olympia oysters in Fidalgo Bay has steadily increased from about 50,000 oysters to about over 5.5 million oysters in 2023. One major surprise was the very high abundance of Olympia oysters in the southern marsh-associated channels where the population of oysters in this area has grown from about 80,000 oysters in 2017 to over 1.2 million, with oyster densities reaching over 1,000/m^2 in some channels. In 2018, two new 1/2 acre shell enhancement plots were added to Fidalgo Bay by Puget Sound Restoration Fund, one just north of the trestle on the east side of the bay and one on Weaverling Spit. The Weaverling Spit plot was then seeded with juvenile hatchery raised juvenile oysters in an attempt to increase larval abundance on the west side of Fidalgo Bay.

Introduction

Native to the marine waters from Sitka, Alaska to Baja California, the Olympia oyster (*Ostrea lurida*) is the only oyster species native to the Pacific Coast of North America (Ricketts and Calvin 1968). Native tribes recognized the Olympia oyster's significance and settled where they could harvest the oysters and other shellfish as food resources. The Skokomish Tribe knew them as Tusa'yad (Steele 1957). Although native American exploitation of the Olympia oyster began in the pre-colonial days, harvest and cultivation of the beds in Willapa Bay, Puget Sound and Hood Canal began in the late 1850's and later included diking systems that were fairly elaborate (Steele 1957). During the California gold rush of the 1850's, oyster prospectors found sparse Olympia oyster resources in California estuaries (Ingersoll 1881) and oyster laden schooners from Puget Sound and Willapa Bay soon filled the need generated in California, transporting Olympia oysters south and garnering as much as a dollar per oyster. In the late 1800's and early 1900's, the commercial viability of the Olympia oyster was seriously compromised due to overharvest and wholesale destruction of their reef-like habitats (PSAT 2003). Additionally, the operation of pulp and paper mills between the 1930's and 1950's created severe water quality problems for Pacific oyster (*Crassostrea gigas*) culture (Couch and Hassler 1989) and may have helped speed the demise of Olympia oysters in some locations, especially in South Puget Sound (Cook et al. 1998, 2000, Baker 1995, Blake and Bradbury 2012). In the 1850's in Puget Sound, 10,000 bushels of Olympia oysters were harvested and that number rose to 130,000 bushels by 1890. During the 1900's harvests declined, and by around 1980 effectively no harvest of wild Olympia oysters was reported.

Olympia oysters are native to the Salish Sea, unlike the Pacific oyster, which was imported from Japan, and is now found naturally in many areas (Suttles 1974). Additionally imported, although unintentionally, Japanese oyster drills (*Ocenebra japonica*) and other potential oyster predators and parasites were brought to Washington from Japan with the Pacific oysters (Robinette et al. 2004; Barsh et al. 2004, Blake and Bradbury 2012). Historic Olympia oyster beds are reported to have existed in the North Puget Sound region in Boundary Bay (just north of the Canadian border), Drayton Harbor, Bellingham Bay, Chuckanut Bay, Orcas and Shaw Island areas, Fidalgo Bay, Similk Bay, Samish Bay, Padilla Bay, Dugalla Bay, Penn Cove (Blake and Bradbury 2012), and Guemes Island (from a report of Indians living on Guemes Island providing Spanish explorers with "verdigones") (Suttles 1974). Early Guemes Island Indians were reported to have harvested oysters as reported by Ashbach and Veal (1986) and additionally from a bay on the northeastern side of Whidbey Island (*Northwest Enterprise* 1884, *Skagit News* 1888, Townsend 1893, Hatch et al. 2005). In Samish Bay (*The Coast* 1907) and perhaps Bellingham Bay (Townsend 1893), quantities of Olympia oysters were historically found but are very rare today (Cook et al. 1998, 2000; Baker 1995). Brady Blake (WDFW retired, pers. comm.) has indicated that there is solid evidence that there were as many 2,000 acres (with the possibility of substantially more) of Olympia oyster beds in both Samish and Padilla Bays prior to their wholesale exploitation (PSRF 2012). In the early 1900's in Similk Bay, an attempt to raise Olympia oysters was made but did not continue (*Anacortes American* 1906). In recent years an occasional Olympia oyster has been identified from various North Puget Sound locations including Bellingham Bay, Cypress Island, (Stahl 1999), Drayton Harbor (Brady Blake, WDFW, pers. comm.), Samish Bay and Lopez Island (Betsy Peabody, Puget Sound Restoration Fund, pers. comm.). Olympia oysters are a small oyster, with maximum sizes being reported as 75 mm (Hertlein 1959) to 90 mm (Harbo 1997). They are much smaller than the Pacific oyster and are usually smaller than the Washington recreational size limit of 2.5" for oysters.

Olympia oysters and their beds are valuable to the local ecosystem. They provide three-dimensional habitat for many marine species (Ayvazian et al. 2020). In addition, oysters are filter feeders, feeding on phytoplankton and purifying the water, which helps to maintain water quality in the estuaries in which they are found. If successfully restored, they may also provide future opportunities for harvest, offering both a recreational and tribal cultural resource (Gregory and Volety 2005, Luckenbach et al. 1999). In order to identify the current populations of Olympia oysters in Puget Sound, to improve, manage and enhance the species and its population by natural and artificial means, and to investigate their genetic integrity, the Washington Department of Fish and Wildlife (WDFW) drafted a Olympia oyster recovery plan in the late 1990's (Cook et al. 1998), although this plan was never implemented by WDFW. However, a consortium of government agencies, tribes, non-profit organizations, industry, academia and citizen volunteers has worked with WDFW to promote native oyster restoration efforts in Puget Sound during the last two decades. In 2004 and 2005, in order to advance Puget Sound restoration projects, NOAA's Community Restoration Fund awarded restoration grants to the Puget Sound Restoration Fund (PSRF). Additional funds were awarded in 2010 to Northwest Straits Foundation (NSF) by the National Fish and Wildlife Foundation to increase restoration works in North Puget Sound and the Rose Foundation for Communities and the Environment provided funds to PSRF for a 2018 shell enhancement in Fidalgo Bay.

The Skagit County Marine Resources Committee (Skagit MRC) worked with the Samish and Swinomish Tribes, PSRF, Taylor Shellfish Farms, Shell Puget Sound Refinery (now HollyFrontier Sinclair), the City of Anacortes and others in 2002 to plant Olympia oyster seed next to the trestle in South Fidalgo Bay as part of North Puget Sound restoration efforts (Robinette and Dinnel 2003, Barsh 2003). This signified the first Olympia oyster restoration effort in the North Sound area other than several minute plantings on Orcas Island (Betsy Peabody, PSRF, pers. comm.). Since the initial seeding of Olympia oysters in Fidalgo Bay in 2002, various other restoration efforts have ensued in the North Puget Sound Region using broodstock or adult oyster transfers from the growing population in Fidalgo Bay. These efforts include: 1) Lone Tree Point and Kiket Island lagoons in Skagit and Similk Bays being managed by the Swinomish Tribe (Barber et al. 2013, 2015, 2016; Greiner et al. 2015), 2) Fisherman Bay on Lopez Island being managed by nonprofit organization Kwiaht (*The Islands' Weekly* 2013), 3) Sequim Bay, Clallam County managed by the Clallam County Marine Resources Committee (Clallam MRC 2015, 2020), 4) Chuckanut Bay, Whatcom County, managed by Whatcom MRC (Rose 2018, 2021), 5) Padilla Bay in Skagit County, managed by the Padilla Bay National Estuarine Research Reserve (Sylvia Yang, pers. com.), and Samish Bay and Drayton Harbor (R. Crim, PSRF, pers. comm.). Since 2002, PSRF has produced approximately 3,000 bags of spat on shell in their hatchery to support these various North Sound restoration efforts with virtually all of the broodstock coming from Fidalgo Bay. In addition PSRF has produced over 1.5 million single oysters to support research on aquaculture strategies and other topics (R. Crim, PSRF, pers. comm.).

In 2001, both Samish Bay and Fidalgo Bay were originally considered as planting sites and Fidalgo Bay was selected when it was found to be free of Japanese oyster drills that can negatively impact restoration efforts. The first seeding took place in 2002. In 2003 and 2004, further oyster seed were planted and growth and survival were monitored (Robinette et al. 2004, Barsh et al. 2004). In 2004, evidence was found of natural spawning when cultch shells deployed to catch spat showed post-larval recruitment (Dinnel et al. 2005) and this monitoring has continued. In 2006, Fidalgo Bay received a supplement of Pacific oyster shell to increase habitat, help in oyster bed building and encourage post-larval recruitment as well as additional seed (Dinnel et al. 2006, 2009a, 2009b). In 2010 through 2016, survival and growth of the Olympia oysters were monitored, cultch shell bags were assessed for natural recruitment, and four future oyster seed planting locations were assessed for suitability (Dinnel et al. 2011, Gabrian-Voorhees et al. 2013). This report covers continuing restoration and monitoring activities carried out from the original seed out planting and specifically updates monitoring since Skagit MRC's last report in 2018 (Dinnel 2018). It also provides a 2023 bay-wide population estimate, the first since 2018.

A number of topics and projects results from previous years are not covered in this report but are covered in previous Skagit MRC reports (see especially Dinnel 2018). These topics include:

1) Sampling history at the original seeding plot (Plot B next to the Fidalgo Bay trestle)
2) Construction and monitoring of six Pacific oyster shell enhancement plots created by PSRF
3) Temperature and salinity data
4) Test seed plots at Cypress Island and in Padilla Bay
5) Results of "wide area" oyster surveys for population sizes through 2018.

Topics and results covered in this report include:

1) A summary of temporal and spatial natural post-larval recruitment in shell cultch bags set out in six areas in and around Fidalgo Bay
2) A summary of bi-weekly post-larval settlement on ceramic plates from 2017 through 2021
3) A summary of restoration attempts at Cap Sante Marina, northwest Fidalgo Bay
4) Effects of the 2021 Heat Dome event on Olympia oyster survival
5) A new (2023) population estimate for Fidalgo Bay coordinated by PSRF.

Project Goals

In May 1998, WDFW published the Department's plan for Olympia oyster restoration in Washington State titled "Olympia oyster stock rebuilding plan for Washington State public tidelands" (Cook et al. 2000). Although never actually implemented by WDFW, the goal of this plan was "to restore and maintain native oyster populations on public tidelands in their former range." The short term goal of WDFW was to identify locations and general abundance of current populations of Olympia oysters in Puget Sound. The long term objectives included:

- ✓ Define the current and historic range of Olympia oysters
- ✓ Develop Olympia oyster genetic integrity guidelines for artificial stock enhancement
- ✓ Define habitat requirements and contemporary habitat limiters
- ✓ Identify areas for protection and restoration
- ✓ Define site-specific habitat limitations and species interactions that would affect Olympia oyster stocks, and
- ✓ Restore and protect stocks as needed to achieve the stock rebuilding goal.

In September 2010, participants in the third West Coast Olympia Oyster Workshop (NOAA/PSRF 2010) held at Suquamish, WA, discussed the current status of Olympia oyster restoration on the West Coast and considered future restoration activities. One informal agreement was that, based on the apparent success of the Fidalgo Bay restoration effort, restoration activities should be extended to up to ten new sites around the North Puget Sound region over the next 10 years.

In 2012, WDFW updated their 1998 Olympia oyster plan to provide a document that summarized the history of the Olympia oyster in Puget Sound and to provide guidance to the many groups now involved in restoration activities (Blake and Bradbury 2012). In that document WDFW identified 19 priority restoration sites in Puget Sound, with six of those sites being in the North Puget Sound sub-basin (Drayton Harbor, Bellingham Bay, [including Portage Island and Chuckanut Bay], Samish Bay, Padilla Bay, Fidalgo Bay and Similk Bay). In 2015, a consortium of groups published "A guide to Olympia oyster restoration and conservation" that described environmental conditions and sites that support sustainable populations of Olympia oysters throughout it's entire Pacific Coast range (Wasson et al. 2015). Wasson et al. (2016) have also described environmental factors that affect natural recruitment of oysters at 37 sites from southern California to British Columbia. Also in 2015, PSRF authored a new protocol using shell strings to standardize the monitoring of post-larval recruitment of Olympia oysters throughout all of Puget Sound (PSRF 2015). In addition, Skagit MRC worked with WDFW to monitor bi-weekly post-larval settlement patterns in Fidalgo Bay during the summers of 2017 through 2021 using stacks of ceramic tiles.

Much can be learned from the substantial amount of work directed at restoring decimated American oyster *(Crassostrea virginica)* populations on the East and Gulf state coastlines of the U.S. Eggleston (1995) has pointed out that a conceptual framework should be developed for guiding oyster restoration efforts and that this framework should address two questions: 1) what are the management goals in terms of restoration efforts and 2) what spatial arrangements (e.g., bed location, size, shape) of oyster habitat best meet these management goals? The management goals of any oyster restoration may include, but are not limited to, maximizing:

- ✓ Recruitment to the fishery
- ✓ Spawning output
- ✓ Species diversity of the oyster bed community, and
- ✓ Water filtration and nutrient cycling.

Given the above goals and guidelines for oyster restoration projects, the following are Skagit MRC's goals for restoration of Olympia oysters in Skagit County waters:

1. Identify areas within Skagit County that might be good sites for restoration
2. Define site-specific habitat limitations and species interactions that would affect Olympia oyster stocks
3. Restore and protect stocks at selected sites to achieve stock rebuilding goals, including:

    - Conduct test seedings at promising sites
    - Monitor survival and growth of seedlings
    - Monitor and assess the spread of Olympia oysters from natural spawning
    - Determine the best "bed structure" for each site, and
    - Control predators where necessary and possible.

4. Identify sources and sinks for natural larval recruitment
5. Engage community volunteers to assist with restoration monitoring efforts
6. Use adaptive management to modify restoration efforts based on lessons learned from local plantings and other information gleaned from other restoration efforts in Puget Sound, and
7. Participate in public education and outreach.

Methods

Restoration Locations

Fidalgo Bay (Figs. 1 and 2) is a relatively shallow, semi-enclosed estuarine embayment located on the eastern side of the San Juan Island Archipelago. Like most of the Salish Sea, it was largely formed by glaciers, which receded about 10,000 years ago. Fidalgo Bay has been substantially impacted by past and present city and industry development, especially development related to wood products processing and fishing and boating, both recreational and commercial. The ecology of Fidalgo Bay is heavily influenced by tides (which can empty a large portion of the bay at extreme low tides) and by temperature (air temperature generally fluctuate from about 10 to 90^{o} F). Air temperatures can have a significant effect on Olympia oyster survival when abnormally high temperatures coincide with extreme summer low tides during the day.

Fidalgo Bay is located adjacent to the city of Anacortes and west of March's Point, which separates it from Padilla Bay to the east (Fig. 2). Fidalgo Island is one of the eastern islands of the San Juan Island Archipelago. Anacortes and Fidalgo Bay have been a long time fishing port and is now home to a variety of marinas. The bay has been chemically and physically impacted by past development by the city of Anacortes and by a past paper and plywood mills as well as a railroad trestle and causeway (not a recreational trail) (Fig. 3). This area is home to the Swinomish and Samish Tribes, which both have a presence on and in the bay. For additional historical information of the area see: https://www.anacorteswa.gov/DocumentCenter/View/4324/Anacortes-History-Overview-PDF?bidId=.

The initial restoration site was located alongside the railroad trestle (now a recreational trail) (Fig. 3) where standing pools of water exist, even at the lowest tides. This area was deemed a worthy location for the initial seeding effort in the bay. It eventually proved to be an excellent choice for oyster survival, growth and reproduction. Once natural reproduction and post-larval oyster recruitment was detected, monitoring of recruitment was conducted throughout most of the bay and at two locations just outside of Fidalgo Bay.

Settlement Bags - Sampling to Assess Natural Recruitment within Fidalgo Bay, 2018-2023

Bags of clean Pacific oyster shell cultch were deployed in the springs of 2018 to 2022 at six locations (a subset of the 19 sites previously monitored through 2018) around Fidalgo Bay (Fig. 5) to continue our monitoring of larval oyster settlement. These bags were collected in the spring of the year following deployment and all shells in each bag were checked for juvenile Olympia oysters. All juvenile oysters found in the bags were recorded and measured for shell length.

Ceramic Tile Sampling for Larval Settlement, 2017-2021

In 2017, WDFW initiated a spatfall collector program aimed at collection of twice per month samples of Olympia oyster larval settlement in various Puget Sound locations, including Fidalgo Bay, with the assistance of community volunteers. The spatfall collectors consisted of stacks of five 10.5 x 10.5 ceramic tiles, glazed sides up. Settling oyster larvae always settled on the rough undersides of the tiles. The tiles were deployed in tile holders fastened to rebar stakes (Fig. 6).

In 2017, spatfall collectors were deployed at the north and south "derelict barges" (Sites 3 and 4 [Fig. 5] - actually old drydock structures) on the east side of Fidalgo Bay and at the trestle plot B alongside the recruitment shell bags. The collectors at both barge locations were collected and replaced at two week intervals from June 25 to September 15, 2017 (except the north barge collection ended August 17) while the trestle collectors were deployed from June 25 and collected only once on August 17. From 2018 through 2021, spat collectors were only deployed at the north barge location (Site 3), with collection/replacement at two week intervals beginning in May and continuing through September.

Upon retrieval, each tile was gently washed and refrigerated in plastic bags until assessed for settlement. The tiles were assessed by scanning the bottom side of each tile with a dissecting microscope at 10x magnification, with oyster verification at 40x. Examples of newly settled Olympia oyster larvae appear in Fig 8.

Cap Sante Marina Seed Plots, 2016-2023

Extensive monitoring of Olympia oysters since 2002 has shown that almost all natural recruitment is limited to the eastern side of Fidalgo Bay. This is likely due to summer current patterns that are chiefly north-south in nature and which do not facilitate larval transport from one side of the bay to the other (Eric Grossman, USGS, pers. comm.). Given the desirability of establishing a population on the west side of the bay to serve as another larval source, Skagit MRC and the Port of Anacortes approved a project to plant oyster seed in the Cap Sante Marina area of northwest Fidalgo Bay (Fig. 10). This effort was funded by the Skagit Restoration Initiative, administered by the Northwest Straits Foundation (NWSF). Skagit MRC worked with Puget Sound Restoration Fund and the Port of Anacortes (the property owner) to add Olympia oyster seed to the Cap Sante Marina area.

In 2016, 20 bags of Olympia oyster seed were produced by Puget Sound Restoration Fund (PSRF) at their Manchester, WA shellfish hatchery and transferred to the marina area. These bags of seed were then assessed for juvenile oyster density in the bags, measured and then half of the seed bags were spread at one location just inside the northern rock breakwater (Area 1, Fig. 10) and the other half at one location at Seafarers Park (Area 2, Fig. 10). In addition, juvenile oysters from the 2015 batch of settlement bags (collected in June 2016) were added to this site to increase the number of Olympia oysters in this area. These two new plots were then monitored using haphazard sampling (1/10 m^2 quadrat samples) for density and oyster sizes in 2017, 2018 and 2023.

Heat Dome Sampling, 2021

In June 2021 the Puget Sound region was subjected to a "heat dome" event that resulted in temperatures exceeding 100^o F for 3 days (June 26-28) in many areas. Coincidental to the timing of the heat dome was the occurrence of some of the lowest daytime summer tides of the year (-1.9 to -3.4' MLLW). Because of reports that some intertidal organisms were faring poorly following the heat dome, Skagit MRC volunteers sampled Olympia oysters in two areas of Fidalgo Bay to assess possible heat dome related mortality. These two areas were the north constructed shell plot at Little Crandall Spit on the eastern side of the bay and the north side of the rip rap causeway running across Fidalgo Bay (Fig. 5). Each of these areas had been assessed for oyster densities in 2018 and density data from these areas were used to compare to the samples collected in June 2021. For both years the same sampling protocol was used: haphazard 1/10m^2 quadrat sampling. In addition to counting live oysters, data were also collected on recent and old dead shells. Recent dead shells, likely the result of heat dome stresses, were obvious by the clean, unsedimented condition of the interior of the gaping valves.

"Wide-Area" Sampling to Assess Natural Recruitment, 2023

In June and August, 2023 staff of PSRF together with community and agency volunteers conducted a sampling program in Fidalgo Bay designed to provide a current population estimate of Olympia oysters now present in the bay.

The methods and locations for the 2023 sampling were different than the methods used in 2018 and were based on a statistical analysis of the 2018 dataset and the provisions of the Quality Assurance Project Plan (QAPP) (Dinnel 2023). Olympia oyster sampling in 2023 was based on a "Bootstrapping" analysis conducted by PSRF staff of the 2018 oyster sampling dataset. Bootstrapping is any test or metric that uses random sampling with replacement (e.g., mimicking the sampling process), and falls under the broader class of resampling methods. Bootstrapping assigns measures of accuracy (bias, variance, confidence intervals, prediction error, etc.) to sample estimates This technique allows estimation of the sampling distribution of almost any statistic using random sampling methods (Efron 1987), and was used in place of the fixed transect method applied in 2018 (Dinnel 2018). Based on PSRF's analysis, the best approach to generate a bay-side population estimate in 2023 was to define a single population that is distributed across four regions (March Point, Weaverling Spit, the rip rap causeway and the south bay channels). In each region, and within discrete polygons, PSRF defined the Olympia oyster distribution between +2' and -1.5' Mean Lower Low Water (approximately where the eelgrass starts), except in the south, where samples were restricted to the channels. Using GPS, PSRF randomly distributed 397 sample positions within these polygons, which were located in the field with a GPS R-1 receiver. The 397-sample size was estimated to give a mean density estimate of +/- 25% of the true population mean (which exceeds the +/-30% standard for this type of fishery resource assessment). Sample placement in the field was determined and marked with temporary flags. Survey teams leapfrogged through the survey, collecting quadrat samples (Fig. 8) at the marked flags and retrieving the flags. Sample size varied with each location. In areas with relatively high oyster densities sample size was usually $1/10m^2$ or $1/4m^2$. For low density areas, the sample size varied up to $1m^2$ by counting oysters in the first $1/10m^2$ sample and then "flipping" the quadrat to adjacent locations up to 9 times and counting oysters in each of these "flipped" locations. The data collected included: 1) sample unit ($1/10m^2$ to $1m^2$ quadrat samples), 2) live oyster counts, 3) oyster sizes (up to the first 10 oysters in each sample), 4) GPS position for each sample, and 5) representative photographs. The data analyses included: 1) descriptive statistics of the population, 2) sample mean densities with 95% confidence limits, and 3) shell height histograms. Additional details of the sampling program are contained in PSRF's Summary Report to Skagit MRC (see Appendix 1).

Results

Settlement Bags – Sampling to Assess Natural Recruitment Within Fidalgo Bay

In 2004, 2005 and 2007, clean Pacific oyster cultch shells in bags were hung along the length of the trestle next to the seed planting beds and were checked for natural recruitment of Olympia oysters at the trestle site one year after deployment. A low density of natural recruitment was found in 2005 and 2007. From 2007 through 2017, bags of clean cultch shells were placed at the trestle and around Fidalgo Bay at as many as 19 sites, as well as nearby locations at northwest March's Point and in Guemes Channel (Fig. 5). From 2018 through 2023, bags of shell were placed at only 6 sites to continue a reduced degree of monitoring of post-larval recruitment. Each of these bags were then recovered approximately one year later and assessed for numbers of settled oysters and their sizes.

No Olympia oysters were found in any bags in 2008 and 2009, indicating recruitment failures in 2007 and 2008. The shell bags recovered from the trestle (average of 3 bags) in 2010 showed high natural recruitment took place in 2009. Minor natural recruitment took place in 2011, 2012 and 2013, with substantial recruitment in 2014 and very high recruitment in 2015. Moderately high recruitment took place in 2016 and 2017 (Table 1; see Dinnel 2018 for detailed results prior to 2019). Settlement in the shell bags set at the trestle from 2018 through 2022 indicated that settlement was relatively low in 2018 and 2020, moderately high in 2022 and high in 2019 and 2021 (Figure 7).

The average recruitment in the three replicate cultch bags at trestle Plot B has ranged from a low of zero to a high of 428 oysters/100 cultch shells but there is a healthy trend of moderate to high recruitment in the last 10 years (Table 1).

Ceramic Tile Sampling for Biweekly Larval Settlement

A stack of ceramic tiles was monitored for recruitment of post-larval Olympic oysters at one location (north barge - Site 3 in Fig. 5) in Fidalgo Bay for five years (2017-2021). Results of this twice per month sampling showed that settlement usually began in early June and continued through September (Fig. 11). Settlement intensity was quite variable by month and by year. Settlement in 2021 was the highest observed with 2019 the second highest. The peak settlement month was August. Total annual settlement on the tiles at the north barge site correlated fairly well with the magnitude of settlement in the shell recruitment bag set out near the tile array.

Cap Sante Marina/Seafarers Memorial Park Seed Plots

Twenty four bags of Olympia oyster seed produced by PSRF were planted at Cap Sante Marina/Seafarers Memorial Park in March 2016 at Area 2 (Fig. 10). Sampling of these bags of seed at planting showed densities of about 230 oyster seed/bag with average shell lengths of 4-7mm. Because the densities of seed in these bags were substantially less than anticipated (target was 300 seed/bag), an additional 3,830 juvenile oysters recovered from our 2015-2016 cultch monitoring bags were also added to this area. The average size of these oysters was 20 mm. A second batch of 10 bags of PSRF seed were obtained in June 2016 and spread inside the northern Cap Sante Marina breakwater (Area 1, Fig. 10). These bags were estimated to contain about 660 seed each, for a total of about 6,600 seed. The average size of these seed was 7.5 mm.

Oyster survival at these two locations was substantially less than anticipated with Area 1 2017 and 2018 survival rates of 5.0% and <0.1%, respectively. Survival at Area 2 was about the same at 0.6% for 2017 and 0.2% for 2018. Collection of 10 quadrat samples in each of these two areas in 2023 found zero oysters in all samples.

Heat Dome Sampling

Olympia oyster sampling about a month after the June 2021 heat dome at the two Fidalgo Bay sites showed the following:

1) For the constructed shell plot at Little Crandall Spit we found an estimated density of 387.0 oysters/m^2 versus a density of 393.0 oysters in 2018 and

2) For the north side of the causeway we estimated a density of 22.6 oysters/m^2 in 2021 versus a density of 20.3/m^2 in 2018.

Statistical comparisons of the above estimates found no significant differences between the two years (Raymond et al., 2022), suggesting that there was no adverse effect on the oyster population due to the heat dome. However, this ignores the probable fact that the bay-wide oyster population had grown between 2018 and 2021, but we have no sampling data to substantiate that claim.

A better indicator of a possible heat dome impact on oyster survival is the count of the shells of newly dead oysters in the samples. The percentages of newly dead shells at the two sites were: Little Crandall Spit = 13.2 and the north side of the causeway = 14.6. These newly dead oysters were easily identified by gaping valves with interiors free of discoloration and sedimentation. Thus, the most likely estimate of Olympia oyster mortality due to the heat dome is around 14%.

“Wide-Area” Sampling to Assess Natural Recruitment

In 2018 when the last "wide-area" survey was conducted in Fidalgo Bay, 19 discrete areas were sampled via quadrates (1/10m^2) spaced along pre-established transects (Dinnel 2018, Table 5). A population estimate was calculated for each of these areas. which provided a bay-wide estimate. The sampling represented a total area of 136,678 m^2 in which 1,067 samples were collected yielding a bay-wide estimate of 2,911,733 oysters.

In 2023 the wide-area sampling effort was consolidated into 4 strata, which contained most of the areas sampled in 2018. This sampling effort, led by PSRF staff and aided by numerous volunteers differed from 2018 as described in the Methods section above. Locations of each of the samples are shown in Figure 9. Results of the 2023 sampling showed that there is a healthy and expanding Olympia oyster population in Fidalgo Bay. A total of 398 samples collected in 2023 were representative of 113,020 m^2 and resulted in a bay-wide population estimate of 5,544,124 oysters for an increase of about 90% over the five years since the 2018 survey (see Appendix 1 for PSRF's Summary Report to Skagit MRC). The largest number of Olympia oysters were found on the March's Point tidelands (4,257,230 oysters), especially in the five constructed shell beds. The second largest number of oysters was in the southern marsh channels (1,267,028 oysters) (Fig. 14 and Appendix 1, Table 1), which was an amazing increase for this area compared to the 18,360 oysters in estimated in 2017. PSRF's sampling program (and Skagit MRC's 2018 survey) largely ignored areas of the bay where qualitative observations indicated oyster densities of <1 oyster/m^2. Thus, the population estimates given above are deemed to be conservative.

Volunteer Monitoring

Marine bivalves, including oysters, provide many "goods and services" to human populations in the areas of water quality, coastal protection, harvests of wild and cultured foods/shells, biodiversity, biotechnology (especially drugs and pharmaceuticals) and volunteerism. Restoration projects and programs benefit from community participation via an added labor force and by fostering community investment and support, which is critical for project success and future restoration investments. Community participants gain physically and psychologically rewarding experiences from being a part of restoration projects, while fostering an environmental ethos. Oyster restoration serves as particularly ideal opportunities for engaging community volunteers (DeAngelis et al. 2019).

Skagit County is particularly blessed with a wealth of great volunteers. A total of twenty-one volunteers participated in Fidalgo Bay Olympia oyster restoration planning, monitoring and report preparation during from 2019 through 2023 (Fig. 15). Volunteer activities included: planning meetings and communications with PSRF, tribal biologists and WDFW personnel; application for WDFW transfer permits; filling, deploying and retrieving cultch shell bags, shell strings and tile stacks to monitor natural recruitment; "wide-area" sampling in 2023; monitoring of the two seed plots at Cap Sante Marina/Seafarers Memorial Park in 2023; sampling to define the effects of the 2021 heat dome; presentations to the 2019-2023 Salish Sea Stewards classes; data entry and analyses; preparation of proposals, quarterly reports and this report covering the last five years of oyster-related activities.

Discussion

In 2002, Skagit MRC committed to working with PSRF, WDFW and other partners in reestablishing Olympia oysters in Fidalgo Bay with the first addition of hatchery-produced seed to the trestle area in the southern portion of the bay. Over the course of the first four years, the total number of hatchery seed added to the bay was about 1.5 million. As of 2023, the number of oysters has gradually grown to approximately 5.5 million oysters (Table 7), thanks in large part to the deployment of 250 yd^3 of Pacific oyster shell in 2013, which now covers an area of 2.5 acres (split between four plots) on the eastern shore of the bay. Two additional shell plots, one near the trestle and the other at Weaverling Spit, were added in 2018 to augment the existing population and facilitate natural recruitment on the west side of the bay.

Since the beginning of our seeding efforts, we continually monitored through 2018 one of the trestle seed plots (Plot B), which is situated in a shallow pool area at low tide. The number of Olympia oysters in Plot B started at about 46,000 and gradually grew to about 130,000 in 2011, only to shrink to about 23,000 in 2018 (Table 1). The primary reasons for the decrease in the number of oysters seems to be the loss of shell substrate due to shell erosion and fragmentation as well as competition for settlement space from sponges, bryozoans and barnacles. The lesson here seems to be, that while the pool area keeps the oysters protected by buffering high and low temperatures, this advantage seems minimal due to the factors noted above. The four new shell plots established north of the trestle in 2013 are higher and drier than Plot B and the integrity of those shells may be aided by periodic drying at low tides, which should help control of competitive fouling organisms.

The use of shell cultch bags to monitor the relative strength of yearly Olympia oyster post-larval recruitment has proven to be very successful in providing information on temporal and spatial settlement patterns. Natural oyster settlement was zero to minimal in Fidalgo Bay from 2004 to 2008, followed by a very strong settlement in 2009. Following 2009, settlement was again minimal until 2015 and 2016, with the 2015 set being exceptionally high (Table 2). Since 2015, settlement has been quite high with the exception of 2018 and 2020 when settlement was moderate.

Annual recruitment of invertebrate broadcast spawner species often tends to be highly variable, and this is no exception for the Olympia oyster. Wasson et al. (2015), who has summarized annual Olympia oyster recruitment patterns in 28 West Coast embayments, found that 14 of the 28 bays had occasional years without any settlement (including Fidalgo Bay) and six bays had routine recruitment failure. The causes of these failures are likely due to various reasons including: 1) bay size and configuration, 2) current patterns within and outside of the bay (Grossman et al. 2020), 3) water temperatures and salinities, 4) abundance of food resources (algae) and 5) oyster population size. Given the dramatic increase in the numbers of Olympia oysters in Fidalgo Bay in the last eight years (Table 7), it appears that permanent bed structures are being maintained and expanded, especially in the southern marsh/channel areas.

Spatial patterns of settlement in Fidalgo Bay have been nicely defined by annual deployment of cultch monitoring bags at 17 locations around the bay and at two locations just outside of the bay entrance. Results of the cultch bag sampling from 2008 to 2018 strongly indicate that most larvae are retained inside the bay and that settlement has almost exclusively been limited to the east side of the bay, with the focal points being the east shore (Areas 7-12, Fig 9) and causeway area (Areas 5 and 6, Fig. 9). Few oyster larvae are making their way to the west side of the bay due to largely north-south flowing currents during the summer on each side of the bay with little mixing between them (Eric Grossman, USGS, pers. comm.). The observation that most larvae are being retained within Fidalgo Bay is reinforced by the total lack of juvenile oysters in the east March's Point and Guemes Channel shell cultch bags (Fig. 18) and the lack of any settlement on southeast Guemes Island. We hypothesize that the oyster settlement pattern will change in the future due to two factors: 1) many more spawning oysters now inhabit the bay and 2) the placement of seed oysters on Weaverling Spit in 2018. These seed oysters should help to export larvae into the north/south flowing current on the west side of the bay.

The four Pacific oyster shell plots established on the eastern side of the bay by PSRF in 2013 have acted as magnets for Olympia oyster larvae, resulting in an average of 202 oysters/m^2 in 2018, which is more than twice the density (100 oysters/m^2) considered by WDFW to constitute a successful Olympia oyster bed. So far, these new shell plots have maintained their structural integrity even though they are located in fairly silty areas. It will be interesting to follow the evolution of these plots in terms of functional structure as well as continued settlement to see if they successfully produce long-term Olympia oyster beds. The initial success of these plots suggested that it was time to deploy additional shell plots on the west side of the bay where both shell habitat and oyster settlement have been virtually absent. This was partially accomplished in 2018 with a 1/2 acre shell deployment to Weaverling Spit.

One surprising thing in 2017 was the discovery of Olympia oysters in four of the channels at the far south end of Fidalgo Bay (Sharpes Corner area, Fig. 10). Oyster larvae settled onto clam shells found in the bottoms of the channels and thrived in this environment, which is kept wet by freshwater runoff during low tides. Dispersal of oyster larvae this far south was unexpected but consistent with current models derived by Eric Grossman, USGS (pers. comm.). At this time, we do not know if these oysters are reproducing and producing larvae that may further populate the south end of the bay. Between 2017 and 2023, the population of oysters in these channels exploded from about 80,000 oysters to over 1.2 million.

Since the initial stocking of hatchery-reared seed (from a small remnant population on Lopez Island) in Fidalgo Bay in 2002, the resulting naturally produced oysters have proven valuable at jump-starting restoration efforts in other areas of North Puget Sound. These areas have included Sequim Bay, Fisherman Bay on Lopez Island, Skagit and Similk Bays, Padilla Bay, Samish Bay, Chuckanut Bay and Drayton Harbor. In some cases adult oysters were collected and used as hatchery broodstock and in other cases adult oysters were transferred to new locations. Most recently Fidalgo Bay has been used as a natural hatchery for the capture of post-larvae on bags of Pacific oyster cultch, which are then transferred to other bays. In addition to providing oysters for other restoration projects, the PSRF hatchery has produced over 1.5 million single oysters that have been used to support research on conservation aquaculture strategies (R. Crim, pers. comm.)

Project Media Coverage
2019-2023

Doughton, Sandi. 2019. Success on the half shell. Pacific NW Magazine. The Seattle Times, September 22, 2019. pp. 10-17.

Lotus, Jean, 2020. Native oysters make comeback, thrive again in Puget Sound. United Press International. https://www.upi.com/Top_News/US/2020/01/29/Native-oysters-make-comeback-thrive-again-in-Puget-Sound/2521579927804/

Cauvel, Kimberly. 2020. An oyster success story. Skagit Valley Herald, October 24, 2020.

Fletcher-Frazer, Emma. 2023. Restoring oysters. Skagit Valley Herald, May 12, 2023.

Fletcher-Frazer, Emma. 2023. Making a comeback. Skagit Valley Herald, August 9, 2023.

References

Anacortes American. February 1906 edition, Anacortes, WA.

Ashbach, D. and J. Veal. 1986. The Samish Indians of Guemes Island, 1792-1986. Linetime.org. (http://www.dogislandrun.com/nativepeoples.cfm).

Ayvazian, S., A. Gerber-Williams, S. Grabbert, K. Miller, B. Hancock, W. Helt, D. Cobb and C. Strobel. 2020. Habitat benefits of restored oyster reefs and aquaculture to fish and invertebrates in a coastal pond in Rhode Island, United States. J. Shellfish Res. 39(3):563-587.

Baker, P. 1995. Review of ecology and fishery of the Native oyster, *Ostrea lurida* with annotated bibliography. J. Shellfish Res. 14(2):501-518.

Barber, J., S. Grossman and C. Greiner. 2013. May 2013 Olympia oyster project report. Report for the Swinomish Indian Tribal Community, La Conner, WA. 6 pp.

Barber, J., C. Greiner and S. Grossman. May 2015. Olympia oyster, *Ostrea lurida*, pilot project in northern Puget Sound, Washington: 2014 monitoring report. Technical Report SWIN-TR-2015-01 for the Swinomish Indian Tribal Community, La Conner, WA. 13 pp.

Barber, J.S., J.E. Dexter, S.K. Grossman, C.M. Greiner and J.T. McArdle. 2016. Low temperature brooding of Olympia oysters (*Ostrea lurida*) in northern Puget Sound. J. Shellfish Res. 35(2):351-357.

Barsh, R. 2003. Native oyster experimental studies in Fidalgo Bay. Progress Report by Center for Study of Coast Salish Environments, Samish Indian Nation for Skagit County Marine Resources Committee, Mount Vernon, Washington. 10 pp.

Barsh, R., R. Castilleja, S. Johnson, H. Hatch, M. Hatch and L. Horton. 2004. Native oyster experimental studies in Fidalgo Bay (Washington). Year two Progress Report for Skagit County Marine Resources Committee by Center for Study of Coast Salish Environments, Samish Indian Nation, Anacortes, WA.

Becker, B., M. Behrens, B. Allen, M. Hintz, H. Parker, M. McCartha and S. White. 2020. Spatial and Temporal distribution of the early life history stages of the native Olympia oyster *Ostrea lurida* (Carpenter, 1864) in a restoration site in Northern Puget Sound, WA.

Blake, B. and A. Bradbury. 2012. Washington Department of Fish and Wildlife plan for rebuilding Olympia oyster (*Ostrea lurida*) populations in Puget Sound with a historical and contemporary overview. Report by Washington Department of Fish and Wildlife, Point Whitney Shellfish laboratory, Brinnon, WA. 25 pp.

Carson, H.S. 2010. Population connectivity of the Olympia oyster in Southern California. Limnol. Oceanogr. 55(1):134-148.

Clallam County Marine Resources Committee. 2015. 2015 Olympia oyster restoration in Sequim Bay. Final Report for Grant No: SEANWS-2014-CICoCD-0007 for Northwest Straits Commission, Mount Vernon, WA. 6 pp.

Clallam County Marine Resources Committee. 2020. Olympia oyster final report. Final Report for Grant No: SEANWS-2019-CICoCD-00004 for Northwest Straits Commission, Mount Vernon, WA. 7 pp.

Cook, A.E., J.A. Shaffer and B. Dumbauld. 1998. Olympia oyster stock rebuilding plan for Washington State public tidelands. Final Report by WDFW Fish Management Program, Marine Resources Division, Olympia, WA. 24 pp.

Cook, A.E., J.A. Shaffer, B.R. Dumbauld and B.E. Kauffman. 2000. A plan for rebuilding stocks of Olympia oysters (*Ostreola conchaphila,* Carpenter 1857) in Washington State. J. Shellfish Res. 19(1):409-412.

Couch, D. and T.J. Hassler. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest): Olympia oyster. Biological Report 82(11.124) for U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers by Humboldt State University, Arcata, CA. 8 pp.

DeAngelis, B., A. Birch, P. Malinowski, S. Abel, J. DeQuattro, B. Peabody and P. Dinnel. 2019. A Variety of approaches for incorporating community outreach and education in oyster reef restoration projects: Examples from the United States. Pp. 335-354 in: Goods and Services of Marine Bivalves (A. Smaal, J. Ferreira, J. Grant, J. Petersen and O. Strand, Eds.). Springer International Publishing, 591 pp.

Dinnel, P.A., J. Robinette, I. Dolph and M. Schwertner. 2005. Restoration of native oysters in Fidalgo Bay, with an update on Pacific oyster enhancement at March's Point. Year three report. Progress Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 20 pp. + appendices.

Dinnel, P., N. Borman, I. Dolph, J. Giboney, E. Pickett, J. Ramaglia, P. Sund, C. Woodward and R. Barsh. 2006. Restoration of the native oyster in Fidalgo Bay: Year four report (with an update on Pacific oyster enhancement). Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 31 pp.

Dinnel, P., N. Borman, I. Dolph, D. Elder, J. Giboney, E. Pickett, J. Ramaglia, T. Richards, P. Sund and C. Woodward. 2009a. Restoration of the native oyster in Fidalgo Bay-Year Seven Report. Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 35 pp.

Dinnel, P.A., B. Peabody and T. Peter-Contesse. 2009b. Rebuilding Olympia oysters, *Ostrea lurida* Carpenter 1864, in Fidalgo Bay, Washington. J. Shellfish Res. 28(1):79-85.

Dinnel, P.A., I. Dolph, D. Elder, C. Woodward and T. Woodard. 2011. Restoration of the native oyster in Fidalgo Bay – Year nine report. Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 35 pp.

Dinnel, P. 2016. Restoration of the native oyster, *Ostrea lurida*, in Fidalgo Bay, Padilla Bay and Cypress Island. Year fourteen report. Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 54 pp.

Dinnel, P. 2018. Restoration of the Olympia oyster, *Ostrea lurida*, in Fidalgo Bay and Cypress Island, Year sixteen report. Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 73 pp.

Dinnel, P.A. 2023. Quality Assurance Project Plan, Fidalgo Bay Olympia oyster population assessment, 2023. Skagit County Marine Resources Committee, Mount Vernon, WA, 32 pp.

Eggleston, D.B. 1995. Application of landscape ecological principles to oyster reef habitat restoration. Chapter 14, pp. 213-227 in: Luckenbach, M.W., R. Mann and J.A. Wesson, editors. 1999. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Proceedings of the Symposium, Williamsburg, VA, April 1995. Virginia Institute of Marine Sciences, College of William and Mary, VIMS Press. 366 pp.

Gabrian-Vorhees, K., P. Dinnel and N. Siu. 2013. Restoration of the native oyster in Fidalgo Bay -- Year ten report. Final Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 56 pp.

Gregory, S.G. and A.K. Volety. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. J. Shellfish Res. 24(4):1007-1012.

Greiner, C.M., S.K. Grossman, and J.S. Barber. 2015. Swinomish Olympia oyster monitoring plan. Swinomish Indian Tribal Community Contribution #SWIN-CR-2015-04. 21 pp.

Grossman, S.K., E.E. Grossman, J.S. Barber, S.K. Gamblewood and S.C. Crosby. 2020. Distribution and transport of Olympia oyster *Ostrea lurida* larvae in Northern Puget Sound, Washington. J. Shellfish Res. 39(2):215-233.

Harbo, R.M. 1997. Shells and Shellfish of the Pacific Northwest. Harbour Publishing, Madiera Park, British Columbia, Canada. 270 pp.

Hatch, M., H. Hatch, R. Barsh, S. Wylie-Echeverria and F. Goetz. 2005. Platform presentation at the 2005 Puget Sound and Georgia Basin Research Conference, Seattle, WA.

Hertlein, L.G. 1959. Notes on California oysters. Veliger 2:5-10.

Ingersoll, E. 1881. The oyster-industry of the United States. In: The History and Present Condition of the fishery industries, 1879-1880, G. B. Goode, editor. Government Printing Office, Washington, D.C. 251 pp.

Lawlor, J. and S. Arellano. 2020. Temperature and salinity, not acidification, predict near-future larval growth and larval habitat suitability of Olympia oysters in the Salish Sea. Scientific Reports, https://doi.org/10.1038/s41598-020-69568-w.

Luckenbach, M.W., R. Mann and J.A. Wesson, editors. 1999. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Proceedings of the Symposium, Williamsburg, VA, April 1995. Virginia Institute of Marine Sciences, College of William and Mary, VIMS Press. 366 pp.

McIntyre, B, E. McPhee-Shaw, M. Hatch and S Arellano. 2020. Location matters: Passive and active factors affect the vertical distribution of Olympia oyster (*Ostrea lurida*) larvae. Eatuaries and Coasts, https://doi.org/10.1007/s12237-020-00771-9.

NOAA/PSRF (NOAA Restoration Center and Puget Sound Restoration Fund). 2010. West Coast native oyster restoration: 2010 workshop proceedings. U.S. Department of Commerce, NOAA Restoration Center, Silver Springs, MD. 49 pp.

Northwest Enterprise. 1884. November 8, 1884 edition, Anacortes, WA.

PSAT (Puget Sound Action Team). 2003. Shellfish informational report. 9 pp.

PSRF (Puget Sound Restoration Fund). 2012. Restoration News, Summer 2012.

PSRF (Puget Sound Restoration Fund). 2014. Fidalgo Bay native oyster project. Final Report 2012-1-PSRF for the Northwest Straits Foundation, Bellingham, WA. 39 pp.

PSRF (Puget Sound Restoration Fund). 2015. Olympia oyster recruitment: Long-term Puget Sound settlement and juvenile monitoring. A protocol by PSRF, Bainbridge Island, WA. 4 pp.

Raymond W. W., Tobin E. D., Raymond A. E. T., Barber J. S. 2022. Effects of the 2021 heatwave on intertidal clam and oyster populations in Washington State. Jamestown S'Klallam Tribe Technical Report. 24 pp.

Ricketts, E. and J. Calvin. 1968. Between Pacific Tides. Stanford University Press, Stanford, CA. 614 pp.

Ridlon, A., A. Marks, C. Zabin, D. Zacherl, B. Allen, J. Crooks, G. Fleener, E. Grosholz, B. Peabody, J. Toft and K. Wasson. 2021. Conservation of marine foundation species: Learning from native oyster restoration from California to British Columbia. Estuaries and Coasts, https://doi.org/10.1007/s12237-021-00920-7.

Robinette, J. and P. Dinnel. 2003. Restoration of the Olympia oyster in North Puget Sound: Will Olympia oysters thrive in Fidalgo Bay? Progress Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 21 pp.

Robinette, J., P. Dinnel, R. Barsh, I. Dolph, J. Giboney, R. Knowles, M. Sato and M. Schwertner. 2004. Restoration of the Olympia oyster in Fidalgo Bay: Year two report. Progress Report by Skagit County Marine Resources Committee for the Northwest Straits Commission, Mount Vernon, WA. 21 pp.

Rose, A. 2018. Whatcom Marine Resources Committee pilot Olympia oyster restoration project. 2017-2018 Final Report by Whatcom County Public Works and MRC, Bellingham, WA. 7 pp.

Rose, A. 2021. Pilot Olympia oyster restoration final report. 2020-2021 Final Report by Whatcom County Public Works and MRC, Bellingham, WA. 9 pp.

Smaal, A., J. Ferreira, J. Grant, J. Petersen and O. Strand. 2019. Goods and Services of Marine Bivalves. Springer International Publishing, 591 pp.

Stahl, K. 1999. In search of the Olympia oyster: Remnant *Ostrea lurida* populations in northern Puget Sound. Senior Project Report, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA. 28 pp.

Steele, E.N. 1957. The Olympia oyster. Fulco Publications, Elma, WA. 126 pp.

Suttles, W.P. 1974. Coast Salish and Western Washington Indians 1. The Economic Life of Coast Salish of Haro and Rosario Straits. Garland Publishing Co., New York. Pp. 246-7.

The Coast. 1907. Oyster growing near Bellingham. Vol. XIV, No. 3, September, 1907, Bellingham, WA.

Townsend, C.H. 1893. Report of observations regarding the oyster resources and oyster fishery of the Pacific Coast of the United States. Report USFC 1889-1891. Pp. 343-372.

Wasson, K., C. Zabin, J. Bible, S. Briley, E. Caballos, A. Chang, B. Cheng, A. Deck, T. Grosholz, A. Helms, M. Latta, B. Yednock, D. Zacherl and M. Ferner. 2015. A guide to Olympia oyster restoration and conservation. Elkhorn Slough National Estuarine Research Reserve. 47 pp. Available from www.oysters-and-climate.org.

Wasson, K., B.B. Hughes, J.S. Berriman, A.L. Chang, A.K. Deck, P.A. Dinnel, C. Endris, M. Espinoza, S. Dudas, M.C. Ferner, E.D. Grosholz, D. Kimbro, J.L. Ruesink, A.C. Trimble, D. Vander Schaaf, C.J. Zabin, D.C. Zacherl. 2016. Coast-wide recruitment dynamics of Olympia oysters reveal limited synchrony and multiple predictors of failure. Ecology 97(12):3503-3516.

White, J.M., E.R. Buhle and J.L. Ruesink. 2009. Evaluation of Olympia oyster *(Ostrea lurida* Carpenter 1864) status and restoration techniques in Puget Sound, Washington, United States. J. Shellfish Res. 28 (1):107-112.

Tables

Table 1. Average number of Olympia oyster post-larval recruits per 100 shells found in the three replicate cultch shell bags deployed at trestle Plot B from 2004 to 2022 and recovered one year later. The "Year" indicates the year that settlement took place.

Year	Average Number of Oysters/100 cultch shells
2004	46.5
2005	0.0
2006	4.6
2007	0.0
2008	0.0
2009	266.4
2010	NS
2011	5.8
2012	18.3
2013	5.8
2014	93.2
2015	428.4
2016	186.0
2017	101.6
2018	43.0
2019	322.1
2020	46.7
2021	325.7
2022	179.4

NS = Not sampled

Table 2. Number of oysters per cultch shell at two locations at Cap Sante Marina located in the northwest area of Fidalgo Bay. In 2016, approximately 7,900 hatchery seed oysters plus 3,800 naturally set seed (from recruitment cultch shell bags) were spread between these two areas.

Date	Average Number of Oysters/Cultch Shell
Cap Sante Marina, Inside North Breakwater	
2017	0.40
2018	0.02
2023	0.00
Sea Farers Park	
2017	0.28
2018	0.11
2023	0.00

Table 3. Estimated number of Olympia oysters in Fidalgo Bay by year.

Year	Number of Oysters
2002	50,000
2003	45,000
2004	40,000
2005	90,000
2006	80,000
2007	100,000
2008	90,000
2009	80,000
2010	140,000
2011	140,000
2012	160,000
2013	240,000
2014	850,000
2015	2,600,000
2016	3,078,000
2017	3,525,000
2018	2,912,000
2023	5,544,124

Figures

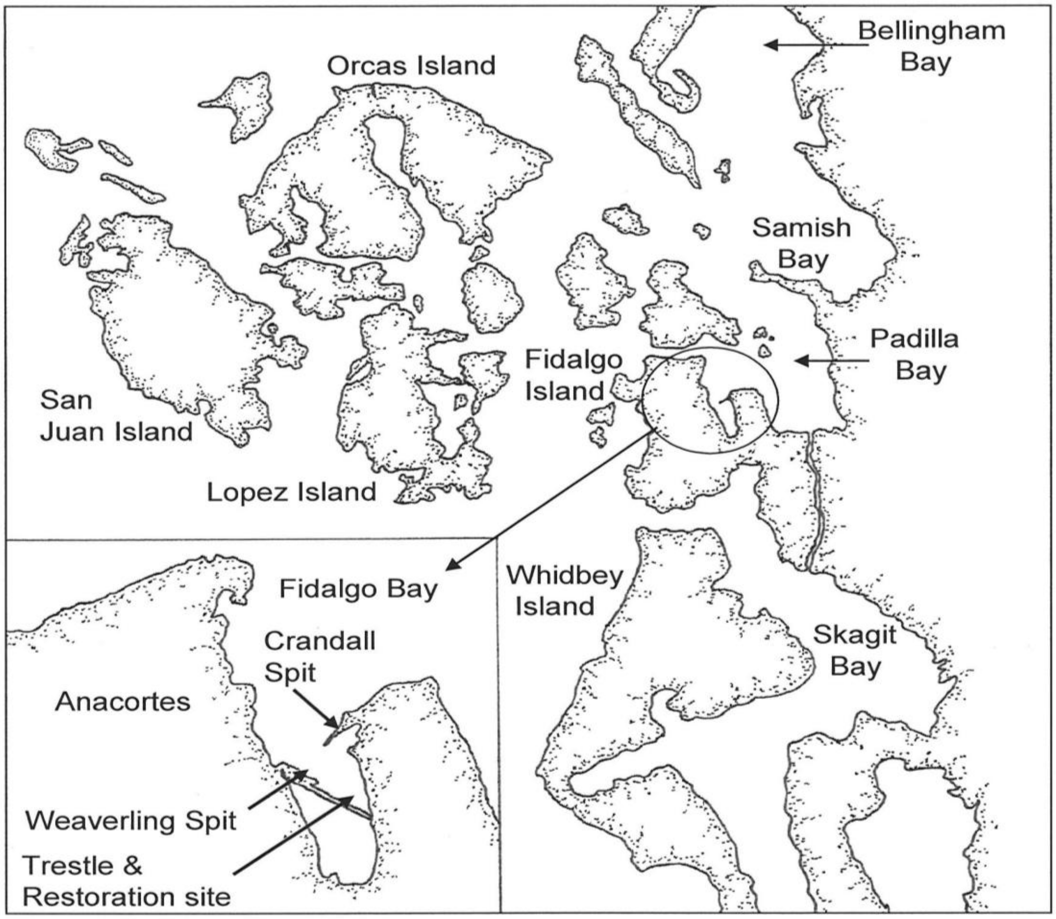

Figure 1. Drawing of North Puget Sound showing the location of Fidalgo Bay. Figure from Dinnel et al. 2009b.

Figure 2. Map showing the locations of Skagit MRC Olympia oyster operations, in and around Fidalgo Bay, 2002-2023. Photo source: Google Earth.

Figure 3. Location of the trestle Olympia oyster restoration site (circle) in South Fidalgo Bay. Photo source: WDOE online Shoreline photo collection.

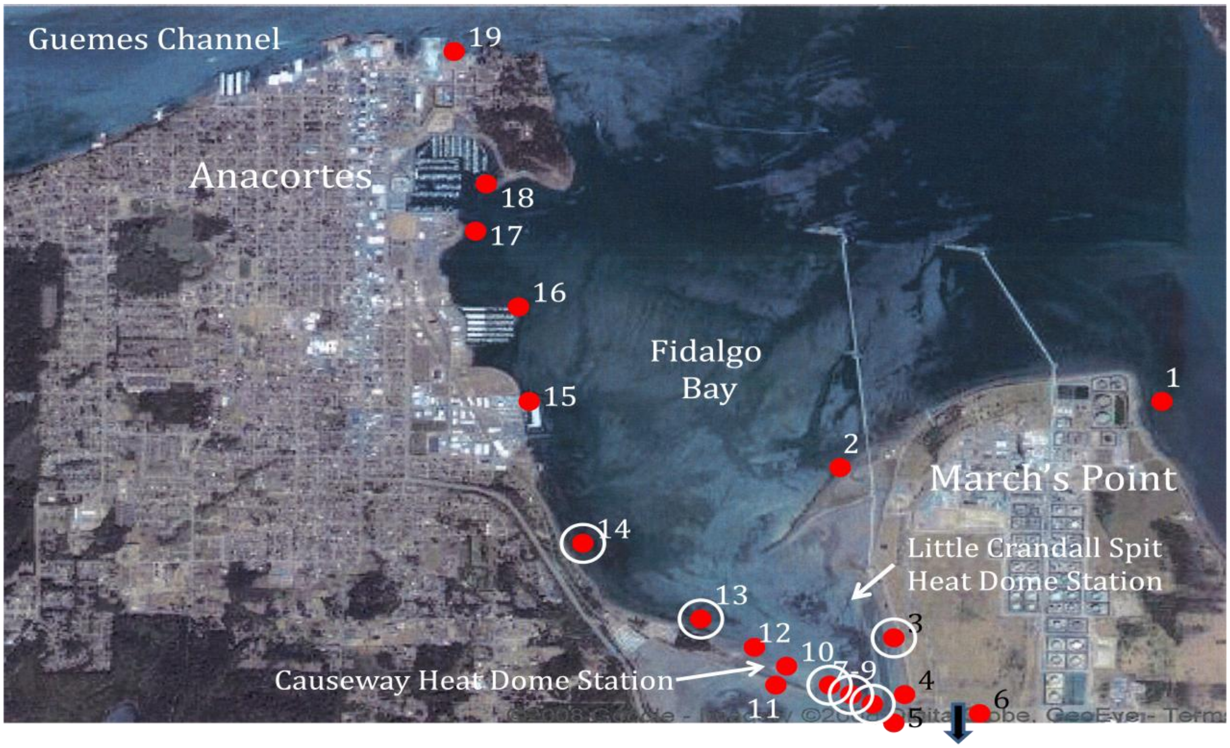

Figure 4. Photograph of Fidalgo Bay showing the locations where larval settlement cultch bags were typically deployed on an annual basis, 2011 to 2018. Station 6 was at the west end of the south Fidalgo Bay shell berm several hundered meters south of the trestle. The sampling sites with the white circles are the stations sampled from 2017 through 2023. Also shown are the two 2021 "Heat Dome" sampling stations. Photo source: Google Earth.

Figure 5. Photograph of post-larval recruitment sampling tools used in Fidalgo Bay. Left: cultch bag of Pacific oyster shells; Middle: shell string (ten shells on a stick - used for PSRF monitoring); Right: ceramic tiles, 5 tiles to a rack.

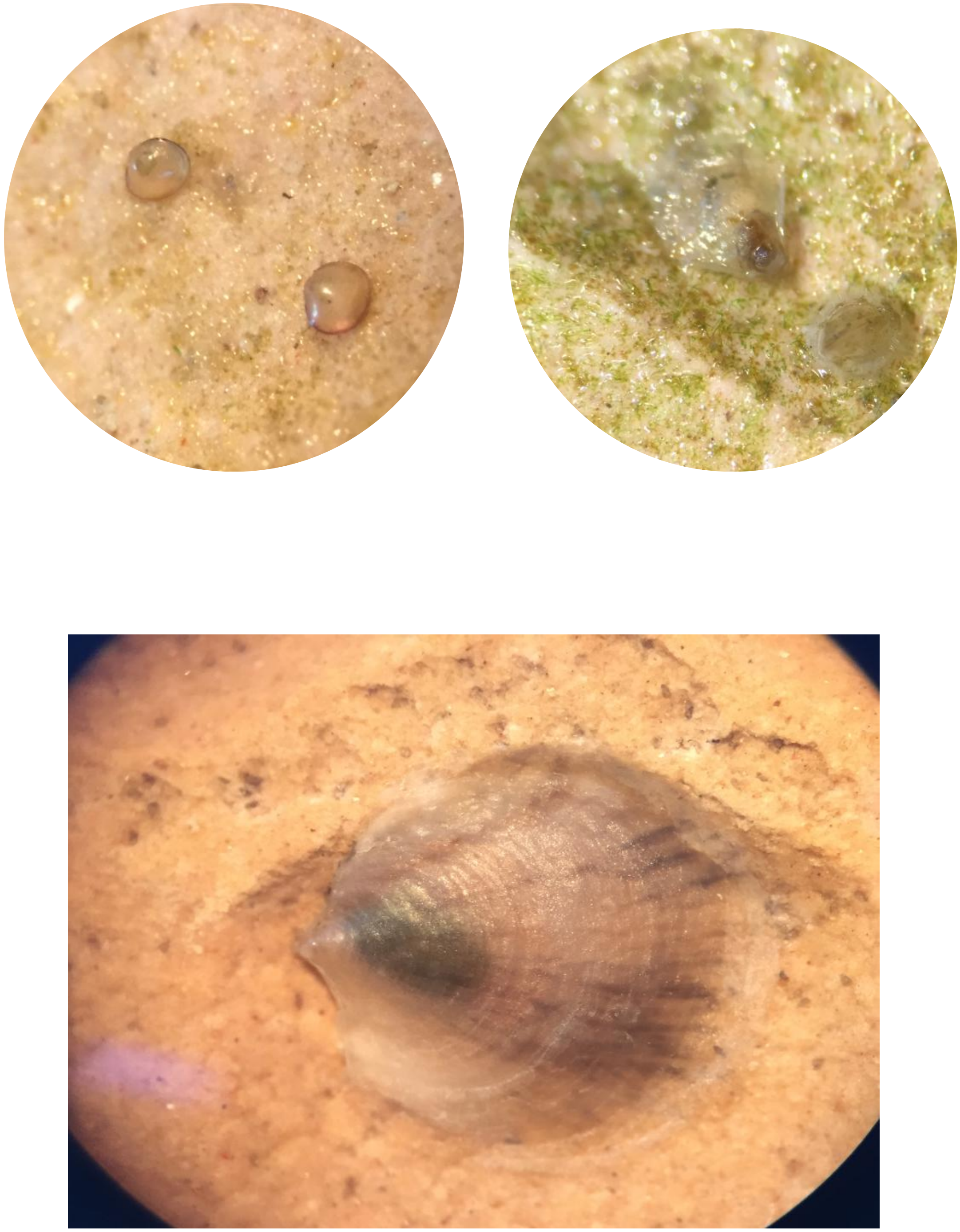

Figure 6. Microphotographs of post-larval Olympia oysters at about 1-3 days post settlement (upper left), about 1-2 weeks post settlement (upper right) and about 4 weeks (bottom).

Figure 7. Photograph of Cap Sante Marina (top, area 1) and Seafarers Memorial Park (bottom, area 2) areas of NW Fidalgo Bay where two new Olympia oyster seed plots were established in 2016. Photo source: Google Earth.

Figure 8. Example of the ¼ m^2 quadrat typically used to sample Olympia oysters, clam shells and oyster shells during trestle Plot B and "wide-area" sampling. A 1/10 m^2 quadrat was also used when oyster densities were high.

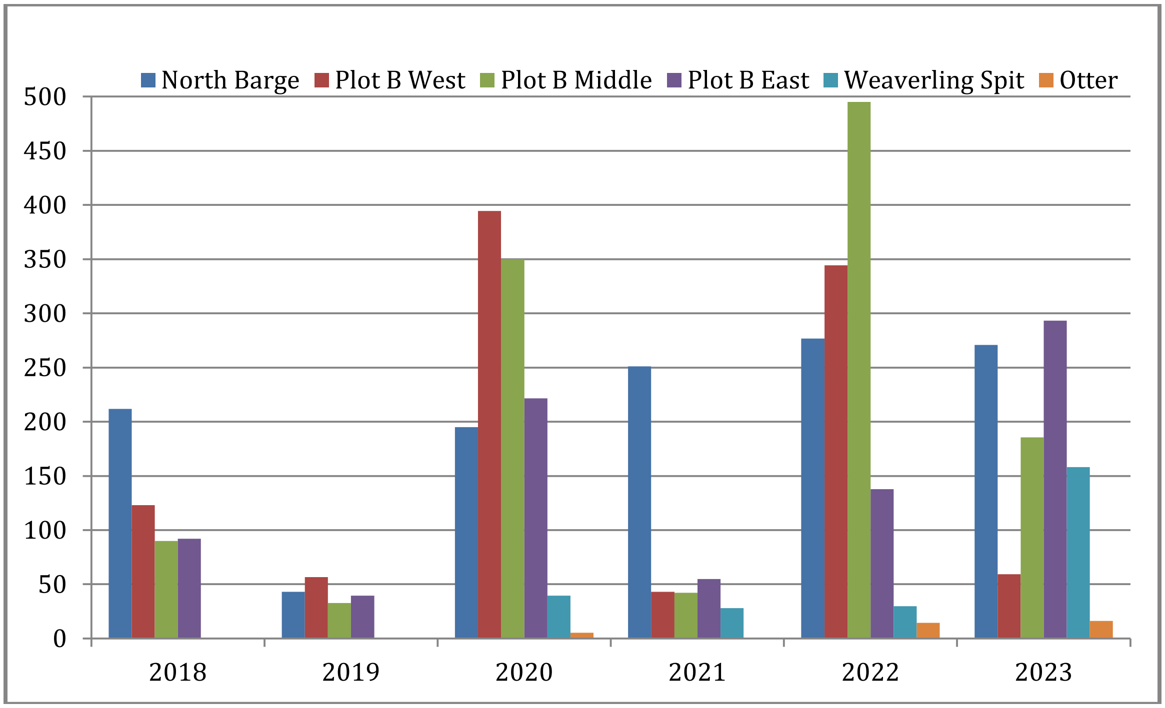

Figure 9. The number of Olympia oyster spat counted in the shell cultch recruitment bags at six locations around Fidalgo Bay, 2018-2023 (note: the bags were set out the year before they were collected and counted. "Otter" refers to Site 14. See Figure 4 for the site locations.

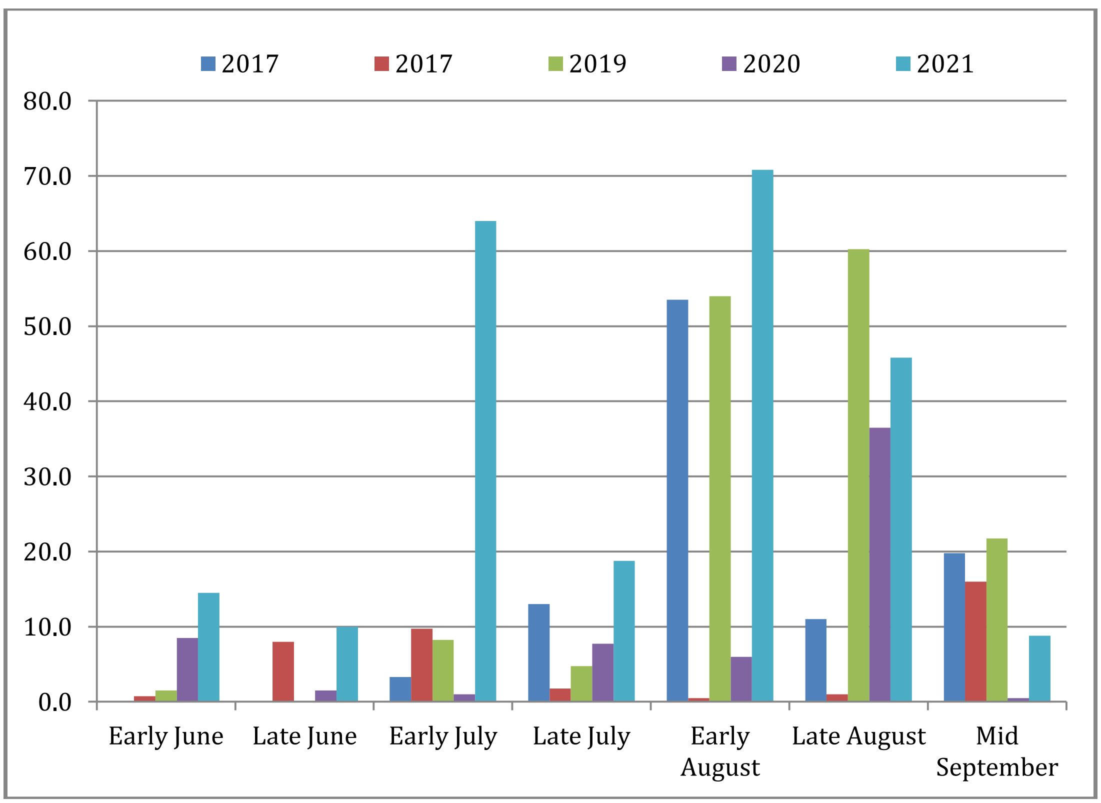

Figure 10. Average number of post-larval Olympia oysters per ceramic sampling tile, 2017 through 2021, at the north barge location on the eastern side of Fidalgo Bay.

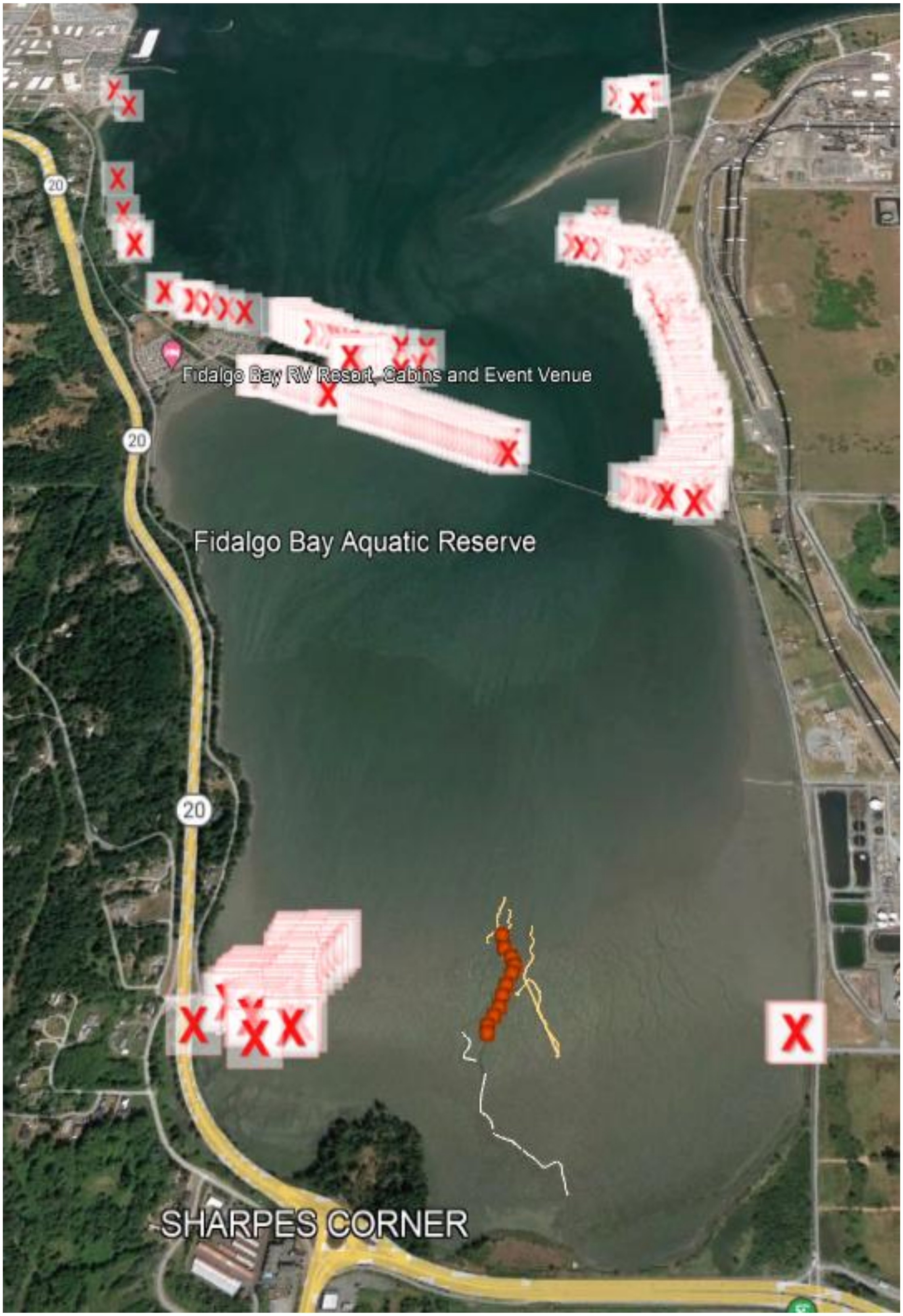

Figure 11. Locations in Fidalgo Bay (red X's and red dots) where quadrat samples were collected during the 2023 population survey. Photo by PSRF.

Figure 12. Examples of Olympia oyster natural recruitment to the marsh channels in southern Fidalgo Bay. Photos by PSEF.

Figure 13. Volunteers receiving pre-sampling training by PSRF staff (top), out in the mud collecting samples (middle), and processing a quadrat sample.

APPENDICES

Appendix 1. Summary data report to Skagit Marine Resources Committee by Puget Sound Restoration Fund.

PUGET SOUND
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Fidalgo Bay

2023 Wide Area Survey

Summary Report to
Skagit County MRC

An Olympia oyster population assessment in Fidalgo Bay was conducted over three days in the summer of 2023. Our first survey, on June 20, focused on the largest aggregation of oysters located on the March's Point tidelands between Little Crandall Spit and the Tommy Thompson Trail trestle. The remaining surveys were conducted on August 2nd and 3rd; population surveys in August targeted productive oyster aggregations on Weaverling Spit, the Crandall Spit lagoon, the trestle causeway tidelands, and the southern sloughs in the marsh at the head of Fidalgo Bay.

This effort was intended to repeat the Wide Area Survey organized by the Skagit MRC in 2018. Survey sites were also based on those surveyed in 2018. The survey data collected in 2018 was then utilized to generate sample size requirements to achieve a 30% margin of error around estimates for sample means. The intent was to assess density and extrapolate an abundance for productive aggregations of Olympia oysters within 3 population strata: shell amendment plots, linear oyster aggregations, and other productive oyster aggregations located on tidelands outside of shell amendments. Shell amendment plots are mostly located within the March's Point survey area, except for one located at Weaverling Spit.

A qualitative reconnaissance of the survey sites was used to delineated productive oyster aggregations (>1 oyster m^{-2}) to survey. Tideland areas empirically identified as having "unproductive" Olympia oyster aggregations, either "absent" or "rare" (<1 oyster m^{-2}), were not included in a survey area. So, this population assessment is restricted to the survey areas identified below where a qualitative survey identified productive oyster aggregations with oysters exceeding 1 oyster m^{-2}. Oysters observed on unproductive tideland spaces outside of the surveyed areas were mapped during the qualitative reconnaissance surveys. Including these unproductive areas in a quantitative survey only lends to increased population variance and margins of error surrounding density means. Focusing our assessments in productive spaces for oysters improves the accuracy of density means estimated for the populations surveyed.

March's Point

March's Point defines the entire eastern shoreline of Fidalgo Bay. The shoreline juts west into the Bay at Crandall Spit, near the mouth with its perched lagoon, and then at Little Crandall Spit further south. The Olympia oyster spatial distribution on this shoreline includes a small area within the drainage channel of the lagoon on Crandall Spit, then largely the tidelands proper from Little Crandall Spit south to the Tommy Thompson Trail trestle. The oyster habitat on the larger tideland lies between the +2 ft. Mean Lower Low Water (MLLW) contour and the -1.5 ft. MLLW contour, near the eelgrass meadow edge.

The survey area here was determined by an empirical reconnaissance to delineate the productive oyster (>1 oyster m^{-2}) distribution. The survey area mapped in 2023 includes tidelands from the shallowest to the deepest productive oyster space observed along this shoreline. This area includes shell amendment plots (3.28 acres or 13,274 m^2), and a relatively large productive area outside the shell plots (21.29 acres or 86,157 m^2). Unfortunately, due to an error during sample collection, PSRF was not able to reliably assign sample data spatially for this survey. As a result, we are unable to examine the two population strata here and can only report our population assessment collectively for the entire survey area.

78 samples were located within the shell amendment plots, and 115 samples were located within the productive distribution of Olympia oysters outside the shell amendments. Collectively, 193 samples composed the population survey at the March's Point area; these were placed haphazardly throughout the 24.6-acre (99,431 m^2) survey area. A variable sample unit was employed during the survey to increase the proportion of non-zero sample count values in the dataset. The mean density estimate reported for the March's Point survey area is 42.8 Olympia oysters m^{-2} (SD=64.8, 95%CI=+/-9.14). Extrapolating the density mean across the entire survey area, we estimate the standing population at 4,257,230 Olympia oysters.

Oyster size data was collected during this survey, shown in Figure 1. The first 5 to 10 oysters encountered in samples were measured for shell height (longest radial dimension measured from the hinge), which is the standard size metric for oysters. 685 observations for shell height were recorded in the March's Point survey and the results estimate mean shell height at 45 mm (SD=46.5). The size distribution is reported in 1mm bins using percent (%) frequency, so that frequency distributions with different sample sizes can be compared directly. The results for the March's Point survey area show a well-developed population, indicated by the single size mode near 50mm. The left tail of the distribution is well-populated which indicates regular annual recruitment to the population here.

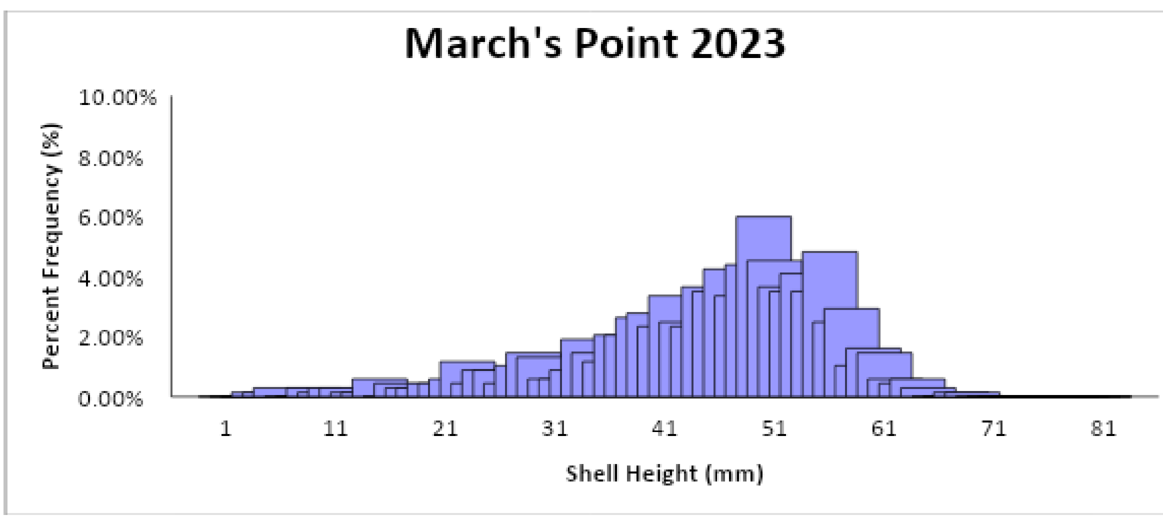

Figure 1. Size frequency distribution for Olympia oysters in the March's Point survey population.

Oyster density in the March's Point survey area is variable, with some patchy high-density aggregations inside the shell amendment plots mixed with both high- and low-density patches outside of the shell amendments. Using the variable sample unit, we were able to mitigate the low-density patches by reducing the number of sample counts with null values. Combined with the large sample size (n=193), sampling 0.08% of the survey area, we get a relatively accurate estimate in this case. The calculated margin of error surrounding our estimate of mean density is +/- 21%, which exceeds our target of a +/- 30% confidence interval about our reported density mean.

This survey included the largest contiguous survey area of productive oyster tidelands in Fidalgo Bay. While the shell amendment plots are where oysters are found in their densest aggregations, the population here is exploiting the available habitat on the tidelands surrounding the shell plots.

Weaverling Spit

Weaverling Spit, on Fidalgo Bay's west shore, was another focus area for this 2023 oyster population assessment. The tidelands on the north shore of the Spit are where a shell amendment was located in 2018, and subsequently a direct oyster enhancement. A reconnaissance of tidelands on the entire northern shore, from the trestle causeway north and west along the tidelands owned by the Samish Tribe, identified the productive area for Olympia oysters (density > 1 m^{-2}). We found some productive area in the margins of the 2018 shell amendment, but otherwise we recorded a rare presence or absence of oysters. So, the survey area for Weaverling Spit was delineated generally around the 2018 shell amendment plot; this was our only survey area within the shell amendment population strata. The shell amendment footprint was mapped in 2023 and compared to the mapped perimeter in 2018; the footprint of emergent shell is largely unchanged. Some shell is moving east, nearly all maintains spatial fidelity after 5 years.

46 samples were collected haphazardly within the 0.88-acre (3,561 m^2) survey area mapped at Weaverling Spit. The mean density for Olympia oysters in this survey was 17.1 m^{-2} (SD=47.2, 95%CI=+/-13.64). Extrapolating the density estimate across the Weaverling Spit survey area, we calculate the standing population here at 60,825 Olympia oysters. The density of oysters in this population were more variable, relative to the developed population on March's Point. The assemblage of Olympia oysters here is markedly patchy, with 65% of samples recording null values. This is characteristic of a young, developing oyster bed within shell amendments.

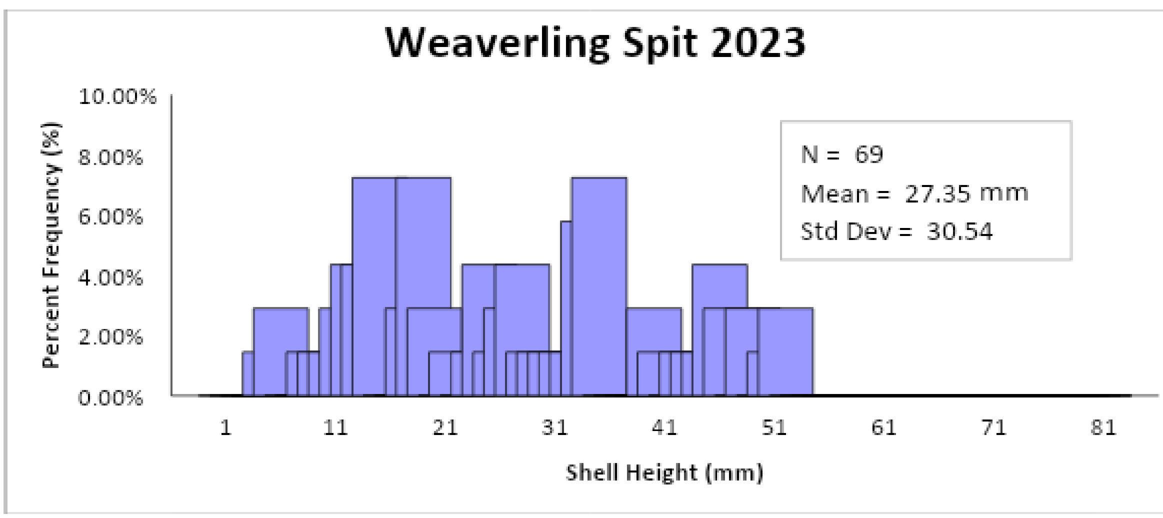

Figure 2. Size frequency distribution for Olympia oysters in the Weaverling Spit survey population.

Sporadic recruitment success [spatially] over a few seasons and the presence of the older oysters from the 2018 seed transfer presents a mosaic of oyster density and size across this relatively small area. Our estimate for oyster density is therefore less accurate than predicted, with a margin of error of our confidence interval at +/- 80% of the density mean. We anticipated pooling these survey data with other samples collected from the shell amendment strata at March's Point, which would have improved the accuracy of this estimate for density. We can reliably report that the order of magnitude in our abundance estimate is correct, with tens of thousands of Olympia oysters within the Weaverling Spit survey area.

The size distribution for Olympia oysters here is multi-modal, as shown in Figure 2. Illustrating the larger oysters, a frequency mode between 40-52 mm are likely survivors from the 2018 oyster enhancement. Multiple class modes of smaller sizes are also shown, indicating regular oyster settlement and recruitment success. Proportionally, young oysters [< 30 mm] compose the majority of this developing population. The mean shell height reported for oysters here was 27.4 mm (n = 69, SD = 30.5). The moderate density (17.1 m^{-2}) and small average size for oysters here is common in our experience for shell amendments of this age. Evidenced by regular recruitment, the survival of older oysters and the spatial fidelity of the shell amendment suggests this population could continue to develop increased oyster density and abundance at this location.

Linear oyster aggregations

Two areas covered by the Skagit MRC 2018 wide-area survey have populations organized in long, narrow spatial distributions. The MRC requested an assessment of oyster populations within this class, creating a strata of linear oyster aggregations. The first area is composed of oysters in a narrow band of favorable habitat found on tidelands to the north and south of the rock prism causeway supporting the west end of the Tommy Thompson Trail trestle. The second area is a collective of drainage sloughs and smaller, connected channels that wend through the substantial salt marsh at the head of Fidalgo Bay. The oyster bed in the marsh sloughs is distinctly different from the aggregation at the trestle causeway; marked differences of these conditions include elevation, exposure, oyster density and size. Both are natural oyster aggregations, developing since a noted population increase in 2015, but the habitat conditions of these discrete populations are different enough to warrant independent assessments.

Trestle Causeway survey area

Proper tidelands surround the rock prism causeway, with oysters distributed in a narrow band near and slightly below MLLW. The distribution of oyster habitat here is defined by a change in grade below the relatively steep upper beach, which releases seep water and keeps the oyster habitat wetted during low tide exposure, see Figure 3. The lower distribution appears to be limited by the lack of emergent structure in the soft sediment, but could also be limited by sedimentation, competition [bioturbator infauna] or predation.

Figure 3. Olympia oyster survey area on the trestle causeway, south side.

The survey here used a haphazard sample placement within the observed oyster distribution band mapped on the north and south sides of the trestle causeway. A variable sample unit protocol was employed to minimize null values in our resulting dataset. The width of the survey area was measured directly by survey teams, on approximately every 3rd sample. The area at the trestle causeway measured collectively 1,051 m in length with a mean distribution width of 5.6 m (n = 21, SD = 2.66, 95%CI = +/-1.13), delineating a survey area of 1.45 acres or 5,886 m^2. The population assessment here collected 89 samples and reported a mean sample density of 33.4 oysters m^{-2} (SD = 40.6, 95%CI = +/-8.43). Extrapolating the density estimate across the trestle causeway survey area, we calculate the standing population here at 196,352 Olympia oysters.

Figure 4. Size frequency distribution for Olympia oysters in the trestle causeway survey population.

The margin of error calculated for the confidence interval here was +/- 25% for the reported density mean. Sample size and the even distribution of oysters within the survey area contributed to the accuracy of the density estimate here.

The size distribution in this population, shown in Figure 4 illustrates the developing oyster bed here. The aggregation here is well supported with regular recruitment as shown in the left tail of the distribution. Mean oyster shell height was 38 mm (n = 311, SD = 39.9).

Marsh Sloughs

We were surprised at what was found within the drainage sloughs and connected channels in the salt marsh at the head of Fidalgo Bay. This area was surveyed by the MRC in 2018, which identified two regions in the marsh on either side and in front of a small point of land on the shoreline near the center of the marsh. We also found a dense aggregation of Olympia oysters here, as was reported by the Skagit MRC in 2018 (mean = 204 m^{-2}, SD = 24.4, 95%CI = +/-10.7). The surprise came when we realized the collective size of this oyster bed, which extended through more than 2 kilometers of salt marsh (Fig. 5). We were able to completely map the oyster bed distributed through the minor sloughs grouped to the east of the marsh, but were unable to exhaustively map the oyster bed distributed through the major sloughs on the west side of the marsh. Therefore, our mapped survey area is conservative relative to the marsh space occupied by this oyster bed.

70 samples were placed haphazardly throughout the survey area delineated within the drainage sloughs and connected channels. The distribution of samples skews east, due to the emphasis of mapping the oyster bed in the western network of sloughs. The collective length of this survey area measured at 1,930 m. The width of the oyster bed was estimated at most sample positions, and reported a mean width of 2.18 m (n = 48, SD = 1.08, 95%CI = +/- 0.30). The calculated survey area for this population is 1.04 acres or 4,207 m^2. The Olympia oysters in this survey reported a mean density of 301.1 m^{-2} (SD = 314.7, 95%CI = +/- 73.7). We calculate the margin of error for our confidence interval at +/- 24% of the density mean. Extrapolating the density estimate across the marsh slough survey area, we calculate the standing population here at 1,267,028 Olympia oysters.

Figure 5. Olympia oyster bed in the salt marsh slough.

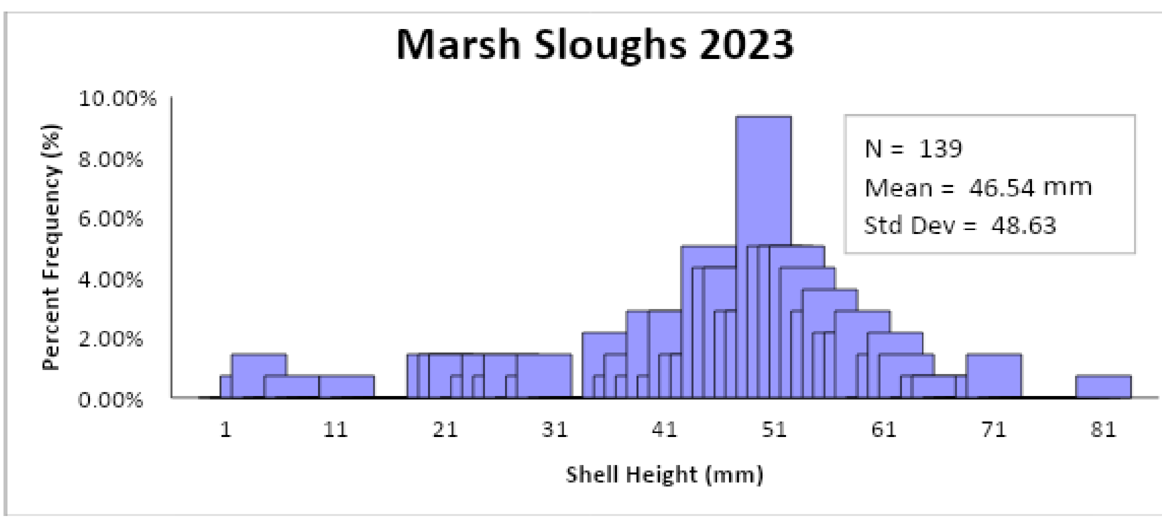

Figure 6. Size frequency distribution for Olympia oysters in the salt marsh slough survey population.

The marsh slough was the densest oyster aggregation observed in 2023, with some samples exceeding 1,000 oysters m^{-2}. The oysters here are so dense, the typical morphology is altered so that they grow tall and narrow as they form a hummock, or structured oyster bed, above the sediment. This is the first time we have measured Olympia oyster shell heights above 70mm anywhere in Puget Sound. The size distribution here, and shown in Figure 6, reports mean shell height at 46.5 mm (n = 139, SD = 48.6). We expect the size distribution would benefit here from a larger sample size; sample sizes over 200 for oyster shell height frequency do a better job of comprising a complete histogram. However, this distribution appears normal with a single mode near the mean, indicating a well-developed adult population. The left tail of the size distribution is sparsely populated, but shows evidence of recent oyster settlement from 2 year-classes.

This oyster bed in the marsh sloughs is certainly a jewel of the Olympia oyster restoration in Fidalgo Bay. It has developed naturally, as the population within Fidalgo Bay was reestablished to find and occupy its zone in the intertidal.

Population assessment summary

The 2023 oyster population assessment conducted in Fidalgo Bay attempted to repeat the Skagit MRC's 2018 wide area survey. For which, PSRF organized qualitative abundance surveys in each of the 14 survey areas identified in the 2018 assessment. Some areas revealed developed or productive oyster aggregations where we focused our quantitative demographic survey. As mentioned previously, tideland areas with a rare (<1 m^{-2}) or absent Olympia oyster qualitative presence were excluded from this assessment to improve the accuracy of reported population means and extrapolated abundance. Unfortunately, this meant excluding some shoreline in Anacortes proper, including the Skagit MRC oyster enhancements near Cap Sante Marina, and the extensive shoreline between Anacortes and Weaverling Spit.

Table 1. Survey area and descriptive statistics for Olympia oyster population assessments in Fidalgo Bay 2023.

Survey Area	Area (m2)	Sample number	Mean oyster density (m^{-2})	SD	CI (95%) +/-	CV (%)	Abundance estimate	Margin of Error (MOE)	Nmin for MOE +/- 30%
March's Point Tidelands	99,431	193	42.8	64.8	9.14	151%	4,257,230	21%	98
Weaverling Spit	3,561	46	17.1	47.2	13.64	276%	60,825	80%	326
Trestle causeway	5,886	89	33.4	40.6	8.43	122%	196,352	25%	63
Southern salt marsh	4,207	70	301.1	314.7	73.73	105%	1,267,028	24%	47
sums	**113,020**	**398**					**5,544,124**		

The resulting quantitative demographic surveys for Olympia oysters were located in the productive oyster aggregations observed in 2023. The data summary in Table 1 reports survey metrics and descriptive statistics for the four discrete populations assessed on March's Point (including Crandall Spit lagoon, and tidelands between Little Crandall Spit and the Tommy Thompson Trail), Weaverling Spit (2018 shell amendment), the trestle causeway (including the north and south side tidelands), and the southern salt marsh. A margin of error for the reported densities is shown for each survey, as well as the calculated minimum sample size [Nmin] for a subsequent survey.

The population assessment for each defined population exceeded the +/- 30% margin of error objective, a standard for shellfish resource assessments, except in the case of the shell amendment on Weaverling Spit where the sample size and variable distribution of oysters affected the accuracy of our estimate for density. On balance, we are confident in our assessments for oyster density for the populations that compose the majority of the Olympia oyster resource in Fidalgo Bay. In total, 28 acres of productive oyster space were surveyed by placing 398 discrete samples, thanks largely to the volunteer surveyors from Skagit MRC and Samish Tribe. Adding up the individual population assessments in this 2023 wide area survey of Olympia oysters in Fidalgo Bay, we estimate the total population abundance at 5,544,124.

Appendix 2. Sampling metrics for all population estimate samples collected in Fidalgo Bay during summer 2023.

Survey Site	Sample ID	Sample Size (m^2)	Live Oysters	Width (m)	Sample Are Factor	Sample Density
March's Point	1A	1	5		1	5.0
March's Point	2A	1	8		1	8.0
March's Point	3A	1	2		1	2.0
March's Point	4A	1	9		1	9.0
March's Point	5A	1	3		1	3.0
March's Point	6A	1	0		1	0.0
March's Point	7A	1	4		1	4.0
March's Point	8A	1	4		1	4.0
March's Point	9A	0.5	2		2	4.0
March's Point	10A	0.2	10		5	50.0
March's Point	11A	0.4	10		2.5	25.0
March's Point	12A	0.5	8		2	16.0
March's Point	13A	0.4	10		2.5	25.0
March's Point	14A	0.1	14		10	140.0
March's Point	15A	0.1	27		10	270.0
March's Point	16A	0.1	32		10	320.0
March's Point	17A	0.2	14		5	70.0
March's Point	18A	0.3	11		3.333333333	36.7
March's Point	19A	0.4	11		2.5	27.5
March's Point	20A	0.3	13		3.333333333	43.3
March's Point	21A	0.2	14		5	70.0
March's Point	22A	0.4	11		2.5	27.5
March's Point	23A	0.5	0		2	0.0
March's Point	24A	0.3	1		3.333333333	3.3
March's Point	25A	0.4	15		2.5	37.5
March's Point	26A	0.1	10		10	100.0
March's Point	27A	0.2	13		5	65.0
March's Point	28A	0.1	8		10	80.0
March's Point	29A	0.2	11		5	55.0
March's Point	30A	0.1	11		10	110.0
March's Point	31A	0.5	2		2	4.0
March's Point	32A	0.5	1		2	2.0

March's Point	33A	0.1	15		10	150.0
March's Point	34A	0.1	18		10	180.0
March's Point	35A	0.1	19		10	190.0
March's Point	1B	0.7	0		1.428571429	0.0
March's Point	2B	0.6	2		1.666666667	3.3
March's Point	3B	0.5	5		2	10.0
March's Point	4B	0.5	0		2	0.0
March's Point	5B	0.7	2		1.428571429	2.9
March's Point	6B	0.6	3		1.666666667	5.0
March's Point	7B	0.7	8		1.428571429	11.4
March's Point	8B	0.7	0		1.428571429	0.0
March's Point	9B	1	1		1	1.0
March's Point	10B	1	0		1	0.0
March's Point	11B	1	0		1	0.0
March's Point	12B	1	2		1	2.0
March's Point	13B	1	2		1	2.0
March's Point	14B	1	3		1	3.0
March's Point	15B	1	0		1	0.0
March's Point	16B	1	0		1	0.0
March's Point	17B	1	4		1	4.0
March's Point	18B	1	7		1	7.0
March's Point	19B	1	9		1	9.0
March's Point	20B	1	6		1	6.0
March's Point	21B	1	14		1	14.0
March's Point	22B	1	4		1	4.0
March's Point	23B	0.75	22		1.333333333	29.3
March's Point	24B	1	6		1	6.0
March's Point	25B	0.5	24		2	48.0
March's Point	26B	0.5	24		2	48.0
March's Point	27B	1	4		1	4.0
March's Point	28B	1	5		1	5.0
March's Point	29B	1	0		1	0.0
March's Point	30B	1	1		1	1.0
March's Point	31B	0.5	18		2	36.0
March's Point	32B	1	1		1	1.0
March's Point	33B	1	1		1	1.0
March's Point	34B	0.5	26		2	52.0
March's Point	35B	1	0		1	0.0
March's Point	36B	1	1		1	1.0
March's Point	37B	0.5	48		2	96.0
March's Point	38B	0.5	25		2	50.0
March's Point	39B	1	13		1	13.0
March's Point	40B	0.25	57		4	228.0

March's Point	41B	0.25	22		4	88.0
March's Point	42B	0.125	9		8	72.0
March's Point	43B	0.125	6		8	48.0
March's Point	44B	0.125	10		8	80.0
March's Point	45B	0.25	4		4	16.0
March's Point	46B	0.125	11		8	88.0
March's Point	47B	0.125	9		8	72.0
March's Point	48B	0.125	7		8	56.0
March's Point	49B	0.125	13		8	104.0
March's Point	50B	1	0		1	0.0
March's Point	51B	0.25	64		4	256.0
March's Point	52B	0.125	13		8	104.0
March's Point	53B	0.125	16		8	128.0
March's Point	54B	0.125	17		8	136.0
March's Point	1C	1	0		1	0.0
March's Point	2C	0.25	8		4	32.0
March's Point	3C	0.25	1		4	4.0
March's Point	4C	0.25	20		4	80.0
March's Point	5C	0.25	1		4	4.0
March's Point	6C	0.25	1		4	4.0
March's Point	7C	0.25	2		4	8.0
March's Point	8C	0.5	1		2	2.0
March's Point	9C	0.25	3		4	12.0
March's Point	10C	0.25	1		4	4.0
March's Point	11C	1	0		1	0.0
March's Point	12C	1	0		1	0.0
March's Point	13C	0.25	3		4	12.0
March's Point	14C	0.25	1		4	4.0
March's Point	15C	1	1		1	1.0
March's Point	16C	0.25	2		4	8.0
March's Point	17C	0.25	3		4	12.0
March's Point	18C	0.1	5		10	50.0
March's Point	19C	0.1	3		10	30.0
March's Point	20C	0.5	2		2	4.0
March's Point	21C	0.25	1		4	4.0
March's Point	22C	0.25	1		4	4.0
March's Point	23C	0.1	4		10	40.0
March's Point	24C	0.1	22		10	220.0
March's Point	25C	0.1	21		10	210.0
March's Point	26C	0.1	1		10	10.0
March's Point	27C	0.1	17		10	170.0
March's Point	28C	0.1	2		10	20.0
March's Point	29C	0.1	5		10	50.0

March's Point	30C	0.1	8		10	80.0
March's Point	31C	0.1	5		10	50.0
March's Point	32C	0.1	4		10	40.0
March's Point	33C	0.5	0		2	0.0
March's Point	34C	0.5	0		2	0.0
March's Point	35C	0.1	3		10	30.0
March's Point	36C	0.3	1		3.333333333	3.3
March's Point	37C	0.2	3		5	15.0
March's Point	38C	0.2	1		5	5.0
March's Point	39C	0.1	1		10	10.0
March's Point	40C	0.1	5		10	50.0
March's Point	41C	0.1	3		10	30.0
March's Point	42C	0.2	2		5	10.0
March's Point	43C	0.1	2		10	20.0
March's Point	44C	0.2	1		5	5.0
March's Point	45C	0.1	12		10	120.0
March's Point	46C	0.1	9		10	90.0
March's Point	47C	0.1	13		10	130.0
March's Point	48C	0.1	6		10	60.0
March's Point	49C	0.1	3		10	30.0
March's Point	50C	0.1	3		10	30.0
March's Point	51C	0.1	5		10	50.0
March's Point	52C	0.1	15		10	150.0
March's Point	53C	0.1	7		10	70.0
March's Point	54C	0.1	2		10	20.0
March's Point	55C	0.1	10		10	100.0
March's Point	56C	0.1	18		10	180.0
March's Point	1D	0.25	1		4	4.0
March's Point	2D	0.25	3		4	12.0
March's Point	3D	0.25	8		4	32.0
March's Point	4D	0.25	2		4	8.0
March's Point	5D	0.25	2		4	8.0
March's Point	6D	1.25	0		0.8	0.0
March's Point	7D	1	1		1	1.0
March's Point	8D	0.75	1		1.333333333	1.3
March's Point	9D	0.25	1		4	4.0
March's Point	10D	0.25	0		4	0.0
March's Point	11D	0.25	0		4	0.0
March's Point	12D	0.75	1		1.333333333	1.3
March's Point	13D	0.75	0		1.333333333	0.0
March's Point	14D	0.25	0		4	0.0
March's Point	15D	0.25	1		4	4.0
March's Point	16D	0.25	1		4	4.0

March's Point	17D	0.25	13		4	52.0
March's Point	18D	0.25	5		4	20.0
March's Point	19D	0.25	3		4	12.0
March's Point	20D	0.25	16		4	64.0
March's Point	21D	0.25	0		4	0.0
March's Point	22D	0.25	0		4	0.0
March's Point	23D	0.25	0		4	0.0
March's Point	24D	0.25	1		4	4.0
March's Point	25D	0.25	7		4	28.0
March's Point	26D	0.25	29		4	116.0
March's Point	27D	0.25	42		4	168.0
March's Point	28D	0.25	8		4	32.0
March's Point	29D	0.25	22		4	88.0
March's Point	30D	0.25	16		4	64.0
March's Point	31D	0.25	0		4	0.0
March's Point	32D	0.25	0		4	0.0
March's Point	33D	0.25	5		4	20.0
March's Point	34D	0.25	1		4	4.0
March's Point	35D	0.25	3		4	12.0
March's Point	36D	0.25	9		4	36.0
March's Point	37D	0.25	19		4	76.0
March's Point	38D	0.25	20		4	80.0
Crandal Spit Lagoon	1	0.1	17		10	170.0
Crandal Spit Lagoon	12	0.1	44		10	440.0
Crandal Spit Lagoon	61	0.1	8		10	80.0
Crandal Spit Lagoon	73	0.1	1		10	10.0
Crandal Spit Lagoon	26	0.1	5		10	50.0
Crandal Spit Lagoon	77	0.1	3		10	30.0
Crandal Spit Lagoon	65	0.1	4		10	40.0
Crandal Spit Lagoon	88	0.3	2		3.333333333	6.7
Crandal Spit Lagoon	54	0.2	3		5	15.0
Crandal Spit Lagoon	38	0.2	0		5	0.0
Causeway - North	29	0.1	0	6.4	10	0.0
Causeway - North	30	0.1	9		10	90.0
Causeway - North	84	0.1	2		10	20.0
Causeway - North	42	0.1	1	3.4	10	10.0
Causeway - North	5	0.1	1		10	10.0
Causeway - North	55	0.1	1		10	10.0

Causeway - North	31	0.1	4		10	40.0
Causeway - North	36	0.1	0		10	0.0
Causeway - North	53	0.2	2		5	10.0
Causeway - North	72	0.2	3		5	15.0
Causeway - North	27	0.2	1		5	5.0
Causeway - North	25	0.1	4		10	40.0
Causeway - North	24	0.2	4		5	20.0
Causeway - North	89	0.1	6		10	60.0
Causeway - North	14	0.1	5		10	50.0
Causeway - North	38	0.1	13		10	130.0
Causeway - North	35	0.2	3		5	15.0
Causeway - North	64	0.1	7	5	10	70.0
Causeway - North	80	0.1	3		10	30.0
Causeway - North	2	0.1	3		10	30.0
Causeway - North	21	0.1	3		10	30.0
Causeway - North	20	0.1	2	6.7	10	20.0
Causeway - North	6	0.1	2		10	20.0
Causeway - North	37	0.1	4		10	40.0
Causeway - North	57	0.1	1	5	10	10.0
Causeway - South	6	0.1	1	1.5	10	10.0
Causeway - South	11	0.1	6		10	60.0
Causeway - South	10	0.1	6		10	60.0
Causeway - South	1	0.1	27	5.3	10	270.0
Causeway - South	91	0.1	8		10	80.0
Causeway - South	7	0.1	1		10	10.0
Causeway - South	16	0.1	1	6.1	10	10.0
Causeway - South	31	0.1	9		10	90.0
Causeway - South	88	0.1	0		10	0.0
Causeway - South	99	0.1	0	1.7	10	0.0
Causeway - South	74	0.1	0	2.6	10	0.0
Causeway - South	69	0.1	0		10	0.0
Causeway - South	48	0.1	2		10	20.0
Causeway - South	44	0.1	5	4	10	50.0
Causeway - South	54	0.1	0		10	0.0
Causeway - South	50	0.1	2		10	20.0
Causeway - South	97	0.1	5		10	50.0
Causeway - South	67	0.1	3		10	30.0
Causeway - South	100	0.1	4		10	40.0
Causeway - South	75	0.1	2	4.8	10	20.0
Causeway - South	2	0.4	0	11	2.5	0.0
Causeway - South	3	0.1	15		10	150.0
Causeway - South	82	0.3	5		3.333333333	16.7
Causeway - South	13	0.1	7		10	70.0

Causeway - South	90	0.1	3	3.7	10	30.0
Causeway - South	8	0.2	3		5	15.0
Causeway - South	93	0.2	6		5	30.0
Causeway - South	12	0.2	2		5	10.0
Causeway - South	71	0.4	1		2.5	2.5
Causeway - South	85	0.3	0		3.333333333	0.0
Causeway - South	73	0.3	1		3.333333333	3.3
Causeway - South	59	0.3	1		3.333333333	3.3
Causeway - South	78	0.2	2		5	10.0
Causeway - South	63	0.3	1		3.333333333	3.3
Causeway - South	62	0.2	3	6.7	5	15.0
Causeway - South	51	0.2	6		5	30.0
Causeway - South	61	0.2	2		5	10.0
Causeway - South	79	0.2	4	5.3	5	20.0
Causeway - South	41	0.1	8		10	80.0
Causeway - South	98	0.1	3		10	30.0
Causeway - South	49	0.1	11		10	110.0
Causeway - South	52	0.2	3		5	15.0
Causeway - South	58	0.3	3		3.333333333	10.0
Causeway - South	46	0.1	5		10	50.0
Causeway - South	43	0.1	6		10	60.0
Causeway - South	5	0.1	0	7.5	10	0.0
Causeway - South	9	0.1	11		10	110.0
Causeway - South	4	0.1	7		10	70.0
Causeway - South	95	0.1	7		10	70.0
Causeway - South	92	0.1	5		10	50.0
Causeway - South	94	0.1	3	3.15	10	30.0
Causeway - South	83	0.1	1		10	10.0
Causeway - South	86	0.1	0		10	0.0
Causeway - South	60	0.1	0		10	0.0
Causeway - South	56	0.1	2		10	20.0
Causeway - South	65	0.1	8	8.2	10	80.0
Causeway - South	70	0.1	1		10	10.0
Causeway - South	77	0.1	4		10	40.0
Causeway - South	96	0.1	0		10	0.0
Causeway - South	32	0.1	4		10	40.0
Causeway - South	75	0.1	2	8.8	10	20.0
Causeway - South	40	0.1	1		10	10.0
Causeway - South	66	0.1	1	11	10	10.0
Causeway - South	45	0.1	3		10	30.0
Weaverling Spit	88	0.4	0		2.5	0.0
Weaverling Spit	77	0.3	0		3.333333333	0.0
Weaverling Spit	12	0.3	0		3.333333333	0.0

Weaverling Spit	73	0.3	0		3.333333333	0.0
Weaverling Spit	61	0.1	13		10	130.0
Weaverling Spit	85	0.3	0		3.333333333	0.0
Weaverling Spit	1	0.3	1		3.333333333	3.3
Weaverling Spit	54	0.1	1		10	10.0
Weaverling Spit	26	0.1	3		10	30.0
Weaverling Spit	65	0.1	5		10	50.0
Weaverling Spit	47	0.2	0		5	0.0
Weaverling Spit	11	0.1	0		10	0.0
Weaverling Spit	92	0.1	0		10	0.0
Weaverling Spit	71	0.1	0		10	0.0
Weaverling Spit	82	0.1	9		10	90.0
Weaverling Spit	3	0.1	1		10	10.0
Weaverling Spit	81	0.1	0		10	0.0
Weaverling Spit	36	0.1	0		10	0.0
Weaverling Spit	52	0.1	0		10	0.0
Weaverling Spit	70	0.1	0		10	0.0
Weaverling Spit	91	0.1	0		10	0.0
Weaverling Spit	67	0.1	0		10	0.0
Weaverling Spit	45	0.1	0		10	0.0
Weaverling Spit	66	0.1	0		10	0.0
Weaverling Spit	53	0.1	0		10	0.0
Weaverling Spit	33	0.1	0		10	0.0
Weaverling Spit	2	0.1	0		10	0.0
Weaverling Spit	80	0.1	0		10	0.0
Weaverling Spit	21	0.1	0		10	0.0
Weaverling Spit	6	0.1	1		10	10.0
Weaverling Spit	9	0.5	0		2	0.0
Weaverling Spit	10	0.1	26		10	260.0
Weaverling Spit	4	0.4	0		2.5	0.0
Weaverling Spit	68	0.4	0		2.5	0.0
Weaverling Spit	31	0.3	16		3.333333333	53.3
Weaverling Spit	24	0.6	1		1.666666667	1.7
Weaverling Spit	46	0.6	0		1.666666667	0.0
Weaverling Spit	94	0.6	0		1.666666667	0.0
Weaverling Spit	99	0.1	12		10	120.0
Weaverling Spit	86	0.5	1		2	2.0
Weaverling Spit	48	0.3	2		3.333333333	6.7
Weaverling Spit	72	0.3	2		3.333333333	6.7
Weaverling Spit	40	0.5	0		2	0.0
Weaverling Spit	64	0.5	1		2	2.0
Weaverling Spit	37	0.5	0		2	0.0
Weaverling Spit	57	0.5	0		2	0.0

Southern Sloughs	1	0.3	3	1	3.333333333	10.0
Southern Sloughs	2	0.4	0		2.5	0.0
Southern Sloughs	3	0.1	11		10	110.0
Southern Sloughs	4	0.1	7		10	70.0
Southern Sloughs	5	0.1	5		10	50.0
Southern Sloughs	6	0.1	32		10	320.0
Southern Sloughs	7	0.1	1		10	10.0
Southern Sloughs	8	0.1	27		10	270.0
Southern Sloughs	9	0.1	39		10	390.0
Southern Sloughs	10	0.1	13	2	10	130.0
Southern Sloughs	11	0.1	21	3	10	210.0
Southern Sloughs	12	0.1	12		10	120.0
Southern Sloughs	13	0.2	1	1	5	5.0
Southern Sloughs	14	0.1	17	2	10	170.0
Southern Sloughs	15	0.1	4		10	40.0
Southern Sloughs	16	0.1	19	1.5	10	190.0
Southern Sloughs	17	0.2	0		5	0.0
Southern Sloughs	18	0.2	1	0.5	5	5.0
Southern Sloughs	19	0.1	2		10	20.0
Southern Sloughs	20	0.2	1		5	5.0
Southern Sloughs	21	0.1	12	1.5	10	120.0
Southern Sloughs	22	0.1	43	1	10	430.0
Southern Sloughs	23	0.2	0		5	0.0
Southern Sloughs	24	0.3	5		3.333333333	16.7
Southern Sloughs	25	0.1	6	1.5	10	60.0
Southern Sloughs	26	0.1	2	1	10	20.0
Southern Sloughs	27	0.1	22	1	10	220.0
Southern Sloughs	28	0.2	6		5	30.0
Southern Sloughs	29	0.1	78	2	10	780.0
Southern Sloughs	30	0.2	13		5	65.0
Southern Sloughs	31	0.1	20	2	10	200.0
Southern Sloughs	32	0.1	21	1.5	10	210.0
Southern Sloughs	33	0.1	34	1	10	340.0
Southern Sloughs	34	0.1	25	2.5	10	250.0
Southern Sloughs	35	0.2	3	0.5	5	15.0
Southern Sloughs	36	0.1	79	2.5	10	790.0
Southern Sloughs	37	0.1	3	3	10	30.0
Southern Sloughs	38	0.1	14		10	140.0
Southern Sloughs	39	0.1	72	3	10	720.0
Southern Sloughs	40	0.1	3	1	10	30.0
Southern Sloughs	41	0.1	32	3	10	320.0
Southern Sloughs	42	0.3	7	0.5	3.333333333	23.3
Southern Sloughs	43	0.1	80	1.5	10	800.0

Southern Sloughs	44	0.4	0		2.5	0.0
Southern Sloughs	45	0.1	30	3	10	300.0
Southern Sloughs	46	0.1	43	4	10	430.0
Southern Sloughs	47	0.1	34	2.5	10	340.0
Southern Sloughs	48	0.1	111	2	10	1110.0
Southern Sloughs	49	0.1	103	3	10	1030.0
Southern Sloughs	50	0.1	62	3	10	620.0
Southern Sloughs	51	0.2	31	1.5	5	155.0
Southern Sloughs	52	0.1	69	2.5	10	690.0
Southern Sloughs	54	0.1	35	1.5	10	350.0
Southern Sloughs	56	0.2	37	2	5	185.0
Southern Sloughs	58	0.1	4	0.5	10	40.0
Southern Sloughs	60	0.2	3	1.25	5	15.0
Southern Sloughs	61	0.1	84		10	840.0
Southern Sloughs	62	0.1	15		10	150.0
Southern Sloughs	63	0.1	8		10	80.0
East Slough	1	0.1	78	3	10	780.0
East Slough	2	0.1	86	3	10	860.0
East Slough	3	0.1	47	5	10	470.0
East Slough	4	0.1	50	5	10	500.0
East Slough	5	0.1	31	3	10	310.0
East Slough	6	0.1	27	3	10	270.0
East Slough	7	0.1	76	3	10	760.0
East Slough	8	0.1	57	3	10	570.0
East Slough	9	0.1	45	3	10	450.0
East Slough	10	0.1	91	3	10	910.0
East Slough	11	0.1	113	3	10	1130.0