Assessing Olympia Oyster, *Ostrea lurida*, Restoration Efforts in South Slough,

Coos Bay, Oregon, U.S.A.

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ABSTRACT

To promote biodiversity and habitat complexity in the Coos Estuary, the South Slough National Estuarine Research launched an Olympia oyster (*Ostrea lurida*) restoration program in 2007. In 2012, oysters were moved to their current location on the mudflats near Valino Island and Long Island Point. The goal of this report is twofold: 1) to assess the progress of *O. lurida* restoration in South Slough, and 2) to establish baseline data for future monitoring. Data collection occurred at two restoration sites in South Slough and two reference sites in nearby Isthmus Slough and followed NOAA's standardized procedure for monitoring and assessing oyster restoration habitat, which is designed to detail the demographic and geographic characteristics of restoration beds. The data indicate the presence a single age cohort at the restoration beds and multiple age cohorts at the reference sites, suggesting the occurrence of minimal self-recruitment at the restoration beds. Oysters at the restoration sites appears to be larger than oysters at the reference sites; differences in shell size across the sites are highly statistically significant ($p < 0.001$). Survivorship and density does not appear to be correlated with bed elevation.

Background and Introduction

Olympia oysters (*Ostrea lurida*) are small bivalves that occur in the intertidal and shallow subtidal zones of Pacific coast estuaries from Southeast Alaska to Baja California (Couch and Hassler 1989; Rumrill and Bragg n.d.) (Figure 1). Shell middens suggest that *O. lurida* was historically abundant in the Coos Estuary and used extensively by indigenous people as a food source (Rumrill, 2006; "Restoration of Native Olympia", 2009). However, due to a basin-wide change in the distribution and input of fine sediments, Olympia oysters became locally extinct prior to written history (Dall, 897; Stubbs 1973; "Restoration of Native Olympia", 2009).

Figure 1. Historic range of the Olympia oyster (O. lurida) Source: Rumrill and Bragg n.d.

By 1988, discontinuous Olympia oyster beds reappeared in the Coos Estuary as the result of an incidental introduction from local commercial culture of non-native Pacific oysters (*Crassostrea gigas*) (Baker 1995; Baker et al. 2000; "Restoration of Native Olympia", 2009). Genetic similarities between Olympia oysters in Coos Bay and those in Willapa Bay, WA, suggest that the local reappearance of this species was likely the result of an introduction event from Willapa (Stick 2011). Since their reintroduction, Olympia oyster populations have stabilized and developed established beds primarily in upper Coos Estuary (Figure 2).

To promote biodiversity and habitat complexity in the Coos Estuary two main oyster restoration projects have were spearheaded in response to growing Olympia oyster populations. These projects are supported by NOAA's Community-based Restoration Program (CRP) and the National Estuarine Research Reserve System (NERRS) Science Collaborative program.

Olympia oyster restoration began in 2007 when South Slough National Estuarine Research Reserve (SSNERR) staff collected 200 *O. lurida* individuals from rip-rap near the North Bend Airport. The oysters were placed in mesh bags, hung from a floating dock at the Charleston

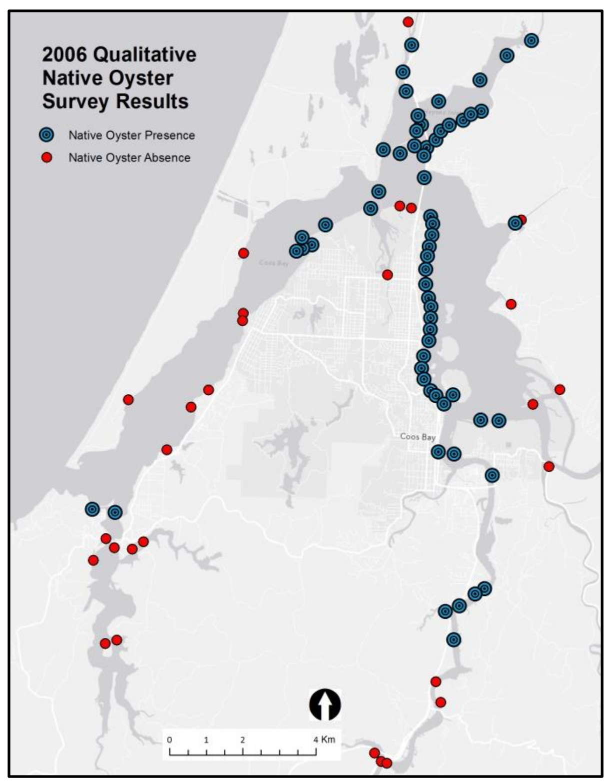

Figure 2. 2006 qualitative native oyster survey results Data: Groth and Rumrill (2009)

Distant Water Fleet Facility, and monitored. They appeared to remain in good health throughout the experiment, suggesting that Olympia oysters are able to survive in high salinity waters that are characteristic of the marine-dominated region of the Coos Estuary near South Slough.

To facilitate native oyster restoration in South Slough, SSNERR designed a “common garden” experiment involving the outplanting of Olympia oyster “clutch” (i.e., juvenile oysters) from multiple sources in the tideflats of South Slough. Oysters were to be sourced from Coos Bay as well as Willapa Bay and Netarts Bay. Willapa and Netarts were chosen based on the genetic similarities between Olympia oysters in those estuaries and locally adapted oysters in Coos Bay. Oysters were to be monitored and transferred to the Whiskey Creek Shellfish Hatchery near Netarts Bay, OR, for spawning and larval culture work. However, in July 2008, the request for the necessary Oyster Transfer Permit was denied by the Oregon Department of Fish and Wildlife (ODFW) due to tissue irregularities, focal meocytosis, and nuclear degeneration in about 12-17% of Coos specimens.

The denial of this request meant that SSNERR was unable to transport Coos oysters to the Whiskey Creek Shellfish Hatchery for spawning due to the potential for pathogen transport across different estuaries. Consequently, SSNERR modified their experimental design to include placement of oysters from different sources in mesh bags for outplantings.

During the late summer of 2008, SSNEERR obtained 22 bags of *O. lurida* clutch from the Whiskey Creek Hatchery and executed the first outplantings in South Slough by placing the bags on PVC racks in the intertidal and shallow subtidal zones near Younker Point. These bags were monitored on a monthly basis starting in January 2009. The bags were checked for sediment accumulation and epifouling organisms (e.g., colonial tunicates and hydroids), and they were repositioned or moved if necessary. In addition to the initial outplanting, 180 bags of Pacific oyster shells were placed at locations in the upper Coos estuary in late summer 2008. These bags, which were designed to collect native in-situ larvae, were placed in areas where Olympia oyster recruitment and settlement have been high for the purpose of providing settlement substrate for the planktonic larvae.

In spring 2009, SSNERR collaborated with the Whiskey Creek Hatchery to conduct broodstock work, including the spawning of adult Olympia oysters and the production of a cohort of juveniles. SSNERR received 300 bags of Olympia oyster clutch from Whiskey Creek Hatchery. These bags, which represent an estimated 4.5 million juvenile Olympia oysters, were affixed to PVC frames and deployed at Younker Point in June 2009.

Although the CRP projects were completed in 2009, SSNERR science staff members continued to monitor the shell bags. In 2012, monitoring efforts revealed that the Olympia oysters at Younker Point were being buried by sediment. As a result, the oysters were moved from Younker to Point to a more suitable location on mudflats near the south end of Valino Island and the north end of Long Island Point. The oysters were removed from the bags and scattered directly on the mudflats (Figures 3 and 4).

Continued research has been on-going in recent years. SSNERR and the Oregon Institute of Marine Biology (OIMB) are partners in several

Olympia oyster research projects supported by the NERRS Science Collaborative program. Graduate students at OIMB are currently investigating sexual development and timing of oyster larval brooding and release; mechanisms of oyster larval retention in the bay; oyster larval abundance vs. settlement throughout Coos Bay; and oyster growth and survival throughout the bay (Sawyer 2011, Oates 2013, Prichard 2013, Rimler 2014).

In addition to this research, on-going monitoring efforts are supported by SSNERR science staff and the Friends of South Slough. In summer 2014, SSNERR launched a research program designed to 1) assess the survivorship and self-recruitment performance of native oyster outplantings in South Slough, and 2) establish standardized baseline metrics for future monitoring efforts. This report details the findings of the 2014 SSNEER native oyster monitoring and assessment efforts.


Figure 4. SSNERR staff work to transfer of broodstock bags from Younker point to their new location near Valino island in 2012.

Methods

Oyster sampling occurred at two restoration sites in South Slough on intertidal mudflats near Valino Island and Long Island Point (Figure 5). Data from the restoration sites were compared against two reference sites at established Olympia oyster beds near the confluence of Isthmus Slough and Coalbank Slough (Figure 5). Data collection followed NOAA's standardized monitoring protocol for oyster restoration projects (Baggett et al. 2014). This protocol uses four "universal metrics" to assess the basic performance oyster restoration projects. The methods used for evaluating these universal metrics in the Coos Estuary are detailed below:

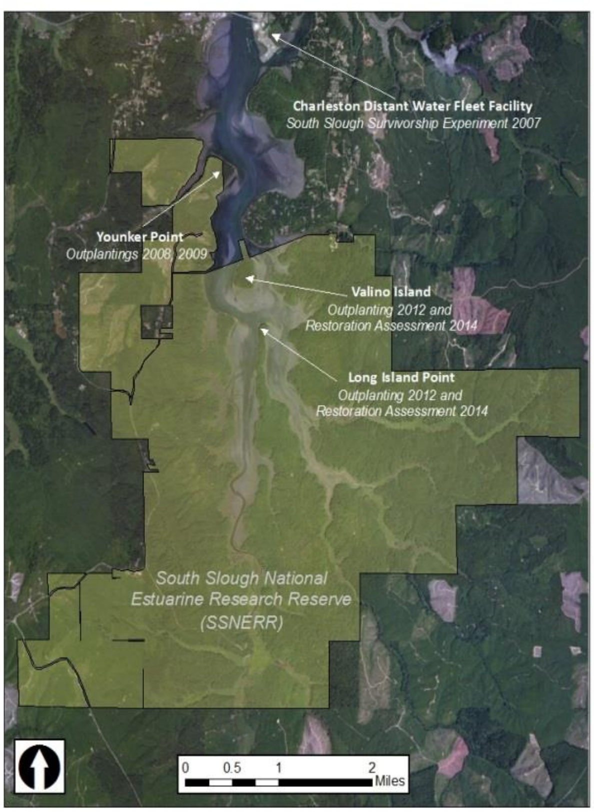

Figure 3. Location of Olympia oyster outplantings (2007-2014) and SSNERR boundaries (shaded area).

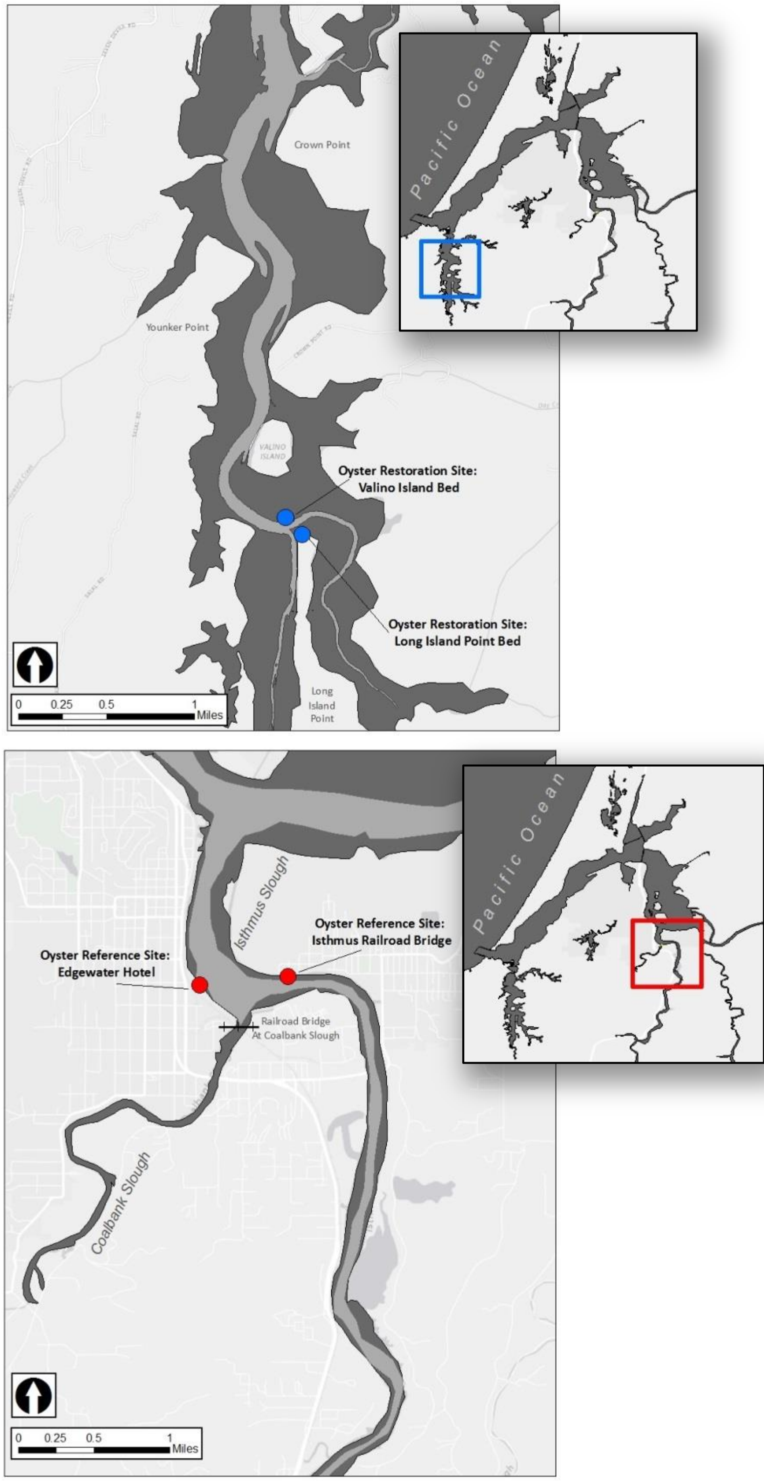

Figure 5. Location of two South Slough restoration sites (blue) and two Isthmus Slough reference sites (red)

Universal Metric #1: Areal Dimensions of Oyster Bed

The geographic area of each oyster bed was estimated using handheld GPS units. Waypoints were recorded continuously while walking the perimeter of both the bed and the project footprint (Figure 6). The project footprint is defined as the "maximum areal extent of the footprint of the [bed]" (Baggett et al. 2014). The bed area is the "actual area (summed) of patches of living and non-living oyster shell… wihin the project footprint," where the edge of the bed is defined as the "continuous line where the percent coverage of substrate… is equal to or greater than 25%" (Baggett et al. 2014).

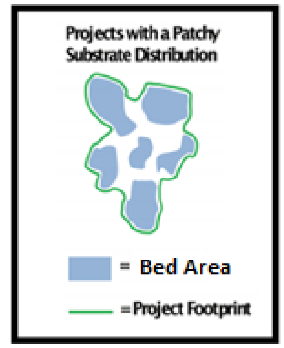

Figure 6. Conceptual diagram of bed area and project footprigs. Image edited from Baggett et al. 2014

Universal Metric #2: Oyster Shell Size

Three 10-meter transects were established at each restoration site, and samples were collected from ½ m^2 quadrats at 2 meter intervals long each transect (Figure 7). A maximum of 10 oyster shells were measured for both height and length in each quadrat (Figure 8). Height is defined as the "maximum linear distance from the umbo to the ventral shell margin" (Arnold et al. 2008). Length is the maximum linear distance across the ventral shell.

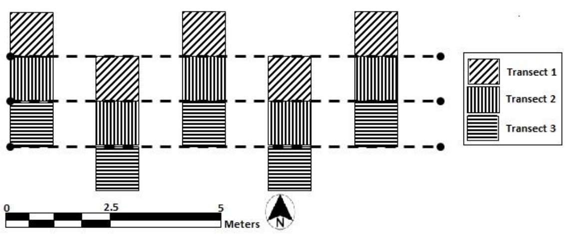

Figure 7. Configuration of sampling transects at restoration sites.

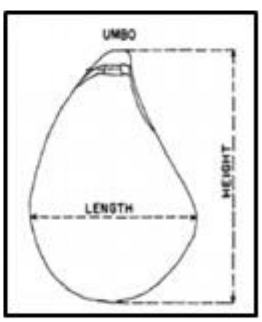

Figure 8. Shell height and length. Source: Baggett et al. 2014

Universal Metric #3: Density

One ¼ m^2 "subquadrat" was randomly selected at each shell size observation quadrat. Density (live oysters ¼ m^{-2}) was measured by counting the number of live Olympia oysters within the selected ¼ m^2. Five density observations were made on each transect at 2 meter intervals, resulting in 15 observations per bed (60 total observations across two restoration sites and two reference sites). Although dead oysters were not used to estimate density, the number of dead oysters in each ¼ $m^2$was counted to estimate survivorship.

Universal Metric #3: Bed Elevation

A perimeter was established around the oyster beds at both restoration sties by pounding four 1 ¼" PVC poles marked with orange paint into the sediment. These poles marked the four corners of the rectangle in which bed elevation data was collected. . The rectangles measured 14m X 15m (Valino) and 11m X 14m (Long Island). These dimensions were chosen, because they completely encompassed the project area at both sites.

A series of ¾" PVC poles into the sediment at 1 meter intervals along one side of the rectangle at both sites; temporary flagging was placed at 1 meter intervals along the opposite side of the rectangle. East-west transects were established by stretching a meter tape across the oyster beds from the ¾" PVC pipes to the corresponding flag on the opposite side. The e east-west transects were partitioned into 1 meter intervals, and the origin of the resulting coordinate system was placed in the southeast corner of the survey rectangle (Figure 9).

A temporary survey benchmark was established by pounding rebar into the sediment just outside the survey area. The elevation of the temporary benchmark was recorded prior to surveying the oyster beds. Data for the elevation of both the sediment and the top of the restoration substrate (including non-native Pacific oyster shells used as settlement substrate) was measured relative to the temporary benchmark using an auto level and stadia rod at each node of the of the survey grid (Figure 10). A post-survey benchmark elevation was recorded after collecting data at each node. The amount of potential error in the bed elevation data was estimated by calculating the difference between the pre-survey benchmark elevation and the post-survey benchmark elevation.

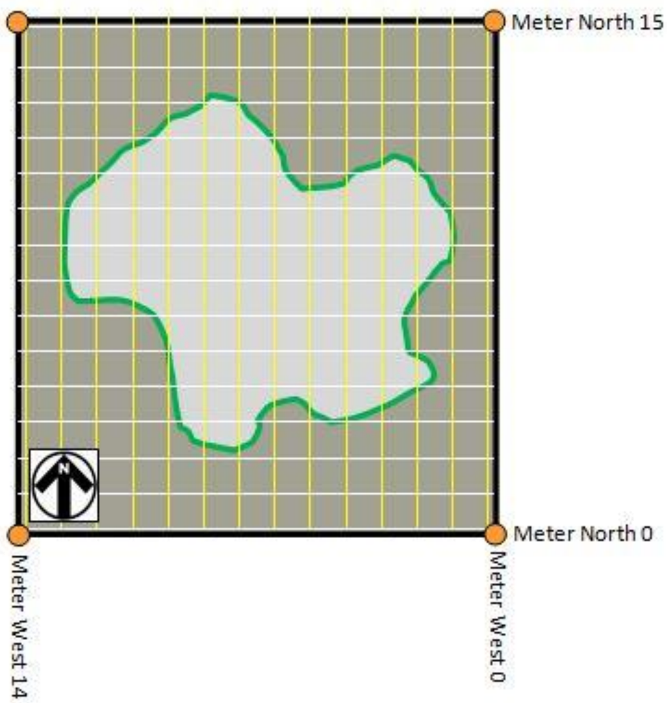

Figure 9. Diagram of bed elevation survey area at Valino. The perimeter of the survey area (black) encompasses the whole project footprint (grey), and was delineated by four 1 ½" PVC poles marked with orange paint. East-west transects (white) were partitioned into 1 meters intervals by north-south transects (yellow). Data was collected at each node of the resulting grid. The origin of the coordinate system was placed in the southeast corner of the survey area at position "(meter north 0, meter west 0)".

Figure 10. Recording bed elevation data with auto level and stadia rod

Additional Metrics

Survivorship (percentage live oysters:dead oysters m^{-2})was estimated at each ¼ m^2 subquadrat (see "Universal Metric #3: Density") by counting dead Olympia oysters in addition to live oysters. A proxy for both live and dead oysters per square meter was calculated by multiplying each ¼ m^2 observation by four.

Statistical Treatment of the Data

This report uses both descriptive and inferential statistics. Descriptive statistics are used to describe the characteristics of a subset of the population (*i.e.*, a sample). Inferential statistics are used to make inferences about the population from the analysis of a sample. This distinction is important, because some inferential statistics require assumptions about the parameters (*i.e.*, mean and variance) of the underlying or "true" distribution (Figure 11). Imposing erroneous parametric assumptions may result in misleading conclusions.

The true value of the parameters that describe the underlying size-frequency PDF of the oyster beds are unknown. Similarly, the parametric specifics of other distributions describing the oyster beds (*e.g.*, survivorship curves) are also unknown. To avoid drawing erroneous conclusions from imposing inappropriate parametric assumtions, non-parametric techniques were used to analyze data for oyster shell size and density.

Shell size data were analyzed using Kernel density estimation, a non-parametric method that estimates the probability density function (PDF) of a continuous random variable. The resulting PDFs represent estimations for continuous size-frequency distribution curves of the oyster population at each bed.

Proxies for both density (live oysters m^{-2}) and survivorship (% live oysters m^{-2}:dead oysters m^{-2}) were calculated by multiplying the value of each ¼ m^2 observation by four (*e.g.*, a field observation of 2 live oysters ¼ m^{-2} was assumed to correspond to approximately 8 live oysters m^{-2}). There data were analyzed using a bootstrap resampling technique, which uses an iterative process to generate 2,000 density and survivorship observations from the existing sample.

An estimate for the total population (live Olympia oysters) of both restoration beds was also calculated. Mean density estimates (live oysters m^{-2}) from field observations were used in this calculation. Lower and upper bound population estimates were calculated using the confidence intervals that were constructed from the bootstrap resampling described above. Survivorship was estimated for both restoration beds by averaging all 30 survivorship observations.

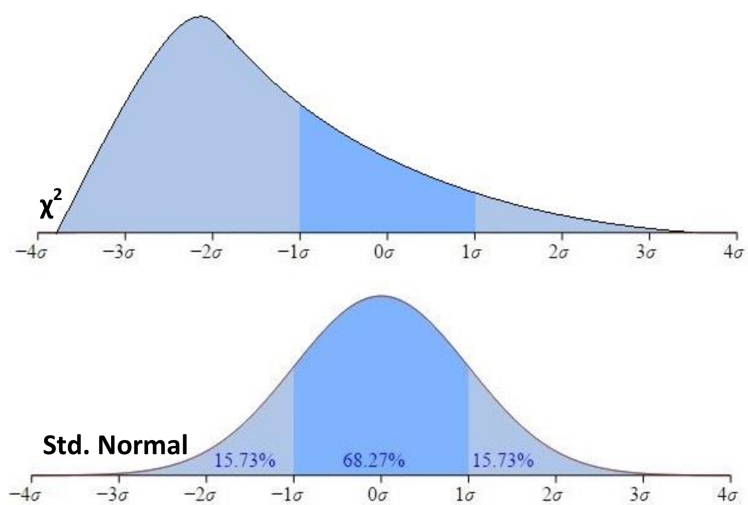

Figure 11. Probability density functions (PDFs) for the χ^2 (top) and standard normal distribution (bottom) distributions. The area within ±1 standard deviation (σ) of the mean (0σ) is highlighted in dark purple. The PDF describes the distribution of data in terms of percent likelihood that a random variable will take on a given value. For example, the parameters of the standard normal distribution dictate that 68% of the data fall within ±1σ. This particular characteristic may not be applicable to other PDFs (*e.g.*, χ^2). Imposing erroneous assumptions about the shape of a PDF may result in misleading inferences about the population. Non-parametric statistical tests allow for analysis when the true shape of the PDF is not known.

Results

Geographic Characteristics

Figure 12 reports the approximate position of center of the project areas as well as the estimated bed dimensions for all four sites. Generally, the beds at the reference sites are characterized by small and/or non-contiguous bed areas (*i.e.*, areas with > 25% shell coverage) within a relatively large project footprint. The oyster beds at the two restoration sites have large bed areas relative to comparatively small project footprints.

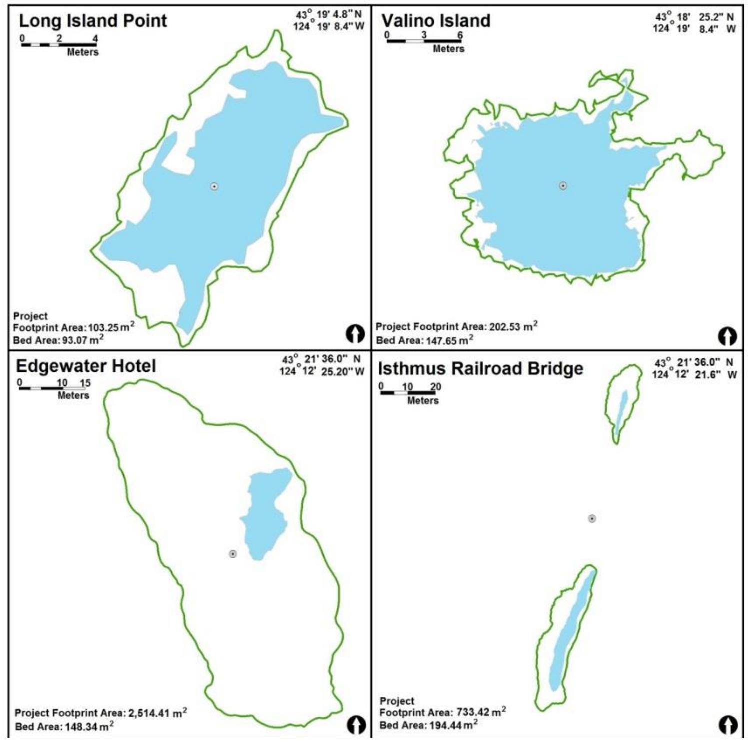

Figure 12. Geographic characteristics of two restoration beds (top) and two reference beds (bottom). The project footprint (green) is represented along with bed area (blue). The approximate position of the center of the (grey dot) is reported in degrees, minutes, seconds (upper right) along with the estimated size of each bed (lower left). Scales are not consistent across quadrants. Reference the scale bars in the upper left corners for scale information.

The sediment at the Valino restoration site slopes southward towards the channel (Figure 13). Sediment elevation ranges from ~1.5 - 2.1m below the elevation of the backsight. Shell elevation at the Valino site averaged ~10cm above sediment elevation, with the highest average shell heights occurring near the middle of the bed at approximately (meter north 7, meter west 7) (Figure 14).

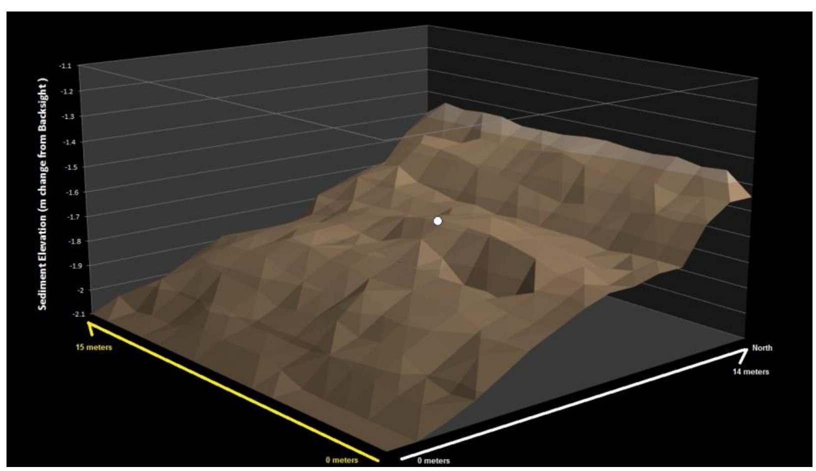

Figure 13. Representation of sediment relief at Valino restoration site. Approximate position of highest average shell height is represented by the white dot.

Demographic Characteristics

A total of 281 shell size observations were made at the reference sites, 196 shell size observations were made at the restoration sites. Table 1 summarizes descriptive statistics for shell size sampling at the reference sites as well as the restoration sites.

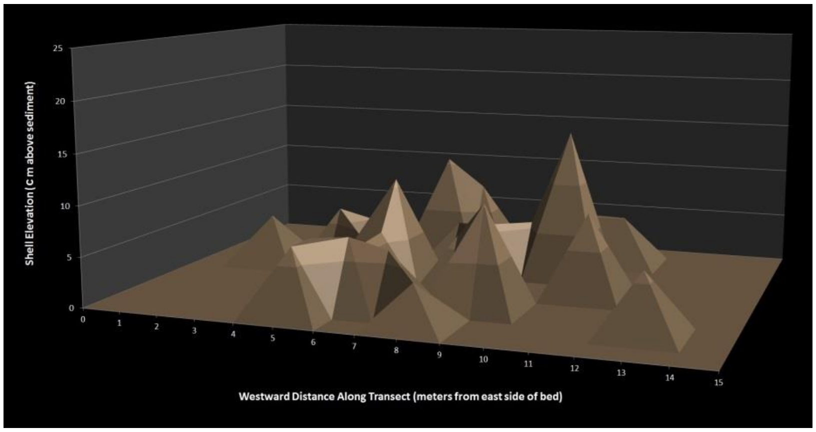

Figure 14. Shell-top elevation at Valino restoration site. Westward distance along transect is represented along the length axis. Northward distance is on the depth axis, which the leading edge being the southernmost edge of the bed (meter north 0).

Table 1. Summary statistics for shell size sampling at reference (N=281) and restoration (N=196) sites.

	N	Mean	Min	Max	Std. Dev.
Edgewater Hotel					
Shell Height	136	21.8	16	52	4.8
Shell Length	"	29.2	14	37	8.5
Isthmus Railroad Bridge					
Shell Height	145	30.6	10	49	8.7
Shell Length	"	25.2	9	39	6.4
All Reference Sites					
Shell Height	**281**	**27.1**	**10**	**52**	**7.8**
Shell Length	**"**	**26.3**	**9**	**39**	**8.3**
Long Island Point					
Shell Height	90	44.9	16	57	8.7
Shell Length	"	37.1	16	58	7.4
Valino Island					
Shell Height	106	40.3	27	59	6.9
Shell Length	"	36.5	22	54	5.7
All Restoration Sites					
Shell Height	**196**	**36.9**	**16**	**59**	**8.1**
Shell Length	**"**	**42.8**	**16**	**58**	**6.5**

Shell heights ranged from 10 – 52mm (reference sites) and 16 – 59mm (restoration sites). The mean shell heights of the samples were ~ 27mm (reference sites) and ~ 37 (restoration sites). Length observations varied between 9 – 39mm (reference sites) and 16 – 59mm (restoration sites). The mean shell length was ~ 26mm (reference sites) and ~ 43 (restoration sites).

Kernel density estimations for the continuous size-frequency PDF of oysters in the reference sites ranged between approximately 10 – 55mm, while PDF estimations for the restoration populations ranged from about 15 – 62mm (Figures15 and 16). The estimated mean size (both height and length) of oysters at the reference site appears to be smaller than the mean size of the restoration population (see Discussion).

A total of 60 oyster density (live oyster m^{-2}) and 54 survivorship (% live oysters m^{-2}:dead oysters m^{-2}) observations were recorded. Tables 2 and 3 summarizes descriptive statistics for density and survivorship sampling at the reference sites as well as the restoration sites.

Oyster density was ranged from 0-72 live oysters m^{-2} (reference sties) and 0-80 live oysters m^{-2} (restoration sites). Mean density was higher at the reference sites (~29 live oysters m^{-2}) than the restoration sites (~17 live oysters m^{-2}). Similarly, mean survivorship was marginally higher at the reference sites (~54%) than the restoration sites (~51%).

A distribution of 2,000 randomly generated mean density and survivorship estimates suggests that both mean density and mean survivorship are may be higher at the reference sites than they are at the restoration sites (Figure 16). Bootstrap analysis suggests with 95% confidence that the true mean density of the population between ~10-33 live oysters m^{-2} at Valino Island and ~2-23 live oysters m^{-2} at Long Island Point (Table 2).

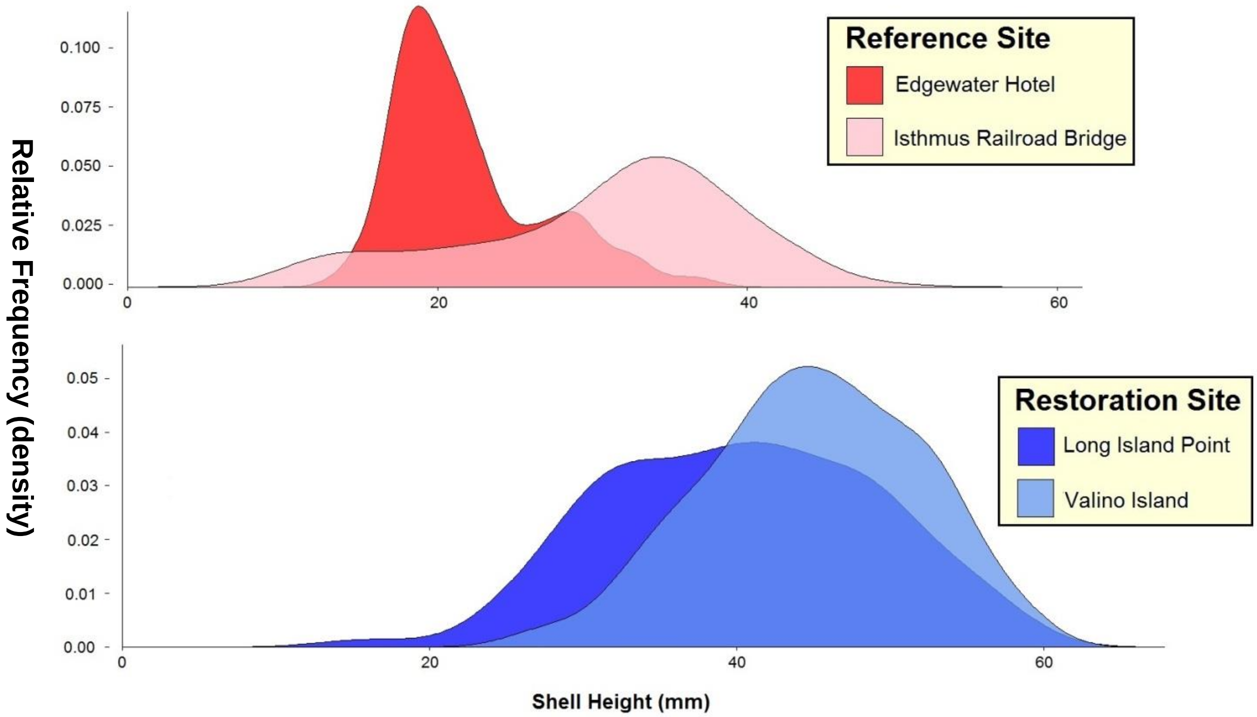

Figure 14. Estimation of size-frequency distribution of oyster shell height at reference (red) and restoration (blue) sites). Vertical axis measures "density," a statistical concept that indicates frequency.

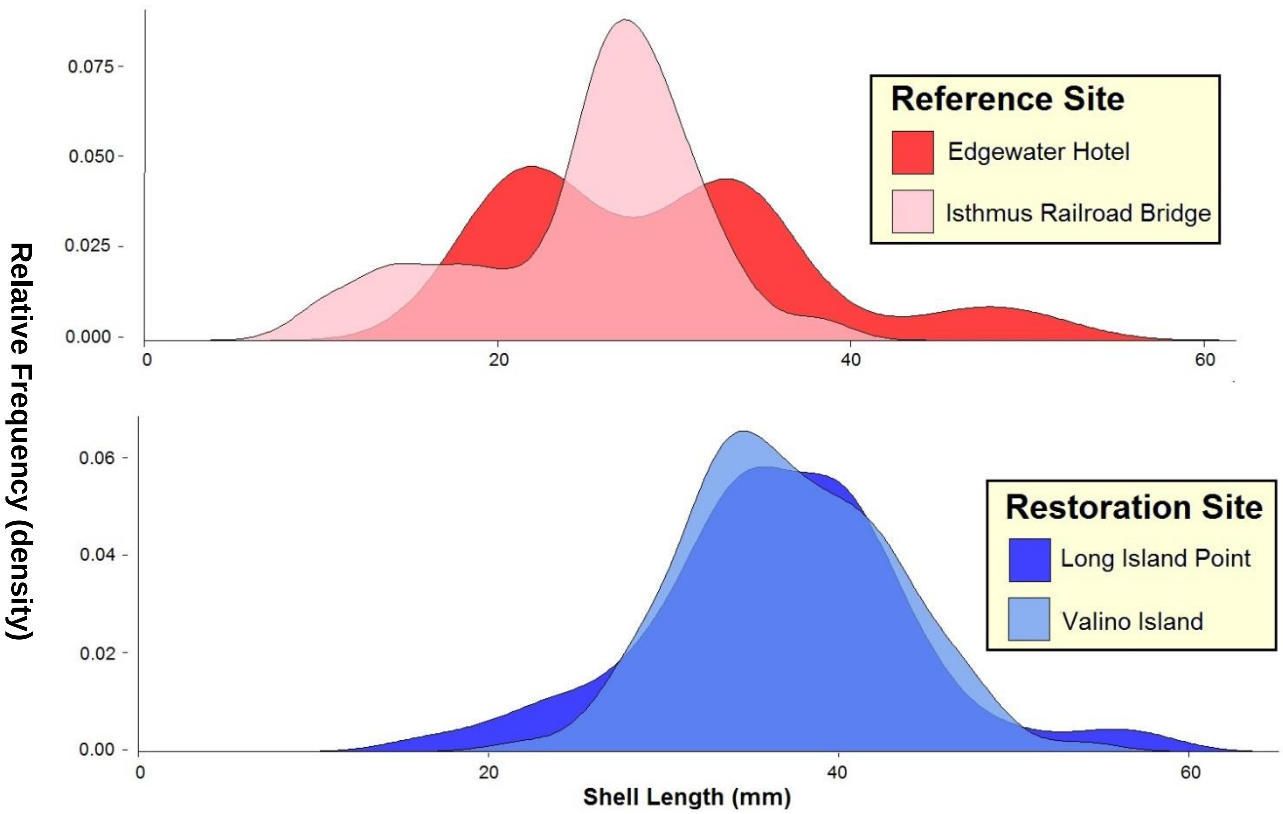

Figure 15. Estimation of size-frequency distribution of oyster shell length at reference (red) and restoration (blue) sites).Vertical axis measures "density," a statistical concept that indicates frequency.

Table 2 Summary of density (live oysters m^{-2}) from sampling (left) and bootstrap resampling (right). Confidence intervals from bootstrap resampling are interpreted as the interval on which the true population means lies with 95% confidence (e.g., the true average density of the population of oysters at the Valino Island bed is between 10-33 live oysters m^{-2} with 95% certainty.

	Statistics from Sample					Bootstrap Confidence Intervals (α=0.05)	
	N	Mean	Min	Max	Std. Dev.	Lower Bound	Upper Bound
Valino Island	*15*	*21.9*	*0*	*76*	*23.32*	*10.41*	*33.1*
Long Island Point	*15*	*12.3*	*0*	*80*	*20.37*	*2.21*	*22.57*
All Restoration Sites	**30**	**17.1**	**0**	**80**	**22.06**	**9.31**	**24.66**
Isthmus Railroad Bridge	*15*	*29.3*	*4*	*72*	*21.63*	*18.38*	*39.77*
Edgewater Hotel	*15*	*28*	*0*	*56*	*17.44*	*19.74*	*36.8*
All Reference Sites	**30**	**28.67**	**0**	**72**	**19.31**	**21.96**	**35.38**

Table 3. Summary of survivorship (% live oysters m^{-2}:dead oysters m^{-2}) from sampling (left) and bootstrap resampling (right). Confidence intervals from bootstrap resampling are interpreted as the interval on which the true population means lies with 95% confidence (e.g., the true average density of the population of oysters at the Valino Island bed is between 10-33 live oysters m^{-2} with 95% certainty.

	Statistics from Sample					Bootstrap Confidence Intervals (α=0.05)	
	N	Mean	Min	Max	Std. Dev.	Lower Bound	Upper Bound
Valino Island	*12*	*63.4*	*0*	*100*	*31.6*	*46.1*	*80.6*
Long Island Point	*13*	*38.6*	*0*	*76.9*	*27.9*	*24.2*	*53.4*
All Restoration Sites	**25**	**50.5**	**0**	**100**	**31.7**	**38.6**	**62.9**
Isthmus Railroad Bridge	*15*	*50.7*	*11.1*	*100*	*25.0*	*38.0*	*63.2*
Edgewater Hotel	*14*	*58.0*	*33.3*	*77.8*	*14.3*	*50.9*	*65.1*
All Reference Sites	**29**	**54.2**	**11.1**	**100**	**20.5**	**47.0**	**61.7**

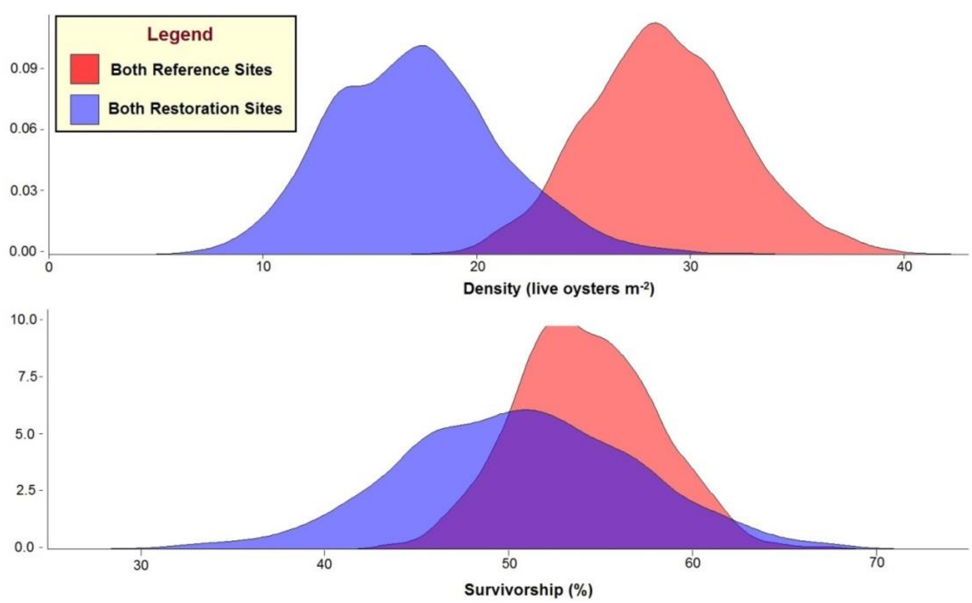

Figure 16. Distribution of mean values for density (top) and survivorship (bottom) at reference sites (red) as well as restoration sites (blue). Data are generated from from bootstrap resampling proceedured (N=2,000). Vertical axis measures "density," a statistical concept that indicates frequency.

Disscussion

Assessing Self-Recruitment Performance and Analysis of Demography

The shapes of the size-frequency curves may evidence of self-recruitment patterns. A poly-modal shape (*i.e.,* a distribution with multiple central tendencies) is assumed to indicate multiple age cohorts and, therefore, greater self-recruitment; a unimodal shape was assumed to be correlated with minimal self-recruitment (Figure 17).

The estimated size-frequency curves for the restoration beds appear to be unimodal, while

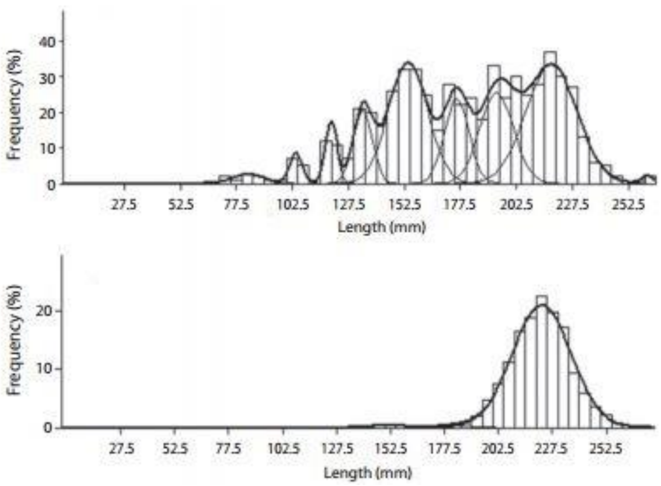

Figure 17. A poly-modal PDF (top) indicates the presence of multiple age cohorts, while a unimodal PDF (bottom) suggests a single age cohort. Source: Cárdenes and Aranda 2014

the curves for the reference sites are bimodal (Figures 14 and 15). This suggests the presence of a single age cohort at Long Island Point and Valino Island and is assumed to correspond to minimal self-recruitment. It's important to note that this is not to be interpreted as the *absence* of new recruits. While collecting shell size data, there were a few instances in which Olympia oysters were observed growing on top of other Olympia oysters (Figure 18). During the genesis of this oyster restoration project, Pacific oyster shells were used as settlement substrate for Olympia oyster clutch. Consequently, the observation of Olympia oysters growing on top of other oysters of the same species is fairly concrete evidence that some self-recruitment exists. However, this self-recruitment may be minimal.

Figure 18. An Olympia oyster growing on top of another oyster of the same species may indicate that some self-recruitment exists at the restoration sites, albeit at minimal levels.

The estimated mean size (both height and length) of oysters at the restoration site appears to be larger than the mean size of the reference population. This is evidenced by the rightward shift of both the shell height and shell length PDFs (Figures 14 and 15).

There is strong evidence to suggest that the apparent difference in the mean size of these two groups is, in fact, statistically significant. The Mann-Whitney U Test is the nonparametric counterpart to an unpaired t-test. Both of these tools test for statistically significant differences between two groups of independent data. The Mann-Whitney U Test generates a test statistic, with high values corresponding to low p-scores and high significance. The test statistic for shell length was 46,719.5 (p <0.001) and for shell height it was 50,214.5 (p<0.001). The interpretation of this result is that the "average" Olympia oyster at the restoration sites is statistically highly likely to be larger than the average oyster at the reference sites.

To examine any potential relationships between bed elevation, survivorship, and/or other demographic characteristics (*i.e.*, shell size), the approximate position of density and survivorship data collection stations were matched to the nearest bed elevation transect (Figure 19).

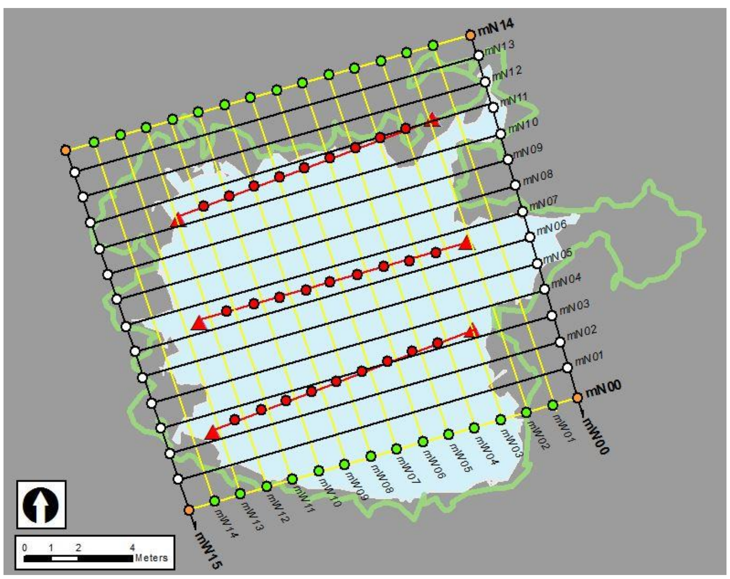

Figure 19. Conceptual diagram showing the location of shell size and survivorship/density observations (red), relative to the grid established by the bed elevation transects. Data for shell size, survivorship, and density was correlated with bed elevation by pairing observations with data from the closest transect (*e.g.*, the southernmost red transect may be matched with bed elevation taken along meter north 03).

Regressing each demographic characteristic individually on bed elevation reveals no immediately apparent linear relationship, suggesting that survivorship, density, and shell size may not be correlated with bed elevation.

Table 4. Output of linear models regressing demographic characteristics on bed elevation reveals no apparent statistical relationship.

	N	R	p-value
Density	15	0.12	0.19
Survivorship	15	0.05	0.45
Shell Length	106	0.03	0.09
Shell Height	106	0.03	0.09

Limitations and Suggestions for Future Research

This technical report establishes baseline demographic and geographic values that are an essential foundation for continued monitoring of South Slough oyster restoration sites. However, since this is the first monitoring effort, it is difficult to discern if time series trends exists, because there is no historic standard of comparison. Continued monitoring is needed to understand how Olympia oyster beds in South Slough are changing over time.

Estimates for parameters detailing the characteristics of these beds are statistically rigorous. However, many of them (*e.g.,* density) are generated from resampling simulations, because the sample size was not sufficiently large enough to estimate confidence intervals from the raw data. Larger sample sizes will increase the "efficiency" (*i.e.*, narrow the confidence intervals) of these estimators.

The data suggest that oysters in South Slough are larger on average than reference oysters. They further indicate that mean density and survivorship appear to be lower at the restoration sites than at the reference sites

(Figure 16). More research is needed to understand if these two demographic differences are correlated (*e.g.*, through difference selection mechanisms, food availability regimes, *etc.*).

The findings also suggest that minimal self-recruitment exists at the restoration sites. This conclusion produces a series of corollary research questions regarding, for example, the productivity of Olympia oyster beds in South Slough, differences across habitats in different parts of the Coos estuary, the behavior of larvae originating from South Slough beds, etc.

There is no apparent link between bed elevation and any measure of survivorship or shell size. The relationship between these variables was recovered by working backwards to pair bed elevation with demography information. Specifically, the approximate position of each sampling stations was mapped and paired with nearby bed elevation transects. These methods allow for the examination of corrolarary research questions without explicitly designing an experiment to examine the potential links between bed elevation and deomography. However, since the data were generated handheld GPS units and paired using best professional estimates during post-processing, the methods may involve up to several meters of error. A more precise understanding of the relationship between bed elevation, shell size, and survivorship can be achieved by implementing an experiment specifically designed to examine these relationships.

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