

The Nature Conservancy of Washington

Liberty Bay Oyster Habitat Enhancement

2007 Two-Acre Shell Placement

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Introduction

This report summarizes the results to date of a 2007 project to enhance settlement habitat for the native Olympia oyster (*Ostrea conchaphila*) in Liberty Bay, Puget Sound.

In recent years, identification and assessment of native oyster (*Ostrea conchaphila* or *O. lurida*) populations have been a focus of interest by the Washington Department of Fish and Wildlife and the public as habitats for these native shellfish have declined in many parts of their historic range. Native oyster beds may be important ecologically by providing habitat for a host of animals and plants that require the provision of hard and emergent substrates or otherwise complex habitat in environments that are otherwise composed of soft sediments. Provisions of complex, hard substrates generally enables the settlement of a diverse variety of invertebrates and marine plants different than soft substrate assemblages, and include bivalve mollusks, annelids, crustaceans and a host of other sessile species. Fishes, including salmonids, and mobile invertebrates may also be attracted to the food resources that recruit to and or are associated with hard substrate environments that are otherwise rare or unavailable. In addition, native oyster beds may contribute to water column clarity via feeding activities (e.g. filtration and concentration of seston followed by deposition of biodeposits) resulting in localized sedimentation and changes in patterns of nutrient cycling including increased coupling of nutrients between the water column and the benthos. It has been long recognized that healthy shellfish populations provide critical habitat attributes, and enhancement activities associated with native oyster populations in west coast estuaries are generally seen as sound management strategies.

Intact, native oyster populations are generally depleted in much of their former range in Puget Sound as extensive changes in land use and near shore habitats due to increased urbanization have occurred, likely limiting distribution of native oysters to remnant pockets where habitat characteristics remain favorable. Native oyster populations are important to document with respect to their abundance, aggregate density, reproductive and recruitment status on an annual basis and habitat requirements relating to temperature, sediments, pollutants and other factors that may impact their longevity over time. In addition, it is similarly important to document the occurrence of other invertebrates, fishes and plants that colonize and/or otherwise utilize the habitat provided by oysters and substrates placed on intertidal sites (e.g. Pacific oyster shell cultch) that enable native oyster settlement on a seasonal, annual and long-term basis. Information on these patterns is necessary to evaluate the enhancement at a functional ecological level over various spatial and time scales.

Background on the Scandia Site

In 2004, Washington Department of Fish and Wildlife (WDFW) and Puget Sound Restoration Fund (PSRF) personnel conducted a survey of intertidal sites in Liberty Bay, near the village of Poulsbo, Washington that contained beds of remnant Pacific oyster shell that had persisted following the cessation of commercial oyster culture activities in 1992. Scattered piles of Pacific oyster shell were observed on the tideland occupied by a

population of native oysters that included multiple age classes. This discovery stimulated a series of substrate enhancement projects in the ensuing three years based on the understanding that intertidal oyster populations in Liberty Bay were likely limited by the availability of hard substrates for settlement and subsequent recruitment.



Figure 1. Scandia habitat enhancement. The treatment plots are surrounded by unstructured or minimally structured, muddy sand beach.

A pilot shell enhancement project completed in 2005 on 0.15 acre resulted in the development of a healthy native oyster bed consisting of multiple year classes with oyster density currently estimated in excess of 90 oysters m^{-2} , a result that helped prompt WDFW biologists to recommend expansion of enhancement efforts to approximately 10 acres adjacent to the initial project site.

Enhancement activities in Liberty Bay are being conducted on portions of a 46-acre site owned by Washington Department of Fish & Wildlife that has been set aside for native oyster enhancement; see Figure 2. A second pilot project in 2006 conducted on $\frac{1}{2}$ acre was also successful as oysters became established at this site. Surveyed in spring 2007, the second pilot project's mean native oyster density was estimated at 14 live oysters m^{-2} . Of the 46 acres owned by Washington State, 10 acres are considered ideally suited for native oyster enhancement by virtue of tidal elevation and evidence of oyster recruitment on shell material left on site by previous commercial oyster aquaculture operations.

In June 2007, The Nature Conservancy and Puget Sound Restoration Fund undertook to enhance an additional 2+ acres within the 10-acre Scandia site in partnership with NOAA, the US Navy, USDA, the Suquamish and Squaxin Island Tribes and other partners. This project is being conducted as part of Puget Sound Restoration Fund's Memorandum of Agreement with WDFW to enhance native oyster habitat through December 31, 2012. It should be noted that Liberty Bay was identified for native oyster production by McMillan (1931) and in the years since the Bay's shorelines have been significantly altered through extensive urbanization on the east and north sides of the bay. On the Scandia side of the bay, less intrusive land use changes have occurred though the shoreline adjacent to enhancement sites are extensively built out with homes, docks and bulkheads present. In addition, Liberty Bay appears to support extensive plankton blooms, generally observed from late spring through late September, significantly affecting visibility and other water quality parameters (J. Davis, personal observations 2005-2007). Nonetheless, significant recruitment of native oysters has occurred on

substrate enhanced sites located adjacent to the NOAA/TNC site. With the success of the two pilot projects, The Nature Conservancy (TNC), PSRF and their multiple partners undertook to enhance an additional 2 acres at the site in 2007.

Habitat Enhancement

Native oyster stock-rebuilding at the 10-acre Scandia site is conducted in accordance with a PSRF Memorandum of Agreement (MOA) with WDFW to “enhance native oyster habitat through December 31, 2012”. On this and other select beaches in Puget Sound, PSRF has experimented with habitat enhancement as a native oyster stock-rebuilding technique. Using seasoned Pacific oyster shell (cultch), this material is placed on the benthic surface to provide emergent settlement substrate to oysters. Habitat enhancement at this location allows native oysters to re-occupy historic habitats while also minimizing impact to the heterogeneity of local populations. The objective of these enhancements is to catalyze repeated juvenile recruitment and to enhance benthic conditions to facilitate adult survival. The long-term goal is a functional, self-sustaining native oyster bed in the lower intertidal zone of this beach. We expect the expansion of the native oyster bed would increase the ecosystem services of Liberty Bay. Based on observations of the remnant shell piles and previous pilot projects, the enhancement plots will continue to recruit native oysters for years to come. With this two-acre shell enhancement, completed in 2007, we increased the amount of available oyster habitat over 200% to three acres. The work on the remaining 7 acres at the Scandia site began in the spring of 2008. The Nature Conservancy received a grant from NOAA to fund additional oyster habitat enhancement on 5 acres in 2008/9, and PSRF completed a two acre shoreline cleanup on the beach in 2008.

The empirical evidence to date suggests that structure, not larval production, is the limiting factor in the return of Liberty Bay’s historic native oyster population. Current and future enhancement activities are therefore intended to reestablish a sufficient concentration of oysters to ensure successful settlement, reproduction and long-term sustainability.

Project Area

The specific location of the 2007 NOAA/TNC project is situated in the tidal waters of Liberty Bay, Washington, northwest of Pearson Point in Kitsap County: Section 22, Township 26 North, Range 01 East WM (Figure 2). The site is composed primarily of lower intertidal mudflats located between approximately –1.0 ft. and –3.5 ft. elevation (MLLW datum) and consists almost entirely of soft substrates interspersed with piles of remnant shell consisting mostly of native and introduced clam shell.

The 2-acre enhancement site in Scandia, Liberty Bay is part of a larger tideland owned by the Washington Department of Fish & Wildlife that has been set aside for native oyster enhancement. As indicated previously, 10 acres of this tideland are considered ideally suited for native oyster enhancement by virtue of tidal elevation and evidence of oyster recruitment on shell material left on site by a previous commercial operation.

The plot is generally positioned adjacent to the 2006 enhancement and the new 2008 enhancement plot. Each successive project continues north where the previous project ends. The GPS positions for the 2007 2-acre enhancement plot are (in WGS 84):

SW corner	N 47°43'23.9"	NW corner	N 47°43'28.5"
	W 122°39'20.6"		W 122°39'27.3"
SE corner	N 47°43'23.3"	NE corner	N 47°43'28.7"
	W 122°39'22.8"		W 122°39'22.9"

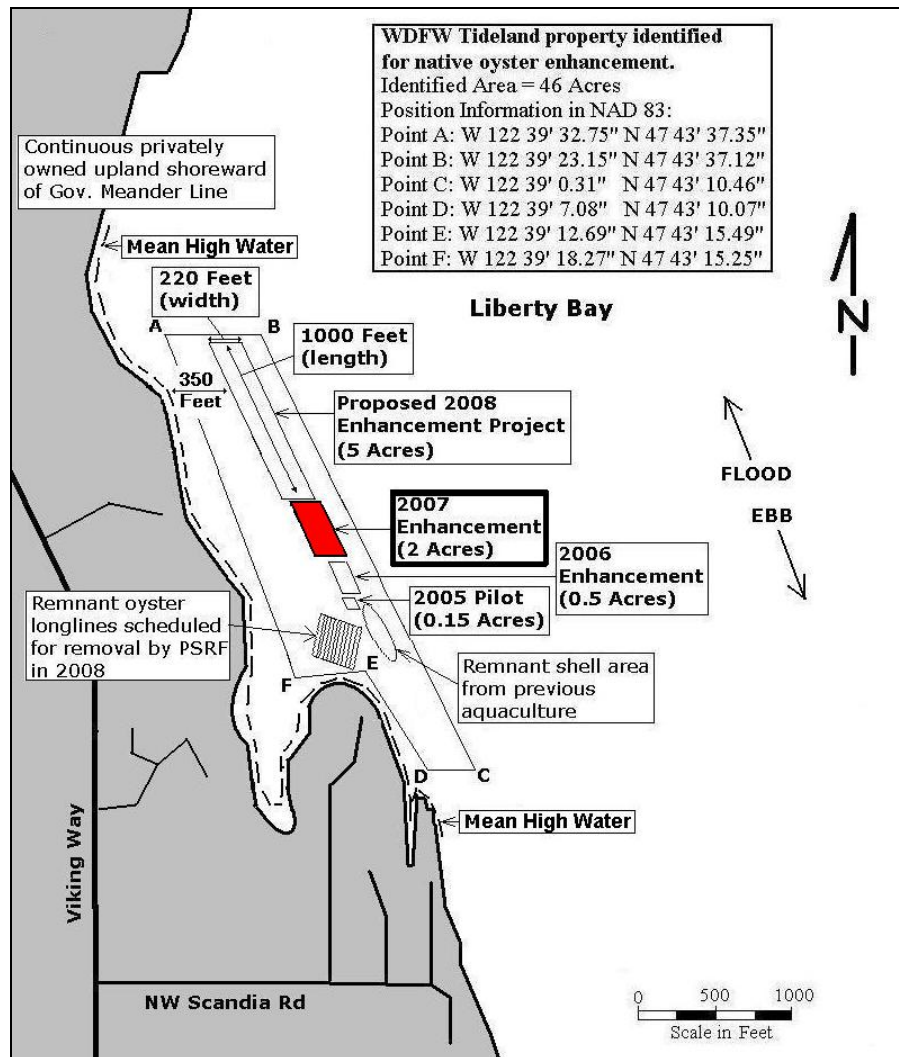


Figure 2. Scaled schematic of the Scandia Shoreline. Red shade indicates the location of the 2007 enhancement plot relative to the larger project area identified by WDFW.

Scope of Work

The objectives, as identified in The Nature Conservancy's NOAA grant, were as follows:

1. Enhance two acres of habitat in Liberty Bay's lower intertidal zone to promote native oyster larval recruitment, thereby increasing water filtration and providing complex habitat for invertebrates and fish.
2. Involve a minimum of 4 partners representing tribal, state, U.S. Navy, and local interests.
3. Publicize project activities with a minimum of 2 articles in local and regional newspapers.
4. Monitor project site to quantify native oyster settlement and associated invertebrates and fish that recruit to enhanced habitat.
5. Disseminate results of monitoring to interested parties through organization networking or professional conferences.

To accomplish the first objective, a series of tasks were identified by PSRF and Dr. Joth Davis of Baywater Inc. Those tasks and approximate implementation/completion dates are listed below.

Task #1 Identify boundaries of 2-acre restoration area & control plots (April 2007)

Task #2 Secure all necessary permits and site access permission (June 2007)

Task #3 Conduct Pre and Post restoration data collection (larvae, temperature, and recruitment sampling) (April-October 2007 & 2008)

Task #4 Coordinate shell transport and placement (June 2007)

The treatment and control plot boundaries were identified and marked during the first daylight low tides of 2007 in early April. The permitting and permissions identified in Task #2 are discussed in the following section. To complete Task #3, there were six concurrent monitoring efforts planned for the 2007 NOAA/TNC enhancement site. They were:

1. Temperature profiling to help assess relationships between seawater temperature patterns, gametogenesis and spawning behavior in native oysters.
2. Plankton sampling for presence of oyster larvae in the water column.
3. Benthic survey prior to placement of cultch materials in Liberty Bay to record the presence of infaunal organisms.
4. Epibenthic sampling of shell enhanced sites in Liberty bay for meiofauna associated with oyster shell substrates.
5. Underwater video assessment of substrate enhanced sites in Liberty Bay to assess for the presence and use of sites by fishes and mobile invertebrates.
6. Survey native oyster recruitment on 2007 enhancement site to monitor settlement and growth following placement of substrate materials.

Permits

All permits/exemptions were obtained prior to the project start date of June 1, 2007, including:

- U.S. Army Corps of Engineers: Nationwide Permit #4
- Department of Ecology: 401 Water Quality Certification (not required for #4 Nationwide Permits issued prior to March 2007)
- NOAA/NMFS: Endangered Species Act consultation (for projects receiving federal funds) for potential impacts to Chinook salmon, Bull Trout, and Bald Eagles
- NOAA/NMFS: National Historic Preservation Act consultation (for projects receiving federal funds) for potential impacts to significant scientific, cultural, or historical resources
- US Navy license to operate on Navy property using Navy equipment
- Washington Department of Fish & Wildlife: Hydraulic Project Approval (HPA)
- Washington Department of Fish & Wildlife: Memorandum of Agreement to conduct native oyster enhancement activities on tidelands owned by WDFW.
- Washington Department of Fish & Wildlife: Transfer Permit for cultch placement
- Kitsap County: Shoreline Substantial Development Permit Exemption
- Port of Poulsbo - moorage for oyster skiff

Each of these permits or permissions is discussed in detail below.

US Army Corps of Engineers – Nationwide Permit #4

On May 23, 2006, Puget Sound Restoration Fund received a 2-year Nationwide Permit #4 to distribute up to 1,300 cubic yards of Pacific oyster shell on Liberty Bay tidelands near Scandia in order to enhance settlement substrate for Olympia oysters on tidelands owned by Washington Department of Fish & Wildlife. The permit covers enhancement activities conducted in 2006 and 2007.

NOAA/NMFS: Endangered Species Act consultation

In May 2006, NOAA Restoration Center staff reviewed the project and "determined that the proposed activities are eligible for inclusion under the Biological Opinion," and not likely to jeopardize ESA-listed salmonid species in the Pacific Northwest. Puget Sound fall Chinook are presumed to use this nearshore environment for rearing prior to ocean migration. However, the site is not located in proximity to a Chinook natal delta, and so is not assumed to be a high use area. (See NOAA Restoration Center concurrence). An additional determination from NOAA and USFWS indicated that the project was "Not likely to adversely affect" bald eagles. WDFW bald eagle biologist Shelly Ament was consulted and mitigation measures adopted, since a nest had been identified 800 -1,000 feet from the project work area. USFWS concluded that the nest was not likely to be occupied in early June 2007, and that the pump noise (used to spread the oyster shell)

was not likely to disturb the nest, since work would occur while fledglings are feathered and “less sensitive” to disturbance (see USFWS concurrence).

NOAA/NMFS: National Historic Preservation Act consultation

With regard to Historic Preservation Act requirements, NOAA Restoration Center staff determined that “the action is not anticipated to cause ground disturbance and so does not have the potential to affect archaeological resources.” To qualify for funding through USDA’s Wildlife Habitat Incentives Program, an archaeologist employed by the Natural Resources Conservation Service visited the site June 6, 2007 and also determined that the project was unlikely to cause disturbance. Similar shell placement actions were reviewed and found to have no potential to affect cultural resources at this location.

Kitsap County – Shoreline Substantial Development permit exemption

An exemption from Kitsap County was received April 6, 2007. The project was determined SEPA-exempt at the County level. A notice was posted near the project site in accordance with described procedures.

WDFW – Hydraulic Project Approval and Determination of Non-significance

WDFW issued a Hydraulic Project Approval June 1, 2007, authorizing work to occur prior to the opening of the fish window on June 15th only if Brady Blake with WDFW was present to ensure that no salmonids were in the project area during the work. WDFW determined that this proposal would have no probable significant adverse impacts on the environment. Therefore, an environmental impact statement (EIS) was not required under RCW 43.21C.030(2)(c). This determination of non-significance (DNS) was made after review of the environmental checklist and other information on file. This information was made available to the public on request for a 15-day period.

WDFW Memorandum of Agreement – extended through December 31, 2012)

Puget Sound Restoration Fund has a Memorandum of Agreement with WDFW to conduct native oyster enhancement at this site. In February of 2007, the MOA was extended through December 31, 2012 in order to qualify for funds through USDA (WHIP).

WDFW Transfer Permit for cultch placement

Taylor Shellfish Farms, from whom the shell was purchased, has an annual permit applicable to all transfers from their cultch piles. Annual inspection of the cultch pile by WDFW certifies the shell to be free of fine sediments and marine organisms.

US Navy License

PSRF obtained a license from the US Navy in order to operate on Navy property (Keyport pier) using Navy equipment (barge and tugs). The in-kind value of the Navy's donation of property and equipment to the project will be "banked" and used as mitigation in the event of an oil spill on Navy property. Use of the pier, a 110' x 30' barge and various tugs was scheduled in advance with Navy Region Northwest Port Operations and Keyport staff.

Port of Poulsbo – moorage for oyster skiff

Kirk Stickles, Port Manager, authorized the use of free dock space March through October of 2007, then again in 2008. An oyster skiff moored at the Port of Poulsbo commercial "D" dock will be used to shuttle project staff and visitors to the enhancement site for the purpose of conducting implementation and monitoring activities.

Implementation

In June 2007, 900 cubic yards of whole Pacific oyster shell was distributed on 2 acres of tidelands to enhance habitat for native oysters. Shell purchased from Taylor Shellfish Farms was transported in dump trucks to a high-security pier located at Keyport Underwater Naval Warfare Center. Upon delivery to the pier, an excavator transferred 450 cubic yards of shell – the limit for each barge load - from the pier to the 110' x 30' material barge on loan from the U.S. Navy. Once loaded, a U.S. Navy tug escorted the barge to Scandia and anchored the barge offsite in deeper water in order to avoid prop damage to the substrate.

To spread the shell within the enhancement plot itself, Jim Hayes, with Hood Canal Oyster Company, tied the bow of his oyster boat to one end of the barge (Figure 3) and maneuvered the barge to the enhancement plot and then back and forth within the enhancement plot. Meanwhile, a high-powered pump borrowed from the Squaxin Island Tribe was used to spray shell off the deck of the barge to achieve a shell



Figure 3. Hood Canal Oyster Co.'s scow is tied to the stern and pushing the Navy barge. The water pump (operated by Betsy Lyons of TNC) is also visible on the right tied to the material barge.

depth of approximately 3-5 inches. The spreading was scheduled to ensure that at least five feet of water covered the enhancement plot at all times – both to facilitate movement by boat and avoid disturbance of the substrate. Once a load of shell was spread, the Navy tug returned to escort the barge back to the Keyport pier for the next load.

The project was scheduled to coincide with the natural spawning cycle of the Olympia oyster in Liberty Bay, since larval oysters are more likely to recruit to clean oyster shell than oyster shell that has been in the water and fouled with other marine organisms.

Conformance with Permit Conditions

- Work was accomplished as specified in federal and state permits.
- Brady Blake with WDFW was onsite to observe and approve the shell placement.
- Monitoring conducted in October 2007 confirmed that the shell remained within the designated enhancement plot, and that no shell had migrated substantially outside the plot.
- The depth of the shell treatment did not exceed 8 inches.
- No entrainment of fishes was observed during shell distribution.
- The shell was distributed in 4 days spanning a 2-week period (June 7, 8, 14, 15).
- No eelgrass was present at the site.
- No disturbance of eagles was observed during the project implementation, and the spreading activities were limited to a 5-hour period on the days identified above.

Monitoring

The NOAA/TNC project specified a number of monitoring objectives during 2007-08 that included an evaluation of benthic conditions both before and following shell enhancement. The regular monitoring of temperature, plankton, epibenthic meiofauna, benthic infauna, fish and macro invertebrates was managed by Baywater Inc. In addition, PSRF organized the monitoring of the shell plot for native oyster settlement on and/or utilization by other organisms. Listed below are the sampling schedule and some protocol for each of the monitoring efforts managed by Baywater Inc. Each of the methodologies will be described later in detail.

Temperature profiling

Water temperature was monitored to assess correlation between water temperature and oyster spawning. A Hobo logger, recording every 15 minutes, was downloaded bi-weekly from April to September.

Plankton sampling for oyster larval presence in the water column
(Every 2 weeks from April to September)

Sediment/Benthic Survey

Sediment cores will be collected at pre and post-restoration intervals within the restoration area and at control plots. 15cm cores will be collected using a 0.01 m² cylindrical corer, along transect oriented perpendicular to the shoreline. Samples will be sieved at 0.5mm and preserved in 10% formalin. Each sample will be catalogued and keyed to order or family.

- In March 2007, 3 cores will be taken each in the restoration area and at a control site for a total of 6 cores.
- In March 2008, 3 cores will be taken each in the restoration area and at a control site for a total of 6 cores.

Epibenthic Survey

This survey will quantify the types and amount of epibenthic fauna including copepods, amphipods and other crustaceans, found pre- and post-restoration. Using an epibenthic suction pump, samples will be collected over shell piles. All species will be identified to at least genera and archived. Sampling will be done monthly both onsite over enhanced shell plots and on off-site control plots on adjacent mud flats.

- Monthly from April - September 2007
- Monthly from April-September 2008

Underwater video

To document pre- and post- restoration use of the habitat by fishes and mobile invertebrates, quantitative sampling will be conducted using an underwater vid3eo cameral mounted on a temporary longline or cable that runds back and forth along a set transect that crosses representative habitats (control and enhanced). This method will allow fish, crabs and larger mobile invertebrates to be documented per unit in a repeatable, non-destructive, non-intrusive way. (Video surveys will be done every two weeks from April to September 2007 and April to September 2008.)

Temperature profiling

Variability in ambient temperature is arguably among the most critical parameters structuring native oyster recruitment patterns and subsequent survivorship of individuals and ultimately local oyster populations. The placement of Pacific oyster cultch on tidelands for the purpose of building native oyster populations in areas that were a part of the original range of this species needs to take into account the physiological tolerances of native oysters prior to making decisions about how and where to precisely place cultch materials. Native oysters are sensitive to temperature extremes with mortalities associated with high temperature during periods of aerial exposure during summer low tides and freezing temperatures during winter low tides, respectively being particularly harmful (Quayle, 1969). Improper placement of cultch materials subsequently utilized by swarms of pediveligers for settlement may ultimately contribute to recruitment failure and local extirpation if environmental conditions are not optimal for the long term health of the

population. Early research on native oyster larval behavior indicated that oysters would readily settle in higher intertidal areas if habitat (e.g. diked tidelands holding a lens of seawater and substrate materials) were available (Hopkins, 1937). Oyster growers noted as well that native oyster settlement often occurred in the higher intertidal portions of diked tidelands. Whether native oysters regularly colonize upper intertidal habitat is not well documented though small populations in pocket habitat (shaded depressions with seawater seepage) are regularly observed in the upper portions of southern Puget Sound bays (Justin Taylor, Taylor Shellfish Farms, Inc., personal communication, 2008). Additionally, small oyster populations in high intertidal pools and associated lagoons are regularly observed, as well (e.g. Discovery Bay, mill pond). Temperature variation on an annual basis and its relationship to tidal height, moisture and shade are factors that likely significantly influence long term survivorship of native oysters in reconstructed, intertidal habitat and a better understanding of the precise environmental conditions that characterize constructed habitats is needed.

Temperature profiling for the NOAA/TNC 2-acre enhancement site was accomplished by installing a HOBO continuous temperature data logger (Onset Computer Corporation) on the tidal flat in contact with the mud shell substrate surface adjacent to the restoration site at an approximate -1.4 ft. tidal height below Mean Lower Low Water (MLLW) on April 1, 2007 with continuous recording occurring through November 13, 2008 (additional temperature loggers remain on site to maintain continuous recording for this and other sites in the immediate area). The logger was programmed to record temperature at 15 minute intervals continuously with data downloads made on-site utilizing an infrared coupling device (ONSET HOBO Waterproof Shuttle); the temperature record includes 96 discreet recording events per 24 hour period over an annual period. A variety of analyses may be made utilizing this data.

Mean daily high tide temperature for this site was calculated for both 2007 and 2008 as the average of the two daily-recorded high water seawater temperatures adjacent to the enhancement site. Mean daily high tide data is useful to help predict both spawning and spat fall events for native oyster populations in the vicinity. Observations made on similar habitats in Puget Sound suggest that native oysters typically initiate spawning behavior during neap tides following the period that mean daily seawater temperatures regularly exceed 12-13 °C with a predicted spat fall occurring during neap tides 30 days later (various WDF Oyster Bulletins from 1950's and PSRF observations). In addition to mean high tide temperature profiling, mean daily and mean weekly tidelands temperature profiles were computed. These measurements take into account both warming and cooling of the tidelands during low tide periods. A long term record of annual differences between average tidelands temperature and the average temperature at high tide when coupled with data on annual oyster recruitment, survivorship and individual growth rates yield an annual benchmark of the overall physiological suitability of the site for native oyster restoration. The annual comparison of daily mean temperature with daily mean high tide temperature enables an analysis of site specific variability in temperature extremes on a temporal basis to be related to native oyster presence, viability, growth, reproductive status or other biological or physiological features.

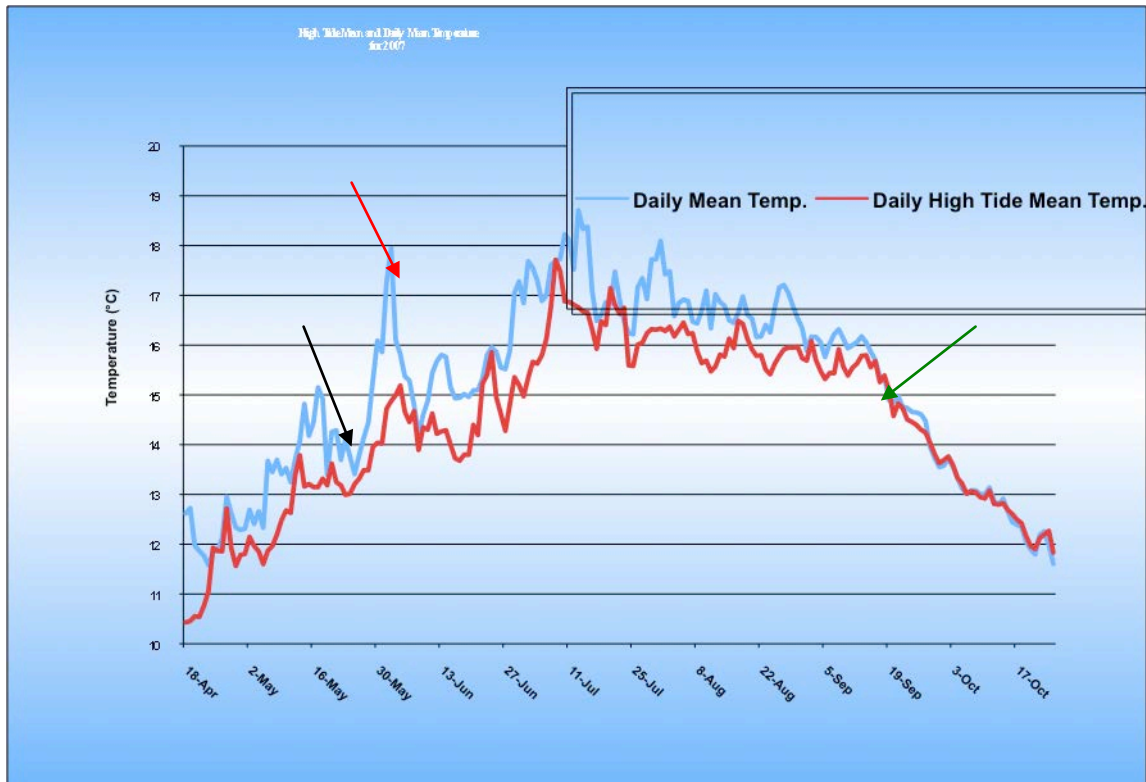


Figure 4. Temperature data for Liberty Bay in 2007 (April – October) plotted as the mean daily tideland temperature and the mean seawater temperature at high tide. Red arrow indicates a series of dates occurring during a spring extreme low tide series. Black arrow points to corresponding period of neap tides. The green arrow indicates a period corresponding to late summer lower amplitude tides, generally.

Temperature records for Liberty Bay in 2007 and 2008 indicate both similarities in annual summertime tidelands and mean high water temperature patterns as well as interannual variability (Figures 4 and 5). An annual temperature record (weekly mean) for the Liberty Bay enhancement site is indicated in Figure 6. The mean tidelands temperature exceeded 18.5 °C in mid July in 2008. A similar temperature peak was noted in early July, 2007 when mean tidelands temperature exceeded 18 °C for a number of days (see Figure 4). Overall, temperature records indicate an overall warmer tidelands environment in 2007 compared to 2008 over the same period. In fact, a significant cooling in mean tidelands and mean high water temperatures occurred in the first half of June, 2008 at a time when larvae would be predicted to be in the water column (see Figure 5 and 6 and plankton monitoring record below).

In both 2007 and 2008 the annual high temperatures for the year occurred in late June through early July with a clear differential between mean daily temperature and mean temperature at high water during extreme tides in spring and summer 2007. Specifically, beginning in May and extending through August 2007 the disparity between mean daily temperature and mean high tide temperature increased as daylight low tides intensified in amplitude through the spring and early summer (Figure 4). At Liberty Bay's mid Puget Sound location, low tide occurs at mid-day and temperatures may often exceed 30 °C on the tidal flats; the greater the disparity between the daily mean temperature and daily high tide temperature indicates the increased likelihood for stress due to heat and possibly

desiccation to impact intertidal oyster populations. This approach also identifies neap tidal periods when spawning and settlement is suspected to occur. The temperature record clearly indicates when mean temperature disparity is minimized as lower amplitude tides begin to dominate in later August and September, a time when oysters are either less exposed to warm air temperatures during early morning low tides or are infrequently uncovered. Similarly, the disparity in mean daily temperature during late fall and winter months, when low tides occur in the late evening and early morning hours, may be a predictor of increased stress associated with temperatures that may regularly dip below 0 °C.

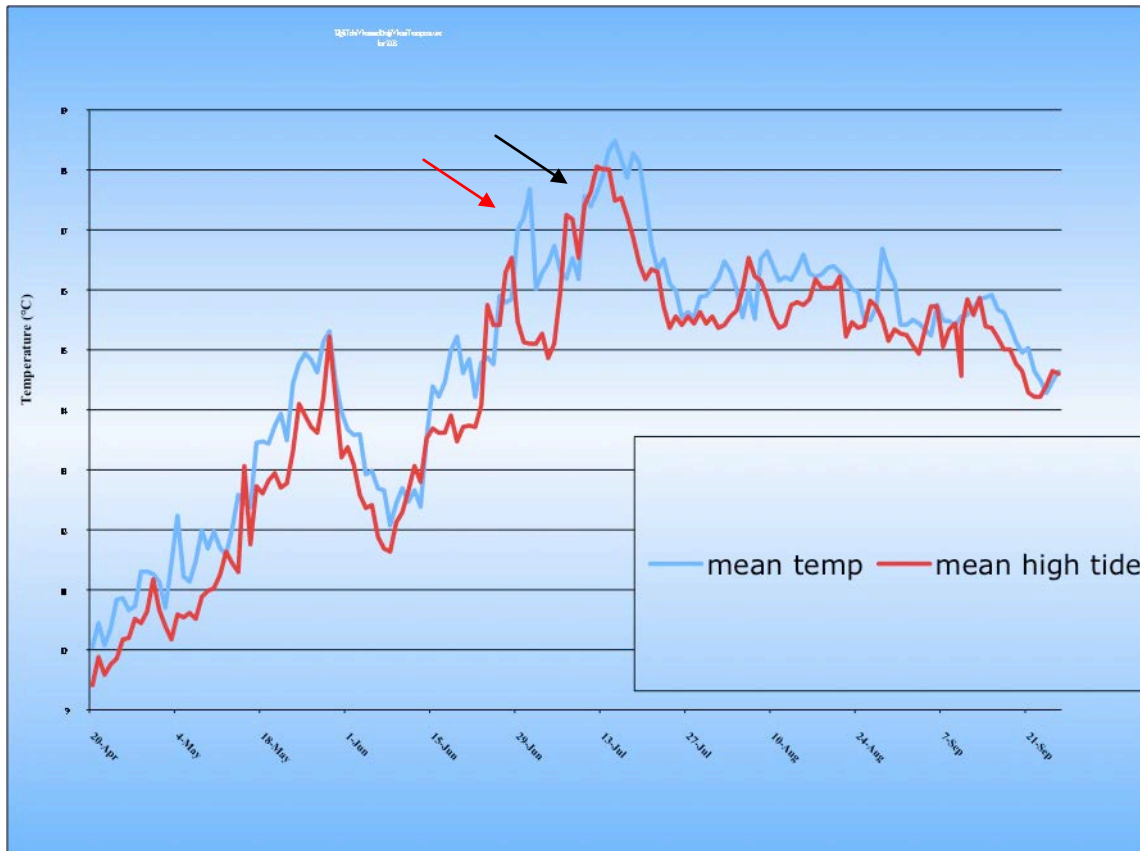


Figure 5. Temperature data for Liberty Bay in 2008 (April –September) plotted as the mean daily tidelands temperature and the mean seawater temperature at high tide. Red arrow indicates an extreme low tide series occurring in late June and early July. Black arrow points to corresponding period of neap tides in later July.

Further work is necessary to integrate temperature records over suitable time scales (e.g. months and years) to assess the suitability of restoration sites for future oyster enhancement efforts, however the disparity between mean daily water temperature and mean daily water temperature at high tide may be a simple yet useful basic indicator for assessing specific sites for their suitability for oyster substrate enhancement. As native oyster enhancement and restoration efforts proceed in Washington State, temperature records analyzed in this manner may be of considerable use in helping to define specific tolerances and or capacities for oysters to thrive in optimal habitats as well as persist in suboptimal habitat (these may be linked spatially as projects are developed where

substrate may inadvertently be distributed sub optimally). As restoration efforts proceed, it is important to have the metrics available that help enable restoration efforts to succeed. These include the assessment of growth rates and gametogenesis including evidence for spawning and/or brooding to discern whether oysters that may settle in fringe habitat remain a part of otherwise ecologically and genetically viable populations. Also, as global climate change threatens a warming of North Pacific ocean waters among other impacts in the years ahead, long term temperature tolerance records will be essential to compile for specific sites with reference to documenting the longevity of enhanced oyster populations.



Figure 6. Mean weekly tidelands temperature record for Liberty Bay NOAA/TNC native oyster enhancement site. Significant downtrend in mean weekly tidelands temperature in early June 2008 occurred at a time when native oyster larvae were predicted to be in the water column. Red line indicates 13 °C temperature threshold. See text for explanation.

Sampling plans for 2009 include utilizing additional data being collected from temperature loggers previously placed in the field at different tidal heights on intertidal oyster plots in Liberty Bay. Micro-scale differences in temperature associated with aerial exposure, proximity to tidal seeps crossing shell enhanced beds and degree of emergence above the tidal flat may all influence ambient annual temperature exposure. In addition, sampling and research plans include constructing “artificial” oysters that have small temperature logging buttons imbedded in their “tissues.” These are constructed by filling empty oyster valves with silicone sealant. Prior research has demonstrated that the biological properties of cured silicone sealant are very similar to living oyster tissues

(Andrew Gracey, University of Southern California, personal communication). Artificial oysters will be placed on different parts of the TNC 5-acre and 2-acre oyster shell plots in early 2009. We hope to utilize this approach and therefore better emulate the thermal conditions living oysters actually experience and yield information on oyster bed growth and longevity with reference to fine-scaled annual temperature variation.

Plankton sampling for presence of oyster larvae

Plankton sampling for the presence of native oyster larvae was accomplished in 2008 at approximate 2-3 week intervals between April and September, 2008. Methods for collecting water samples included pumping a known volume (100 L) of seawater from approximately 1 foot above oyster shell substrates through a 100 micron mesh nytex screen at the mid-point of the 2 acre TNC plot during high water. In practice this was accomplished by suspending a 12 volt bilge pump attached to 1" diameter hosing marked at 12" intervals above the oyster plot. Samples were pumped from just above the oyster shell plot through the sampling sieve. Calibration of the pumping rate was accomplished for each sampling date by measuring the time to fill a 20L bucket just prior to sample collection. The time required to pump 100L was easily computed and replicate samples collected and either returned to the laboratory and examined within 12 hours or preserved in the field by adding formalin in a ratio of 1:9 formaldehyde in filtered seawater. In one case when the sampling pump was not available, sampling was accomplished by towing a weighted net (100 micron mesh size) over the shell enhanced plot. Preserved samples were allowed to settle prior to examining using a stereomicroscope (Zeiss Stemi DV4). Live samples were sampled qualitatively as the primary objective was to identify for the presence of larvae of native oysters. In practice, without the aid of QPCR techniques (see below), it will only be possible to identify bivalve larvae generally as no definitive, routine method works for the positive identification of live, native oysters (*Ostrea conchaphila*). A developing technique based on the observation of behavioral differences among larvae and their response to disturbance was utilized during the latter half of the sampling season when live samples were available for examination. In this case, it has been noted that native oyster larvae observed swimming in the water column (e.g. seawater holding on a glass microscope slide) will drop out of the water column briefly when the slide is gently tapped, only to resume swimming shortly thereafter. Other oyster larvae (e.g. Pacific oysters) tend to not show this behavioral response (personal communication, Brian Allen (PSRF) from Alan Trimble (UW)).

Based on 2008 temperature records, mean high water seawater temperature consistently exceeded 12.5 °C on May 18 and persisted through June 6th. Following about a week of cooler ambient temperatures when mean high water seawater temperature dipped below 12.5 °C (June 7-12), seawater temperatures again exceeded 12.5 °C for the remainder of the summer (Figures 5-6). Based on this data, oysters in the region would be predicted to initiate brooding during the neap tide series following (May 26th through May 30th) with a predicted spatfall 30 days later during a similar neap tide series (June 24 –June 28). The influence of a brief period of reduced mean seawater temperature during June 7-12 on spawning or brooding behavior is not known, however as noted above and based on this

simple model, the onset of cooler weather would have occurred as larvae were either being brooded in female oysters or recently spawned.

Results of sampling for the presence of native oysters are presented in Table 1. Sampling was initiated on May 11, 2008. Mechanical problems with the sampling boat precluded regular sampling in early June but regular sampling occurred at approximate 2-3 week intervals over the remainder of June through early September.

Table 1. Results for pumped plankton samples examined for the presence of native oyster larvae in 2008.

<i>Date</i> <i>*live sample</i>	<i>Mollusk</i> <i>larvae</i>	<i>Native</i> <i>oyster</i> <i>larvae</i>	<i>Barnacle</i> <i>nauplii</i>	<i>Decapod</i> <i>larvae</i>	<i>Annelid</i> <i>larvae</i>	<i>Calanoid</i> <i>copepods</i>
5/11/08	5	0	X	X	X	X
5/18/08	0	0	numerous	X	X	X
5/27/08	0	0	numerous	X	X	
6/23/08	2	0	numerous		X	X
7/6/08	3	0				X
7/13/08	5	0				X
7/25/08	3	0				X
8/8/08*	0	1(putative)				X
8/24/08*	0	0				
9/10/08*	0	0			X	X

Results of plankton sampling were generally inconclusive with few molluscan larvae observed overall and no definitive identification of native oysters. Barnacle nauplii dominated samples in May and early June with numerous decapods, other crustacean larvae and annelids as well as copepods observed regularly. Live samples were obtained in August and September, 2008. A single native oyster larva (based on the behavioral response to tapping) was observed in the 8/8/08 sample.

In 2009 we plan to continue a comprehensive sampling program utilizing a PCR based quantitative approach to water column sampling initiated in 2006 through collaboration with the University of Washington School of Aquatic and Fishery Sciences (SAFS). We anticipate initiating sampling for oyster larvae in spring and summer 2009 with focused collections of plankton utilizing plankton pumps in different parts of Liberty Bay. We plan to subsequently assess for the presence of native oyster larvae using QPCR molecular techniques. Sampling will commence when brooding is first observed in reference oysters obtained on site. This approach should yield better resolution and an overall more accurate assessment for the presence of native oyster larvae in the plankton and hopefully provide insights on the geographical distribution of larvae in this area prior to the settlement phase.

Benthic survey post-placement

Sampling for the presence of infaunal animals was accomplished for the NOAA/TNC 2 acre enhancement plot on June 7, 2008. Sampling consisted of taking 3 replicate benthic cores (core diameter = 10.16 cm; core depth = 15.24 cm; core volume = 1,235 cm³) along two transects during low tide. Transect 1 was established within the 2-acre shell plot at a tidal height of approximately -2 ft. below MLLW. A control transect was established above the shell plot in muddy substrates at a tidal elevation of approximately 0.0' tidal height. For each transect, three randomly determined sampling points were identified along an approximate 10-meter long line demarked on the tideflat. Sediment samples were taken by inserting a PVC coring device into the substrate and removing all sediment (including infaunal animals). The shell plot samples were obtained after first removing all oyster shell and associated fauna on the surface prior to inserting the coring device into the underlying substrate. Samples (three per transect) were placed into numbered plastic baggies and returned to the laboratory. Samples were subsequently rinsed through a 2000-micron sieve. Biological material was either processed immediately or preserved in 10% seawater buffered formalin and stored in 70% ETOH prior to taxonomic assessment using appropriate taxonomic keys including a newly developed reference collection for polychaetes.

The biomass recovered in core samples consisted largely of bivalve mollusks and various polychaetes. Deposit feeding clam abundance dominated the organisms recovered for the control transect while few organisms were observed in samples obtained within the shell plot. Shell plot samples consisted mainly of buried oyster shell. Sampling results for control (offsite) and oyster plot cores are presented in Table 2. With respect to infaunal organisms, the relative abundance of organisms sampled in the control plot suggests a shift in abundance based on the presence of large quantities of buried substrate materials observed on the experimental plot relative to the total biomass of materials sampled. The tubicolous polychaete *Owenia fusiformis* dominated the infaunal biomass for the three cores sampled in the control transect. This was the same species observed in abundance in 2007 core sampling in the same area. Clearly, the placement of oyster shell substrates has the potential for decreasing benthic diversity immediately below the layers of emergent shell substrate. Also, it was noted that the cores sampled within the shell plot uniformly consisted of largely anoxic sediments as the materials were black in color and were accompanied by the odor of hydrogen sulfide. It is apparent that the placement of oyster shell substrates has the effect of potentially disrupting benthic communities over the immediate to intermediate (12 month) time frame. These are preliminary results and further work to better assess sediment characteristics, including changes in sediment grain size over time and variability in sediment redox potential (an indicator of anoxia in sediments) are anticipated for addition to monitoring activities in 2009 for the 5-acre TNC site.

Table 2. List of observed invertebrates in transects sampled in 2008 for the NOAA/TNC 2-acre restoration site.

<u>Transect 1 (0' MLLW) 10 meter length</u>	<u>Species Observed</u>	<u>Quantity/Shell Length of Bivalves</u>
Control Sample 1	<i>Glycera americana</i>	1
	<i>Owenia fusiformis</i>	15
	<i>Macoma nastuta</i>	14mm, 23mm
	<i>Clinodardium nutalii</i>	54mm
Control Sample 2	<i>Glycera americana</i>	2
	<i>Owenia fusiformis</i>	12
	<i>Nereis procera</i>	2
	<i>M. nastuta</i>	11mm, 44mm, 18mm
	<i>Tapes phillipinarum</i>	28mm
Control Sample 3	<i>Owenia fusiformis</i>	28
	<i>M. nastuta</i>	12mm
Shell Plot Sample 1	<i>M. nastuta</i>	12mm
Shell Plot Sample 2	No benthic organisms retained	
Shell Plot sample 3	No benthic organisms retained	

Epibenthic for meiofauna associated with oyster shell substrates

A prime rationale for native oyster enhancement efforts is the development of habitat types that may then be of benefit to native fishes, including salmonids, and mobile invertebrates, including decapod crustaceans. In particular, intertidal areas appear to be vitally important to out migrating juvenile salmonids by providing habitat types that support specific prey items that include polychaete worms, barnacles, gammarid amphipods among others (Brennan et al., 2004). Habitat that increases overall complex structure (and as a consequence overall surface area) likely increases the overall quantity and variety of microstructure. Enhanced habitat microstructure may be described as an increase in hard substrate area available for settlement, increased availability of edge or crevice habitat, increased variability in habitat with sediment accretional or depositional characteristics that are dependent on boundary layer flow characteristics that themselves vary on spatial and temporal scales, or other features that serve to increase the variety and amount of habitat suitable for small, epibenthic and infaunal animals to utilize for shelter or foraging. Recent studies have focused on the habitat value of intertidal oyster beds and structures associated with intertidal aquaculture. Pacific oyster beds containing both oysters and oyster cultch materials show a similarity in ecosystem function to native eelgrass beds and other structured habitats and accommodate invertebrate prey known to

be important to salmonids (Hosack et al., 2006). Other studies have demonstrated that netting and other gear associated with intertidal aquaculture provides biogenic structure that supports a wide variety of small, surface dwelling benthic invertebrates that may serve as prey for fishes and other mobile invertebrates (Powers et al., 2007).

Initial work has been done on the US west coast relative to the habitat value of intertidal sites modified for native oyster restoration efforts. A recent study by Cordell et al., 2007 demonstrated that intertidal sites in Liberty Bay that had been modified through the addition of cultch materials having attached native oysters contained higher densities of epibenthic organisms, including harpacticoid copepods compared to sampling a year earlier prior to the addition of oysters. Increased density of the epibenthic fauna was attributed to increased habitat complexity associated with the oysters and cultch material.

A preliminary epibenthic survey of shell enhanced areas compared to control plots was accomplished during summer 2007 on the NOAA/TNC site in Liberty Bay. In 2008, similar paired sampling was accomplished in April (4/21) and May (5/22). Specifically, samples for epifaunal invertebrates were taken utilizing an epibenthic pump (15cm diameter x 150 micron mesh size). The pump samples surface dwelling invertebrates via suction created by a 12 volt bilge pump operating within the confines of a cylinder of specific volume. Sampling consisted of taking 7 replicate pumped samples over the 2007 enhanced site in Liberty Bay on two occasions during an incoming (April sample) and outgoing (May sample) tide, respectively. A mud substrate reference site was similarly sampled for both sampling dates. Water depth over the site was typically less than one meter at the time of sampling. Contents of the evacuated cylinder were passed through a 100 micron screen, rinsed with seawater and contents fixed in 10% buffered formalin for 24 hours prior to storage in 70% ETOH. Samples taken over oyster shell typically contained significant quantities of sediment and extensive screening of these and the reference sites was required to reduce the organic load to a minimum for preservation. Samples were returned to the laboratory for enumeration and taxonomic analysis. A portion of the samples collected in April and May, 2008 were assessed for this report. Remaining samples will be assessed as part of 2009 sampling and monitoring effort on the adjoining TNC 5-acre enhancement plot.

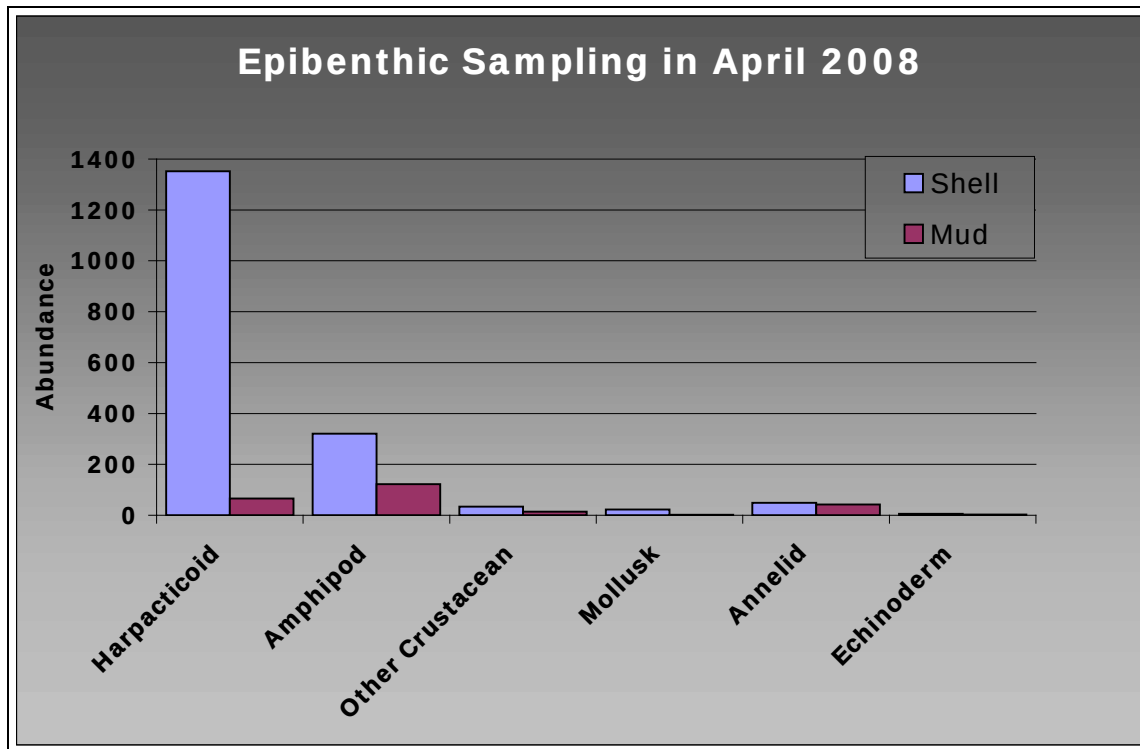


Figure 7. Mean abundance of individuals in major taxonomic groups with emphasis on harpacticoid copepods sampled in April, 2008 by epibenthic pump.

Preliminary results indicate that shell bearing sites contained significantly greater numbers of epibenthic invertebrates compared to reference (mud) sites for both sampling dates in 2008 (Figures 7 and 8). Preliminary results also suggest that overall abundance of harpacticoids on shell substrates was significantly less than that observed in the report by Cordell et al. (2007) for a nearby site in Dogfish Bay. This may be due to differences in sampling technique or other factors associated with season or sites. It was also noted that significant quantities of sediment was retained in samples and created a significant impediment to enumeration of retained meiofauna. Further analysis of samples taken in 2008 will be a focus for 2009 sampling on the adjacent 5 acre enhancement site with the goal of better assessing overall changes in species diversity and richness within shell enhanced sites compared to adjacent mudflats.

Epibenthic sampling for meiofauna associated with Pacific oyster shell enhancements and or native oyster populations will remain an enhanced priority in 2009 as funds for sampling are available to better complete this monitoring objective. Sampling will focus on Liberty bay and specifically compare sites that were enhanced with Pacific oyster shell in 2005, 2006, 2007 NOAA/TNC and 2008 NOAA/TNC site with more intensive sampling planned in 2009. This will also require submitting reference samples to qualified specialists to confirm tentative classification of specific taxa assigned as well as identify specific (potential) salmonid prey.

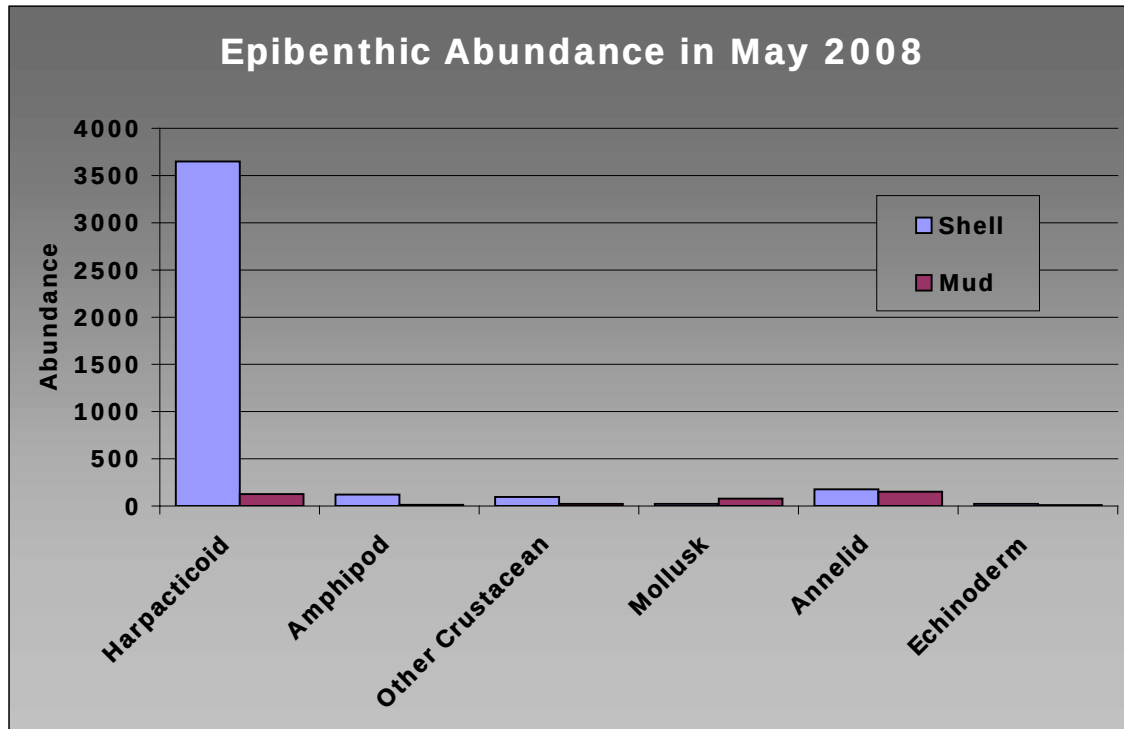


Figure 8. Mean abundance of individuals in major taxonomic groups with emphasis on harpacticoid copepods sampled in May 2008 by epibenthic pump.

Underwater video assessment of enhancement utilization by fishes and mobile invertebrates

In addition to sampling for native oysters, there is interest in assessing the potential utilization of oyster shell enhanced sites by fishes and mobile invertebrates. Observations of forage fish on or near the enhanced sites in Liberty Bay are common, but there is no information on whether fish and mobile invertebrates demonstrate any specific preference and potential utilization of shell-enhanced plots for habitat needs. The question of whether native oyster beds have an ecological role in terms of habitat provision for native salmonid fishes is of particular interest as many restoration sites for native oysters are in channels and low intertidal areas (potentially) seasonally occupied by salmonids. An objective for 2008 sampling was to observe whether substrate and non-substrate covered plots were differentially utilized by fishes and other organisms.

The underwater video camera is a drop style weighted color camera with wide-angle lens manufactured by Ocean Systems, Inc. (www.splashcam.com), model Deep Blue Pro. The camera is equipped with a 100' cable and lighting to enable illumination at depth. The video camera was mounted on a Sintra plastic vane and the camera apparatus weighted with a ten lb lead weight (Figure 10). The apparatus was designed to be slowly towed at a depth approximately 0.5 meters off bottom by a boat overhead along a prescribed transect. Camera distance off-bottom remained flexible as visibility varied considerably and at times it was necessary to maintain the camera at a depth of less than 0.5 meter to enable better resolution and picture quality.

For the Liberty Bay NOAA/TNC 2 acre site a transect was established between a reference buoy located on the centerline of the plot on the south end of the plot with a second mark located at the north end of the plot (Figure 9). Sampling consisted of slowly towing the camera array along the prescribed experimental transect (approximate length was 450') at a depth to maintain the camera approximately 0.5 meter above the bottom along the prescribed line running down the length of the plot. Following this procedure, a second transect was run parallel to the experimental transect that extended along the mudflat based bedlands just east (seaward) of the enhancement site. Together, the transects represent coverage of the enhanced site and a reference mudflat based site.

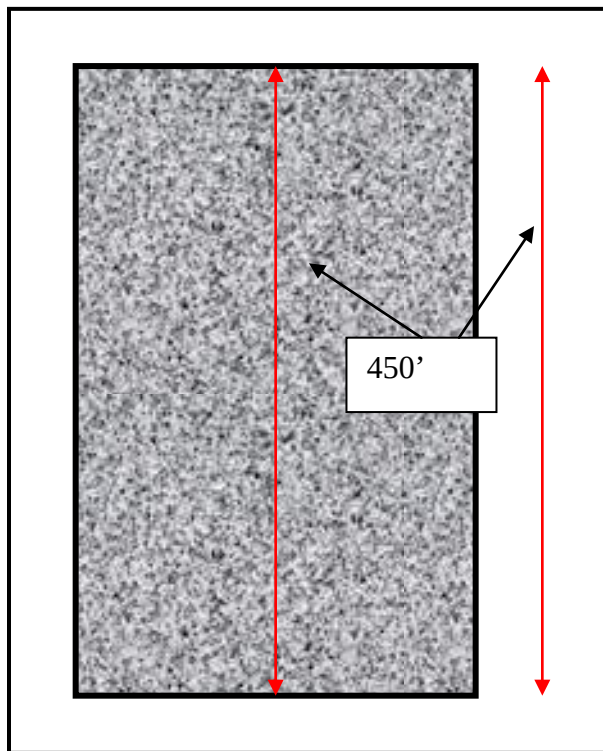


Figure 9. Diagram of NOAA/TNC 2.1-acre enhancement plot with video transects delineated. Buoys marking enhanced site are at positions of arrow heads. The experimental transect (approximate length 450') extends length of shell plot and the control transect extends along seaward (easterly) border over adjacent mud substrates.

Video transects were performed at approximate two-three week intervals between early May and mid September. The recording device utilized for these studies is a Video Recording Drive (VRD- VC20) manufactured by Sony Corporation. In order to directly view what the camera is recording at depth, a 6" diameter video monitor manufactured by Coby Corporation (www.cobyusa.com) is employed. The camera, recorder and monitor are powered by two 12-volt (7.5 amp hour) DC gel cell batteries (Haze Battery Company). The monitor and DVD recorder are additionally wired so that real time recording can occur while viewing the monitor. All components except the camera are housed in a watertight box fitted with a Plexiglas top for viewing the monitor (Figure 11).

Following video transect sampling, the MP4 clips were downloaded to a laptop computer and assessed frame by frame using Apple Computer's Quicktime Player for the presence of fishes and mobile invertebrates. Organisms were scored as to the type of habitat type they were observed associated with for each date.

Habitat types included:

- a) oyster shell covered substrate
- b) mix of shell and mud
- c) mud only substrate.

Following video recording, files were transferred to a laptop computer. Clearly identifiable organisms observed in the video were tallied for each date and transect habitat type. Results of organisms observed over different portions of the oyster bed were tallied for each sample date (see Table 3 for dates.)



Figure 10. Drop camera apparatus used in sampling for fish and mobile invertebrates

Video transect sampling was conducted on ten dates between May and September, 2008. In addition to the occasional shiner perch (*Cymatogaster aggregata*), the primary



Figure 11. Monitor and recording equipment contained in weatherproof housing.

organism regularly observed on all sample dates in 2008 was the decapod crab, *Cancer gracilis*. *C. gracilis* presence was quantified for each of ten sample dates and there was a significant preference for crabs to be associated with either shell or mixed shell habitats compared to adjacent mud habitats (chi square, $df=1$, $P < .0001$) (Table 3). Preliminary results from footage attained in September and October 2007 had indicated a similar pattern.

On a qualitative basis, larger decapod crabs (mainly *Cancer gracilis*) were present primarily on the margins between shell enhanced plots and the surrounding mud substrates. Footage taken over plots that contained a mix of shell and mud and associated with drift and/or attached Ulvoids showed a similar increased frequency of crab presence, especially on the margins of plots that contained high concentrations of Pacific oyster shell cultch.

Table 3. Results of video monitoring on 2 acre TNC oyster plots in 2008. Mainly crab (*C. gracilis*) were seen in 2008 as the major mobile invertebrate utilizing shell plots preferentially to adjacent mud flats.

<u>Date of Sample</u>	<u>Shell Habitat</u>	<u>Mixed Shell</u>	<u>Mud Habitat</u>
5/11/08	4	4	1
5/18/08	5	3	3
5/27/08	3	1	0
6/15/08	5	3	1
6/23/08	2	1	0
7/13/08	3	4	2
7/24/08	5	4	3
8/10/08	3	3	0
8/30/08	0	4	1
9/14/08	7	2	3

Enumeration of small fish and small mobile invertebrates other than the dominant crab inhabiting this site proved difficult to document with the equipment used for this sampling program. Sampling priorities for 2009 include changes to sampling equipment and protocols associated with video monitoring of shell enhanced sites. Specifically, a self-contained, watertight enclosure to hold the recording harddrive and batteries for powering the storage device and camera are being constructed to enable long-term (12+ hour) stationary monitoring over complete tidal cycles. The drop camera is capable of recording in low light conditions and will enable recording into early evening and morning hours. Appropriate lighting can also be deployed if nighttime recording is desired. The apparatus will be designed for deployment on the tidelands for longer term monitoring in 2009 as the equipment can be left on site with no surface tethering with adequate hard drive space and battery power to last a full tidal cycle.

Shell enhancement intertidal survey

The spring 2007 enhancement at the Scandia site was intended to present available substrate for recruiting larval native oysters during the 2007 reproductive season. In order to measure any changes to native oyster abundance within our plot, a population assessment for oysters was included in the scope of work. To accomplish the assessment, PSRF employed their 2007 native oyster methodology, titled “Intertidal *Ostrea conchaphila* Population Assessment Procedures; Applications for surveying natural populations and restoration areas.” This procedure was designed specifically for projects such as this to track changes in oyster abundance and to record the community-level responses to our habitat enhancement technique. The procedure uses a standardized-random sample protocol for sample collection. The data collected from samples is primarily focused on the population parameters of the native oyster; we also use the area samples to monitor the performance of the enhancement shell material and the emergent community of organisms within our treatment plot. This protocol randomly selects independent $\frac{1}{4} \text{ m}^2$ sample positions to the frequency required to estimate population parameters within an

established precision for confidence intervals. This protocol is similar to Campbell (1996) used by the Washington Department of Fish & Wildlife to assess clam and oyster populations in Puget Sound.

The population of concern in this case is the native oyster; therefore sample sizes for our intertidal surveys are determined by this population's variability within the enhancement plots and calculated to generate density means approaching a $\pm 30\%$ relative error for confidence intervals. Initially these enhancement plots are expected to have low densities of oysters; this fact makes the confidence interval goals of our survey method impractical until continued recruitment increases density and decreases population variability over time. The protocol used in the Scandia



Figure 12. A spring intertidal survey at Scandia shell plot.

2007 enhancement was altered slightly to reduce sample size, as the presumed low density of oysters precluded a practical sample size for a more precise population estimate. As this area continues to recruit native oysters in subsequent years, precise estimates of population parameters will become more practical.

The population will be defined as those oysters occurring within the footprint of each contiguous shell area. The data collection methodology focuses on descriptions of the survey area, live oyster counts and length frequency observations for native oysters. We will also make observations of the amount, condition and fouling community associated with the emergent oyster substrate (shell habitat). Predator and competitor species for the native oyster will be quantified and other emergent macro invertebrate species recorded to generate relative emergent species richness estimates. One objective for native oyster enhancement activities is to assess changes in abundance, diversity and richness of sessile and mobile organisms as a consequence of modifying substrates through the addition of Pacific oyster shell. These sites may also serve to supply substrates for the settlement and/or immigration of non-target organisms including non-native organisms that are present in the Bay. The methodology described above records information on abundance patterns for several species that utilize the habitat enhancement and are encountered during a survey. Some of these species compete with oysters for space and food resources and receive special attention to quantify their abundance. For example, two native *Crepidula* species, *C. dorsata* and *C. nummaria* are both suspension-feeding gastropods that showed significant recruitment into the enhancement plot during the first four months. (J. Davis, unpublished). In terms of comparative recruitment success, native oyster abundance was calculated at 4.5 m^{-2} in late October, 2007 while *Crepidula* abundance was estimated at $467 \text{ gastropods m}^{-2}$, a 100-fold difference. Another mollusk, the introduced Japanese oyster drill (*Ocenebrellus inornatus*) is

common on oyster shell substrate modified plots nearby, but has not yet been observed on the 2007 NOAA/TNC site. Of interest was the observation made in March 2007 of large numbers of *O. inornatus* that after just nine months had moved onto the 2006 ½-acre substrate modified plot, presumably from adjacent oyster beds, that had coincidentally been subjected to a significant barnacle (*Balanus glandula*) set the previous year. Significant numbers of *O. inornatus* egg cases were also observed indicating that this muricid gastropod was successfully reproducing and extending their foothold in Liberty Bay based on additional availability of suitable substrates for their preferred prey (barnacles, oysters and other epibenthic bivalves). These observations suggest that first, organisms other than the target of enhancement activities are clearly recruiting to modified substrates as appropriate benthic habitat becomes available and second, species that are (putatively) in high abundance as larvae in the water column such as *Crepidula* may be amenable to more targeted analysis as better documentation of settlement patterns and overall distribution is obtained through efforts to document native oyster settlement patterns in sites selected for enhancement activities.

Survey schedule

While many of the monitoring tasks of this project focus in on the months surrounding and including the reproductive season (May through August), surveys for oyster population assessment are best done in spring and fall. Resource managers sometimes choose to do this because they are interested in measuring summer recruitment with a fall survey, and/or winter mortality with a spring survey. Since the placement of the 2-acre Scandia enhancement plot in June 2007, intertidal surveys were conducted at low tides in fall and spring, with three surveys to date.

The first intertidal survey of this shell plot, conducted by PSRF and Baywater Inc. on October 26th, 2007 was able to confirm the presence of young-of-the-year native oysters on the cultch substrate. The goal of the initial assessment was threefold:

1. Monitor the condition of the shell habitat, 4 months post-placement.
2. Confirm presence or absence of native oyster recruits on this plot for 2007.
3. Establish a permanent transect within the plot and collect preliminary population statistics for native oysters to facilitate future population assessments.

A spring survey followed at 11 months post-placement on May 8th, 2008. This survey intended to collect a second density estimate for 2007 recruits and record observations on the oyster habitat amount and quality. The final survey was recently completed on November 13th, 2008. This last survey was to make a third oyster population estimate, anticipated to include any 2008 natural oyster set into the enhancement plot.

Shell enhancement: amount and condition

As for many of the sites in Puget Sound selected for a habitat enhancement treatment for native oyster stock rebuilding, the Scandia intertidal area has a soft, unstructured benthic surface. The Pacific oyster shell used to enhance the oyster settlement habitat only works while it remains epibenthic, or above the sediment surface. At or below the benthic interface, there is too much silt or perhaps anoxic conditions that would cause spat and juvenile mortality. Any sessile organism that fouls a piece of shell and then becomes buried under beach sediments eventually dies if it is not regularly exposed to the water

column. We are therefore interested in monitoring the amount of shell material that remains emergent above the benthic surface. Shell amount is evaluated using two measures; the first is the sample mean of shell height above the benthic surface and the second is the amount of beach area covered by shell, averaged from percent cover estimates in samples. Survey results are shown in Figure 13 and report 1.3 inches average shell height for the 2007 plot.

Estimates of shell height are a crude measure of “available substrate,” perhaps with the preface that, in general, each inch of material approximates a single layer of shell. Two or more inches would indicate multiple layers of emergent shell which creates a hummock of interstitial, cryptic surfaces exposed to the water column for oyster settlement, often increasing oyster density if available over time. Firmer benthic substrates are able to maintain emergent oyster shell for longer than softer benthic substrates where oyster shell sinks, at some rate, into the benthos.

Habitat enhancement areas that include softer substrates may require a thicker application of material to maintain emergent shell. Though many intertidal areas where we have applied this stock-rebuilding technique are unstructured, the benthic conditions are quite variable on surprisingly small spatial scales. Shell enhancements that were relatively uniform in application at the time of placement, over time develop into a mosaic of microhabitats revealing a spectrum of benthic conditions. This is mostly an effect of physical disturbance, a characteristic feature of the intertidal zone, or also a biological process like organic particulate deposition or bioturbation which can transform littoral habitat. Empirically the Scandia plot takes on softer edges and is bisected by drainages, presenting everything from multiple layers of emergent shell down to unstructured benthic surface to channels of moving water.

Natural aggregations surveyed by PSRF have shown emergent oyster substrate is generally a single layer thick and substrate height measures about one (1) inch. In applying the Pacific oyster cultch shell to the treatment plots, it is our intention to ultimately achieve a single layer of emergent substrate, supported by firmer benthic sediments. Sometimes softer beach sediments within the treatment area can be mitigated by an additional inch or two of enhancement shell, though this is uncommon. PSRF has observed that, more typically, very soft benthic conditions will not support any amount of emergent shell after two years. Beach sediments that support walking (sinking only 2-3 inches) are generally firm enough to support enhancement shell. Previous habitat enhancements have shown that shell applications in areas that support emergent oyster shell generally maintain one inch or more of emergent shell after 2 years. In observed natural populations in Puget Sound, the substrate material is typically mollusk shell of some variety or rock, where also a single layer is maintained (about one inch) emergent with reduced silt. In Liberty Bay we hope to encourage the development of a natural oyster bed through catalyzing juvenile recruitment, made possible through the addition of Pacific oyster shell.

Transport and deposition of sediments (organic or inorganic) is a natural condition of the Puget Sound nearshore. Sediments are scoured from some locations by physical

processes and are deposited in other locations by those same processes. Higher energy shorelines are too exposed to maintain oyster aggregations, or cultch material. Oyster beds are typically found on beaches that are somewhat protected from exposure. Alternatively, protected shorelines that minimize fine sediment transport are typically

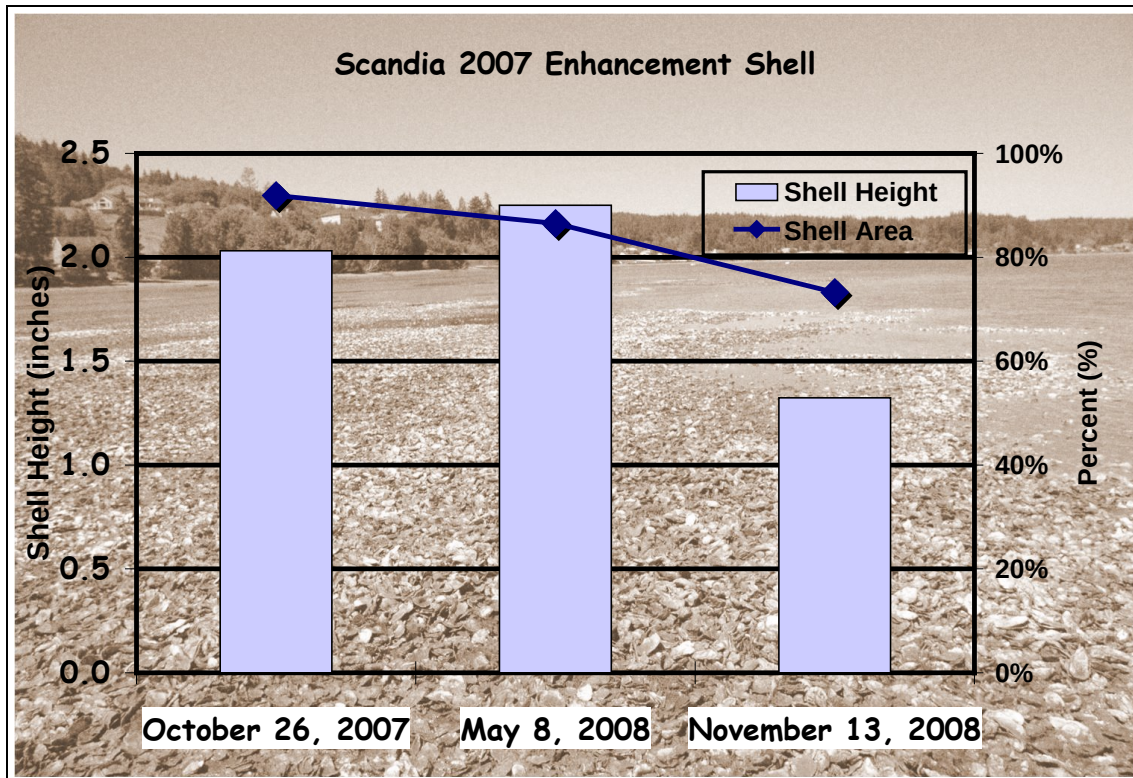


Figure 13. Shell material monitoring data from the 2007 Scandia plot. "Shell Height", reported in inches, is averaged from samples and estimates the height of the shell layer above the benthic surface. "Shell Area", reported as mean percent cover, estimates the amount of beach surface within each $\frac{1}{4}$ m² sample that is covered by the emergent shell substrate.

areas that experience regular deposition of sediments. Natural aggregations of oysters are encountered in littoral areas that are protected from physical exposure, but include features that maintain emergent substrate relatively sediment-free. PSRF has observed these features to include moving water on the intertidal, either by a surface drainage or ebbing water currents in middle to lower elevations that maintain the emergent substrate. We expect the habitat enhancement technique can only be successful in areas that present benthic sediments firm enough to support a substrate enhancement as described and include localized physical and biological conditions that maintain some amount of emergent substrate sediment free.

The second measure of shell amount is reported as "shell area" and refers to the amount of emergent shell (reported in percent cover) over the benthic surface. This is the mean condition of emergent shell within samples taken from the survey area, which is usually the original footprint of the treatment plot. Examining all measures of shell amount describes the mosaic of microhabitats discussed above. In November 2008 the shell plot

reported 1.3 inches of emergent shell, covering 73% of the beach surface over the 2.7 acre treatment.

The “condition” of the emergent shell is another important aspect of the enhancement PSRF continued to monitor throughout each survey. This assessment examines reports of shell amount, and then includes measures that effect “available” oyster substrate. Marine algae and a host of sessile invertebrates typically foul or collect on any hard emergent substrate that would facilitate access to the water column. Over time, this seasonal and highly variable recruitment of organisms will be affected by environmental and biological factors such as predation, competition, parasitism and disease to eventually shape the mature reef community.



Figure 14. Scandia shell enhancement shell plot. Red circles indicate native oyster recruits. Visible in the photo also are barnacle and algal recruits to the silt-covered emergent shell.

This maturation or succession period for the shell habitat in this project is ongoing, in fact, many of the emergent organisms (including native oysters) encountered in surveys of this plot were juveniles. We also know this from examining older habitat enhancement projects on this same beach. Competing for space is something the native oyster does relatively poorly, so the monitoring of successional species to characterize the competition setting for native oysters within the habitat treatment becomes important. During the intertidal survey, we recorded coverage estimates of the emergent oyster shell for the following groups of fouling organisms:

- Algae
- Barnacles
- Mussels
- Hydroid Polyps
- Bryozoans
- Ascidians
- Poriferans

The 2007 shell plot is relatively clear of fouling organisms at 18 months post-placement. Algal fouling is absent and only barnacles were observed, reporting total animal fouling at 3%. Silt cover of emergent shell was estimated at 82% in fall 2008, similar to the fall 2007 report. Silt cover was observed at 50% in spring 2008, which occurred between the two fall surveys. The increase of silt cover estimate in the fall surveys may be due to increased organic deposition after the end of the summer season. The variation could also be explained by observer bias, as these estimates are made by many people under a variety of survey conditions. Many observations made of the enhancement shell during the intertidal surveys are intended to objectively characterize the habitat, and therefore may individually fall short of drawing conclusions based on the result of that single measurement.

Population data summary

Summary data tables are shown in the Appendix for all three intertidal surveys; in this section we will address the most recent assessment of the oyster population and include data from previous surveys to demonstrate the changes over time observed in the 2007 treatment. Native oyster density was estimated in November 2008 to be 17.6 oysters m^{-2} . As shown in Figure 15, the 2008 oyster set has nearly doubled the density estimate from May 2008. Low density and moderate variability within the native oyster population have saddled previous estimates with a relatively large confidence interval (relative precision=77% in fall 2007).

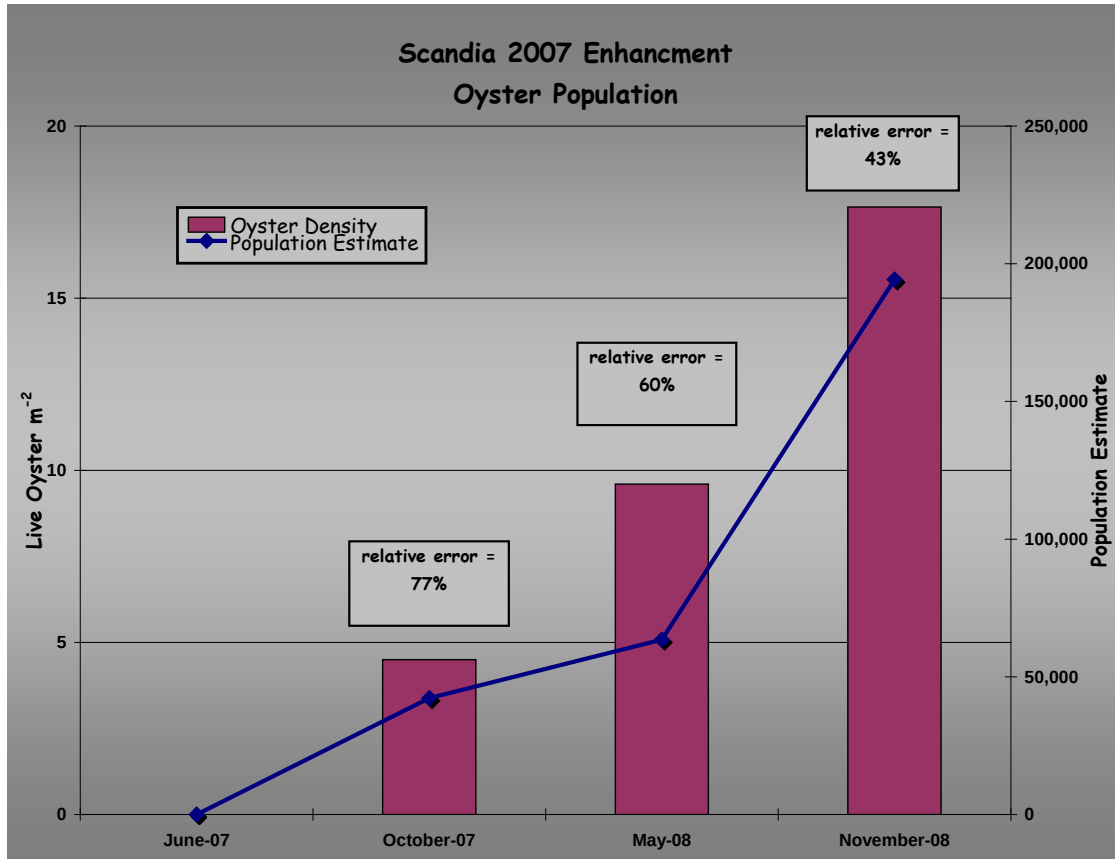


Figure 15. Density and total population estimates for the native oyster, *O. conchaphila*. Data from three intertidal survey efforts in the 18 months post-placement at the 2007 Scandia enhancement. Relative error is shown for each mean density estimate.

The current estimate in the 2007 shell plot from 17 random samples shows lower variability in oyster density ($\text{CV}=22\%$) and the relative precision of the mean is reported as $\pm 43\%$. It is the increase in oyster numbers from the 2008 year-class that have allowed for dramatic improvements in our estimates of oyster density and total population.

The survey protocol indicates a relative error goal of $\pm 30\%$ for the density mean when determining sample size. This standard has been used by resource managers in Washington when estimating shellfish biomass. Alex Bradbury, WDFW shellfish biologist, admits that this standard can be impractical to achieve with limited staff and low densities or highly variable beds of shellfish (pers. comm.). Our latest assessment in November 2008 gets close to this standard, and reveals a sample

size of 37 would be needed to approach +/- 30%. PSRF survey teams can typically collect 8 to 10 samples each survey.

The population of oysters here is between approximately 110,000 and 277,000 animals over the estimated 2 ½-acre plot; the survey results from November 2008 estimate the population at 194,729 oysters. The oysters observed in samples ranged in size from 4mm to 44mm, with modes surrounding 7mm (2008 set) and 32 mm (2007 set); see Figure 17. Juvenile mortality was rare and is empirically due to sedimentation, crab predation or unknown causes equally.

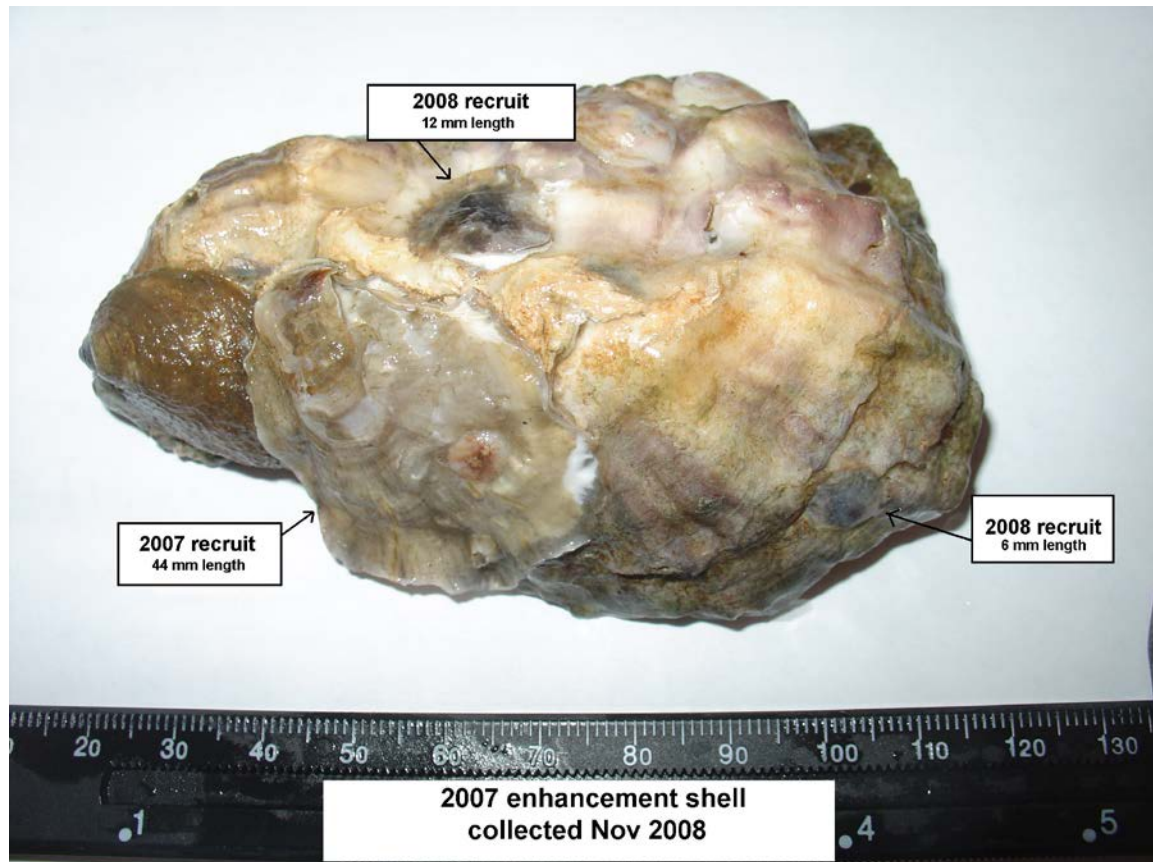
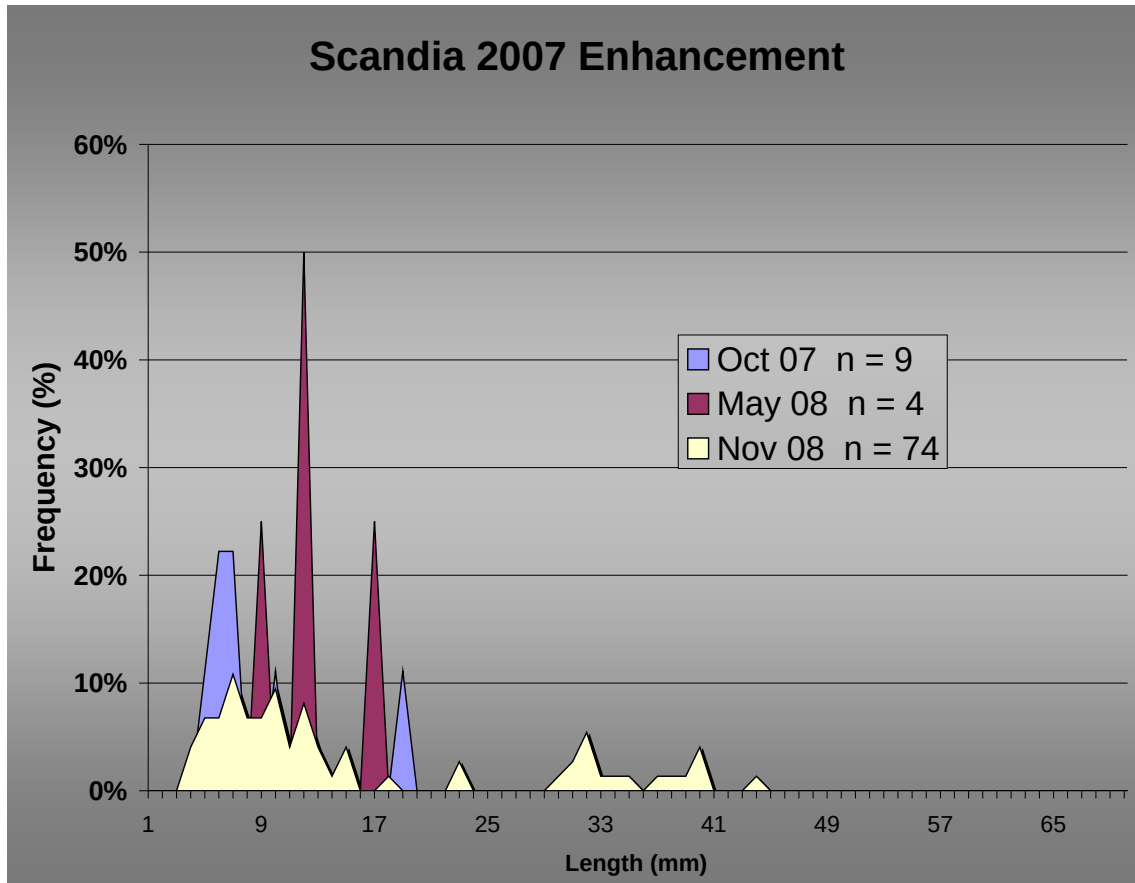


Figure 16. Cultch shell recovered from the 2007 plot during the November 13th, 2008 survey. Separate year-classes of the native oyster are shown attached to the cultch shell. Both *Crepidula* species observed in the November survey are also shown; *C. nummaria* (30 mm) on the left margin and *C. dorsata* (5 mm) on the larger oyster recruit near the center of the photo.

Almost all of the oysters observed are set onto the enhancement shell within the plot. On rare occasions we would find oysters set on a live Pacific oyster found in the plot (4%), or on other bivalve shell (1%). No single oysters were encountered. No native oysters were encountered in the treatment area prior to the habitat enhancement.



Figure

17. Percent length frequency distribution for native oysters observed in surveys. The November '08 results (in yellow) show two distinct modes indicating the two year-classes of juvenile recruitment.

Community data summary

The dominant fauna observed in November 2008 were, in order: Two native *Crepidula* species recorded together, estimated at 572 m⁻², and the Jingle shell *Pododesmus cepio*, estimated at 19 m⁻²; both compete with oysters (reported above at 17.6 m⁻²) for food resources, though competition for food does not seem to limit oyster growth or abundance; both measures are increasing for oysters across time in this plot. The most common epibenthic macro invertebrate species are shown in Figure 11. A complete list of observed species can be found in Table 4. Most common species observed are not quantified, except for those species identified as direct competitors or predators of the native oyster. All observed species are recorded; some are collected for identification, which is made to species when practical. Reports for total observed species are used to characterize the richness of species that utilize the shell habitat. These estimates are not measures of true 'species richness,' which would account for all species, instead we focus on those species that are observable during low tide exposure. This limits the list of potential species to macro invertebrate and algae. We typically preface our estimates of richness by qualifying it as *relative emergent macro species richness*. This measure does not account for evenness or diversity of species, simply their presence. Beyond the species that are quantified, monitoring species richness records the variety of species to utilize the enhancement. The relative emergent macro species richness for this 2007 plot was estimated at 28 (see table 4).

The *Crepidula* species found within the 2007 enhancement were likely present within the area prior to the enhancement or emigrated from the adjacent beach. Like the native oyster, they are protandrous hermaphrodites, but with an extremely short larval period, the juveniles and smaller adults found in the shell plot likely originated from the Scandia area.



Figure 18. Unidentified fish egg mass. (close-up inset). This photo, taken in early April, is of the adjacent 2006 shell plot. The dense algal mat and egg masses were absent in a survey of this shell plot one month later. An estimated ½ acre of enhancement shell substrate was covered in the mass. The eggs (and dense algae) were only observed on the emergent structured portions of the lower intertidal beach.



Figure 19. *Ocinebrellus inornatus* collected from the Scandia site. These were not observed in surveys until November 2008, reported at 0.5 m⁻².

Table 4. Observed species from Scandia 2007 treatment plot intertidal surveys. Native oysters and their direct competitor and predator species are quantified from samples. All other species observations are recorded to characterize the macro invertebrate richness within the shell plots.

	Species	Survey Date			Abundance Estimate
		Oct-07	May-08	Nov-08	
1	<i>Ostrea conchaphila</i> (native oyster)	x	x	x	17.6 m ⁻²
2	<i>Pododesmus cepio</i> (Jingle shell)	x	x	x	19 m ⁻²
3	<i>Crepidula dorsata</i> (slipper shell)	x	x	x	572 m ⁻²
4	<i>Crepidula nummaria</i> (slipper shell)	x	x	x	pooled genus
5	<i>Ocenebrellus inornatus</i> (Japanese drill)	x	x	x	0.5 m ⁻²
6	<i>Mytilus sp.</i> (mussel)	x		x	0.5 m ⁻²
7	<i>Balanus sp.</i> (barnacle)	x		x	3% cover
8	<i>Cancer gracilis</i> (crab)			x	0.2 m ⁻²
9	<i>Crassostrea gigas</i> (oyster)			x	0.5 m ⁻²
10	<i>Lophopanopeus bellus</i> (crab)		x		
11	<i>Hemigrapsus oregonensis</i> (crab)		x		
12	<i>Lacuna sp.</i> (snail)	x		x	
13	<i>Nassarius mendicus</i> (snail)	x	x	x	
14	<i>Nucella lamellosa</i> (snail)		x		
15	Unkn snail, <i>Margarites</i> sp? (snail)	x			
16	<i>Haminaea vesicula</i> (mollusk)	x		x	
17	<i>Macoma nasuta</i> (bentnose clam)	x	x		
18	<i>Cryptomya californica</i> (clam)			x	
19	<i>Mopalia sp.</i> (Chiton)		x	x	
20	<i>Pholis laeta</i> , unconfirmed (fish)	x			
21	<i>Platichthys stellatus</i> (fish)		x		
22	Unkn Platyhelminth, brown (flat worm)	x			
23	Unkn Polychaete #1 (segmented worm)	x	x	x	
24	<i>Haliclona</i> or <i>Halichondria</i> sp? (sponge)		x		
25	Unkn Hydroid Polyp		x		
26	<i>Schizoporella unicornis</i> (Bryozoan)			x	
27	Unkn Bryozoan, white	x			
28	Unkn Cnidarian			x	



Figure 20. These mollusks constitute the bulk of the epibenthic biomass within the 2007 shell plot. The two *Crepidula* species (pooled density at 572 m⁻²) are native suspension feeding snails; the *Nassarius* snail is a native scavenger. *C. dorsata* and *Nassarius* were found qualitatively more abundant in the southern Puget Sound (Dethier and Schoch, 2005).

Nassarius mendicus, along with other molluskan macro invertebrates, are identified as a preferential prey for the harlequin duck populations in Sequim Bay in the Stait of Juan de Fuca. Gaines and Fitzner (1987) noted that harlequin ducks fed nearshore (within 50 meters) where there was some complex structure (ie. Cobble, eelgrass, algae bed). Perhaps mollusk abundances in Liberty Bay are higher or more accessible in structured littoral habitats. While it might be uncommon to encounter the harlequin duck in Liberty Bay (harlequin winter habitats are more exposed rocky shorelines, typically farther north), a variety of species may utilize the enhancement plots in Liberty Bay as each year sees continued recruitment and emigration. As mentioned before, one consequence of habitat modification is that unknown non-target species will utilize the enhancement, especially during the succession period, and bring with them their trophic and community relations. We have watched this occur on the 2006 shell plot with an abundant barnacle set, followed closely by the emigration then recruitment of *O. inornatus* (Japanese drill) in large numbers. Perhaps the diving ducks of Liberty Bay are already exploiting the abundant emergent mollusk populations within the shell enhancements.

Recommendations

Based on monitoring activities conducted to date the following recommendations are proposed to assist in optimizing oyster enhancement activities here and at other sites in the future.

1. Multiple temperature monitors placed at different tidal heights within the perimeter of the overall enhancement site, including microhabitat that is either exposed regularly and/or covered with seeps or in slightly depressed locations will significantly help enable a fine tuned assessment of native oyster tolerance to heat and cold conditions and by association exposure to increased desiccation. Deployments of “artificial” oysters with imbedded temperature loggers will better refine the physiological tolerance of native oysters to annual temperature variation.
2. More refined characterization of meiofauna associated with substrates on sites established at different times to test the hypothesis that successional processes are occurring with respect to the increased colonization of substrate enhanced sites by native oysters and other sessile invertebrates. As sites develop mature oyster populations, how is community structure, food web dynamics and other ecological processes affected at differing spatial scales? Funds are in place to enable a comprehensive analysis of oyster recruitment and growth on enhanced beds of increasing size and area established in 2005, 2006 and 2007 and compare these results to 2008 recruitment.
3. Use of longer term, self-contained, stationary video monitoring to include better assessment of mobile invertebrate and fish utilization using the modified techniques described above with a focus on assessing plot edge effects and utilization of different types of habitat by crabs and fishes. This monitoring will enable better assessment of substrate enhanced plots for presence of fishes that likely utilize oyster shell substrates for habitat (e.g. Pholidae and Cottidae) that are small and difficult to observe using video techniques presently used.
4. Continued focus on epibenthic organisms and their association with emergent, hard substrates. Continued monitoring in spring 2009 from enhanced beds of different ages will be sampled and epibenthic diversity assessed with help from taxonomy professionals to assist in identifying organisms to the species level.
5. Focus by PSRF and other practitioners of oyster enhancement activities to continue annual monitoring of organisms associated with enhanced plots including non-native oyster drills. A focus in late winter, 2009 will be examination of shell enhanced beds to investigate the tendency for *O. inornatus* to aggregate for mating and deposition of egg capsules (March and April).
6. Focus on regular assessment of other macro invertebrates that utilize Pacific oyster shell substrates for settlement to document patterns of settlement, growth

and survivorship for species that have high larval abundance, capability to settle in hard substrate habitats and compete with native oysters for space and resources.

7. Now that we have developed a list of observed species, one focus of continued monitoring funding should be to make comparative assessments of biodiversity between shell treatment areas and the surrounding unstructured intertidal.
8. Larval abundance or larval “potential” has been of primary interest in habitat enhancement areas. What we have learned is that assessing the presence of native oyster larvae via preserved plankton samples can be difficult and subjective at best. Ultimately we are interested in monitoring the annual spatfall. Therefore we recommend employing a shellstring program in enhancement plots to directly measure annual recruitment potential, instead of collecting plankton.

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Appendix

PSRF Native Oyster Survey Results Page

Survey Information			Survey Area		
Date:	Nov 13 2008				Start Position
Area:	Liberty Bay		Latitude:	N47 43.393	
Site:	Scandia		Longitude:	W122 39.361	
Enhancement Date:	2007		Elevation:	-1.5	
Surveyor:	Brian,BetsyL.,Joth,BetsyP.		Baseline Orientation:	310 °Magnetic	
Surveyor Contact:	PSRF				Area Estimate
			Baseline Length:	156.0 meters	
			Mean Width:	70.6 meters	
			Total Area:	11,009 Sq meters	
			2.7 Acres		
Survey Results			Emergent Oyster Substrate Results		
Sample Size:	17		Amount		
Sample mean:	4.4		Mean Emergent Substrate Height:	1.3 inch	
Mean oysters m ⁻² :	17.6		Mean Emergent Substrate Area (%):	73.2%	
Population est:	194,279		Emergent Substrate Density m ⁻² :	101.6	
			Condition		
Sample s ² =	16.3		Wet Emergent Substrate (%):	47%	
SE =	0.98		Anoxic Benthic Condition (%):	88%	
CV =	22%				
relative precision:	43%		Fouling		
% Single Oyster:	0%		Mean Algal Cover (%):	0%	
			Mean Silt Cover (%):	82%	
Mortality Information			Mean Barnacle Cover (%):	3%	
	<u>Sample Mean</u>	<u>% of Total</u>	Mean Mussel Cover(%):	-	
Unknown Mortality:	0.1	33%	Mean Bryozoan Cover (%):	-	
Drill Mortality:	-	0%	Mean Hydroid Polyp Cover (%):	-	
Crab Mortality:	0.1	33%	Mean Poriferan Cover (%):	-	
Silt Mortality:	0.1	33%	Mean Colonial Ascidian Cover (%):	-	
			Total animal fouling cover (%):		
			3%		
Predator / Competitor Results			Oysters on Substrate		
	<u>Sample Mean</u>	<u>est. m⁻²</u>	Mean Oyster Count per Substrate Piece:	0.2	
C.productus	-	-	Mean Mortality per Substrate Piece:	0.0	
C. gracilis	0.1	0.2	Setting Substrate	Percent	
C.inornatum	0.1	0.5	Native Oyster (live)	-	
N.lamellosa	-	-	Native Oyster shell	-	
P.brevispinus	-	-	Pacific Oyster (live)	4%	
E.troschelli	-	-	Pacific Oyster shell	75%	
P.cepio	4.8	19.1	Other Shell	1%	
Mytilus sp.	0.1	0.5	Rock	-	
Crepidula sp.	143.1	572.2	Other Substrate	-	
C.gigas	0.1	0.5	Community Information		
			Relative Emergent Species Richness:	17	
	-	-	Next Survey		
	-	-	<u>Minimum Sample Size for next survey</u>		
	-	-	Nmin @ +/-20% for next survey:	84	
	-	-	Nmin @ +/-30% for next survey:	37	

PSRF Native Oyster Survey Results Page

<u>Survey Information</u>			<u>Survey Area</u>	
Date:	5/21/2008		<u>Start Position</u>	
Area:	Liberty Bay		Latitude:	N47 43.393
Site:	Scandia 07 plot		Longitude:	W122 39.361
Enhancement Date:	6/29/1905		Elevation:	-1.5
Surveyor:	PSRF / TNC		Basline Orientation:	310 °Magnetic
Surveyor Contact:	B. Allen 360-280-7410		<u>Area Estimate</u>	
			Basline Length:	156.0 meters
			Mean Width:	42.4 meters
			Total Area:	6614 Sq meters
<u>Survey Results</u>			<u>Emergent Oyster Substrate Results</u>	
Sample Size:	10		<u>Amount</u>	
Sample mean:	2.4		Mean Emergent Substrate Height:	2.3 inch
Mean oysters m⁻²:	9.6		Mean Emergent Substrate Area (%):	86.5%
Population est:	63,498		Emergent Substrate Density m ⁻² :	249.6
Sample s² =	5.4		<u>Condition</u>	
SE =	0.73		Wet Emergent Substrate (%):	78%
CV =	31%		Anoxic Benthic Condition (%):	90%
relative precision:	60%		<u>Fouling</u>	
% Single Oyster:	0%		Mean Algal Cover (%):	0%
			Mean Silt Cover (%):	50%
			Mean Barnacle Cover (%):	0%
			Mean Mussel Cover(%):	0%
			Mean Bryozoan Cover (%):	0%
			Mean Hydroid Polyp Cover (%):	0%
			Mean Poriferan Cover (%):	0%
			Mean Colonial Ascidian Cover (%):	0%
			Total animal fouling cover (%):	0%
<u>Mortality Information</u>			<u>Oysters on Substrate</u>	
	<u>Sample</u>	<u>% of</u>	Mean Oyster Count per Substrate Piece:	0.0
	<u>Mean</u>	<u>Total</u>	Mean Mortality per Substrate Piece:	0.0
Unknown Mortality:	-	-	<u>Setting Substrate</u>	<u>Percent</u>
Drill Mortality:	-	-	Native Oyster (live)	-
Crab Mortality:	-	-	Native Oyster shell	-
Silt Mortality:	-	-	Pacific Oyster (live)	-
			Pacific Oyster shell	100%
			Other Shell	-
			Rock	-
			Other Substrate	-
<u>Predator / Competitor Results</u>			<u>Community Information</u>	
	<u>Sample</u>	<u>est. m⁻²</u>	Relative Species Richness:	15
	<u>Mean</u>		<u>Next Survey</u>	
<i>C.productus</i>	-	-	Minimum Sample Size for next survey	
<i>C. gracilis</i>	-	-	Nmin @ +/-20% for next survey:	93
<i>C.inornatum</i>	-	-	Nmin @ +/-30% for next survey:	41
<i>N.lamellosa</i>	0.1	0.4		
<i>P.brevispinus</i>	-	-		
<i>P.ocraceas</i>	-	-		
<i>E.troschelli</i>	-	-		
<i>P.ceprio</i>	12.0	48.0		
<i>Mytilus sp.</i>	-	-		
<i>C.fornicata</i>	67.6	270.4		
<i>C.gigas</i>	-	-		

PSRF Native Oyster Survey Results Page

<u>Survey Information</u>			<u>Survey Area</u>	
Date:	10/26/2007		<u>Start Position</u>	
Area:	Liberty Bay		Latitude:	47 43.393
Site:	Scandia		Longitude:	122 39.361
Enhancement Date:	2007		Elevation:	-1.5
Surveyor:	Brian & Joth		Basline Orientation:	310 °Magnetic
Surveyor Contact:	PSRF		<u>Area Estimate</u>	
			Basline Length:	156.0 meters
			Mean Width:	60.2 meters
			Total Area:	9391 Sq meters
<u>Survey Results</u>			<u>Emergent Oyster Substrate Results</u>	
Sample Size:	8		<u>Amount</u>	
Sample mean:	1.1		Mean Emergent Substrate Height:	2.0 inch
Mean oysters m ⁻² :	4.5		Mean Emergent Substrate Area (%):	91.9%
Population est:	42,260		Emergent Substrate Density m ⁻² :	292.0
Sample s ² =	1.6		<u>Condition</u>	
SE =	0.44		Wet Emergent Substrate (%):	13%
CV =	39%		Anoxic Benthic Condition (%):	0%
relative precision:	77%		<u>Fouling</u>	
% Single Oyster:	0%		Mean Algal Cover (%):	0%
			Mean Silt Cover (%):	77%
			Mean Barnacle Cover (%):	0%
			Mean Mussel Cover(%):	0%
			Mean Bryozoan Cover (%):	0%
			Mean Hydroid Polyp Cover (%):	0%
			Mean Poriferan Cover (%):	0%
			Mean Colonial Ascidian Cover (%):	0%
			Total animal fouling cover (%):	0%
<u>Mortality Information</u>			<u>Oysters on Substrate</u>	
	<u>Sample</u>	<u>% of</u>	Mean Oyster Count per Substrate Piece:	0.0
	<u>Mean</u>	<u>Total</u>	Mean Mortality per Substrate Piece:	-
Unknown Mortality:	-	-	<u>Setting Substrate</u>	
Drill Mortality:	-	-	<u>Percent</u>	
Crab Mortality:	-	-	Native Oyster (live)	-
Silt Mortality:	-	-	Native Oyster shell	-
			Pacific Oyster (live)	-
			Pacific Oyster shell	100%
			Other Shell	-
			Rock	-
			Other Substrate	-
<u>Predator / Competitor Results</u>			<u>Community Information</u>	
	<u>Sample</u>	<u>est. m⁻²</u>	Relative Species Richness:	16
	<u>Mean</u>		<u>Next Survey</u>	
<i>C.productus</i>	-	-	<u>Minimum Sample Size for next survey</u>	
<i>C. gracilis</i>	-	-	Nmin @ +/-20% for next survey:	123
<i>C.inornatum</i>	-	-	Nmin @ +/-30% for next survey:	55
<i>N.lamellosa</i>	-	-		
<i>P.brevispinus</i>	-	-		
<i>P.ocraceas</i>	-	-		
<i>E.troschelli</i>	-	-		
<i>P.ceprio</i>	6.0	24.0		
<i>Mytilus sp.</i>	0.4	1.5		
<i>C.fornicata</i>	116.8	467.0		
<i>C.gigas</i>	-	-		
<i>Crepidula sp.</i>	0.3	1.0		
	-	-		
	-	-		
	-	-		