Final Project Report-

Shellfish at Work – Reducing Nutrient Pollution in the Budd Inlet Watershed

National Estuary Program (NEP) Toxics and Nutrients

Award No. G1300037

Prepared for
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December 2014

This project has been funded wholly or in part by the United States Environmental Protection Agency under Puget Sound Ecosystem Restoration and Protection Cooperative Agreement grant PC-00J20101 with Washington Department of Ecology. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Suggested citation:

Pacific Shellfish Institute. 2014. Shellfish at Work – Reducing Nutrient Pollution in the Budd Inlet Watershed. Final Project Report for National Estuary Program Toxics and Nutrients Award No. G1300037. Prepared for the Washington Department of Ecology by Aimee Christy, Bobbi Hudson and Andrew Suhrbier of the Pacific Shellfish Institute, Olympia, WA. December 2014. 80pp.

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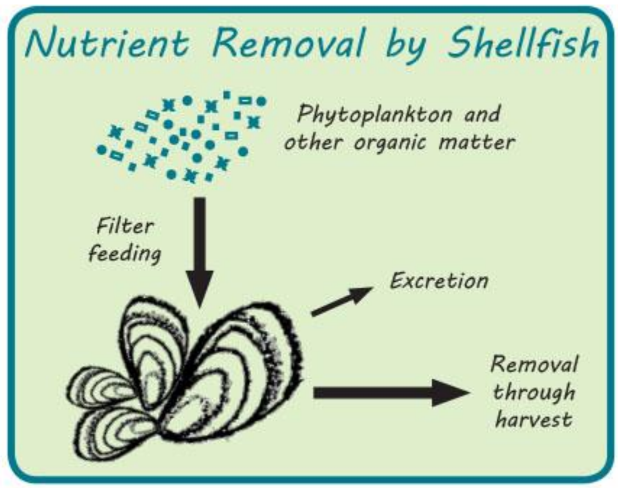
EXECUTIVE SUMMARY

This project demonstrates a creative strategy to mitigate anthropogenic nutrient loads in urban watersheds. Between 2012 and 2014, the Pacific Shellfish Institute (PSI) engaged waterfront businesses, residents and students in the cultivation of mussels for nutrient bioextraction in Budd Inlet, southern Puget Sound, Washington State. Nutrient bioextraction, or bioharvesting, is the act of growing and harvesting shellfish or seaweed to remove nutrients from natural water bodies. It can be used as a complement to traditional source control efforts and is viewed as being the only way to remove nitrogen after it enters the marine environment. The question: "Are enhanced shellfish populations an effective tool to combat eutrophication?" is being asked on state, national and international platforms, and could not be more relevant than in Budd Inlet. Budd Inlet is one of five shallow, dead-end inlets in Puget Sound's southernmost marine water body. The Inlet's circulation and residence time makes it a prime candidate for utilizing bivalve shellfish to control eutrophication. This is because bivalves are only effective at reducing seston (microscopic living and non-living suspended particles) concentrations where water resides long enough for filter feeding to have an impact (Konrad, 2013).



Simplified graphical representation of how shellfish remove nutrients through filter feeding.

A primary goal of this project was to remove a quantifiable amount of nutrients from Budd Inlet. To this end, both the actual and potential amount of nitrogen and phosphorus were determined based on the pounds of mussels harvested and the potential biomass generated. Laboratory results indicate that total percent nitrogen (wet weight) was 1% and percent phosphorus averaged 0.08% in mussels harvested from demonstration systems in Budd Inlet. We estimate a potential harvest from the three Budd Inlet nutrient bioextraction demonstration sites of 7988 pounds of mussels, or 80 pounds of nitrogen, based on mussels grown on 1101 cubic feet of space (length of demonstration sites x 1-ft width x depth) with 233 straps. This information may be used to extrapolate the area, or number of straps, needed to remove any given amount of nitrogen.

Mussels were harvested from each site and provided to various partners for compost trials. Mussels were delivered to The Evergreen State College's (TESC) Organic Farm; Washington State University (WSU) - Puyallup's Research and Extension Service; and the Washington Department of Correction's (DOC) Cedar Creek facility. Following composing processes, triplicate samples of mussel compost generated by partners were tested by Soiltest Farm Consultants, a Seal of Testing Assurance (STA) Certified compost testing laboratory located in Moses Lake, Washington. Soiltest analyzed the mussel compost for moisture, solids, pH, total nitrogen, organic carbon, C/N ratio, macronutrients, micronutrients, sodium, sulfur, and heavy metals. Results indicated that the mussel compost is of suitable quality for agricultural and garden use, and that all metals were within compost limits set by the Ecology solid waste handling standards for composting facilities. Of the macronutrients (Phosphorous, Potassium, Calcium, and Magnesium) only Calcium (13%) exceeded the typical range, a unique signature reflecting the calcium carbonate contained within the mussel shells. Micronutrients (Boron, Zinc, Copper and Iron) were within or below the typical range for compost and all heavy metals were well below Washington State compost standards (WAC 173-350-220). Sodium levels were also within a safe range.

The southern portion of Budd Inlet hosts a vibrant waterfront, marinas, Port of Olympia, LOTT wastewater treatment facility, and former Cascade Pole cleanup site. Most areas are closed for commercial and recreational harvest due to pollution, or are under a harvest advisory due to unknown but expected poor water quality. As such, toxicology analyses of mussels are strongly warranted for any use of shellfish harvested from Budd Inlet. Whole mussels (tissue and shell) were therefor tested for PCBs, PAHs and trace elements by harvesting 3 composites from each of the lower Budd Inlet sites and delivering them to AmTest, a Washington State Department of Ecology accredited laboratory in Kirkland, Washington. PAHs and PCBs in all mussel samples were reported at levels below the detection limit (DL) at 3.0 and 87.0 ug/kg-dry respectively. Heavy metal concentrations for arsenic, cadmium, copper, lead, mercury, and nickel were all below the national mean and well within compost limits set by the Ecology solid waste handling standards for composting facilities (WAC 173-350-220).

This project's results demonstrate that nutrient bioextraction with shellfish can be a viable component toward improving Budd Inlet water quality. At the same time, the project increased public awareness of local water quality issues including bacterial pollution, eutrophication, and harmful algal blooms and offered activities that empower citizens to envision a swimmable, fishable Budd Inlet. Although nutrient removal with shellfish is a relatively new development, nutrient bioextraction using farmed mussels has been conducted on the Swedish west coast (Smith et al., 2013). A similar scenario can be envisioned for Budd Inlet, using wild-set mussels, destined for compost rather than human consumption, as demonstrated through this project.

INTRODUCTION

History of study area

Budd Inlet is one of five shallow, dead-end inlets in Puget Sound's southernmost marine water body. Currently the southern portion of Budd Inlet supports wood product loading and processing facilities, recreational marinas, and the Port of Olympia. Defunct industries range from plywood manufacturing plants to the Cascade Pole wood treating facility, now a capped superfund cleanup site. The northern part of the inlet is primarily residential properties. Moxlie Creek flows through a culvert that discharges into the southern end of East Bay. The Swantown Marina and Boatworks are located on the eastern side of the peninsula. Tribal and then commercial harvest of Olympia oysters (*Ostrea lurida)* occurred in Budd Inlet until the late 1800's when sewage and industry discharge deemed them unsafe to eat. Shellfish harvest is presently not allowed for consumption in most of the inlet.

Budd Inlet is part of the 186-mi² watershed [Water Resource Inventory Area (WRIA) 13] extending from the headwaters of the Deschutes River northward through Capitol Lake and Budd Inlet. The watershed includes portions of Thurston and Lewis Counties, the Cities of Olympia, Lacey, and Tumwater, and the town of Rainier. The Lacey, Olympia, Tumwater and Thurston County (LOTT) Alliance provides secondary wastewater treatment before discharging into Budd Inlet, as well as denitrification from April to October.

Budd Inlet is Puget Sound's southernmost marine water body and several hundred miles inland from the Pacific Ocean. The Inlet's water volume equals about 0.1% of Puget Sound's overall total volume. However, the volume of water within the Inlet varies considerably between high and low tides. On average, the tide drains approximately 73% of the inner Inlet's volume between its highest and lowest tide levels (Aura Nova Consultants et al., 1998). The Deschutes River, the second largest river draining into south Puget Sound, empties into Capitol Lake. Because of Puget Sound's overall circulation, the Inlet's water volume is comprised of approximately 75% oceanic inputs and 25% river input. In addition, the Inlet's shallow sea floor (~10 m), large tidal range (4.4 m) and episodic river input (0-100 m^3/s) combine to produce a circulation that ranks it as one of the Sound's more active water bodies. Flushing times range from 1–700 days for various Puget Sound inlets, as compared to 8 - 12 days for Budd Inlet (Aura Nova Consultants et al, 1998).

The expansion of industrial and residential areas along Budd Inlet has led to negative environmental impacts on the Inlet and surrounding areas. Portions of the Deschutes River, Capitol Lake, and Budd Inlet currently do not meet water quality standards and are on the Clean Water Act Section 303(d) list for fecal coliform bacteria, temperature, DO, pH, and fine sediment (WDOE, 2012), resulting in an in-process total maximum daily load (TMDL).

Excess nutrient loads, particularly in shallow, dead-end inlets, can result in excessive algae growth, which robs water of oxygen upon decomposition. The Deschutes River was identified as having the 4th largest nutrient load south of Snohomish County (excluding Hood Canal) in the Washington Department of Ecology 2011 South Puget Sound Dissolved Oxygen Study (Mohamedali et al., 2011). Budd, Case, and Carr Inlets were also identified as "most impaired" for dissolved oxygen (DO) (Figure 1).

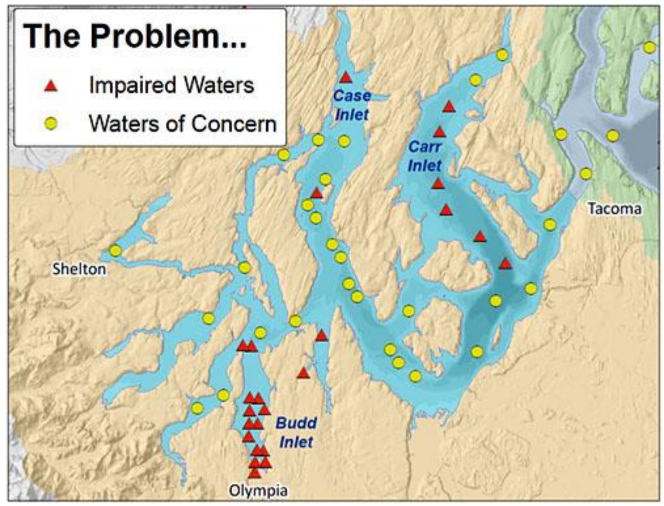


Figure 1. 2008 Water Quality Assessment for dissolved oxygen (Mohamedali et al., 2011).

Nutrient bioextraction

Nutrient bioextraction, or bioharvesting, is the act of growing and harvesting shellfish or seaweed to remove nutrients from natural water bodies. It can be used as a complement to traditional source control efforts and is viewed as being the only way to remove nitrogen after it enters the marine environment. Nutrient bioextraction using farmed mussels was explored on the Swedish west coast between 2005 and 2011 (Lindahl et al., 2005). The term "agro-aqua recycling" was used to describe the process of recycling nutrients from the land to sea by using mussel farming as the recycling engine (Figure 2). In that case study, a nutrient trading agreement was made between the community of Lysekil and a private mussel farmer, allowing the Lysekil sewage treatment plant to continue emitting 29 tons of nitrogen while the same amount of nutrients were "harvested" by the shellfish farm through 3500 tons of blue mussels (*Mytilus edulis*).

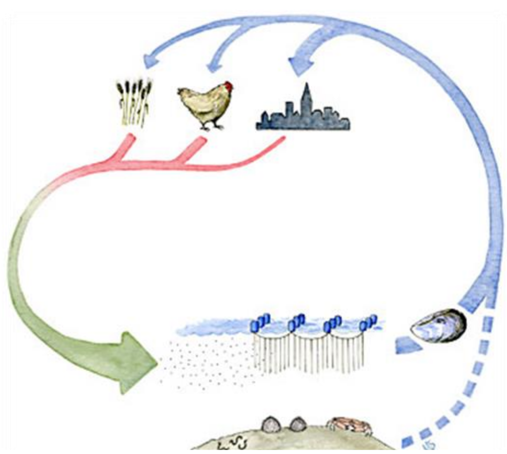


Figure 2. The principle of recycling nutrients from sea to land by mussel farming (Lindahl 2005).

As part of the 2009 Long Island Sound Study, a Bioextractive Technologies for Nutrient Remediation workshop was held to discuss opportunities for nutrient bioextraction throughout the region. Nutrient bioextraction was evaluated as a way to reduce nutrients in an effort to reduce widespread and recurring problems with algal blooms, loss of seagrass, and hypoxia in Long Island Sound and Great Bay, New Hampshire (http://longislandsoundstudy.net).

In 2011, Puget Sound Restoration Fund, funded by King County and the Russell Family Foundation, installed a nutrient mitigation demonstration site using mussels in Quartermaster Harbor on Vashon Island. Quartermaster Harbor suffers from hypoxic conditions similar to Budd, Case and Carr inlets. The pilot project affixed 140 polyethylene socks filled with *Mytilus trossulus* seed from Penn Cove, Washington, to an 8ft by 30ft raft. Mussels were harvested, tested for nutrient content and metals, and sent to the Washington State University (WSU) Extension facility in Puyallup for compost trials. The project proved to be a successful way to connect citizens to their watershed and develop a potentially marketable product from the harvested mussels. The pilot trial paved the way for the recent Budd Inlet nutrient bioextraction work.

PROJECT GOALS AND OBJECTIVES

This project offered a creative strategy for mitigating anthropogenic nutrient loads in urban watersheds by engaging waterfront businesses and residents directly in the development of watershed-level data, tools, approaches, and outreach to support safe and productive water resources in Olympia's urban nearshore environment. The goal of this project was to engage community members in the cultivation of a local species of bay mussel (*Mytilus trossulus*), to quantify the nutrient sequestering abilities of this process, and to demonstrate market-based mechanisms for cleaning South Puget Sound's Budd Inlet. To accomplish this goal, the project team proposed the following tasks: 1) implement demonstration aquaculture systems under docks at several marinas along Olympia's waterfront and along Budd Inlet; 2) determine the nutrient removal capability of growing and harvesting suspended mussels in Budd Inlet; 3) engage local organic farms in developing marketable soil compost from harvested mussels; 4) provide outreach and project promotion through citizen monitoring opportunities, hands-on education, and public presentations; and 5) establish a community network to support aquaculture sequestration technologies and develop a plan for implementing nutrient trading scenarios. The project team accomplished these tasks.

By doing so, the project increased public awareness of local water quality issues including bacterial pollution, eutrophication, and harmful algal blooms and offered activities that empower citizens to envision a swimmable, fishable Budd Inlet. This work supported the long-term restoration goals set by the City and Port of Olympia, Thurston County, LOTT Alliance, and the Squaxin Island Tribe (Budd Inlet Restoration Partnership).

PROJECT RESULTS

TASK 1 – IMPLEMENT NUTRIENT MITIGATION DEMONSTRATION SYSTEMS

Install demonstration systems

In April 2012, PSI worked with the Port of Olympia and local marinas to establish 4 nutrient bioextraction sites in Budd Inlet: West Bay Marina (WBM), Port of Olympia Hearthfire (HF), Port of Olympia Boatworks (BW), and Boston Harbor Marina (BHM) (Figure 3). Sites were selected based on willing partnerships, water depth at low tide, dock suitability, and suspected variations in water properties (salinity, food availability, etc.). In early May, 314 nylon straps, each weighted with a small segment of rebar, were affixed beneath existing dock structures at the 4 locations. The straps provided a substrate for wild blue mussels and other invertebrates and algae to set upon.

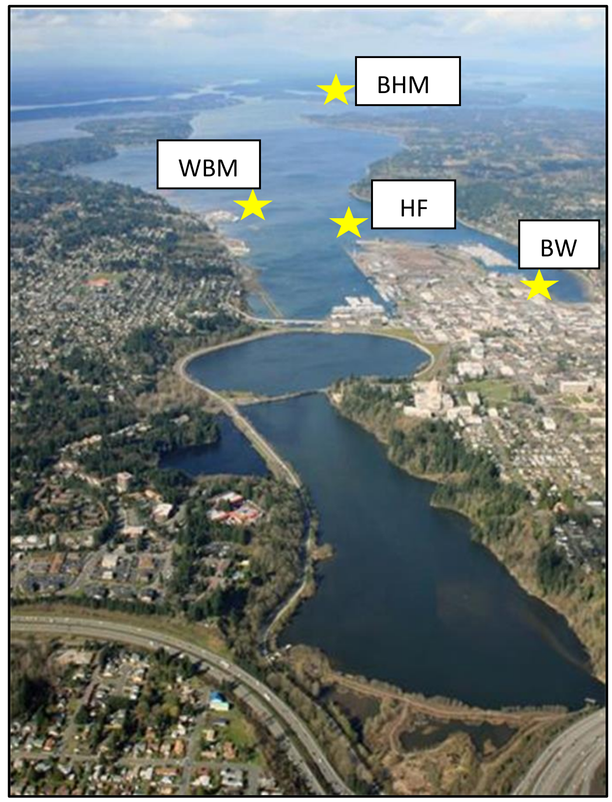


Figure 3. Mussel demonstration sites, Budd Inlet.

At West Bay Marina, 101, 5-foot straps were tied directly to metal cross sections along a 77-foot by 6-foot section of Slip I. At Port of Olympia's Boatworks site, 76, 5-foot straps were tied to 8, 10-foot boards affixed to the side of the dock and positioned just above water level. At Port of Olympia's Hearthfire site, 56, 3-foot straps were attached to 7 completely submerged boards running perpendicular to the length of the dock. At Boston Harbor Marina, 81, 3-foot straps were also affixed to submerged boards running perpendicular to the length of the dock. These shorter 3-foot straps were required to prevent predation should the straps touch bottom during extreme low tides.

FIELD SAMPLING METHODS

Data were collected at the four mussel demonstration sites every two weeks from June-October of 2013. At each sampling event, water temperature (˚C), salinity (ppt), DO (mg/l and %), and pH (pH units) readings were recorded at a depth of 2.5 or 1.5 feet (halfway down the strap length) using a regularly calibrated YSI Professional Plus Instrument (Pro Plus) handheld multi-parameter meter. Secchi disc readings (meters) and a vertical plankton tow (3 meter depth) were performed in addition to photo documentation. Overall site conditions, the fouling community (biodiversity), and density/distribution of mussel set were also recorded (Appendix A). Mussel growth was monitored monthly at each site by randomly removing 30 mussels from the center portion of 3 replicate mussel lines (n=90). Individual mussel lengths (umbo to farthest posterior margin) and composite weights (g) were measured using a Portable Ohaus Scout II scale with measurement accuracy of 0.01 g (Appendix B). Phytoplankton samples were viewed using an Olympus inverted microscope, Model IMT-2, to generate a complete species list and designate each as Dominant, Prominent or Present (Appendix C).

Mussel biomass was measured once per month during August, September, and October. At each site, 3 randomly selected mussel lines (replicates) were scooped out of the water using a handheld fishing net, placed in a bucket equipped with a hole for drainage, and weighed separately using a Berkley® digital fishhook scale. "Mussel only" weights from the three straps were averaged and used to calculate the potential biomass per site. The potential biomass was calculated by multiplying the number of straps times the average weight per strap. By multiplying biomass by the nitrogen content of mussels, the total amount of nitrogen removed from Budd Inlet was calculated.

On October 7th, triplicate composites of 150 mussels each were collected at each of the 3 sites for chemical analyses. Bivalves were rinsed, using water from the collection site, bagged and delivered on ice to Amtest, Inc. (Kirkland, Washington), an Ecology accredited, analytical, laboratory. Mussels were tested for nutrients (total nitrogen, phosphorus), trace metals, PCBs and PAHs. Sampling procedures were performed in accordance with Puget Sound Estuary Program's 1997 publication, *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound* (PSEP, 1997). Refer to the Quality Assurance Project Plan (QAPP) for details (WDOE, 2013). Fecal coliform concentrations in mussel tissue or the final compost were not tested during this project, but temperature readings were monitored during the composting process to ensure adequate treatment of bacteria.

LABORATORY METHODS

At the laboratory, strict attention and documentation of sample receipt, analyses, and chain of custody were maintained. Laboratory Standard Operating Procedures were followed and all analytical methods were performed in accordance with the accepted procedures of the USEPA, the American Society for Testing Materials (ASTM) and the Association of Analytical Chemists (AOAC). At the laboratory, mussel shells and tissues were homogenized together prior to analysis. Results were reported in µg/g (mg/kg, ppm) for metals and µg/kg (ng/g, ppb) for PAHs and PCBs. Refer to the QAPP for details (WDOE, 2013).

Water quality results

Water quality parameters from June to October followed typical seasonal patterns for the southern Puget Sound region. Temperatures continued to rise throughout the summer peaking in August at 19.5°C. Salinity remained somewhat constant between 25-29 ppt with the exception of two sharp drops due to rainfall events. DO and pH displayed downward trends at all sites with the highest readings in June and July and lowest in October, which is typical at the heads of southern Puget Sound estuaries (Figure 4).

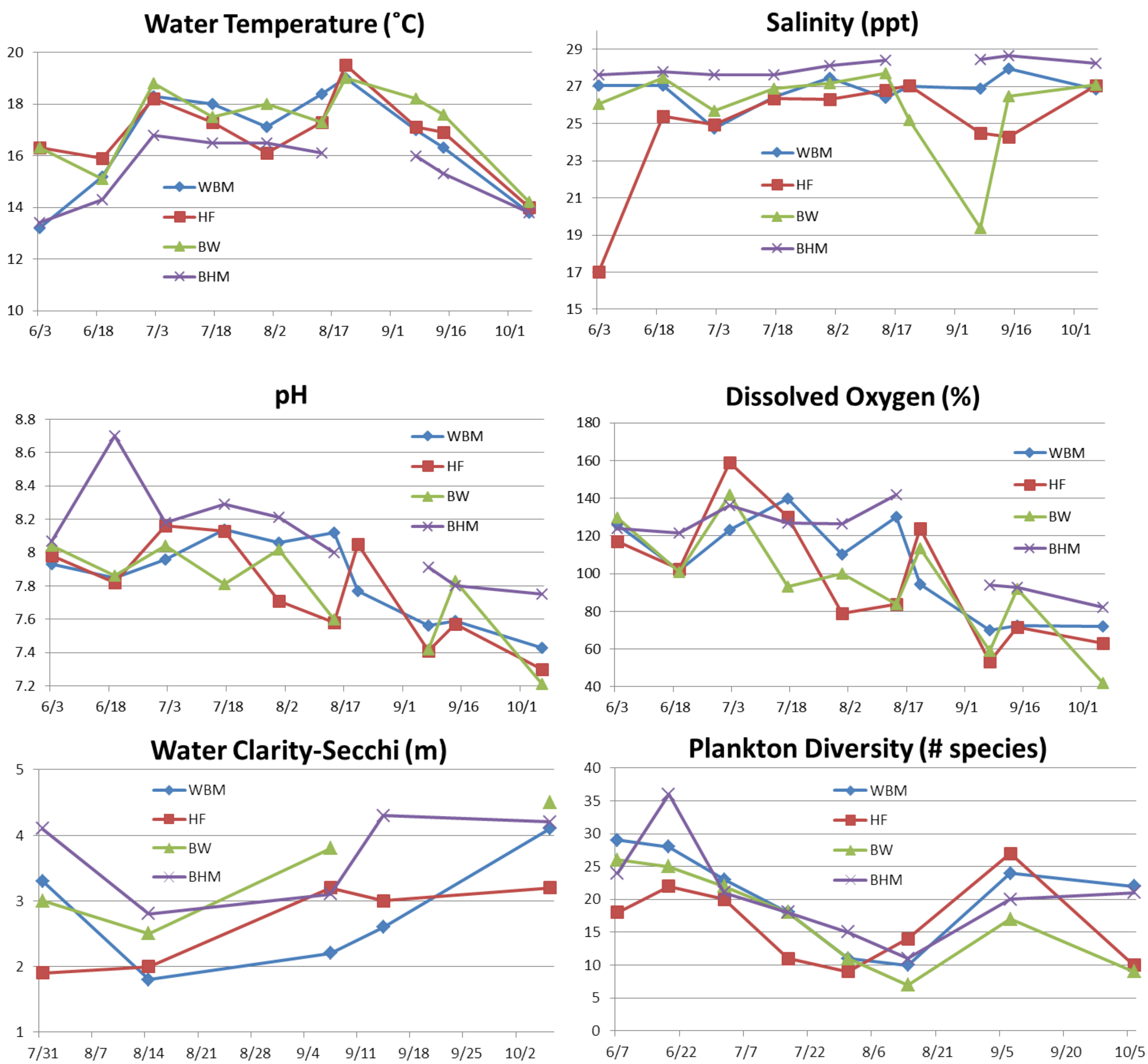


Figure 4. Seasonal water quality parameters at the four demonstration sites.

Plankton diversity was greatest during the spring and early summer bloom at which time *Leptocylindrus* and *Rhizosolenia* were dominant. Diversity and water clarity decreased in July and August as dinoflagellates, *Akashiwo sanguinea* and *Ceratium fusus* became dominant (Figure 5). In mid-July, elevated numbers of *Dinophysis spp*., the species responsible for Diarrhetic Shellfish Poisoning (DSP), were detected resulting in Budd Inlet's first state-mandated closure to recreational shellfish harvesting as elevated DSP toxin was found in monitored mussel tissue. In early September, the first significant storm event stirred up the water column introducing nutrients and spurring a short-lived bloom of *Skeletonema*. By October, despite the dominance of *Akashiwo*, water clarity remained greater than 3 meters.

While overall trends were similar, subtle differences were detected between the four stations. BHM, located at the northernmost end of Budd Inlet, was strongly marine influenced compared to the lower Budd Inlet locations. Water temperatures were colder and salinity, pH, and dissolved oxygen (DO) were higher reflecting a more oceanic, well mixed environment.

As water exchanges into and out of Budd Inlet, it follows a counter clockwise circulation pattern with water from the greater Puget Sound flowing into lower Budd Inlet along the western shore and exiting along the eastern shore (Aura Nova Consultants et al., 1998). WBM, positioned along the western shore receives this incoming flow. This site had slightly greater DO and pH values coinciding with the greatest plankton concentrations (Figure 6) when compared to the other lower Budd locations.

Figure 5. *Akashiwo sanguinea* bloom in lower Budd Inlet. Photo: Kelsey Browne, LOTT Clean Water Alliance.

Figure 6. Phytoplankton net tows (WBM, HF, BW, BHM).

The HF and BW sites are both more susceptible to fresh water inputs from the Deschutes River and Moxlie Creek (East Bay). Fresh water dam releases periodically drop salinity levels as low as 5-10 ppt near the HF site and were responsible for the lower value detected on June 3rd. In early September, a salinity drop was detected at BW after a significant rainfall event. Both sites experienced slightly lower DO and pH levels throughout the season, the lowest levels detected at BW in October (41.8%=DO, 7.2=pH). These findings support analyses in the recent TMDL report indicating that present day circulation patterns in lower Budd Inlet with the Capitol Lake dam intact contribute to lower DO levels in East Bay (WDOE, 2012).

Mussel strap biodiversity

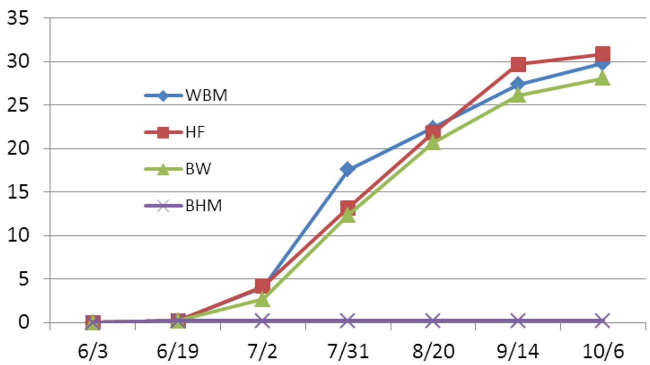
A list of species inhabiting or feeding on the mussel straps was recorded every 2 weeks from June until October. At the 4 sites, 15-23 species were observed per visit including 6 types of algae, 5 fish species, and 20 marine invertebrates (Appendix D). While many species were found utilizing the straps, they were dominated almost entirely by blue mussels and, with the exception of BHM and to a lesser degree WBM, experienced very little predation (Figure 7). Kelp crabs were found clinging to a majority of straps at BHM and were likely responsible for the disappearance of existing mussel set between June 19th and July 2nd. Beyond that time, the straps were dominated by anemones, ulvoids and hydroids. WBM experienced minor predation from sea stars which were found at greater numbers than at any other site. HF straps typically supported more macroalgae, as well as nudibranchs, barnacles, and hydroids.

Straps at BW were primarily utilized by amphipods, isopods, and flatworms. In May, prior to mussel set, the straps at BW were covered by small fish eggs, likely deposited by Pacific herring. Pacific herring schools have been noted in South Sound estuaries but not at the sample sites during times of sample collection as spawning can occur swiftly and often at night. Schools of stickleback and other small fish were often found utilizing the mussel straps for shelter and food at all 4 lower Budd Inlet locations.

Figure 7. Sea stars removed from one strap at WBM (left) and a kelp crab at BHM.

Mussel lengths and weights

Mussel set was first observed in early and mid-June at all four sites. In July, mussel size and density was noticeably greater at West Bay Marina. Set was light and sparse at Boston Harbor Marina in June and completely absent on July 2nd possibly due to predation by kelp crab. No subsequent mussel set was detected throughout the duration of the season. As summer progressed, mussel lengths and weights continued to increase at the remaining three lower Budd Inlet sites with an end-of-season (2013) harvest size averaging 29.6 mm and 2.3 grams/mussel respectively (Figure 8).



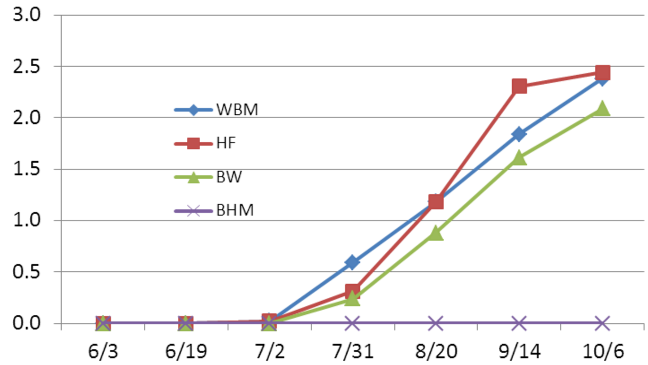


Figure 8. Lengths (mm) (left) and weights (g) (right) per mussel.

Past trials conducted in Quartermaster Harbor revealed that large amounts of biomass can be lost due to drop-off at this time of year. In September, as a preventative measure, mussels from 10 straps were removed, placed into approximately 60 polyethylene "socks," and reattached to the docks to prevent drop-off due to increasing weight (Figure 9). By February 2014, lengths and weights for the socked mussels averaged 44.3 mm and 8.2 grams/mussel.

Mussel biomass

Mussel growth continued throughout the season with some variation between sites. By mid-September, straps at all locations were densely populated with mussels and had to be lifted out of water with the assistance of a net, to prevent sloughing off due to sheer weight (Figure 10). Several individual strap weights exceeded 40 pounds at both WBM and BW in mid-September with a maximum recorded weight of 49 pounds per strap at BW in early-October. HF had slightly larger mussel lengths and weights overall, and the greatest mussel weight per foot of strap (Figure 11).

Figure 9. Mussel socks, West Bay Marina.

Mussels sloughing off the straps were observed in late-September. Mussels at HF and BW tended to adhere to the straps better perhaps due to the shorter strap lengths at HF and less tidal flow stress at BW. Harvesting mussels in mid-September is highly recommended to avoid biomass losses. Mussels were harvested at WBM on September 25th, HF on October 6th, and BW on October 23rd.

Figure 10. Mussel strap at Boatworks, August, 2013.

Total potential biomass was calculated by multiplying the peak average weight of mussels per strap and multiplying by the number of straps per site (WBM=101, HF=56, BW=76). Peak average strap weights for WBM, HF and BW were 31.93 (October), 30.73 (October), and 40.03 (September) pounds respectively, yielding a total potential biomass of 7988 pounds.

TASK 2 – DETERMINE NUTRIENT REMOVAL CAPABILITY

One of the primary project goals was to remove a quantifiable amount of nutrients from Budd Inlet. To this end, both the actual and potential amount of nitrogen and phosphorus were determined based on the pounds of mussels harvested and the potential biomass generated (7988 lbs.) at the 3 sites. The amount of nutrients removed was calculated by multiplying the amount of harvested mussels or potential biomass by the total percent nitrogen. Laboratory results indicated that total percent nitrogen (wet weight) in mussels was 1.02% at WBM, 1.08% at HF, and 0.81% at BW for an average of 0.97%, or essentially 1% (Figure 12). Percent phosphorus was 0.09% at WBM, 0.09% at HF, and 0.06% at BW for an average of 0.08%. The three demonstration sites had the *potential*, therefore, to remove 79.88 pounds of nitrogen and 6.40 pounds of phosphorus.

The amount of mussels harvested from each site was as follows: 1223 pounds at WBM, 462 pounds at HF, 1279 pounds at BW, and 1325 pounds aggregated from all sites for education and outreach, laboratory testing, and biomass sampling for a total of 4289 pounds. The *actual*

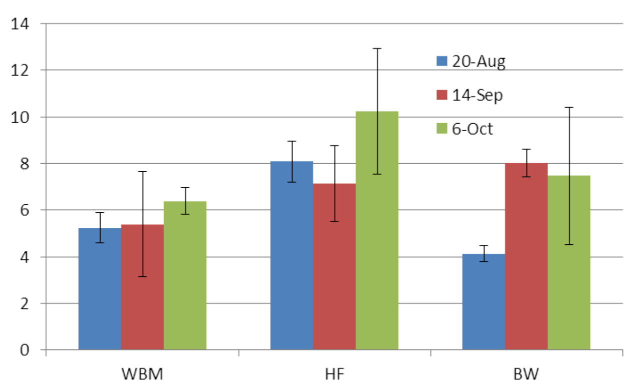


Figure 11. Average mussel weights per foot of strap (lbs.). October WBM weights measured at harvest (Sept 25).

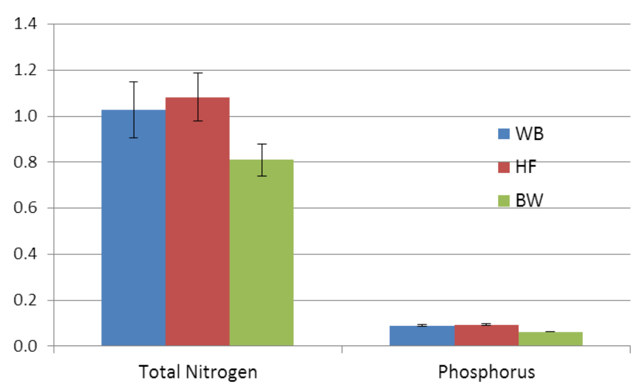


Figure 12. Total Nitrogen (%-wet weight) in mussels. AmTest Laboratories.

amount of nutrients removed by the pilot sites was 42.89 pounds of nitrogen and 3.43 pounds of phosphorus, based on the 4289 pounds of mussels harvested.

The discrepancy between the potential biomass and actual harvested biomass can be attributed to various factors, many of which are avoidable in the future. Mussel losses were encountered due to the socking process, late season drop-off, and the harvesting procedure itself. These losses are largely preventable by harvesting in mid-September which would also eliminate the preventative step of socking mussels to avoid drop-off. Additional losses were attributed to collecting 1325 pounds of mussels early in the season for outreach and biomass sampling. While accounted for in the harvest figures, these mussels, if left on the straps, had the potential to nearly double in size. Finally, some losses might be associated with water loss during the harvesting process. Biomass measurements are recorded immediately after harvest and draining, whereas, mussels during harvest can sit on the dock releasing mussel liquor for a period of time before being loaded into tubs and weighed.

We estimate a potential harvest from the three demonstration sites of 7988 pounds of mussels, or 80 pounds of nitrogen, based on mussels grown on 1101 cubic feet of space (length of demonstration sites x 1-ft width x depth) with 233 straps. This information may be used to extrapolate the area, or number of straps, needed to remove any given amount of nitrogen.

As a theoretical example, if straps were hung from both sides of docks A-L at West Bay Marina (including boat slips), an area covering approximately 13 acres, the site could support 16,400 straps (Figure 13). At a harvest size of 35 pounds per strap, the site would generate 574,000 pounds of mussels and remove 5740 pounds of nitrogen upon harvest. This is equivalent to the annual nitrogen output of 574 people based on 4.5 kg per year, or 10 lbs. per year. This example is purely theoretical, but helps illustrate the amount of space needed to extract a specific amount of nitrogen.

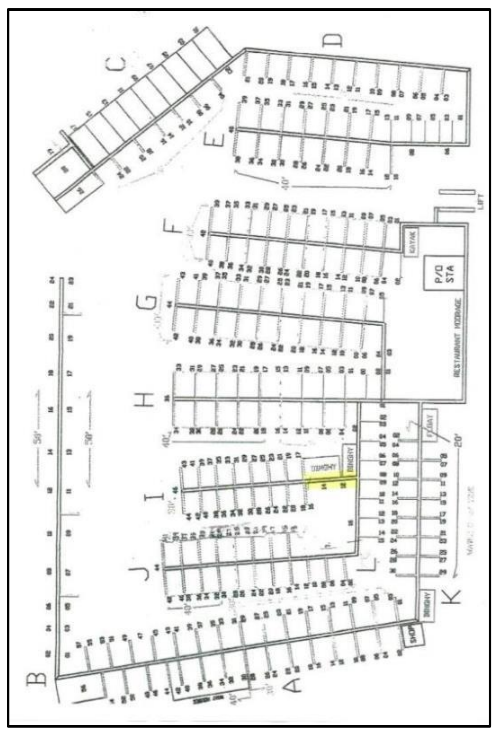


Figure 13. West Bay Marina. Highlighted section represents 120 straps.

The exact amount of nitrogen removal needed to meet TMDL requirements for Budd Inlet is still being determined. Once this value is published, it will reveal how much of a role nutrient bioextraction might play in improving water quality in the Inlet. Barring these figures, nutrient bioextraction still serves as a complement to the array of nutrient removal efforts currently underway including source control in the upper watershed, septic and sewer repairs, farm management plans, outreach, and LOTT's nutrient removal technology.

Toxicology Analyses

Budd Inlet is the receiving water body for the Deschutes watershed, which is highly urbanized in many parts. The southern portion of the Inlet hosts a vibrant waterfront, marinas, Port of Olympia, LOTT wastewater treatment facility, and former Cascade Pole cleanup site. Most areas of Budd Inlet are closed for commercial and recreational harvest due to pollution, or are under a harvest advisory due to unknown but expected poor water quality. Toxicology analyses of mussels are strongly warranted for any use of shellfish harvested from Budd Inlet.

Available Science - Dioxins, PAHs, PCBs, Trace Metals

In 2007, Ecology launched an investigation of Budd Inlet dioxin sediment contamination and found elevated levels in sediments near stormwater discharge pipes and the Port of Olympia's shipping berths. The Port of Olympia is currently investigating contamination and developing a plan for cleanup in the areas adjacent to port property in the West and East Bays of Budd Inlet.

In 2008, the Washington Department of Health (WDOH) issued a Health Consultation for Budd Inlet (WDOH, 2008) to evaluate the potential human health hazard posed by contaminants in sediments, clams and bottom fish tissue from the Inlet. The WDOH sediment study found three compounds that exceeded standards: Dioxins, Polychlorinated biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs). WDOH estimated exposure doses, exposure assumptions, and hazard quotients for dioxins, carcinogenic PAHs (cPAHs), and PCBs in sediment and tissues and concluded that dioxin and PCBs represent "no apparent public health hazard" for children or adults exposed in a one-day-per-week (52 days per year) exposure scenario to contaminants present in sediments. The study also evaluated bottom fish and Manila/Littleneck clam dioxin exposure to the general public and Squaxin Island Tribe based on consumption rates and found that dioxin represents "no apparent public health hazard" for both populations consuming bottom fish or shellfish in Budd Inlet.

While mussels were tested for PCBs, PAHs and trace elements in this study, testing shellfish for dioxins was cost prohibitive and perhaps redundant given Port of Olympia's current contaminant testing and the WDOH's Health Consultation results. It is likely that shellfish accumulate very little dioxin because the substance builds up in fatty tissue and shellfish have a very low fat content. Furthermore, mussels from this study were suspended in the water column from clean substrate (not placed on sediment or creosote-treated pilings) and harvested after a short duration of time (4.5 months).

NOAA's Mussel Watch program monitors metal levels for several shellfish species located throughout the U.S. with sampling stations located throughout Puget Sound. Table 1 displays metal concentrations in mussel tissue (mg/kg dry weight – ppm) collected from Budd Inlet from 1986-2010, national mean and ranges, and WDOE compost limits. (Data source: National Centers for Coastal and Ocean Science (NCCOS) Chemistry Data – Mussel Watch, Mearns, 2001). Heavy metal concentrations for arsenic, cadmium, copper, lead, mercury, and nickel in mussels harvested from Budd Inlet were all below the national mean and well within compost limits set by the Ecology solid waste handling standards for composting facilities (WAC 173-350-220) (Table 1).

Table 1. Metal concentrations previously measured in Budd Inlet mussels compared to national range and WDOE compost limits.

	Budd*	Budd**	National Mean**	National Range**	Compost Limit***
Arsenic	6.62±0.96	7.4	10.5	4.8-23.7	<20
Cadmium	2.11±0.50	2.5	2.68	0.4-10.4	<10
Copper	6.20±1.19	5.2	11.9	5.2-22.0	<750
Lead	0.92±0.80	0.57	2.62	0.02-11.6	<150
Mercury	.012±0.03	0.15	0.18	0.04-0.70	<8
Nickel	1.00±0.41	1.2	3.1	0.59-11.3	<210

*Mussel tissue (ppm-dry), 1986-2010 (NCCOS-Mussel Watch)

**Mussel tissue (ppm-dry), 1997-1998, National Mean and Range Data (Mearns, 2001)

***Source: WAC173-350-220 Composting facilities - Metal Limits (ppm-dry)

Study Results

In October, whole mussels (tissue and shell) were tested for PCBs, PAHs and trace elements by harvesting 3 composites from each of the lower Budd Inlet sites and delivering them to AmTest laboratories. PAHs and PCBs in all mussel samples were reported at levels below the detection limit (DL) at 3.0 and 87.0 ug/kg-dry respectively (Figure 14 and Appendix E).

Results indicated that all metals, with the exception of copper, were below the national mean and well within compost limits set by the Ecology solid waste handling standards for composting facilities (Figure 15 and Appendix E). Copper values were significantly higher than Mussel Watch data which analyzes tissue only. Metals are known to bind to chitin within mussel shell. Chitin and its derivative, chitosan, have demonstrated a high sorption capacity for heavy metals, particularly zinc and copper, in numerous studies (Craggs et al., 2010). In fact, the Port of Edmonds and Port of Seattle (airport and seaport) have used crushed oyster shell to remove copper and add hardness, further reducing bioavailability of metals, to stormwater. Nickel values were all reported as being below the detection limit (DL) of 3.62 mg/kg-dry.

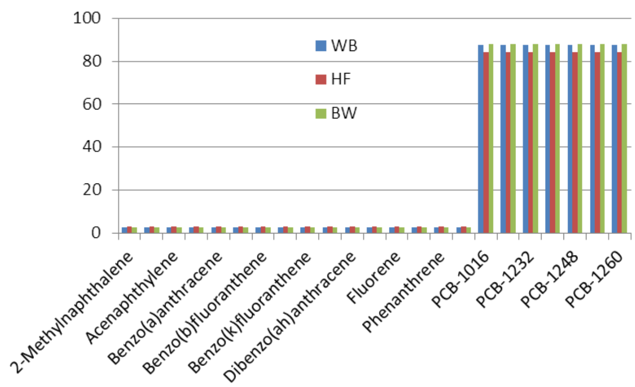


Figure 14. PAHs and PCBs (ug/kg-dry wt) in mussel composites (tissue + shell). All values at or below DL.

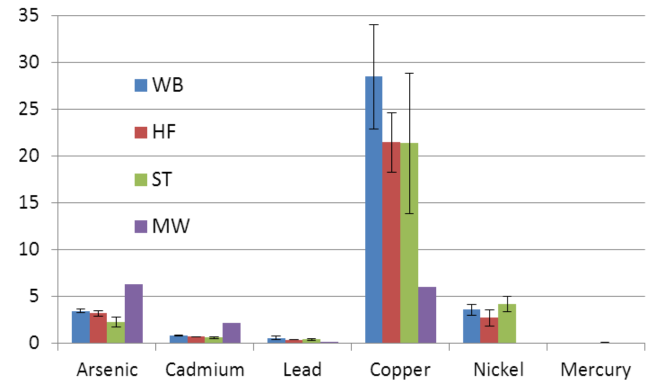


Figure 15. Trace metals (ug/g-dry wt) in mussel composites (tissue + shell). MW represents 2013 Mussel Watch data from HF site (tissue only). Nickel values all below DL.

TASK 3 – DEVELOP MUSSEL COMPOST

Mussels were harvested from each site and immediately delivered to various partners for compost trials. Mussels were harvested from West Bay Marina on September 25th and delivered to The Evergreen State College's (TESC) Organic Farm; Hearthfire on October 6th and delivered to WSU-Puyallup's Research and Extension Service; and Boatworks on October 23rd and taken to WA Department of Correction's (DOC) Cedar Creek facility.

TESC Organic Farm

Compost trials were performed at TESC Organic Farm by undergraduate student, Helen Dziuba, and faculty member, Melissa Barker. Mussels (901 lbs.) were delivered to TESC Organic Farm where they were processed in a wood chipper, transferred into 5-gallon buckets and weighed. Mussel weight decreased by 21.5% (901 lbs. to 741 lbs.) after chipping due to water loss and the inherently messy process of chipping mussels. One part mussels was combined with 1 part unsifted on-farm compost, 2 parts green field waste (mostly eggplants), and 2 parts wood chips (by volume). Feedstocks were placed into a manure spreader and mixed directly into a "negative aeration compost reactor" lined with a 6-inch layer of wood chips (Figure 16). The compost remained in the reactor for 28 days during which time pile temperatures were monitored weekly and the pile was turned on Day 8 and Day 19. Temperatures above 130˚ F

Figure 16. Helen Dziuba loading mussel compost into the reactor at TESC Organic Farm.

were reached and maintained over 3 days, meeting U.S. EPA's requirements to reduce pathogens. The finished compost was transferred to a covered storage bay to cure. No odor problems were encountered after the feedstocks were mixed. After one month, triplicate samples were collected from random points in the pile, sifted through sieves with an opening of 0.375 inches, and sent to Soiltest Farm Consultants for analysis. The C:N ratio for the final compost was 22:1, a bit higher than expected due to the 6-inch layer of wood chips from the base of the reactor being inadvertently mixed into the compost. Nonetheless, the compost was used, with great result, on the Farm's strawberry crop which prefers a higher ratio to encourage fruiting as opposed to leaf production. Refer to Appendix F for Helen Dbiuza's senior paper.

WSU Research and Extension Service, Puyallup

Compost trials were performed at WSU's Research and Extension Service in Puyallup by Senior Scientific Assistant, Andy Bary. Fresh mussels (446 lbs.) were passed through a portable chipper-shredder to grind shells and tissues before mixing with ground yard debris obtained from a local composter. The ground mussels (367 lbs.) and yard debris were mixed by layering measured volumes into a manure spreader and discharging onto a tarp. The mixture was loaded into an aerated 2.5 year capacity micro-bin compost system made by O2Compost in Snohomish, Washington (Figure 17). The unit was covered with a loose lid to divert rainfall but still allow airflow. The bin was equipped with an aeration system consisting of a blower connected to two perforated 4-inch pipes placed on the bottom of the composting chamber. Blowers were operated on a cycle to maintain temperatures in the 55 to 70˚ C range during active composting. Typically, this was a cycle of 30 to 60 seconds on and 30 minutes off. Specific times of the on and off cycles were adjusted based on the temperatures and temperature trends in the pile.

Figure 17. Andy Bary, Liz Myhre (WSU) and Steve Booth (PSI) load future mussel compost into the micro-bin.

Temperatures were measured at a minimum of two locations within the unit (approximately 50 and 100 cm above the bottom) five times per week throughout the active phase of composting, and less frequently thereafter. Temperatures were measured using dial-type probe thermometers placed into the pile through openings in the side of the compost unit. When the temperature fell below 35 to 45˚ C the aeration was turned off and the pile began a curing phase. After curing (typically a 4 week period) the compost was passed over a vibrating screen with pre-determined openings, and the screened compost (Figure 18) was used for laboratory analysis and vegetative growth experiments.

Figure 18. WSU mussel compost: Budd Inlet-HF (left), Quartermaster Harbor vermi-compost (right).

Washington Department of Corrections – Cedar Creek Facility

Compost trials were performed at Washington Department of Corrections' (WDOC) Cedar Creek Facility under the guidance of Environmental Planner, Eric Heinitz. Mussels were harvested (1279 lbs.), chipped at the Port of Olympia's Boatworks property, and delivered to DOC's Cedar Creek facility on October 23rd. WDOC's composting facility hosts the Enviro-Drum, an in-vessel composting system (8-yard operational capacity) made by DT-Environmental (Lynden, Washington) originally designed to compost dairy waste (Figure 19). The system is equipped with a biofilter for odor control. Chipped mussels (1048 lbs.) and additional

Figure 19. DT-Environmental's Enviro-Drum at WDOC's Cedar Creek Facility.

feedstocks (recycled, chipped bed mattress frames, unscreened compost, kitchen food waste, shredded paper) were loaded into a mixer at a ratio of 1:3 where they were mechanically shredded, blended and conveyed into the rotating drum via a feed auger. Markers were placed at the leading and trailing end of the mussel mixture to delineate the trial from other compost. October drum temperatures were typically 131˚ F and as high as 160˚ F on several days. November temperatures ranged from 101˚ F to 150˚ F. The compost was discharged from the drum after 20 days and conveyed to a covered curing bay where samples were collected and sent to TestAmerica for soil analysis. Inmates assisted with all aspects of the composting process.

Compost Analyses

Triplicate samples of mussel compost generated at TESC's Organic Farm and WSU-Puyallup were cured and screened prior to being tested at Soiltest Farm Consultants, a Seal of Testing Assurance (STA) Certified compost testing laboratory located in Moses Lake, Washington. Compost from WDOC was unscreened and may have contained both mussel compost as well as extraneous compost also discharged into the same curing bay. One WDOC compost sample was sent to TestAmerica, an analytical laboratory in Fife, Washington.

Soiltest analyzed the mussel compost for moisture, solids, pH, total nitrogen, organic carbon, C/N ratio, macronutrients, micronutrients, sodium, sulfur, and heavy metals. Test America analyzed the compost for metals, salmonella, moisture and solids. Variation was low between triplicates collected at each site and all were assigned a "Pass" rating.

Compost analysis (Table 2) indicates that the mussel compost is of suitable quality for agricultural and garden use. Compost from TESC and WDOC both had a moisture content of 60%, whereas WSU's was 21%. The moisture content reflects the percentage of organic matter in the compost indicating a higher water holding capacity in the TESC and WDOC compost. The percent nitrogen was 1.4% (dry weight) for both TESC and WSU and was untested at WDOC. Most compost contains approximately 1% total nitrogen meaning that an application of 1,000 lbs (0.5 dry tons) per acre would add 10 lbs. of nitrogen per acre, or in this case, 14 lbs. at 1.4% nitrogen.

The C/N ratio was 22 for TESC and 14 for WSU. Typical compost recipes may start as high as 30, but decline steadily as the composting process proceeds and microbes utilize the carbon. A final ratio of 15-20 generally indicates a finished product with ratios less than 20 offering a significant supply of nitrogen upon decomposition (http://soiltest.umass.edu/fact-sheets/interpreting-your-compost-test-results). The C:N ratio of 14 is low enough to expect net mineralization of nitrogen in the soil during the first season after application, and continued slow release of N in subsequent years. The C:N ratio of 22 is ideal for crops (i.e. strawberries) that benefit from less nitrogen which promotes fruiting and flowering as opposed to extensive leaf development (M. Barker, personal conversation).

Table 2. Compost Analyses, Soiltest Farm Consultants (TESC, WSU) and TestAmerica (WDOC). Quartermaster Harbor data (2013) also included. Moisture and Solids reported "as received;" remaining reported as dry weights.

	TESC (WBM)	WSU (HF)	WDOC (BW)	WSU (QMH)	Units	Typical
Moisture	58.00	20.63	61.00	0.00	%	15 to 40
Solids	42.00	79.37	39.00	100.00	%	60 to 85
Total N	1.37	1.45		1.52	%	1 to 5
Organic C	30.37	21.27		22.30	%	18 to 45
C/N ratio	22.00	14.33		14.70	ratio	18 to 24
Phoshorous	0.26	0.19		0.28	%	
Potassium	0.52	0.39		0.48	%	
Calcium	13.27	4.70		12.40	%	0.5 to 10
Magnesium	0.30	0.26		0.35	%	0.05 to 0.7
Sodium	0.48	0.36		0.48	%	0.05 to 0.7
Sulfur	0.28	0.29		0.32	%	0.1 to 1.0
Boron	19.33	16.33		24.50	mg/kg	25 to 150
Zinc	66.33	147.67	51.00	138.00	mg/kg	100 to 600
Manganese	295.00	228.00		251.00	mg/kg	250 to 750
Copper	29.00	17.67	26.00	61.00	mg/kg	100 to 500
Iron	6185.00	4439.67		5581.00	mg/kg	1000 to 25000
						WAC limit
Arsenic	0.40	2.77	11.00	2.83	mg/kg	20
Cadmium	0.33	0.37	ND	0.57	mg/kg	10
Chromium	11.13	10.27		10.73	mg/kg	
Cobalt	2.30	2.03		2.40	mg/kg	
Copper	29.00	17.67	26.00	61.00	mg/kg	750
Lead	1.03	3.57	ND	21.50	mg/kg	150
Mercury	0.01	0.04	ND	0.05	mg/kg	8
Molybdenum	0.40	2.23	ND	1.70	mg/kg	9
Nickel	8.67	7.50	8.20	8.90	mg/kg	210
Selenium	0.80	0.50	ND	0.80	mg/kg	18
Zinc	66.33	147.67	51.00	138.00	mg/kg	1400

Of the macronutrients (Phosphorous, Potassium, Calcium, and Magnesium) only Calcium (13%) exceeded the typical range, a unique signature reflecting the calcium carbonate contained within the mussel shells. Compost produced from the Hearthfire site was within normal range possibly due to the smaller volume of mussels (500 vs. 1000 lbs.) used from the HF location. Soils west of the Cascade Mountains are often depleted in calcium making mussel compost an attractive soil amendment. Micronutrients (Boron, Zinc, Copper and Iron) were within or below the typical range for compost and all heavy metals were well below Washington State compost standards (WAC 173-350-220, Table 220-B "Testing Parameters"). Sodium levels were also within a safe range.

Vegetative growth trials

Vegetative growth trials were performed July through September (68 days) of 2014. Marigold (n=16) and sunflower seeds (n=16) were placed in five, 32-well seed germination trays (total of 160 plants) to test SunGro potting soil (control) against four compost treatments. Each treatment consisted of a 50:50 blend of SunGro potting soil and compost: Cedar Grove municipal compost (CG), Budd Inlet/WSU mussel compost (BI), Quartermaster Harbor vermi-composted mussel compost (QMH), and Green Pet dog waste compost (GP) (Figure 20). Percent germination (Days 1-10), leaf lengths (Days 12, 19, 40), and plant height measurements (Day 68) were recorded. On Day 50, the healthiest 50 plants (5 sunflowers and 5 marigolds from each tray) were transplanted into larger pots containing a similar 50:50 blend of potting soil and compost. Upon completion, plants were used for classroom presentations and compost displays.

Figure 20. Vegetative growth trials using four compost treatments: GP, QMH, BI, CG, SG (from left to right).

The QMH mussel compost yielded 100% germination (32/32) followed by SG and GP at 90.6% and CG and BI at 75%. Seedlings had a more difficult time pushing up through BI's coarser woody shell blend as opposed to the finer, lighter mixes. Early in the growth trials, seedlings grown in the vermi-composted QMH blend and SG potting soil were robust and displayed vigorous leaf growth. The seedlings grown in the BI compost trailed behind significantly (Figure 21). By Day 40, plants in the SunGro potting soil lagged behind and were slightly more yellow and spindly, likely due to nutrient depletion (Figure 22). Plants grown in all four compost treatments were robust and exhibited complex branching structure. While plant heights among all 5 treatments on Day 68 were essentially the same, those grown without compost were spindly and yellowish green.

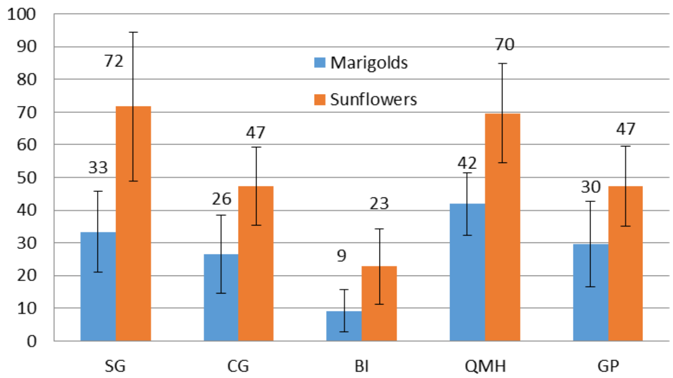


Figure 21. Length across secondary leaves (mm) on Day 19.

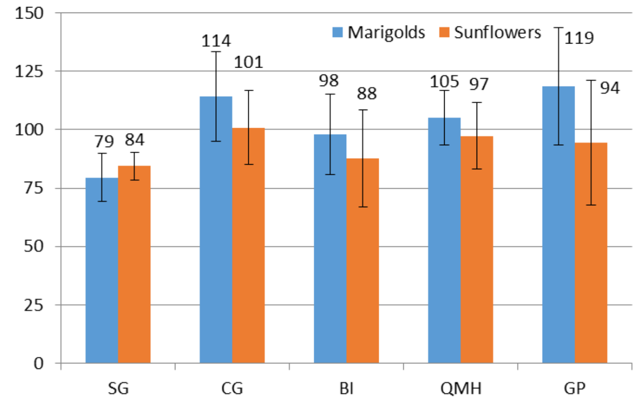


Figure 22. Length across leaves (mm) on Day 40.

Marigolds and sunflowers were successfully grown in the mussel compost, particularly the QMH mussel compost that had been extensively colonized with red worms while being stored at a PSI staff member's home (whose personal compost pile had been amended with the worms.) All four compost blends provided adequate nutrients to the plants over the 68 day growth trial period and lacked any contamination concerns. The coarser BI blend from WSU is recommended for use on already established plants as opposed to those requiring germination.

TASK 4 – COMMUNITY EDUCATION AND PROJECT PROMOTION

This project aimed to decrease nutrients in Budd Inlet both directly through the removal of cultivated mussels and indirectly through outreach and education. Because mussels and other bivalves alone cannot solve all septic and wastewater issues in Budd Inlet, public outreach and education were performed to increase awareness and motivate citizens to make personal behavior choices to reduce nutrient and bacteria loading. Mussels and other shellfish are highly visible and recognizable constituents of the marine environment. The demonstration sites, therefore, served as a valuable tool to engage the community and provide an opportunity for discussing and developing other possible nutrient reduction solutions. The community was invited to participate in many aspects of the project including scientific data collection and the end-of-season mussel harvest. Public outreach was also conducted in the form of public workshops, K-12 and college level presentations, student mentoring, professional conferences and meetings with key stakeholders.

Student outreach

The project provided many opportunities for student engagement. PSI mentored 6 students from TESC and UW-Tacoma in aspects of data collection, entry, and analyses; and mussel composting. High school students from New Market Skills Center's Natural Resources Management class visited the HF demonstration site and collected usable water quality, biodiversity and mussel growth data. In late summer, SSGREEN advertised the "Shellfish-at-Work" classroom presentation and/or site field trips to participating teachers in the Olympia and North Thurston school districts. Presentations (Appendix G) were delivered to 18 classrooms, reaching over 500 students. Content, activities, and worksheets (Appendix H) were adapted for elementary, middle school and high school levels. Presentations focused on the nutrient cycle and eutrophication, hands-on scientific data collection, creative solutions, and behavior changes related to source control. Two classes walked or used public transportation to the BW demonstration site, where they recorded data, harvested bags of mussels, and then transported them to LOTT's Wet Science Center classroom to collect biodiversity and mussel length/weight data. The presentations were well received with one teacher commenting, "Thank you so much for coming to my three classes Friday! It was a great way to give real-life examples of local problems and solutions. I'd love to have you come back next year." (Heidi Kirk, Olympia High School science teacher) (Appendix I). To meet demand for future presentation requests, PSI acquired Russell Family Foundation funds during 2014 to provide hands-on experiential learning opportunities to middle and high school students in Thurston County. The presentation will remain advertised on Thurston County's Environmental and Sustainability Education (ESE) Guide through 2015 (www.thurstoneseguide.org).

Community outreach

Figure 23. Mussel compost display at TugBoat Annie's Restaurant.

In addition to classroom presentations, PSI provided citizen monitoring opportunities to the general public at two Community Sampling Days. These events allowed citizens to collect and record real data, use a GoPro underwater video camera, and participate in the final mussel harvest. Additional workshops were also provided to the public: one at LOTT's Wet Science Center as part of their weekend family activities series (Appendix J), and one at an East Bay Homeowner Association meeting focusing on shellfish gardening, ecosystem services of shellfish, Budd Inlet water quality and nutrient bioextraction.

The Shellfish-at-Work project was also advertised to the public via newsletter articles and interpretive signs. PSI published an article in Stream Team's Fall 2013 newsletter (Appendix K) highlighting the project and advertising two Community Sampling/Harvest Days. Two additional articles were published in Longlines, the Pacific Coast Shellfish Growers Association's Fall 2013 and Winter 2014 newsletters (Appendix L). Finally, the project was highlighted in the Salish Sea Currents online magazine in an article titled, "Gifts from the sea: shellfish as an ecosystem service" (www.eopugetsound.org/magazine/shellfish) published in December 2014.

Interpretive signs were placed at each of the demonstration sites throughout the growing season. After the mussels were harvested and composted, a second interpretive sign was produced (Appendix M). These signs were placed into 3 galvanized feeding troughs filled with mussel compost and plants and placed at Tugboat Annie's Restaurant (by the WBM site), LOTT Clean Water Alliance (by the HF and BW sites) and at the Eastside Urban Farm and Garden store during the mussel compost giveaway event (Figure 23).

PSI further promoted the project at public events and conferences. PSI attended the Thurston County Fair, Belfair's Shellfest, Warm Beach's Summerfest, and South Sound Estuary Association's Turning the Tide Festival and Open House Celebration. PSI also presented findings to inmates graduating from an Environmental Literacy course offered through the Sustainability in Prisons Program at the Cedar Creek Correctional Facility. Finally, results were presented to the scientific community and regulators at a number of professional conferences including ACES (A Community on Ecosystem Services) in Washington DC during December 2014; the Salish Sea Ecosystem Conference in Seattle, WA in May, 2014; the joint Pacific Coast Shellfish Grower's Association (PCSGA) and National Shellfisheries Association (NSA) Pacific Coast Section's Annual Shellfish Conference in Sunriver, OR, in September 2013; the NSA 106th Annual Meeting and Conference in Jacksonville, Florida in March 2014; the South Sound Science Symposium in Shelton, WA, in October 2014; the International Conference on Shellfish Restoration (ICSR) in Charleston, SC, in December 2014; and WDOE's Environmental Assessment Program (EAP) Seminar in Lacey, 2014. One-page information sheets (Appendix N) and Surf-to-Turf mussel compost samples were distributed at public events and conferences. The project was advertised on PSI's web-site and Facebook page.

This final report will be distributed to project partners and volunteers including, but not limited to, marina owners, Port of Olympia staff, LOTT Clean Water Alliance, WDOE, composting partners, participating teachers and graduate students, citizen scientists, and the mayor of Olympia.

TASK 5 – ESTABLISH COMMUNITY NETWORK AND DEVELOP PLAN FOR IMPLEMENTING NUTRIENT TRADING SCENARIOS

Community network

The purpose of establishing a network was to link the community to Budd Inlet water resource management efforts and to help identify information needs and educational opportunities. Establishing a network helps ensure that nutrient mitigation and other aspects of ecosystem services provided by shellfish are supported beyond completion of the project. This project relied on the support and guidance of a number of project partners including waterfront businesses, residents, students, and resource managers. Those assisting with the establishment of the mussel demonstration systems included Port of Olympia managers and staff, the manager at Hearthfire Restaurant, and owners of West Bay and Boston Harbor Marinas. Community connections through education and outreach were made possible by Thurston County Conservation District South Sound Green (SSGREEN), City of Olympia's Stream Team, LOTT Wet Science Center, South Sound Estuary Association (SSEA), Puget Sound Restoration Fund (PSRF), and the Environmental Education Technical Advisory Committee (EETAC). Composting guidance was provided by TESC, WSU-Extension, and Washington Department of Corrections. Additional participation included a multitute of teachers, students and citizen scientists involved in collecting data and learning about nutrient bioextraction. Finally, the network was faciliated by attending Deschutes River TMDL meetings, consulting with members of WDOE's Environmental Assessment Program, LOTT Clean Water Alliance, and the Mayor of Olympia.

Nutrient trading

Nutrient trading is a specific type of water quality trading. Water quality trading is a voluntary market-based approach that, if used in certain watersheds, might achieve water quality standards more efficiently and at lower cost than traditional approaches (EPA, 2004). In 2003, the US Environmental Protection Agency (EPA) released a policy statement regarding water quality trading (EPA, 2003). The policy includes the following:

> "*The purpose of this policy is to encourage states, interstate agencies and tribes to develop and implement water quality trading programs for nutrients, sediments and other pollutants where opportunities exist to achieve water quality improvements at reduced costs. More specifically, the policy is intended to encourage voluntary trading programs that facilitate implementation of TMDLs, reduce the costs of compliance with CWA regulations, establish incentives for voluntary reductions and promote watershed-based initiatives. A number of states are in various stages of developing trading programs. This policy provides guidance for states, interstate agencies and tribes to assist them in developing and implementing such programs*."

Furthermore, it states that:

> "*EPA supports implementation of water quality trading by states, interstate agencies and tribes where trading:*
>
> - *Achieves early reductions and progress towards water quality standards pending development of TMDLs for impaired waters.*

- *Reduces the cost of implementing TMDLs through greater efficiency and flexible approaches.*
- *Establishes economic incentives for voluntary pollutant reductions from point and nonpoint sources within a watershed.*
- *Reduces the cost of compliance with water quality-based requirements.*
- *Offsets new or increased discharges resulting from growth in order to maintain levels of water quality that support all designated uses.*
- *Achieves greater environmental benefits than those under existing regulatory programs. EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains and wildlife and/or waterfowl habitat.*
- *Secures long-term improvements in water quality through the purchase and retirement of credits by any entity.*
- *Combines ecological services to achieve multiple environmental and economic benefits, such as wetland restoration or the implementation of management practices that improve water quality and habitat.*"

Following the policy, EPA released a comprehensive document Water Quality Trading Assessment Handbook: Can Water Quality Trading Advance Your Watershed's Goals? (EPA, 2004). The purpose of the handbook is to provide a resource to evaluate when and where water quality trading is the right tool for a watershed, and if trading will work (EPA, 2004). In addition to a water quality trading summary introduction, sections include: Pollutant Suitability in a six-step suitability analysis; Financial Attractiveness; Market Infrastructure; and Stakeholder Readiness. Overall, the handbook focuses on conducting an analysis to determine if watershed scale trading is likely to be viable once environmental and economic factors are considered. Of particular relevance to this project's work in Budd Inlet is the handbook's Appendix B: Water Quality Trading Suitability Profile for Nitrogen. This appendix briefly summarizes the influence of excessive nitrogen on eutrophication, and recommends an understanding of how nitrogen loads connect to specific water quality problems in a watershed.

Specific to the Pacific Northwest, water quality agency staff from Idaho, Oregon, and Washington, EPA, along with the Willamette Partnership and The Freshwater Trust, released draft recommendations for approaches to water quality trading in August 2014 (Willamette Partnership and The Freshwater Trust, 2014). The purpose of the recommendations are to guide a consistent approach to water quality trading in the region. According to the Willamette Partnership (2014a), the participating states have committed to testing their recommendations, beginning in 2014, and are currently working to identify pilot projects. Both the Draft Regional Recommendations for the Pacific Northwest on Water Quality Trading (Willamette Partnership and The Freshwater Trust, 2014), and the more recent guidance document: Building A Total Maximum Daily Load To Better Support Water Quality Trading (Willamette Partnership, 2014b) are valuable resources for Ecology to consider as it evaluates water quality trading possibilities in Washington State, including nutrient trading. These guidance documents are also relevant to full filing House Bill 2454 of the 2013-2014 legislative session, which directs the Washington State Conservation Commission, in partnership with Ecology, to explore whether there are a sufficient number of potential buyers and sellers for a water quality trading program to be successful in watersheds where TMDLs have been established.

Shellfish as a component of nutrient trading scenarios

Significant resources have been invested to better understand and communicate water quality problems in Budd Inlet, including the LOTT Budd Inlet Scientific Study (LOTT Alliance, 2000) and Ecology's TMDL for the Deschutes River watershed (Ecology, 2012). In 2008, the Budd Inlet Restoration Partnership (BIRP) was formed between the City of Olympia and Port of Olympia, Thurston County, LOTT Alliance, Squaxin Island Tribe, and WSU Extension with the shared goal of working together to improve the health of Budd Inlet. In 2011, the BIRP – Phase II Report was completed, which included a science-based priority list of restoration projects for the Inlet. Growing mussels to test the effects of nutrient removal is one of the BIRP report's recommendations (Ross and Associates, 2011).

Shellfish such as mussels can serve as a means to recycle nutrients that enter our waterways from human and agricultural sources. A recent study (Golen and Sulkowski, 2009) found that shellfish can be "an integral part of an overall strategy for the removal of the effects of over-nitrification of estuarine waters in the Total Management Daily Load process" and that such tools "meet both the statutory requirements of the Clean Water Act (CWA) and its policy objectives of restoring water quality." As filter feeders, mussels and other bivalve shellfish feed on a wide range of suspended particles in the water column, including phytoplankton, bacteria and detritus (Figure 24). The shared ecosystem functions of nutrient remediation, water clarification, biodeposition, and habitat creation make suspension-feeding bivalves a valued provider of ecological services to the shallow-water ecosystems (Carmichael et al., 2012; Peterson et al., 2010; Rose, 2010; Newell, 2005). There has been a concerted effort to identify the

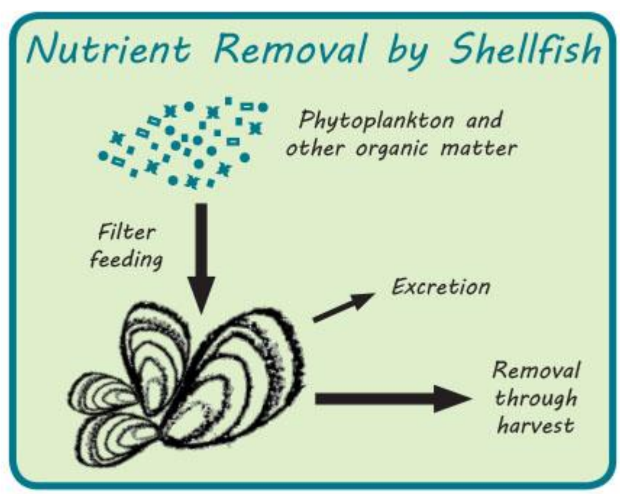


Figure 24. Simplified graphical representation of how shellfish remove nutrients through filter feeding.

ecological roles of shellfish and shellfish culture on estuarine and marine habitats to: help offset habitat decline; improve water quality; and provide essential ecological function (Ferreira et al., 2011). The question: “Are enhanced shellfish populations an effective tool to combat eutrophication?” is being asked on state, national and international platforms, and could not be more relevant than in Budd Inlet. The Inlet’s circulation and residence time makes it a prime candidate for utilizing bivalve shellfish to control eutrophication. This is because bivalves are only effective at reducing seston (microscopic living and non-living suspended particles) concentrations where water resides long enough for filter feeding to have an impact (Konrad, 2013).

The possibility of using bivalves in nutrient trading schemes has been explored (Lindahl, 2011; Ferreira et al., 2007; Higgins et al., 2011; Stephenson et al., 2011; Beseres Pollack et al., 2013), and is beginning to be explored in Washington State (Northern Economics, 2009; Steinberg and Hampden, 2010). Newell and Mann (2012) also detail specific considerations toward the potential of including shellfish in nutrient trading. Shellfish have been specifically considered for inclusion in TMDL processes for nutrient management (STAC, 2013; Grizzel, 2012; Rose, 2010) but to date the focus has been on Eastern oysters (*Crassostrea virginica*) and reliable denitrification rates for inclusion in TMDL implementation is not possible without direct measurements on individual oyster reefs (Grizzle, 2012). In contrast, PSI’s pilot-scale bioextraction research in southern Puget Sound has utilized enhanced wild-set mussels, enabling clear nitrogen reduction calculations based on the nitrogen content of harvested mussels (see Task 2 section for calculations derived from this project).

Buyers and sellers of nutrient credits involving shellfish

Although nutrient removal with shellfish is a relatively new development, nutrient bioextraction using farmed mussels has been conducted on the Swedish west coast (Smith et al., 2013). Specifically, a nutrient trading agreement was made between the community of Lysekil, Norway, and a private mussel farmer, allowing the Lysekil sewage treatment plant to continue emitting 29 tons of nitrogen while the same amount of nutrients were “harvested” by the shellfish farm through 3500 tons of blue mussels (*Mytilus edulis*). In this case, the buyer of nutrient credits was the community of Lysekil, coordinated through a trial project (INTERREG) approved by a county board, who also monitored the project. The seller of nutrient credits was a private mussel farming enterprise, with payments based on the quantity of nitrogen found in the harvested mussels. The scheme successfully removed nitrogen from coastal waters, with the mussel farm cost-effectively removing 100% of the waste water treatment plant’s nitrogen emissions, but unfortunately, in 2011 the farming enterprise at Lysekil went bankrupt due to lack of market demand for the mussels produced (Smith et al., 2013).

A trading scenario similar to the community of Lysekil Norway can be envisioned for Budd Inlet, using wild-set mussels, destined for compost rather than human consumption, as demonstrated through this project. Potential buyers of nutrient credits include National Pollutant Discharge Elimination System (NPDES) permitted entities in the Deschutes River, Percival Creek, Budd Inlet Tributaries, Capital Lake, and Budd Inlet directly. Accordingly, these entities are involved with the in-process TMDL. Previous research (ENTRIX, 2009, and citations therein) suggests that if a tidal area existed where nitrogen treatment was reaching limits of technology, then shellfish may provide an economical and environmentally viable nitrogen removal method. The ENTRIX technical memorandum (2009), suggests that the question becomes whether space to expand shellfish exists in the same geographic region as tight constraints on nitrogen loads. This project's results, combined with the in-process TMDL, demonstrates that these two criteria overlap for Budd Inlet, and therefor nutrient bioextraction with shellfish can be viable component toward improving Budd Inlet water quality.

Future research

There are additional ecological parameters which must be evaluated when considering shellfish for nutrient removal in TMDL processes, such as the Deschutes River, Capital Lake and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment TMDL. A significant consideration for the marine component is the combined effect of shellfish on nutrient removal and dissolved oxygen. It is well-established that shellfish influence nutrient availability, but using shellfish for nutrient management toward the goal of improved DO requires additional information. The degree to which shellfish can positively influence Budd Inlet DO is dictated by the complex interplay of multiple processes, some of which are understood for Budd Inlet (water circulation, residence time) and somewhat understood (nutrient inputs, phytoplankton production time).

Other variables are poorly understood, including critical variables influencing nutrient dynamics. Most significant is shellfish clearance rate, commonly defined as the volume of water filtered completely free of particles per unit time (Barnes, 2006 and citations therein; Pascoe et al., 2009). Clearance rate varies by season (Prins et al., 1994; Cranford and Hill, 1999), temperature (Prins et al., 1994; Pomeroy et al., 2006; Cerco and Noel, 2007), food availability (Ward and Shumway, 2004), stocking density (Pomeroy et al., 2006), prey preferences (Ward and Shumway, 2004) and shifting nutritional demands (Kreeger and Newell, 2001; Dumbauld et al., 2009). Furthermore, the full effect of bivalve filter feeding depends not only on nutrient uptake through consumption, but also the secondary effects mediated by trophic dynamics and biogeochemical nutrient processing in the water column and sediments (Konrad, 2013). Bivalve shellfish regenerate nutrients through production of feces and psuedofeces (undigested mucus-bound particles) which can contribute to local eutrophication and promote phytoplankton growth (Nizzoli et al., 2005; Olin, 2002).

The source and exact mechanisms of local eutrophic conditions have been the focus of numerous and ongoing research by the Washington Department of Ecology and others in the region (Roberts et al., 2008; Roberts et al., 2009), but the influence of shellfish populations and shellfish respiration on Puget Sound eutrophic conditions remains largely unknown. For these reasons, future research should focus on an in-depth examination of biophysical indicators and nutrient dynamics surrounding shellfish cultivated for nutrient bioextraction in Budd Inlet. During preparation of this final report, PSI was pleased to be notified by Ecology that our NEP Reducing Nutrients in a Watershed proposal addressing the research needs outlined above, will be funded in 2015-2017.

CONCLUSIONS

The question: "Are enhanced shellfish populations an effective tool to combat eutrophication?" is being asked on state, national and international platforms, and could not be more relevant than in Budd Inlet. The Inlet's circulation and residence time makes it a prime candidate for utilizing bivalve shellfish to control eutrophication. This is because bivalves are only effective at reducing seston (microscopic living and non-living suspended particles) concentrations where water resides long enough for filter feeding to have an impact (Konrad, 2013).

This project provided a creative strategy to mitigate anthropogenic nutrient loads in urban watersheds by engaging waterfront businesses and residents in the cultivation of mussels for nutrient bioextraction. By doing so, the project increased public awareness of local water quality issues including bacterial pollution, eutrophication, and harmful algal blooms and offered activities that empower citizens to envision a swimmable, fishable Budd Inlet. This work supported the long-term restoration goals set by the City and Port of Olympia, Thurston County, LOTT Alliance, and the Squaxin Island Tribe (Budd Inlet Restoration Partnership).

Laboratory results from this project indicated that total percent nitrogen (wet weight) was 1% and percent phosphorus averaged 0.08% in mussels harvested from demonstration systems in Budd Inlet. We estimate a potential harvest from the three Budd Inlet nutrient bioextraction demonstration sites of 7988 pounds of mussels, or 80 pounds of nitrogen, based on mussels grown on 1101 cubic feet of space (length of demonstration sites x 1-ft width x depth) with 233 straps. This information may be used to extrapolate the area, or number of straps, needed to remove any given amount of nitrogen. The exact amount of nitrogen removal needed to meet TMDL requirements for Budd Inlet is still being determined, and once this value is published, it will reveal how much of a role nutrient bioextraction might play in improving water quality in the Inlet. Nutrient bioextraction serves as a complement to the array of nutrient removal efforts currently underway including source control in the upper watershed, septic and sewer repairs, farm management plans, outreach, and LOTT's nutrient removal technology.

This project's results demonstrate that nutrient bioextraction with shellfish can be a viable component toward improving Budd Inlet water quality. Future research should focus on an in-depth examination of biophysical indicators and nutrient dynamics surrounding shellfish cultivated for nutrient bioextraction in Budd Inlet, and this research is planned for 2015-2017, utilizing NEP Reducing Nutrients in a Watershed funding.

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