Puget Sound Committee

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Hood Canal Salmon Enhancement Group
Molluscan Study
Final Report
10/30/2006

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Executive Summary

The Hood Canal Salmon Enhancement Groups Molluscan Study is an investigation into the ecological value of filter feeders in Hood Canal. Phase 1 consisted of a literature review that resulted in the identification of data gaps related to filter feeder ecology in Hood Canal. This document is the report from Phase I of the Molluscan Study. Phase one was to: 1) research knowledge of the ecological importance of filter feeders. This will include their importance to sediment composition and sediment processes, phytoplankton control, seagrass productivity, and carbon/nutrient storage. 2) develop methods to understand theses processes spatially and temporally. The approach taken was to determine how bivalves have been found to be beneficial in other eutrophied bodies of water and determine the body of knowledge that supports these concepts in Hood Canal. The result of this effort is a plan to build a spatial model that relates filter feeder distributions to the processes that effect the water column, and sediments while characterizing the variability of these processes as it relates to environmental conditions such as latitude, depth, and density of filter feeders.

1.0 Introduction

The filter-feeding molluscan community (oysters, clams, mussel, geoducks) are integral to and dependant upon the water quality and marine processes of Hood Canal. The intertidal habitat of this molluscan community is a dynamic place. It is influenced in part by terrestrial nutrient inputs, sunlight, changing temperatures, and phytoplankton populations. In turn, the molluscan community plays a role as filter feeders in the fate of sediments (Newell 2002, Newell 2004, Officer 1982, Peterson and Heck 1999, Peterson and Heck 2001, Prins 1990, Prins 1995, Souchu 2001, Swanberg 1991, Dame 1991, Doering 1986, Hatcher 1994), seagrass productivity (Enriquez 2001), and carbon and nitrogen storage (Hammer 1996).

The commercial shellfish industry in Hood Canal relies on the healthy condition of these processes to provide oysters, clams and mussels to a world market. The mid to low intertidal geoducks have recently been targeted for aquaculture as well. Because of the deeper water environment in Hood Canal where the geoduck live, there is much less known about how this mollusk may influence those marine waters, or even how the marine waters of Hood Canal may influence the geoduck community.

Hood Canal was recently included as a "dead zone" in the PEW Ocean Commission's "America's Living Oceans, Charting a Course for Sea Change" (2003) due to the processes of eutrophication. Eutrophication is the concept of an increased nutrient load in a body of water, increasing primary productivity. This resultant high productivity eventually leads to increased decomposition and reduces dissolved oxygen levels in the bottom waters. Hood Canal's eutrophication is exacerbated by strong stratification, slow circulation and a demonstrated high rate of primary productivity. Extreme low levels of dissolved oxygen have caused localized fish and shellfish kill events, which have been recorded periodically over the last several decades. Unusual behavior of many fish species has been observed by recreational divers during these times.

Bivalve filter feeders have been studied in other bodies of water as mediators of the factors contributing to eutrophication (Officer 1982, Haamer 1996). There are several mechanisms by which filter feeders are thought to impact eutrophication. Bivalves have the ability to alter sediment processes via biodeposits of their wastes (Newell et al. 2004, Pietros and Rice 2002), controlling phytoplankton population levels (Cloern 1982, Mohlenberg and Riisgard, 1979, Souchu 2001), increasing seagrass productivity (Peterson and Heck 1999), and by assimilating nutrients and organic matter into their tissues. Each of these mechanisms has been shown in other bodies of water to alter the fate of the nutrients and organic matter that contribute to low dissolved oxygen. The Hood Canal Salmon Enhancement Group's Molluscan Study serves to investigate the specific ecosystem services that are provided to Hood Canal from bivalve filter-feeders and quantify the role played by bivalves in mediating the current low dissolved oxygen levels.

2.0 Mechanisms of bivalve benefits in eutrophic waters

2.1 Filter-feeders as a functional group

The role of bivalve filter feeders in marine ecosystems has recently become a larger question as anthropogenic factors increase the processes of eutrophication. The factors contributing to eutrophication in marine ecosystems are a blend of natural processes that cannot be controlled (sunlight, residence time, ocean inputs) and those which are contributed by anthropogenic processes (such as agriculture, septic inputs, land use changes). The phytoplankton production in the marine system of Hood Canal has been demonstrated to be nitrogen limited, and the anthropogenic contributions can tip the balance by increasing the 'natural' rate for primary productivity. The increase in primary productivity (typically phytoplankton) in the upper water layers, eventually ends up in the sediments decomposing, a process that consumes oxygen. Filter feeders are thought to be a link between phytoplankton (their food) and the benthic environment where decomposition and nutrient regeneration occur. This process of moving organic matter from the water column to the sediments is called benthic-pelagic coupling. The ecosystem services provided by benthic-pelagic couplers vary from location to location based on the environmental conditions at a particular site. Microbial communities, oxygen levels, rates of flushing and turbation, bioturbation in the sediments, and many other factors likely contribute to the fate and quantity of the flow of organic matter caused by benthic-pelagic coupling.

Different benthic-pelagic coupling organisms play different roles, driven by the mechanism of their outputs (wastes, carcasses, etc.) as well as their method of inputs or filtration. Bivalve filter feeders such as clams, oysters and mussels actively pump water to capture their food, effectively concentrating the deposition of organic material to the vicinity around the organism. In comparison to passive filter feeders, such as barnacles that rely on the current of the water to bring food to them, active filter feeders are able to collect organic matter from a larger volume of water.

There have been several positive effects caused by filter feeders on eutrophied bodies of water seen around the world. These effects include filter-feeders ability to increase rates of coupled nitrification-denitrification (Newell 2002), increase rates of sedimentation (Pietros and Rice 2003), control phytoplankton biomass (Souchu et al 2001, Cloern 1982), stimulate seagrass productivity (Peterson and Heck 2001, Peterson and Heck 1999), and store nutrients and carbon in their tissues as they grow. Bivalve benefits in Hood Canal have not been empirically measured and are therefore poorly understood. Quantifying these mechanisms will give insight to the degree to which bivalves affect the processes surrounding the fluctuating low dissolved oxygen conditions.

2.2 Sediment Effects

2.2.1 Physical character of Biodeposits

Bivalve filter feeders take in organic matter and nutrients in the form of phytoplankton and deposit wastes on the sediment in the form of feces and pseudofeces. These biodeposits are composed of ammonium waste from digestion (feces) as well as organic and inorganic matter from particles that were filtered and could not be digested (psuedofeces). Ammonium is water-soluble and is easily dispersed into the water column to promote further phytoplankton production. If no other processes were to occur, then filter feeders would serve to simply regenerate nutrients and promote complete recycling of phytoplankton (Newell et al. 2004). However, there are other processes occurring that affect this loop. By actively pumping water to capture their food then depositing wastes onto the sediments, bivalves can increase sedimentation rates (Pietros and Rice 2002). This results in the nutrients that would fuel further phytoplankton growth and the carbon metabolized by microbes consuming oxygen to become buried and unavailable to perpetuate these processes (Newell et al. 2004).

2.2.2 Fate of Biodeposits

The fate of the nutrients in biodeposits is thought to be controlled by light availability and oxygen content in the sediments (Newell et al. 2004). In shallow water where there is both an aerobic sediment layer and available light for photosynthesis, nitrification can occur, converting ammonium waste into nitrite and nitrate, which is trapped by photosynthetic plants in and on the sediments as well as photosynthetic bacteria. This trapping represents temporary storage of these nutrients that slows the recycling of phytoplankton production, In moderate depths without enough light to promote photosynthesis but enough oxygen to create a boundary layer between aerobic sediments and anaerobic sediments, the nitrate and nitrite produced by nitrification can diffuse to the anaerobic sediments where denitrification can occur (Newell 2004). Denitrification is the conversion of nitrite and nitrate to nitrogen gas, which is not bioavailable and escapes to the atmosphere. This combination is called coupled nitrification-denitrification and represents the removal of nitrogen from the system. In terms of eutrophied bodies of water such as Hood Canal, this is the path of most complete nutrient removal.

Deeper water lacks the aerobic sediment layer necessary to convert ammonium to nitrate and nitrite, eliminating necessary components of denitrification (Newell 2004). Eliminating coupled nitrification-denitrification leaves burial as the sole benefit of deep-water filter feeders on eutrophied waters. However, it is likely that burial is enhanced in deeper waters by reduced tidal and wave action that could resuspend ammonium and other nitrogenous wastes in intertidal or shallow subtidal waters. — except for harvest

2.2.3 Remaining Questions

Several questions remain when trying to apply these concepts to Hood Canal. First, how much oxygen is needed to promote adequate coupled nitrification-denitrification? If there were a high oxygen demand of coupled nitrification-denitrification, it would severely limit the spatial extent over which it could occur. If coupled nitrification-denitrification can occur at low levels of oxygen in the sediments, bivalve filter feeders may be a dominant force in nutrient cycling in Hood Canal and other deep eutrophied waters. Also, how do different species and populations of the same species vary in terms of the types of biodeposits contributed to the sediments and what effect would these differences have on nutrient cycling? If there is a significant difference in the quality of the wastes deposited it may indicate that certain species or populations bounded by specific environmental conditions are more beneficial in terms of nitrogen removal or storage. Answering some of these questions as well as measuring the rates of sedimentation and coupled nitrification-denitrification will give insight to filter-feeders role in the nitrogen cycling that occurs in Hood Canal.

2.3 Phytoplankton Population Control

In a study performed by James Cloern (1982) in South San Francisco Bay it was inferred from direct measurement of phytoplankton concentrations, nutrient levels, and sunlight availability that bivalves in the bay were exerting a control that limited phytoplankton production for much of the year. It was assumed that bivalves drove this system because of their high abundance and the low phytoplankton populations despite environmental conditions that would support high rates of growth. Previously, filtration rates were drawn from an average of 5 species by weight and applied to the biomass found in South San Francisco Bay (Mohlenberg and Riisgard, 1979). From this information and the calculated water volume of the bay it was determined that the quantity of bivalve filter feeders was sufficient to filter the entire volume of the bay in less than one day.

These results show a potential mechanism of phytoplankton regulation that may or may not be occurring at significant levels in Hood Canal. South San Francisco Bay where the study was performed has a maximum depth of approximately 3 m, while Hood Canal reaches depths of over 150 m (HC has depths over 180 m). The access of filter feeders to the water column is far greater in South San Francisco Bay than in the depths of Hood Canal, and in Hood Canal there is a far larger volume of water to be filtered.

A study performed by Phillippe Souchu et al. (2001) in Thau lagoon on the French Mediteranean coast showed a decrease in phytoplankton populations due to suspended oyster pens. In this study two monitoring sites were established within the boundaries of the pens and two outside the pens. Parameters monitored included salinity, dissolved oxygen, nutrients, organic matter and chlorophyll. Sampling occurred over several time scales to assess seasonal and day-to-day variations. They found significant decreases in the concentration of chlorophyll and particulate organic carbon, 44% and 26%, respectively, inside the shellfish-farming site. However, nutrient analysis showed significant increases of ammonia, phosphates and silica in the sites within the farm.

Applying the results of this study to Hood Canal have some of the same exceptions of the Cloern study, since Thau lagoon is also a shallow body of water (the sampling locations are located in approximately 4m of water). In addition, the shellfish farming system used suspends the organisms in the water column, facilitating the re-suspension of the oysters' wastes. This probably played a role in the large nutrient increases seen. Had the oysters been naturally anchored on the bottom more of the waste would have settled out of the water column.

Bernard (1983) performed a series of experiments that determined clearance rates for 9 bivalves in a laboratory setting. The term used in the study was ventilation, meaning the minimum flow of water and particles that approached a limit of particle removal. These rates were compared to respiration rates across the varying physiological conditions of temperature and salinity. The results based on dry tissue weight show the Manila Clam (T. philippinarum) as the most effiecient ventilator, followed by the Pacific Oyster (C. gigas) while the Horse Clam (T. capax) was the least efficient. These results give little insight into the seasonal variability and as a result the ecological effects of the filtered water.

2.4 Seagrass Productivity

An increase in seagrass productivity has a positive influence on eutrophied bodies of water such as Hood Canal through two pathways; by storing nutrients and by producing oxygen. There are two mechanisms identified by which bivalve filter feeders increase seagrass productivity; fertilization through nutrient deposition and by reducing turbidity. In the summer months when phytoplankton production is typically at its highest, the density decreases light penetration into the water, effectively reducing available seagrass habitat. Typically, seagrasses are limited by both nutrient availability and light availability. These limitations are exacerbated by the fact that when nutrient availability increases, so does turbidity resulting in a decrease in available light. Bivalves have been shown to be able to reduce the concentrations of plankton to the degree that there is an increase in light penetration, increasing opportunity to seagrasses, while at the same time depositing nutrients in the sediments where they are most valuable.

Peterson and Heck (1999) found that experimental plots containing the American Horse Mussel (*Modiolus americanus*) showed increases in net above ground primary production, along with decreases in the seagrass *Thalassia testudinum's* leaf carbon:nitrogen ratios. A decrease in the carbon:nitrogen ratios indicates that the concentration of nitrogen in the plant has increased. According to Peterson and Heck, these results are evidence that the nutrient rich biodeposits are stimulating increased seagrass growth and the nutrients are being incorporated into the plants.

The underwater topography of Hood Canal is strikingly different than the location where this study occurred. Peterson and Heck describe their site as:

> "St. Joseph Bay is a protected shallow coastal embayment where salinities usually range from 30-36 ? Ä with water column nitrogen and phosphorus values seldom exceeding 3 and 0.2 μM respectively. Phytoplankton abundance is also low, usually below 5μg/l. Therefore, photosynthetically active radiation is high, with approximately 40% of measured light at the water surface reaching the seagrass canopy."

The contrast between Hood Canal and St. Joseph Bay is significant, especially in size and depth. Both of these factors play a role in the amount of seagrass (*Zostera marina* in Hood Canal) habitat in relationship to the volume of water. St. Joseph Bay is composed almost entirely of a large shallow flat, while in Hood Canal, this type of habitat is found exclusively in estuaries.

2.5 Carbon and Nutrient Storage in Tissue

Another way bivalves can mediate excess nutrients and carbon is through the assimilation of nutrients into their tissue. Tissue growth can store nutrients and carbon for a variable amount of time depending on the species. Intertidal clams and oysters have life spans on the order of 10-15 years and 40 years, respectively, while geoducks can live to be over 100 (Goodwin and Pease 1989). Nutrients are assimilated at the highest rates when the organism is growing at a high rate. In the case of geoducks, their growth slows after 10-15 years, making their role primarily storage as they age, for clams and oysters growth slows after 5-7 years. Harvesting the organisms amplifies the benefits of nutrient storage by removing the organism and the assimilated nutrients from the environment. This especially true for intertidal oysters and clams or geoducks under intensive aquaculture, as natural geoducks show a low natural recruitment rate and regeneration of the bed is far slower than that naturally occurring geoduck beds, where recruitment is sporadic.

As to measuring the rates of carbon and nutrient storage in populations of geoducks, there will be a study performed by WDNR/WDFW as a part of House Bill 1896 that will look at ages and sizes of geoducks from each of the three geoduck index stations established in Hood Canal.

3.0 Distribution and Abundance of Hood Canal Bivalves

Hood Canal is home to many different species of bivalve filter feeders. Detailed information exists for geoduck clams, pacific oysters and intertidal clams. Currently, information on abundance and distribution of Hood Canal bivalve mollusks is primarily limited to species of economic value. Information on these species has been developed for areas of commercial density and recreational interest. Geoduck populations and biomass are inventoried in commercial geoduck tracts through a partnership between the Washington Department of Fish and Wildlife and the Washington Department of Natural Resources. Clam and oyster populations are monitored by WDFW and local Native American Tribes with an interest in commercially harvestable populations and public beaches. The Tribes have collected information on both public and private beaches, while WDFW primarily collects information on DNR, State Parks, Recreation Commission publicly owned tidelands (Personal communication, Eric Sparkman, Skokomish Tribe). However, the habitats and general distributions of these organisms have been described (Goodwin and Pease 1989, Pauley et al. 1989, Shaw 1986).

3.1 Geoduck Clams

Geoducks inhabit the lower intertidal down to depths over 100m (as seen in Case Inlet Puget Sound), but in Hood Canal the deepest reported confirmed geoducks were at around 50m (personal communication, Brent Vadapolas, UW SAFS). Commercial intertidal geoduck harvest may have occurred since the turn of the century or before (WDFG 1905). By 1904 the Department of Fisheries and Game noted that the population may have been declining:

> "The large "Washington clam," formerly so abundant is still used very largely by those living near the beaches, bit is not found it he markets and in many places where it was once abundant it is hardly known now."

A three-year moratorium on all harvest was enacted in 1926 (WDFG 1930). In the 1928-1929 Annual report, WDFG recommended permanent closure of the commercial fishery and adoption of a personal-use bag limit of 3 clams (WDFG 1930). These were enacted at the end of the three-year closure in 1931 (WDFG 1932).

Management-related SCUBA surveys for geoducks started in 1967, preceding the subtidal commercial fishery that 1970 (Goodwin and Pease, 1987). The first surveys consisted of exploratory surveys that defined commercially viable densities with relatively low precision in many areas, coupled with some high-precision surveys in locations with high densities of geoduck. As the fishery enlarged tracts were defined and the methods for quantifying biomass and been refined to increase the statistical power of the estimates. The surveys performed in Hood Canal resulted in the conclusion that the vast majority of geoducks, and all the commercially available geoducks exist north of Seabeck.

Another result of these surveys is the characterization of geoduck associations with both habitat and other organisms. The divers performing the surveys make note of substrate types as well as the species present in geoduck survey transects. Some of the conclusions about geoduck density in relation to their habitats as a result of this data will be summarized. Geoduck density was found to be inversely related to latitude in Puget Sound (Goodwin and Pease 1987). The highest densities were found in Southern Puget Sound, however the opposite latitudinal trend was seen within Hood Canal (Goodwin and Pease 1987). Density was directly related to depth within the survey boundaries of -18' to -70' MLLW throughout the surveyed areas (Goodwin and Pease 1987). Although geoduck density increased within the survey depth, surveys in British Columbia have shown that density increases with depth to 90 MLLW and tends to decrease deeper than that. The substrate also played a role in geoduck density. Geoducks were found in mud, sand, mud-sand mixtures, and pea gravel-gravel mixtures. Densities were highest in sand and sand-mud mixtures with no significant difference between the two, and lowest in mud. Pea gravel-gravel mixtures had densities less than mud-sand and sand, but greater than mud (Goodwin and Pease 1987).

Current geoduck tract surveys in Washington consist of 900 square foot transects that are 6 feet wide and 150 feet long. Two divers begin the transects at -18 ft MLLW and extend to -70 ft, each with side-by-side three foot strips. A new transect begins if the -70ft has not been reached at the end of a 150 ft transect. A series of these transects begin at a random location on the 18 ft water depth contour (MLLW) within a predefined tract area and occur at approximately 1000 ft intervals perpendicular to the shoreward tract boundary. Variations on straight lines are made for narrow or otherwise oddly shaped tracts to obtain a representative sample of the population. The density estimates are used to create biomass estimates by multiplying the average density with the average tract weight. Biomass estimates are one of the many criteria used to approve harvest. The biomass estimate is also used in allocation of pounds to be harvested from a particular tract (Bradbury et al 2000).

3.2 Intertidal Oysters and Clams

These organisms have been grouped together because the information regarding their abundance and distribution is similar. A protocol for their survey is carried out by both the WDFW, as well as local Native American tribes (PNPTC, 1997). The surveys are limited to public tidelands managed by WDNR and private beaches harvested by Native American Tribes. Pacific Oysters live on hard or rocky beaches in the intertidal, down to -20' (Pauley 1988). They exist in very large but unquantified numbers in Hood Canal. Intertidal clams (native little neck and manila) are also inventoried by WDFW and local tribes. Aside from the public lands where they have been surveyed, little is known about their abundance. They inhabit substrates ranging from mud to gravel and live intertidally to depths of -10' (Shaw 1986). In Hood Canal, significant quantities of Native Littleneck clams have been seen subtidally down to -60 ft (MLLW)

4.0 Data Gaps related to bivalve filter-feeder ecology in Hood Canal

The strategy for identifying data gaps in the understanding of geoduck ecology can be broken into two distinct ideas, processes and the spatial extent of these processes. By measuring the rates of processes influenced by geoducks and spatially relating these rates to the different geography and depths at which they occur will give the magnitude of geoducks impact on nutrient budgets.

4.1 Processes

4.1.1 Sediment Processes:

Filter-feeding bivalves affect the sediments in two primary ways. First they 1) increase_sedimentation through the excretion of feces (their metabolic wastes) and pseudo-feces (the materials that are filtered but rejected because of a lack of nutritional value to the organism). This sedimentation is a product of the concentration of volume of seawater actively filtered as a result of their feeding behavior. These wastes are rich in nutrients (particularly ammonia) as well as inorganic matter formerly suspended in the water column. As the waste accumulates, the older organic matter and nutrients are buried which results in the storage of these substances. The newest deposits are still available to diffuse back into the water column, promoting phytoplankton regeneration (Newell, 2002).

The enriched sediments caused by filter-feeders can also 2) promote denitrification in sediments with a sufficient oxic/anoxic boundary layer. By providing NH4 and nitrite, two primary precursors to denitrification, the rates of nitrogen gas (result of denitrification) production have been seen to increase in laboratory studies (Newell, 2002). An additional likely effect of these enriched sediments is an increase in oxygen consumption over sediments not enriched by bivalve biodeposits (Newell, 2002).

Data Gaps:

- Sedimentation rate comparison between areas populated by bivalves and areas not populated by bivalves
- Rates of denitrification and oxygen consumption
- Chemical constituents of biodeposits
- How much oxygen is necessary for appropriate oxic/anoxic boundary

- Where do these conditions exist

4.1.2 Seagrass Productivity

Filter-feeder biodeposits can act as fertilizer to aquatic plants. Studies have looked at the increase in sea-grass productivity when co-located with bivalves (Peterson and Heck, 1999). This can be a benefit to ecosystems in several ways. First, sea-grass beds are recognized as important rearing areas for juvenile salmonids, as well as many other organisms that forage and hide there. In addition, plants produce oxygen through photosynthesis. In Hood Canal the production of oxygen by aquatic plants is not likely to help the low dissolved oxygen because of the strong stratification and low vertical mixing. In fact, the phytoplankton that is suspected to play an important role in the depletion of dissolved oxygen produces oxygen while it is alive, but depletes deep water dissolved oxygen when they die and fall into the lower strata of water.

Data Gaps:

- Rates of mixing between saturated and supersaturated upper water layers and hypoxic bottom waters

4.2 Water-column Processes:

4.2.1 Phytoplankton Population Control

It has been hypothesized and measured by (Cloern, 1982) that bivalves can exist in large enough numbers to control the production of phytoplankton through grazing. In this study the body of water was a large shallow estuary where oysters could exist over a very large percentage of the area, unlike Hood Canal's steep sloped shorelines.

Data Gaps:

- *in situ* filtration rates of filter feeders present in Hood Canal
- Impact of intertidal and subtidal bivalves on phytoplankton production

4.3 Spatial Distribution:

There is an abundance of information on the biomass of bivalve filter feeders. Commercial geoduck tract surveys, public intertidal clam and oyster surveys, aquaculture operation estimates, and some private beach information all exist. The WDFW and local Native American Tribes survey 22 tidelands on a regular basis. These consist of public DNR beaches, public WDFW beaches, and State Parks. The limitation of this information, when attempting to make Hood Canal wide ecosystem level calculations, is that they all start out with a predefined area. A commercial geoduck tract is bounded by -18 to -70 tidal elevations, and beach surveys are bounded by both public and private property lines. What is important to the Molluscan Study is what lies between and outside these boundaries.

The processes being investigated are governed by environmental conditions, as well as the relation of environmental conditions to habitat preferences of these species. Sediment effects of filter feeders are likely to be quite different in locations that are anoxic than in locations that have sufficient oxygen to promote coupled nitrification/denitrification. Water column effects are also affected by environmental factors. If a location is too deep for bottom living filter feeders to reach the photic zone, they are less likely to have a significant top-down effect on phytoplankton production.

Data Gaps:

- Spatial distribution of the conditions necessary for filter-feeder benefits (oxic sediments, and depth)
- Poplulation estimate of bivalves Hood Canal wide
- Spatial representation of filter feeder distributions

5.0 Strategy and Methods for addressing Data Gaps

5.1 Measuring Processes

5.1.1 Sediment Processes

The routes through which geoducks can affect nutrient processes take place in two places/processes, sediment processes and water column processes. Geoducks affect sediment process by actively pumping particles out the water column and concentrating them in the sediments in the form of biodeposits. These biodeposits consist of inorganic mater, organic matter, and organic nitrogen. The fate of these compounds is determined by two paths, microbial mediated and physically mediated. In the physically mediated pathway, the biodeposits either diffuse back into the water-column or become buried by more biodeposits. Nutrient burial in the sediments can be long-term storage, depending on the timeframe of benthic disturbance. Microbial pathways lead to metabolism of carbon compounds and the conversion of nitrogen compounds to other nitrogen species. The metabolism of carbon compounds consumes oxygen, while nitrogen compounds can be converted to nitrogen gas in an environment that provides an appropriate boundary layer between aerobic and anaerobic sediments.

Sediment measurements will consist of a series experiments comparing sediment flux rates of carbon, nitrogen, and oxygen in different environmental conditions. These conditions will include intertidal shellfish beds, subtidal shellfish beds at varying depths, and controls for each site. In addition, these experiments will be performed at locations that represent northern, central and southern Hood Canal. In addtion to the measurement of benthic fluxes from these areas, rates of denitrification will be determined from a variety of methods. Upper and lower limits will be calculated from gradients found in sediments, while *in situ* rates will be determined with a benthic chamber.

5.1.2 Water Column Processes

The interactions between filter feeders and the water column are simple to describe, but likely difficult to measure due to currents and mixing. By removing particles from the water column, thereby reducing turbidity, bivalves have been seen to increase the light penetration and allow marine plants to exist in lower tidal elevations (Peterson and Heck, 1999). Also, in San Francisco Bay, where there are extensive shallows and oyster beds, oysters can control the biomass of plankton by exerting top-down grazing control. Another process by which bivalves and specifically geoducks can affect the water-column is by the resuspension or regeneration of nutrients and organic matter from biodeposit-enriched sediments. Through both diffusion and resuspension these sediment constituents can be recycled to fertilize phytoplankton growth or be metabolized by water-column microbes, consuming oxygen.

Phase 2 water column monitoring will see the addition of the Index Sites established by House Bill 1896, and the addition of a turbidity probe to the suite of probes currently installed on our CTD. The CTD casts will be performed at the same locations as the sediment samples, but will be monthly instead of quarterly. CTD casts will be calibrated with discrete water samples. Discrete dissolved oxygen samples will be analyzed using a modified Winkler method. Discrete water samples will additionally be collected for the analysis of chlorophyll a in order to calibrate the fluorometer readings. The CTD will be measuring chlorophyll (an indicator of phytoplankton), dissolved oxygen, turbidity and a suite of standard physical measurements (conductivity, salinity, temperature, etc.).

Another way that filter feeder's effects on the water-column will be measured is by determining the rate at which filter feeders remove material from the water. Using a variety of techniques that compare the concentrations of influent water to that of the effluent we will be able to determine removal rates, excretion rates and seasonal variability.

To measure the rates of filtration and the seasonal variation in geoduck clams, a technique called InEx (Yahel et al 2005) will be used. This technique involves determining rates of water being pumped by timing the advancement of a trailing edge of dye through a pipette. The pipette filled with dye is held at the exit vent of a geoduck and uncapped; then using underwater video, the time it takes for the pipette to clear is used to calculate a pumping rate. Determining clearance rates of phytoplankton is achieved by using a similar apparatus that is not filled with dye. Two pipettes are held in place, one at the inlet siphon, one at the exit siphon, for three times the length of time necessary to clear the dye from the pumping rate measurements, then capped. The two pipettes are then analyzed for POC, phytoplankton (species and quantity), NH4, or any other species of interest.

Rates will be determined for 10 individual organisms at each index station on a monthly basis to give some insight to the annual variability of filtration. This method was developed on small bivalves and sponges, so adapting the pipettes to the large aperture of a geoduck siphon will be necessary. The critical element of this method will be disturbing the animals as little as possible. When a geoduck detects a threat it retracts into its burrow, so the divers performing the sampling will need to use extreme care not to disturb the animal during sampling and on the approach to sample. At the conlusion of the experiment, the animals will be harvested, aged, tissue dryed, and weighed to relate the filtration rate to the size and age of the animal.

For intertidal clams and oysters, a different method will be used consisting of small closed boxes through which seawater is circulated. Similar measurements will be able to be made from these apparatus as the InEx technique, except the water will be collected in a different manner.

5.2 Spacial Extent

Geographical considerations such as depth and location in respect to the low oxygen waters in Southern Hood Canal define the constraints of the processes by which geoduck benefit Hood Canal's eutrophication. The benefit of increased denitrification is dependent on the presence of oxygenated sediments. This is most likely to occur at shallower and more northern locations where waters have higher oxygen levels. At depth and in southern Hood Canal the sediments are likely to be very low in oxygen and instead of representing a path of nitrogen removal, they instead are a source of oxygen demand.

Determining the spatial extent of these areas and understanding where positive and negative filter feeder effects might occur is a primary goal of this study. Currently available distribution data will be augmented by mapping potential habitats, both intertidally and subtidally. The subtidal habitats will be identified using sonar data from the US Navy to determine where substrate facilitates bivalve populations. By overlaying commercial tract information on a substrate map additional potential habitats can be identified. These identified potential habitats will be first explored with drop cameras, and if the presence of filter feeders is note, followed with divers to quantify the resource. Intertidal habitats will be characterized using the available WDFW/Tribal survey information. Since much of this information is based on public lands where put and take fisheries exist, some additional surveys of private lands will occur to represent the beaches left to natural propagation.

The outcome of the spatial relationships will be a GIS model of processes and distributions as they are known. With the overall HCDOP effort in mind, this model will be able to be easily interfaced to the hydrodynamic modeling occurring at the University of Washington.

6.0 Conclusion

One of the largest benefits from Phase 1 of the Molluscan Study is the relationships that have been formed for technical advice. We have been dealing with researchers from Taylor Shellfish, The University of Washington, WDFW, HCDOP and WDNR. The work to implement House Bill 1896 also complements our study by providing locations with well defined populations of geoducks and historical DO data for performing our studies on filtration and both sediment and water column processes. Coordination with the work associated with staff performing the work will also lead to calibration of our ROV survey technique to be performed in future studies.

Assimilating the information sought in Phase 2 of the Molluscan Study will provide some insight to the relationships between filter feeders and low DO in Hood Canal. We hope to be able to identify the areas where there are beneficial processes taking place as well as where they do not. In future work when the surveys will be performed we will be able to relate these processes geographically and determine ecosystem wide impacts of filter-feeders and their role in Hood Canal.

7.0 Molluscan Study Literature Reviewed

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