Interim Progress Report

October 1, 2009, through September 30, 2010

Geoduck Aquaculture Research Program

House Bill 2220

Report to the Washington State Legislature

House Committee on Agriculture and Natural Resources

House Committee on the Environment

Senate Committee on Natural Resources and Marine Waters

Senate Committee on the Environment, Water and Energy

March 2011

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Interim Progress Report

Publication and Contact Information

This report is available on the Washington Sea Grant Web site at *wsg.washington.edu/research/geoduck/index.html*

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I. Summary

The geoduck (*Panopea generosa*) is North America's largest burrowing clam. It is found in soft intertidal and subtidal marine habitats in the northeast Pacific Ocean to depths of more than 200 feet. In Washington state, this large clam has been cultured for enhancement of wild stocks since 1991 and on a commercial scale since 1996. However, there was little scientific information available on the ecological impacts of applicable culture practices. In 2007, at the direction of the State Legislature, Washington Sea Grant, based at the University of Washington, established a six-year geoduck aquaculture research program to assess possible effects of geoduck aquaculture on the Puget Sound and Strait of Juan de Fuca environments. This interim report summarizes the progress of the program to date and provides detailed reports on studies conducted between October 1, 2009, and September 30, 2010.

II. Background

The 2007 law (Second Substitute House Bill 2220; Chapter 216, Laws of 2007) directed WSG to review existing scientific information and commission scientific research studies to examine key uncertainties related to geoduck aquaculture that could have implications for the health of the ecosystem and wild geoduck populations. The legislation established six priorities to measure and assess:

1. The effects of structures commonly used in the aquaculture industry to protect juvenile geoducks from predation;
2. The effects of commercial harvesting of geoducks from intertidal geoduck beds, focusing on current prevalent harvesting techniques, including a review of the recovery rates for benthic communities after harvest;
3. The extent to which geoducks in standard aquaculture tracts alter the ecological characteristics of overlying waters while the tracts are submerged, including impacts on species diversity and the abundance of other organisms;
4. Baseline information regarding naturally existing parasites and diseases in wild and cultured geoducks, including whether and to what extent commercial intertidal geoduck aquaculture practices impact the baseline;
5. Genetic interactions between cultured and wild geoducks, including measurement of differences between cultured and wild geoduck in term of genetics and reproductive status; and
6. The impact of the use of sterile triploid geoducks and whether triploid animals diminish the genetic interactions between wild and cultured geoducks.

The Legislature assigned top priority to the assessment of the environmental effects of commercial harvesting (2) and directed Washington Sea Grant (WSG) to complete the research studies and report the results to the Legislature by December 1, 2013. The Shellfish Aquaculture Regulatory Committee, established by the 2007 law, and the Department of Ecology were tasked with overseeing the program.

In October 2007, WSG issued a request for proposals and after rigorous scientific review selected four projects for funding, two of which were combined to develop a more integrated and comprehensive study. Selected projects addressed five (1, 2, 4, 5, 6) of the six legislatively established priorities. Funding for priority 6 and selection of a project to address the remaining priority (3) were deferred until later in the program, subject to the availability of additional resources. Project titles, principal investigators, research institutions and a brief description of the studies are as follows:

1. **Geochemical and Ecological Consequences of Disturbances Associated with Geoduck Aquaculture Operations in Washington.** *(Glenn VanBlaricom, University of Washington; Jeffrey Cornwell, University of Maryland)* The project is examining all phases of the aquaculture process — geoduck harvest and planting, presence and removal of predator exclusion structures and ecosystem recovery. It will assess effects on plant and animal communities, including important fish and shellfish, in and on Puget Sound beaches, as well as the physical and chemical properties of those beaches.
2. **Cultured-Wild Interactions: Disease Prevalence in Wild Geoduck Populations.** *(Carolyn Friedman, University of Washington)* The study is developing baseline information on pathogens to improve understanding of geoduck health and management of both wild and cultured stocks.
3. **Resilience of Soft-Sediment Communities after Geoduck Harvest in Samish Bay, Washington.** *(Jennifer Ruesink, University of Washington)* Capitalizing on eelgrass colonization of an existing commercial geoduck bed, this project is examining the effect of geoduck aquaculture on soft-sediment tideflats and eelgrass meadow habitats.

The current program schedule and funding are summarized in the table on page 3. Funding for research and related program activities initially was provided through a state appropriation to the geoduck aquaculture research account established under the 2007 law. This state funding of $750,000 supported the program through June 30, 2010. Although no additional monies were deposited in the account in fiscal year 2010-2011, the Department of Natural Resources (DNR) provided $255,000 through an interagency agreement with the university. The largest project, the VanBlaricom-led disturbance study, also secured $39,972 from the university's Royalty Research Fund to supplement student and technical support that was not included in the DNR agreement.

Scientists have adjusted their efforts to minimize research costs, and the DNR and university funding has ensured continuation of the three ongoing research studies and program support. In recent months, however, environmental conditions delayed cooperating geoduck farmers' removal of aquaculture structures from the VanBlaricom study sites, extending the required study period and creating increased fiscal needs for sampling (about $60,000). If not addressed, this budget shortfall will limit sampling and hinder the team's ability to evaluate ecological effects associated with the removal of aquaculture structures from geoduck aquaculture areas.

For the upcoming biennium, the National Sea Grant College Program has awarded the VanBlaricom research team a competitive aquaculture grant to investigate the effects of aquaculture structures on related predator-prey interactions and food web dynamics in geoduck aquaculture. While the goals of the new project differ somewhat from the priorities established in the 2007 law, the studies are complementary and permit resources to be leveraged as part of a shared program infrastructure.

As directed by the 2007 law, the final results of the three funded studies will be reported to the legislature by December 2013. Deferred priorities (3, 6) addressing the effects of geoduck aquaculture on overlying waters and use of sterile triploid geoduck will not be included due to insufficient funds to carry out the research.

Project Title	**Study Duration**	**Funding Source, Timing and Level**			
		WA State Geoduck Research Account 7/1/2007 – 6/30/2010	DNR Agreement 7/1/2010 – 6/30/2011	UW Royalty Research Fund July 2010 – June 2011	National Sea Grant Strategic Investment in Aquaculture Research (competitive grant) 10/1/2010 – 9/30/2012
Ecological and Geochemical Consequences of Disturbances Associated with Geoduck Aquaculture	Apr 2008 – June 2013	$459,935	$164,563	$39,972	$397,672
Cultured-Wild Interactions: Disease Prevalence in Wild Geoduck Populations	Apr 2008 – July 2011	$104,000	$65,688		
Resilience of Soft-Sediment Communities after Geoduck Harvest in Samish Bay, Washington	Apr 2008 – July 2011	$86,612	$11,000		
Program Administration	Jul 2007 – Dec 2013	$99,453	$13,749		
TOTAL		**$750,000**	**$255,000**	$39,972	**$397,672**

III. Summary of Research Progress

In 2009 and 2010, field samples were gathered and analyzed, with initial results providing some indication of environmental response to geoduck aquaculture activities. It is important to note that these results remain preliminary and must be confirmed by additional fieldwork and analyses of full sample sets. Among the tentative observations at this stage in the program:

> Preliminary analyses of total abundance and diversity of infauna and epifauna indicate no significant effect of harvest, likely because of high temporal and spatial variability. Declines after harvest were noted from some species, with recovery observed within six months. Pronounced seasonal response of mobile macroinvertebrates within planted areas and reference beaches and increased use of planted areas by kelp crabs and red rock crab from October through March have been noted. Data suggest that structures associated with geoduck aquaculture may attract pipefish and other species observed infrequently on reference beaches but may displace species (such as starry flounder) that typically occur in these areas.
>
> Data reveal that nutrients (nitrogen and phosphorus) released from a typical commercial geoduck operation into Puget Sound are low — on a par with the daily discharges from a septic system serving a four-person household. On a whole-system basis, this is a very small release. Even in a small, poorly flushed embayment, this level of input is unlikely to result in any local change in water quality.
>
> Preliminary analysis of samples reveals the presence of a microsporidia-like parasite previously unknown in geoducks. The biology of this parasite is poorly understood. Several other parasites or diseases were observed in preliminary screening, including a *Rickettsia*-like organism in the gills and protozoa in the siphon tissue.
>
> In Fisk Bar, where eelgrass recruited to the area after geoducks were planted, harvest activities produced effects on almost every measured biological and physical parameter of the farmed and reference sites. Future work will prove crucial in determining the persistence of these effects. It has already been shown that the effects of harvest on sediment elevation are temporary, while the effects of net installation on eelgrass growth are likely to be longer lasting and more pronounced. Spillover effects of geoduck farming may emerge only after one year into the aquaculture cycle. However, the spatial extent of this effect and rates and patterns of recovery have yet to be determined.

Detailed project descriptions and overviews of research progress as of September 30, 2010, are presented in Section IV of this report. Detailed technical progress reports are available in the 'project updates' section of each project on the WSG Web site at *www.wsg.washington.edu/research/geoduck/current_research.html*. A list of presentations generated by the program to date is contained in the appendix to this report.

During the report period, WSG continued to work with the Department of Ecology, Shellfish Aquaculture Regulatory committee and other interested parties. WSG staff and program researchers provided an update to the full SARC on June 2, 2010. Copies of presentations are available on the SARC Web site at *http://www.ecy.wa.gov/programs/sea/shellfishcommittee/meetings.html#06-10*. Copies of additional relevant research and public presentations are available on the WSG Web site at *www.wsg.washington.edu/research/geoduck/current_research.html*.

Copies of the Geoduck Aquaculture Research Program's Interim Progress Report (July 1, 2007, through September 30, 2009) are available in a downloadable PDF format on the WSG Web site at *http://wsg.washington.edu/research/pdfs/reports/GeoduckIntProReport.pdf* or as hard copy on request.

IV. Detailed Research Reports

1. Geochemical and Ecological Consequences of Disturbances Associated with Geoduck Aquaculture Operations in Washington

Glenn VanBlaricom, David Armstrong and Tim Essington, School of Aquatic and Fishery Sciences, University of Washington, and Jeffrey Cornwell and Roger Newell, Horn Point Marine Laboratory, University of Maryland

This large-scale multidisciplinary study will contribute to improved understanding of the effects of geoduck production and harvesting on key marine nearshore and intertidal animal communities and their habitats. The project will be conducted over a six-year period to ensure investigation of all stages of culture activity and provide balanced scientific information to make better-informed management decisions. The study seeks answers to several pressing questions regarding the effects of geoduck aquaculture on the Puget Sound ecosystem:

> What are the effects of aquaculture structures on plant and animal communities in or on Puget Sound beaches?
>
> Do structures change the behavior or movements of commercially and ecologically important fish and shellfish?
>
> How does disturbance during geoduck harvesting affect plant and animal communities and subsequent recovery of the ecosystem?
>
> How does the disturbance alter the physical and chemical properties of harvested beaches?

The study is divided into two components:

- ***Ecological effects***, focusing on the densities and diversity of soft-sediment invertebrates (infauna) and attached invertebrates (epifauna) and densities and diversity of mobile animals attracted to culture-associated structures
- ***Geochemical effects***, focusing on changes in geochemical attributes of sediments and overlying water as a consequence of culture activities.

Approach

Research is conducted in active commercial geoduck aquaculture plots to ensure that spatial and temporal scales of the research match those of a typical geoduck aquaculture operation. In cooperation with growers and as a result of extensive survey work, six study sites were selected (Figure 1) that represent all stages of culture activity and have environmental conditions that allow meaningful comparisons among sites.

Ecological effects. To accommodate the fact that different sites are at different stages of the culture cycle, researchers are employing two sampling approaches:

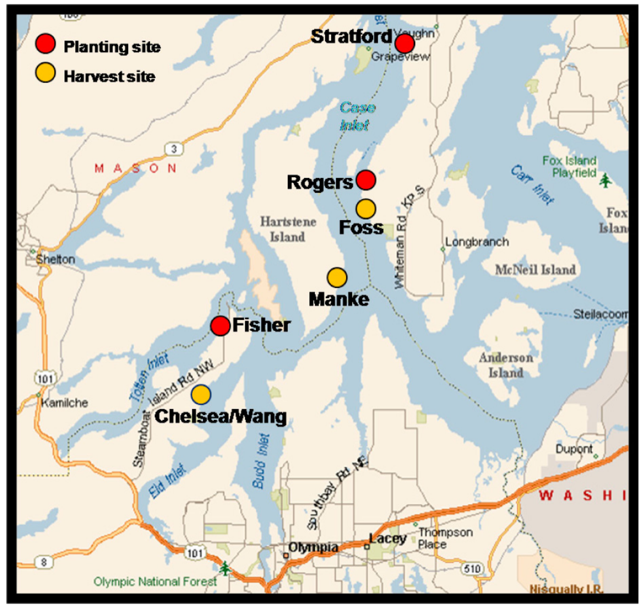

Figure 1. *Map of study sites currently established in southern Puget Sound to study planting effects (red circles) and harvest effects (yellow circles). The Rogers and Stratford sites were outplanted in November 2008 and June 2009, respectively; planting at the Fisher site was completed in December 2009. Harvest of mature geoducks at Foss/Joemma (i.e., Foss) was completed in December 2008, while harvest at the Chelsea/Wang and Manke sites was completed in March 2010.*

> Field experiments that sample before and after a specific culture activity (e.g., harvest), known as "before-after control-impact" (BACI) design
>
> Comparative analytical approaches that focus on multiple sites in various stages of culture activity, sampling in a manner that effectively substitutes spatial variation for temporal variation.

Work to date has focused on the resident communities of infauna and epifauna at harvest and planting sites as well as fish and mobile macroinvertebrates that visit planting sites during high tides. Infaunal and epifaunal communities were sampled using sediment cores for smaller invertebrates, excavation samples for larger invertebrates (e.g., sand dollars) and photo quadrats to assess sediment types and percentages of vegetation cover and to make estimates of densities of burrows, such as those made by ghost shrimp. Samples were taken randomly from within the farmed and unfarmed plots at each site, and additional core samples were taken at set intervals on either side of the farmed plot to determine whether effects extend beyond the farmed area (Figures 2, 3). All research sites were visited and sampled extensively between May 2008 and September 2010 (Table 1). Mobile organisms were surveyed using two techniques: Shore-based surveys were developed as a method of monitoring fine scale use of shallow nearshore areas by juvenile salmonids, and diver surveys are conducted to assess presence of bottom-dwelling fishes and small benthic invertebrates during high tide.

Research team members have also conducted pilot studies to investigate trophic linkages between resident prey and mobile predators, recruitment by fouling organisms on predator exclusion devices (Figure 4) and effects of aquaculture practices on the survival and growth of non-target species, including Manila clams (Figure 5).

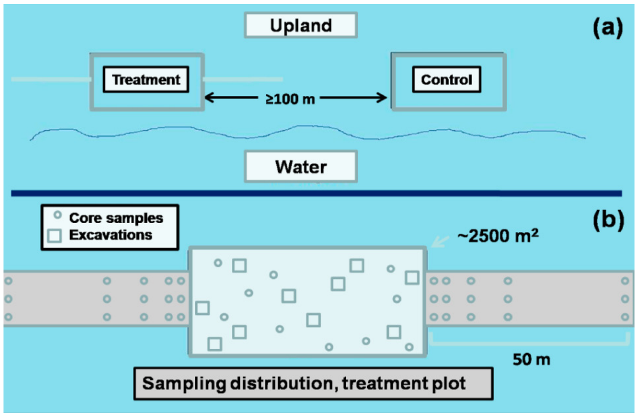

Figure 2. *Schematic showing (a) site design and (b) the two categories of samples collected at each sites: randomly distributed, within-plot samples and linear arrays that begin at the edge of a cultured pot and extend away from the plot parallel to the shoreline.*

Figure 3. *Researchers establish sampling points in a plot of mature geoducks at the Manke site on Hartstene Island, WA, during a night tide.*

Table 1. *Summary of samples collected and processed through September 30, 2010.*

	Site	Type	# Collection Trips	# Samples Collected	# Samples Processed
Infaunal Samples					
	Chelsea/Wang	Harvest	14	583	91
	Fisher	Planting	13	560	49
	Foss/Joemma	Harvest	13	720	612
	Manke	Harvest	18	700	700
	Rogers	Planting	13	745	521
	Stratford	Planting	10	350	4
Epifaunal Samples					
	Chelsea/Wang	Harvest	11	220	220
	Fisher	Planting	6	120	120
	Foss/Joemma	Harvest	9	180	180
	Manke	Harvest	12	240	240
	Rogers	Planting	8	160	160
	Stratford	Planting	5	100	100
Photo Samples					
	Chelsea/Wang	Harvest	13	260	40
	Fisher	Planting	12	240	100
	Foss/Joemma	Harvest	9	180	180
	Manke	Harvest	13	260	180
	Rogers	Planting	11	220	160
	Stratford	Planting	10	200	100
Macrofauna Surveys*					
	Chelsea/Wang	Harvest	--	--	--
	Fisher	Planting	13	416	100
	Foss/Joemma	Harvest	--	--	--
	Manke	Harvest	--	--	--
	Rogers	Planting	13	416	20
	Stratford	Planting	14	448	120

**Surveys only conducted at planting sites.*

__Figure 4.__ A research assistant secures a large-mesh fiber net over PVC tubes as part of an experiment to investigate recruitment of fouling organisms on commonly used geoduck aquaculture materials.

***Figure 5.** Research assistant deploys paired treatment and control enclosures to study the survival and growth of non-target Manila clams (*Venerupis philippinarum*) within a cultured plot of geoducks in Totten Inlet, WA.*

Geochemical effects. This component of the research is designed to quantify the extent to which culturing and harvesting of geoducks increases the release of inorganic nutrients into the surrounding water. Initial work conducted in 2008 focused on evaluating a variety of methods for collecting pore water (the water contained in sediment samples) at various depths to quantify inorganic nutrient concentrations of nitrogen, sulphur, phosphorus and iron.

Work in fall 2008 and summer 2009 focused on harvest operations at the Foss-Joemma and Chelsea/Wang sites and an additional site in Thorndyke Bay. Pore water samples were collected pre- and post-harvest, and samples of water runoff were collected during harvest operations. Samples were analyzed for concentrations of nitrogen and phosphorus. To determine the exchange of nutrients between the sediment and overlying water during the geoduck grow-out phase, sediment cores were collected from farmed and unfarmed locations at the Thorndyke site, incubated under laboratory-controlled conditions and analyzed for concentrations of oxygen, nitrogen, silicate and soluble reactive phosphorus.

One additional field-sampling trip was conducted in November 2009 during harvest activities at the Manke site. Pore water analysis was carried out on transects in harvest and reference areas. Samples were analyzed for ammonium, nitrate + nitrate and soluble reactive phosphorus (SRP).

Project status

Ecological effects. The initial phase of this component of the project has been completed and significant progress has been made toward completing tasks in subsequent phases.

Statistical analysis is underway of patterns in taxa richness (a measure of the number of distinct species or taxa that are found in a sample) and abundance among aquaculture areas and reference beaches before, during and after harvest (Foss, Manke and Chelsea/Wang sites) and planting (Rogers, Stratford and Fisher sites).

Data collection and processing of benthic infauna at all three harvest sites has been completed (Table 1). The sites vary spatially and in the timing and length of the harvest period. The data suggest strong seasonal patterns, as well as spatial patchiness at the scale of sites and plots (Figure 6). Preliminary analyses of total abundance and diversity across the entire data set indicate no significant effect of harvest, likely because of high temporal and spatial variability. Nevertheless, declining trends in a few taxa coincident with harvest disturbance were observed at some sites, including reduced abundance of some worms and small crustaceans within the harvest zone and adjacent areas. There is evidence of recovery of these populations within six months. Continued analyses of the data are required to determine whether response of important taxa differ from the general community.

Work at the three sites where planting and structure (PVC + netting) effects are being investigated is ongoing (Table 1). Benthic infauna samples are being collected at regular intervals, but patterns cannot be interpreted until all data processing is completed. SCUBA surveys of mobile macrofauna at these sites continue to yield interesting results. The data support previous observations that habitat complexity associated with geoduck aquaculture may attract some structure-associated species observed infrequently on reference beaches, while displacing other species that typically occur in areas lacking epibenthic structure. Preliminary analyses of shore survey data have not indicated differences in use of habitats by juvenile salmonids, although these data are presently limited by low sample sizes. Observations suggest a pronounced seasonal

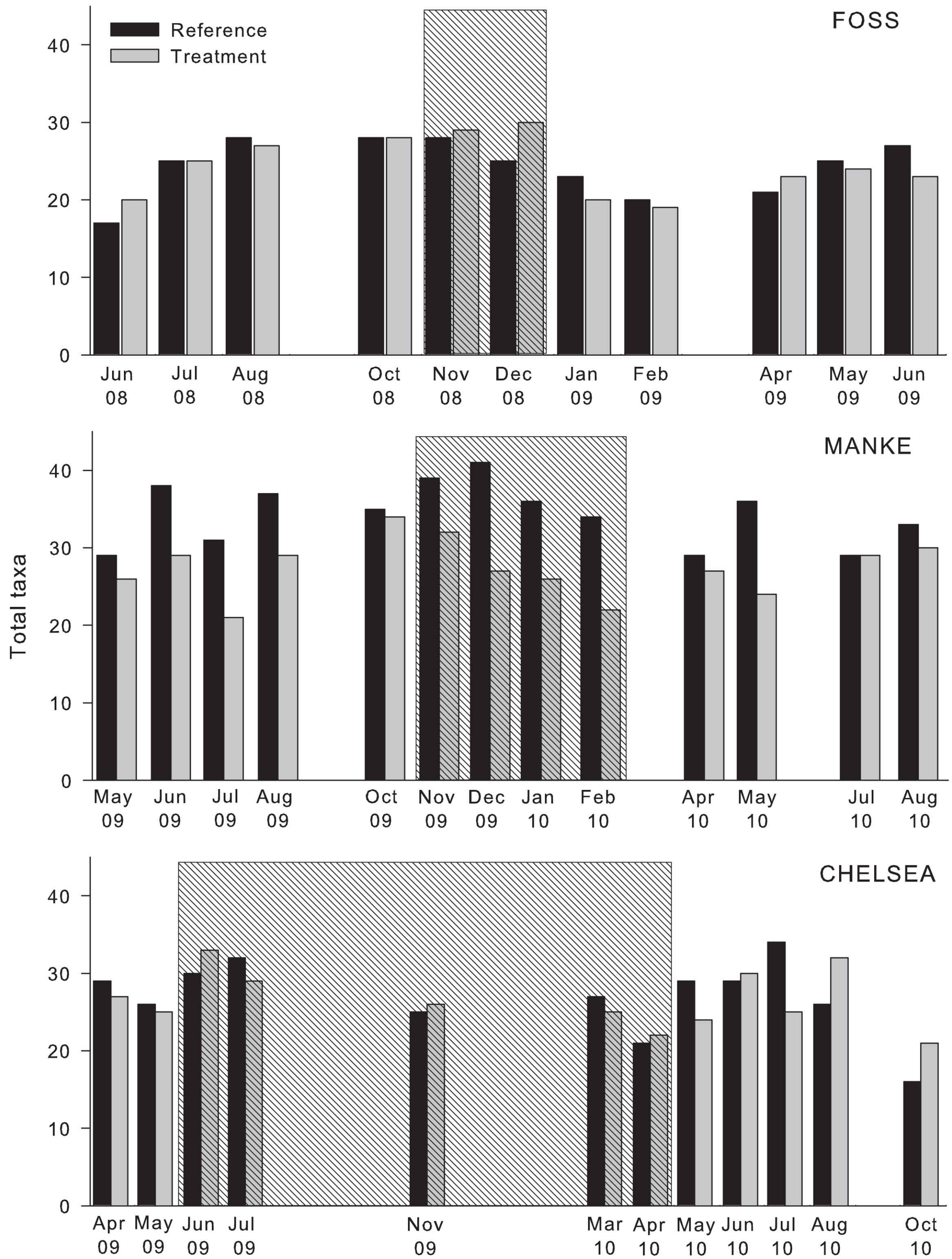

Figure 6. *Monthly taxa richness, as number of identified taxonomic categories, for the harvest plot and adjacent reference beach at the Foss (upper), Manke (middle), and Chelsea/Wang (lower) sites. Shaded boxes indicates period when harvest of mature geoducks occurred.*

response of mobile macroinvertebrates found within planted areas and reference beaches, and increased use of planted areas by kelp crabs and red rock crabs from October through March. Graceful crabs, Pacific staghorn sculpin and speckled sanddab are apparently ubiquitous at reference beaches at Fisher, Rogers and Stratford sites. As the geoduck culture cycle progresses, changes in benthic infauna and the macrofauna assemblages that may occur when aquaculture structures are eventually removed will be tracked.

Geochemical effects. Pore water nitrogen concentrations were dominantly ammonium. Both of the Chelsea/Wang sampling sites had high ammonium concentrations in sediment where geoducks had been previously harvested and at sites where harvest-sized geoducks were still being grown. High ammonium concentrations were also observed at geoduck sites in Thorndyke Bay. High concentrations of SRP were observed at the Chelsea/Wang sites. Pore water silicate concentrations were variable, but very high at the Chelsea/Wang sites.

Although data analyses are continuing in this project, the data clearly show that nutrients (nitrogen and phosphorus) released from a typical commercial geoduck operation into Puget Sound are low (Figure 7) — on a par with the daily discharges from a septic system serving a four-person household. On a whole-system basis, this is a very small release. Even in a small, poorly flushed embayment, this level of input is unlikely to result in any local change in water quality.

The SRP concentrations were not high, relative to pore water observations; however, they suggest an imbalance in nitrogen and phosphorus regeneration. If the nitrogen and phosphorus was from decomposing algae, one would expect that the molar ratio of SRP to ammonium would be < 0.15. The release of mineral-bound phosphorus is the likely explanation for these unusual ratios.

Elevated silica concentrations suggest that diatom tests are dissolving in the geoduck beds. Both diatoms and phosphorus bound to inorganic particles would be focused by geoducks into these intertidal environments.

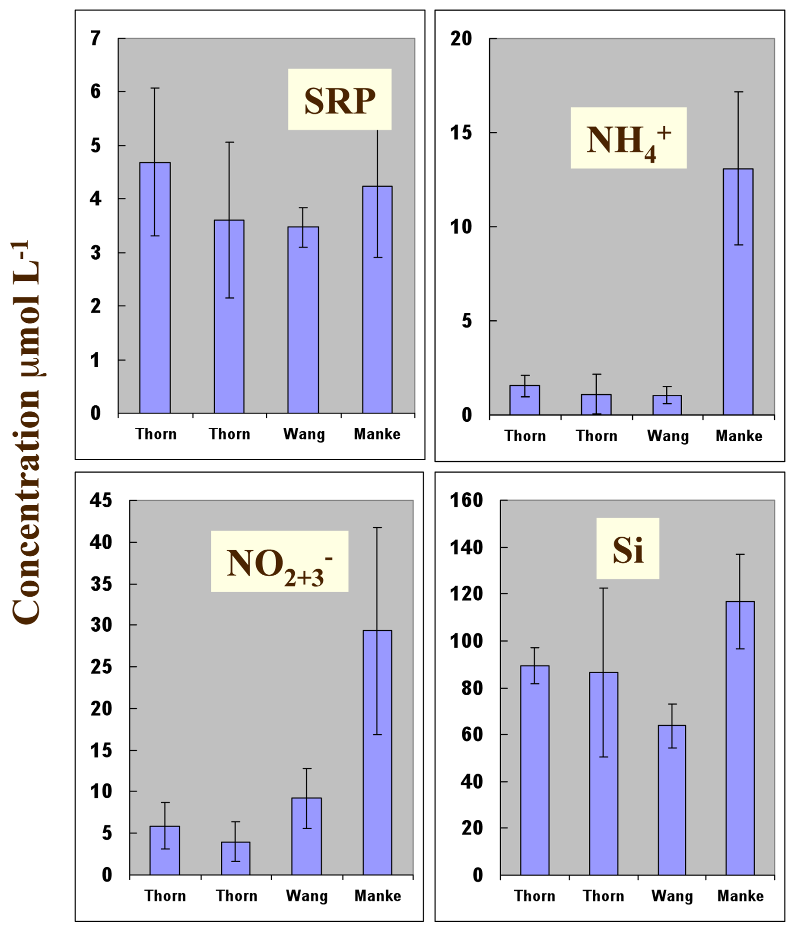

Figure 7. *Average effluent nutrient concentrations from samples collected immediately downstream of geoduck harvesting. SRP is soluble reactive phosphorus, also referred to as "othosphosphate". "Thorn" is Thorndyke Bay, which was sampled on both June 21 and June 23 2009; the Chelsea/Wang and Manke sites were harvested on June 22 and November 7, 2009, respectively. Error bars are standard deviations (N ≥5).*

2. Cultured-Wild Interactions: Disease Prevalence in Wild Geoduck Populations

Carolyn Friedman and Brent Vadopalas, School of Aquatic and Fishery Sciences, University of Washington

The lack of baseline information on geoduck health and condition hinders its management. Without prior knowledge of parasites and disease prevalence, it can be difficult to identify the causative agent of an epidemic. Baseline data provides information on possible pathogens and also provides insights into whether the initial outbreak or re-emergence of a disease is related to an endemic or newly introduced parasite.

In this three-year project, researchers have been characterizing parasites and other disease organisms associated with geoducks and determining their prevalence in three wild populations representing southern Puget Sound, Hood Canal and the Strait of Juan de Fuca. Geoducks were collected during summer and winter to facilitate detection of both warmwater and coldwater infectious organisms.

Approach

For this project, three sites reflecting the geographic range of geoduck aquaculture in Washington were selected (Figure 8). Samples from each site were taken in summer (July-August 2008) and winter (February 2009) to determine seasonality in disease prevalence, should it exist. The samples were collected with assistance from the Washington Department of Natural Resources, Washington Department of Fish and Wildlife, Jamestown S'Klallam Tribe and Lower Elwha Klallam Tribe. All samples have been processed, slide-mounted, stained and analyzed.

Figure 8. *Map of sample sites. Source: soundwaves.usgs.gov/2005/01/puget-soundLG.jpg.*
A — Freshwater Bay; B — Thorndyke Bay; C — Totten Inlet

Table 2. *Most commonly observed pathogens and their prevalence.*

Pathogen	Tissue	Number of samples	Prevalence
Rickettsia-like organism	Gill	247	39.0%
Protozoa	Siphon Epithelium	220	34.7%
Microsporidia-like organism	Intestine	104	16.4%
Steinhausia-like organism	Ova (egg)	99	15.6%
Microsporidia-like organism	Siphon Muscle	27	4.3%
Bacteria	Intestinal Epithelium	3	0.5%

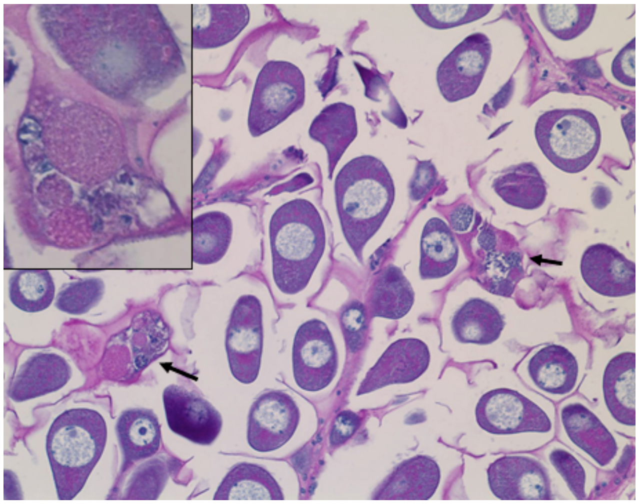

Figure 9. *Steinhausia-like parasite (arrows) within geoduck ova.*

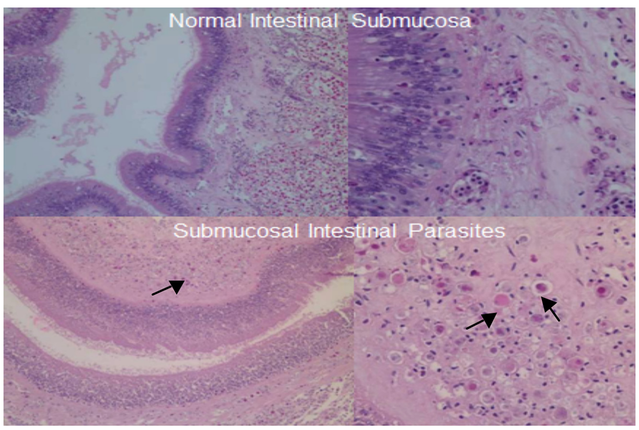

Figure 10. *Possible microsporidian parasite within intestinal submucosa (arrows).*

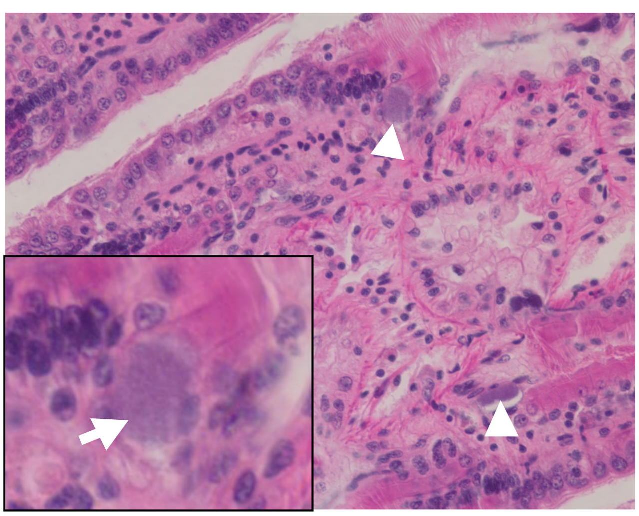

Figure 11. *Rickettsia-like colonies within gills (arrow).*

Project Status

Researchers observed a parasite, previously unknown to geoducks: a *Steinhausia*-like microsporidian parasite within geoduck eggs (ova). *Steinhausia* spp. infections typically consist of a 'cyst' containing many small spore-like unicells inside a bivalve mollusk egg. Low intensity infections are not thought to influence organismal health; however, high-intensity infections could impact fecundity.

The most common abnormalities observed include the following: *Rickettsia*-like organisms infecting geoduck gills; microsporidia-like protists in the siphon and intestine; *Steinhausia*-like parasite in eggs; and tissue abnormalities in the digestive gland and gill (Figures 9, 10, 11). The most *Rickettsia*-like organisms were observed in fall and spring; prevalences of the protozoa and the unknown microsporidia-like parasites were relatively similar throughout the year. The *Steinhausia*-like microsporidian parasite was observed more commonly in the winter and spring samplings.

Other observations include a ciliate-like organism within gill tissues as well as numerous other parasites in association with the surface tissue of the siphon. Several other parasites or diseases have also been observed, including the presence of "warts" and a possible fungus associated with dark discoloration on the siphon and exposed mantle surface. The most common of these parasites and their prevalence is presented in Table 2.

Activities planned for 2010-2011 include continued compilation and full analysis of baseline levels of infection and disease. Some infectious organisms will likely be novel to science. As possible, molecular characterization of the *Steinhausia*-like microsporidian and other novel parasites will also be conducted. Full analysis to illustrate the suite of parasites and diseases associated with geoducks and to quantify the prevalence and severity of the diseases/agents within current project budget will be completed and reported by December 2013.

3. Resilience of Soft-Sediment Communities after Geoduck Harvest in Samish Bay, Washington

Jennifer Ruesink and Micah Horwith, Department of Biology, University of Washington

Commercial geoduck beds share waters with soft-sediment tideflats and eelgrass meadows — two habitat types that host diverse communities of plants and animals. In 2002, geoducks were planted in a soft-sediment tideflat in Samish Bay to establish a commercial shellfish bed. Since then, eelgrass has colonized the bed. The 2008 harvest and replanting of geoduck clams offered a unique opportunity to study the effects of geoduck aquaculture on soft-sediment tideflat and eelgrass meadow habitats. The project is exploring habitat changes associated with a commercial geoduck bed during the aquaculture cycle, from harvesting through replanting. Detailed surveys from before and after these events, both inside and outside the geoduck bed, will produce data on initial impacts on and rates of recovery for eelgrass meadow and soft-sediment invertebrate communities. These data will shed light on interactions between commercial geoduck aquaculture practices and local marine habitats.

Approach

Two research locations were established on Fisk Bar, Samish Bay: within an active geoduck aquaculture operation (farmed plot) and within an adjacent unfarmed area (control plot). The location and characteristics of the plots are provided in Table 3 and Figure 12. To determine the response of the local marine habitat to geoduck aquaculture practices, 13 surveys were conducted between April 2008 and August 2010, timed to coincide with geoduck harvest, PVC tube installation, reseeding and net installation, and net replacement (Figure 13).

During each survey, each site was sampled using randomly positioned quadrats. Quadrats in the unfarmed plot were placed at set distances from the farm boundary to determine the spatial extent of the habitat response to aquaculture practices. Within each quadrat, the number of native eelgrass (*Zostera marina*) vegetative shoots, flowering shoots and seedlings were counted, as well as the number of non-native Japanese/dwarf eelgrass (*Zostera japonica*) shoots, if present. Samples of sediment, infauna and eelgrass were collected for later analysis in the laboratory. In addition, pre- and post-harvest sediment height was measured to assess whether harvest practices result in a change of sediment elevation, which would indicate a loss or addition of sediment to the harvest location.

Preliminary analyses of eelgrass and sediment samples have been completed. Full analysis, which will include analysis of infaunal samples, all remaining eelgrass and sediment samples and the performance of quality-control measures, will be completed and reported by December 2011.

Project Status

Researchers used a "before-after control-impact" (BACI) experimental design to evaluate the effects of geoduck harvest and subsequent aquaculture activities on a range of environmental factors in the farmed and unfarmed areas of Fisk Bar.

Table 3. *Locations and characteristics of "Farmed" and "Control" research sites*

Site Name	Location	Site Description
Fisk Bar (Farmed Area)	Samish Bay, WA (48°36'N, 122°26'W) -1.5ft MLLW	Taylor Shellfish geoduck farm, approximately 140m x 36m, adjacent to channel and colonized by Z. marina between the summers of 2002 and 2008. When Z. marina occurred on the bar, summer shoot densities averaged ~360/m2. This site was harvested, reseeded, and netted in the summer of 2008, with new nets installed in the summer of 2009. All nets and tubes were removed in the summer of 2010. This serves as the impact site for the project.
Fisk Bar (Unfarmed Area)	Samish Bay, WA (48°36'N, 122°26'W) -1.5ft MLLW	Extensive Z. marina meadow, where shoot densities average ~400/m2 in summer. This serves as the control site for the project.

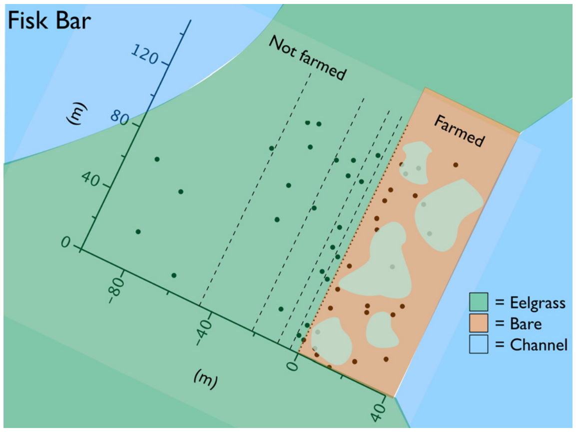

Figure 12: *Fisk Bar, Samish Bay, WA (48°36'N, 122°26'W). Upper schematic represents a simplified birds-eye view of Fisk Bar on 4/9/2008, showing adjacent farmed and unfarmed areas. Points represent the placement of quadrats. The dotted line represents the harvest boundary, and dashed lines demarcate portions of the unfarmed area that are sampled equally through the stratified random design of quadrat placement. Right schematic represents the geographic location of Fisk Bar as a yellow star.*

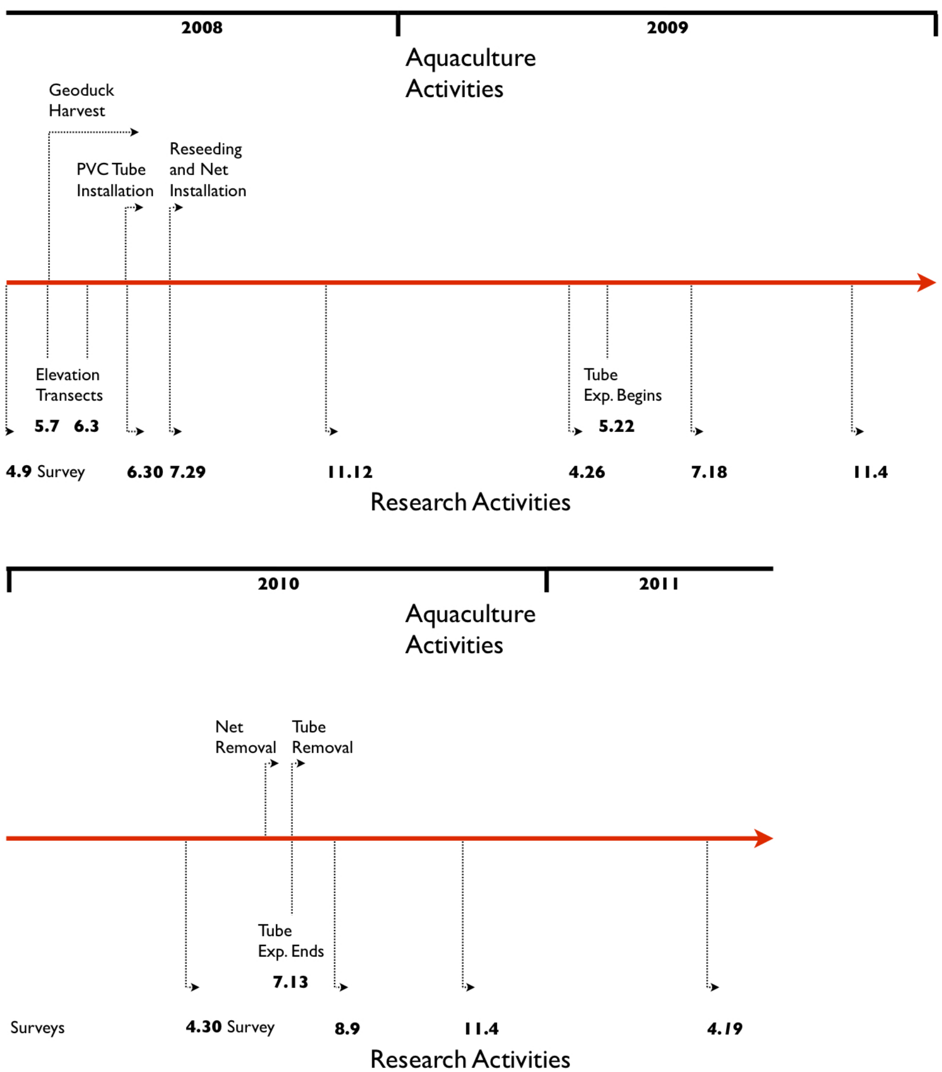

Figure 13. *Timeline for aquaculture (above arrow) and research (below arrow) activities completed to date, with projected date of one future survey (4/19/2011).*

The initial, pre-harvest survey found little difference between farmed and unfarmed areas of Fisk Bar. After harvest, a range of effects on ecologically relevant aspects of Fisk Bar was detected. Within the farmed area, *Z. marina* exhibited an immediate and significant reduction in shoot density, rate of flowering, and in the size of aboveground structures, and a delayed and significant reduction in belowground branching activity. *Z. marina* was lost from the farmed area between 4/26/09 and 7/18/09, due in part to reduced light levels created by a thick covering of *Ulva* algae on the predator exclusion nets (Figure 14). After harvest, the farmed area had a significantly lower sediment organic content than the unfarmed area on every survey date. The farmed area also demonstrated a significant post-harvest loss of elevation that was not evident in one subsequent survey, suggesting a quick recovery.

Figure 14: *Fisk Bar, with ulvoid algae massed over predator exclusion nets, 4/26/2009. The farm is to the left of the transect tape, and the control plot is to the right.*

Preliminary analysis indicates some evidence for “spillover” effects of geoduck aquaculture on the adjacent eelgrass meadow. Possible effects include smaller, more densely packed *Z. marina* shoots and increased organic content of sediment nearer the farm. Together, these patterns may represent typical “edge effects,” where geoduck aquaculture has effectively formed a meadow edge where none existed before.

Future surveys and full analysis of infaunal samples will prove crucial in determining whether *Z. marina* and the associated infaunal community can re-colonize the farmed area of Fisk Bar. Evidence suggests that the effects of harvest on sediment elevation are temporary, and it is possible that the farmed area presents a suitable habitat to *Z. marina*, once nets and tubes have been removed.

V. Appendix

Program-Related Presentations

1. VanBlaricom et al.

Cornwell, J.C., Newell, R.I.E., and Owens, M. *The influence of geoduck clam culture and harvest in Puget Sound on sediment nutrient biogeochemistry.* Presentation to the Coastal and Estuarine Research Federation 20th Biennial Conference. Portland, OR. Nov. 1-5, 2009.

Cornwell, J.C., Newell, R.I.E., and Owens, M. *The influence of geoduck clam culture and harvest in Puget Sound on sediment nutrient biogeochemistry.* Presentation to the 102nd Annual Meeting of the National Shellfisheries Association and World Aquaculture Society, Aquaculture 2010. San Diego, CA. Mar. 1-5, 2010.

Galloway, A., *Effects of geoduck aquaculture planting practices on fish and macroinvertebrate communities in southern Puget Sound, WA.* Presentation to the 63rd Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR, Sept. 28-Oct. 1, 2009.

Galloway, A., *Culture Practices and Structure Effects of Intertidal Geoduck Aquaculture Operations in Puget Sound: An evaluation of influence on mobile macrofauna.* Presentation to the Coastal & Estuarine Research Federation 20th Biennial Meeting. Portland, OR. Nov. 5, 2009.

Larson, K. *Trophic implications of structure additions associated with intertidal geoduck aquaculture.* Presentation to the 63rd Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR. Sept. 28-Oct. 1, 2009.

McDonald, P.S., *Trophic implications of complex littoral habitats: comparison of aquaculture structure, natural structure, and unstructured habitat, Washington.* Presentation to the Coastal & Estuarine Research Federation 20th Biennial Meeting. Portland, OR. Nov. 5, 2009.

McDonald, P.S., *Challenges to the evaluation of ecological effects of bivalve aquaculture: social and economic constraints, and contradictory incentives from ecological and statistical theory.* Presentation to the 102nd Annual Meeting of the National Shellfisheries Association and World Aquaculture Society, Aquaculture 2010. San Diego, CA. Mar. 1-5, 2010.

McDonald, P.S., *A fisheye perspective on habitat complexity: Do structures associated with intertidal geoduck aquaculture affect trophic dynamics of nekton in unique ways?* Presentation to the 102nd Annual Meeting of the National Shellfisheries Association and World Aquaculture Society, Aquaculture 2010. San Diego, CA. Mar. 1-5, 2010.

McDonald P.S., *Biotic communities associated with aquaculture structures: some aspects of recruitment, growth, and predation.* Presentation to the 64th Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Tacoma, WA. Sept. 20 - 23, 2010.

Price, J., *Disturbance and recovery of a benthic community in response to geoduck aquaculture harvest.* Presentation to the 63rd Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR. Sept. 28-Oct. 1, 2009.

Price, J., *Assessing the Impacts of Geoduck Aquaculture Harvest Practices on Benthic Infaunal Communities.* Presentation to the Coastal & Estuarine Research Federation 20th Biennial Meeting. Portland, OR. Nov. 5, 2009.

Price, J., *Difference in benthic community structure between geoduck* (Panopea generosa) *aquaculture sites and response to harvest events.* Presentation to the 102nd Annual Meeting of the National Shellfisheries Association and World Aquaculture Society, Aquaculture 2010. San Diego, CA. Mar. 1-5, 2010.

Price, J., *Geoduck aquaculture harvest practices in southern Puget Sound, Washington: Assessing patterns of impact and recovery in benthic infaunal communities.* Presentation to the 64th Joint Annual National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Tacoma, WA. Sept. 20 - 23, 2010.

VanBlaricom, G., *Relative abundances of native* (Americorophium salmonis) *and invasive* (Monocorophium spp.) *gammaridean amphipods in geoduck aquaculture plots on intertidal habitats in southern Puget Sound.* Presentation to the 63rd Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR, Sept. 28-Oct. 1, 2009.

2. Freidman et al.

Friedman, C.S., Santacruz, A. and Vadopalas, B. *Endosymbiotic, commensal, and parasitic organisms associated with wild geoduck clams* (Panopea generosa). Presentation to the 102nd Annual Meeting of the National Shellfisheries Association and World Aquaculture Society, Aquaculture 2010. San Diego, CA. Mar. 1-5, 2010.

Vadopalas B., Pietsch, T.W., Friedman, C.S. *Resurrection of Panopea generosa* (Gould, 1850, *from the synonymy of* P. abrupta (Conrad, 1849). Presentation to the 63rd Joint Annual Meeting of the National National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR. Sept. 28-Oct. 1, 2009.

3. Ruesnik and Horwith

Horwith, M. Presentation to the 63rd Joint Annual Meeting of the National Shellfisheries Association - Pacific Coast Section and the Pacific Coast Shellfish Growers Association. Portland, OR, Sept. 28-Oct. 1, 2009.

Horwith, M. Presentation to the Washington State Shellfish Aquaculture Regulatory Committee. Olympia, WA. June 2, 2010.

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