Interim Progress Report

October 1, 2010, through September 30, 2011

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

February 2012

Sea Grant Washington

University of Washington • Seattle, Washington

Interim Progress Report

Publication and Contact Information

This report is available on the Washington Sea Grant website 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 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, 2010, and September 30, 2011.

II. Background

The 2007 law (Second Substitute House Bill 2220; Chapter 216, Laws of 2007) directed Washington Sea Grant (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 WSG to complete the research studies and report the results to the Legislature by December 1, 2013. The Shellfish Aquaculture Regulatory Committee (SARC), established by the 2007 law, and the Department of Ecology (ECY) 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 (UW); 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 tideflat and eelgrass meadow habitats.

The current program schedule and funding are summarized in Table 1. 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 $300,827 through an interagency agreement with the University of Washington (UW). The largest project, the VanBlaricom-led disturbance study, also secured $39,972 from the UW's Royalty Research Fund and $22,207 from ECY to supplement student and technical support that was not included in the DNR agreement.

Scientists have adjusted their efforts to minimize research costs, and DNR, UW and ECY funding has ensured continuation of the three ongoing research studies and program support. In October 2010, the National Sea Grant College Program 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. In the meantime, delays in the growers' harvest schedule in the VanBlaricom study area necessitated an extension in the study duration and collection of more samples to ensure continuity of measurements. The situation has created a budget shortfall of $60,000-$75,000, and WSG is working with state agency partners to ensure that funds are available to process samples, analyze data and fully evaluate results.

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) that address the effects of geoduck aquaculture on overlying waters and the use of sterile triploid geoduck may be discussed as part of a general research overview. However, they are outside the direct scope of the report on this six-year research effort.

Table 1. Funding Source, Timing and Level

Project Title	Study Duration	Funding Source, Timing and Level				
		WA State Geoduck Research Account 7/1/2007 – 6/30/2010	ECY Agreement 4/1/2010 – 6/30/2010	DNR Agreement 7/1/2010 – 6/30/2011	UW Royalty Research Fund 7/1/2010 – 6/30/2011	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	$22,207	$210,390	$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**	$22,207	**$300,827**	$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, analyses of full sample sets and peer review of final reported results. Among the observations for the October 1, 2010 to September 30, 2011 reporting period:

- Infaunal communities at all three harvest study sites show high spatial and seasonal variability; such variability is common to benthic communities in Puget Sound.
- Results of the geoduck harvest study suggest that current practices have minimal impacts on benthic communities of infaunal invertebrates, with no observed "spillover effect" in habits adjacent to cultured plots. These results suggest that disturbance at the scale of current harvest practices is within the range of natural variation experienced by benthic communities in Puget Sound.
- Preliminary statistical analyses suggest significant differences in the structure of mobile macrofauna communities between planted areas with nets and tubes and nearby reference beaches. These differences do not persist once nets and tubes are removed from aquaculture areas during the grow-out culture phase.
- Nutrients released from a typical commercial geoduck operation are low. Moderate concentrations of nitrogen and phosphorus found in sediments and released during harvest make a relatively small contribution to overall nutrient discharges into Puget Sound. Localized effects are likely to be negligible.
- High densities of geoducks filter out algae and their constituent nitrogen and phosphorus in shallow intertidal areas and the digested algae are incorporated into geoduck biomass or remineralized to inorganic nitrogen and phosphorus. In the absence of geoduck culture, algae may still be efficiently remineralized within the water column, processed in deeper water sediments or ingested by other organisms. The overall effect of aquaculture is to change the location of nutrient recycling from the water column to the sediments, rather than fundamentally change the overall rate of nutrient release.
- Analyses of disease data for wild geoduck indicate no distinct patterns in the distribution of disease organisms as a function of geographic location or water depth. The occurrence of two organisms (*Rickettsia*-like and protozoans) show seasonal influences. Three remaining parasites — in the siphon muscle, intestine and ova — have no distinct environmental drivers (season, collection depth or geographic location).
- 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 with limited "spillover effects" from the farmed site to adjacent reference areas. However in 2011, one year after the removal of tubes and nets from the new culture cycle, the first signs of eelgrass recovery were observed, indicating that current farming practices do not make sites unsuitable for later colonization by eelgrass.

Detailed project descriptions and overviews of research progress as of September 30, 2011, 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 website, at *www.wsg.washington.edu/research/geoduck/current_research.html*. A list of presentations and communications products generated by the program during this reporting period (October 1, 2010, to September 30, 2011) is contained in the appendix to this report.

During the report period, WSG continued to work with ECY, SARC and other interested parties. WSG staff and program researchers provided an update to the full SARC on April 4, 2011. Copies of presentations are available on the SARC website at *www.doe.wa.gov/programs/sea/shellfishcommittee/meetings.html#4-11.* Copies of additional relevant research and public presentations are available on the WSG website at *www.wsg.washington.edu/ research/geoduck/current_research.html*.

Copies of the 2009 and 2010 Geoduck Aquaculture Research Program reports are available in downloadable PDF formats on the WSG website at *http://wsg.washington.edu/research/geoduck/index.html* 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 (UW), 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. Initiated in 2008, 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:

> What are the effects of geoduck 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 densities and diversity of soft-sediment invertebrates (infauna and sedimentary epifauna) and densities and diversity of mobile invertebrates (epifauna on culture-associated structures) as well as sessile, attached invertebrates (fouling organisms) dwelling on 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:

> 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.

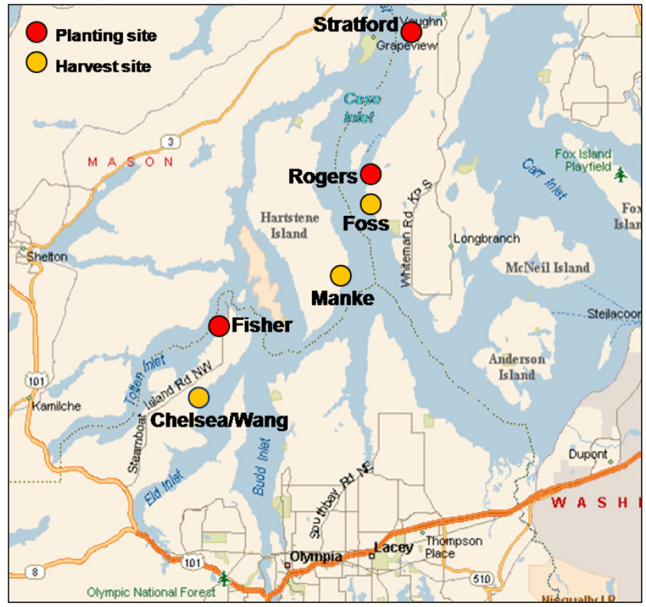

Figure 1. Map of sites currently established in southern Puget Sound to study planting effects (red circles) and harvest effects (yellow circles). The Rogers and Stratford sites were outplanted in November 2008 and June 2009, respectively; planting at the Fisher site was completed in December 2009. Harvest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

Work has focused on the resident communities of infauna and epifauna at harvest and planting sites. It also has focused on 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 during the summer months of 2008 to 2011, with post-gear-removal sampling of planted sites initiated in April 2011 at the Rogers and Stratford sites and in May 2011 at the Fisher site after partial gear removal (Table 2). Mobile organisms were surveyed using two techniques: shore-based surveys, developed as a method of monitoring fine-scale use of shallow nearshore areas by juvenile salmonids; and diver surveys (Figure 4), conducted to assess the presence of bottom-dwelling fishes and small benthic invertebrates during high tides. Surveys were conducted monthly during March to September and bimonthly during October to February in 2009-2011.

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

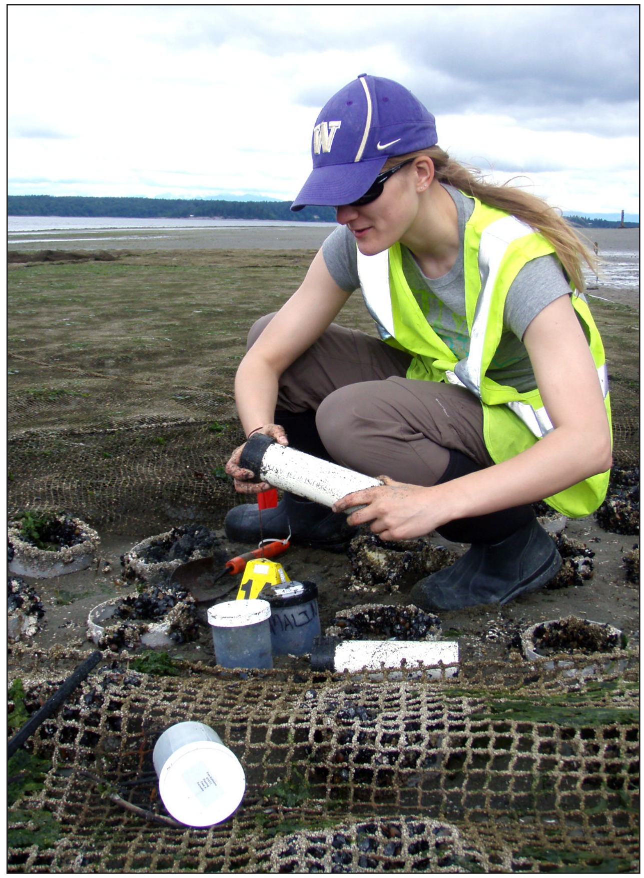

Figure 3. Technician Brittany Cummings collects core samples at a planting effects site in Case Inlet. Core samples are sieved and processed in the laboratory to investigate the effects of aquaculture gear on the community of organisms living within the beach sand. (Photo credit: P. Sean McDonald)

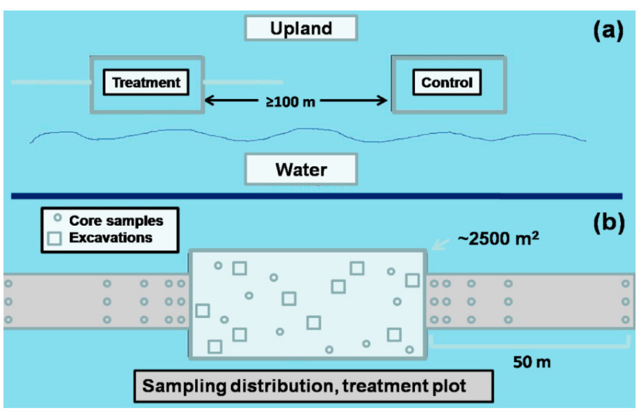

Figure 2. Schematic showing (a) site design and (b) the two categories of samples collected at each site — randomly distributed, within-plot samples and linear arrays that begin at the edge of a cultured plot and extend away from the plot, parallel to the shoreline.

Figure 4. UW SCUBA divers prepare to collect survey data at the Stratford planting effects site in September 2011. Surveys are done regularly to investigate the response of fish and mobile invertebrates (crabs, sea stars, snails) to aquaculture gear. (Photo credit: Ava Fuller)

Table 2. Summary of samples collected and processed to date. Samples collected and processed since September 30, 2010 are shown in parentheses.

	Site	Type	# Collection Trips	# Samples Collected	# Samples Processed
Core Samples					
	Chelsea/Wang	Harvest	14	583	91
	Foss/Joemma	Harvest	13	720	612
	Manke	Harvest	18	700	700
	Fisher	Planting	13 (+9)	560 (+315)	49 (+315)
	Rogers	Planting	13 (+9)	745 (+315)	521 (+315)
	Stratford	Planting	10 (+8)	350 (+280)	4 (+315)
Excavation Samples					
	Chelsea/Wang	Harvest	11	220	220
	Foss/Joemma	Harvest	9	180	180
	Manke	Harvest	12	240	240
	Fisher	Planting	6	120	120
	Rogers	Planting	8	160 (+140)	160 (+140)
	Stratford	Planting	5	100 (+160)	100 (+160)
Photo Samples					
	Chelsea/Wang	Harvest	13	260	40 (+159)
	Foss/Joemma	Harvest	9	180	180
	Manke	Harvest	13	260	180 (+80)
	Fisher	Planting	12	240	100 (+109)
	Rogers	Planting	11	220	160 (+61)
	Stratford	Planting	10	200	100 (+102)
Macrofauna Surveys*					
	Chelsea/Wang	Harvest	--	--	--
	Foss/Joemma	Harvest	--	--	--
	Manke	Harvest	--	--	--
	Fisher	Planting	13 (+9)	416 (+332)	100
	Rogers	Planting	13 (+10)	416 (+366)	20
	Stratford	Planting	14 (+10)	448 (+368)	120

*Surveys only conducted at planting sites.

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 and on methods for evaluating nutrient release during geoduck harvest. For this study, samples of deep pore waters were collected from intertidal environments without geoduck aquaculture, with intact geoduck aquaculture, during harvest and after harvest. To quantify nutrient release during harvest operations, the rate of water flow from high-water-volume hoses used to remove geoducks from the sediment was measured and nutrient concentrations in small rivulets flowing away from the harvest area were assessed. To understand the physical conditions at each site, the water level in sediments at low tide and the grain size of sediments were measured.

Work in fall 2008 and summer 2009 focused on harvest operations at the Foss/Joemma and Chelsea/Wang sites and at an additional site in Thorndyke Bay. Pre- and post-harvest pore water samples were collected, and samples of water runoff were collected during harvest operations. Samples were analyzed for concentrations of pore water nitrogen (ammonium, nitrate) and soluble reactive phosphorus (SRP).

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 Bay site, incubated under laboratory-controlled conditions and analyzed for changes in the concentrations of oxygen, nitrogen, silicate and SRP over time.

One additional field-sampling trip was conducted in November 2009 during harvest activities at the Manke site. Samples of pore water from transects in harvest and reference areas were analyzed for nitrogen and SRP.

Project status

Ecological effects. The initial phase of this component of the project, including refinement of sampling techniques and three pilot studies, has been completed. Substantial progress has been made on the final two phases of the project: measuring effects of harvest and planting on infaunal and epifaunal communities; and observing the response of mobile fish and macrofauna to aquaculture structures.

- *Effects of harvest and planting on infauna and epifauna.* Sampling at planting sites (Fisher, Rogers and Stratford) is ongoing. Sampling and processing at all three harvest sites (Foss/Joemma, Manke and Chelsea/Wang) have been completed (Table 2). These data have been analyzed by graduate student Jennifer Price and form the basis of her recently completed thesis (cited in the appendix of this report) for the UW School of Aquatic and Fishery Sciences. Patterns in taxa richness and species abundance of infauna within and among sites indicate high degrees of seasonal and spatial variation in community structure. Each site presents a slightly distinct benthic community structure and, therefore, responds to harvest practices differently. Statistical analyses indicate that variance in infaunal data is primarily attributable to time of year (season), plot status (cultured versus uncultured) and harvest state (pre- versus post-harvest). However, there are no significant statistical interactions between plot status and harvest state, suggesting that harvest itself does not significantly alter the benthic invertebrate assemblages under study. Transect data were also analyzed and indicate substantial temporal and spatial variation, even over tens of meters. There were no patterns of increasing or decreasing organism density or species diversity as the distance from cultured plots increased, except for the Foss south transect during the mid-harvest period. All other variations within transects at all three sites appeared to be random or were caused by as-yet unknown processes not accommodated in the study design.
- *Response of mobile organisms to presence of aquaculture structures.* SCUBA surveys at planted sites, focusing on demersal fishes and invertebrate macrofauna, are ongoing. 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. As the data set of SCUBA surveys increases, observations suggest a pronounced seasonal response of mobile macrofauna found within planted areas and reference beaches. Observations also suggest increased use of planted areas by kelp crabs (*Pugettia producta*) and red rock crab (*Cancer productus*) during autumn and winter (October-March). Graceful crab (*Cancer gracilis*), Pacific staghorn sculpin (*Leptocottus armatus*) and speckled

sanddab (*Citharichthys stigmaeus*) are apparently ubiquitous at Fisher, Rogers and Stratford sites. Data collected to date suggest that structures associated with geoduck aquaculture may attract species observed infrequently on reference beaches (e.g., bay pipefish, *Syngnathus leptorhynchus*) but may displace species that typically occur in these areas (e.g., starry flounder, *Platichthys stellatus*). Preliminary statistical analyses suggest significant differences in the structure of macrofauna communities between planted areas with nets and tubes and nearby reference beaches. These differences do not persist once nets and tubes are removed from aquaculture areas during grow-out.

- *Pilot study on fouling community recruitment.* In May-August 2010, Erika Pinney, an undergraduate at the UW, conducted an experimental investigation of recruitment by fouling plants and animals to predator exclusion devices, specifically, PVC tubes and three varieties of aquaculture netting — large-mesh fiber net covers, small-mesh plastic net covers and small-mesh plastic net caps. Across the four-month sampling period, small-mesh plastic net caps developed fouling community assemblages that were more diverse and contained a higher abundance of taxa than large-mesh fiber net covers and small-mesh plastic net covers. Conversely, the large- and small-mesh net covers accumulated more fouling green algae (*Enteromorpha spp.*) than did net caps, with peak biomass occurring in July. This effort will be expanded during summer 2012 to investigate the effects of fouling algae on geoduck growth and carbon sources in fouled aquaculture plots.
- *Pilot study of the survival and growth of non-target clams.* In July 2010, UW undergraduates Hans Hurn and Julia Eggers investigated the effects of aquaculture practices on the survival and growth of non-target clams within cultured plots of geoducks and adjacent reference beaches at the Rogers, Fisher and Stratford sites. Survival of non-target clams was lower within planted areas than on adjacent beaches and, when combined with results from predator exclusion cages, suggests higher predation in the aquaculture areas. Non-target clams showed a tendency toward slower growth in aquaculture areas than on adjacent beaches; however, results were not statistically significant. The students presented results of the experiment at the American Fisheries Society meeting in Seattle in September 2011. They are currently preparing a manuscript for submission to a peer-reviewed research journal.
- *Pilot study on the trophic linkages between resident prey and mobile predators.* Pilot work conducted in 2008 by Rachel Smith, a National Science Foundation Research Experience for Undergraduates Program participant, was recently published in Northwestern University's Northwestern Undergraduate Research Journal. This work was continued in 2009 by UW volunteer Kristin Larson and formed the basis for a new ongoing project funded through NOAA Sea Grant and the NOAA Aquaculture Program as part of the National Marine Aquaculture Initiative. The project, which supports thesis work for a UW graduate and undergraduate student, continues to investigate the effects of geoduck aquaculture structures on trophic relationships in intertidal communities.

Geochemical effects. At all sites, nitrogen concentrations in pore water samples consisted primarily of ammonium. At the Chelsea/Wang site, ammonium concentrations were higher in sediment where geoducks had been previously harvested and at sites where harvest-sized geoducks were still being grown than in adjacent reference areas (where geoducks were not being grown or harvested). Similarly at the Thorndyke Bay site, high ammonium concentrations were observed only in plots with geoducks. High concentrations of SRP were observed at harvest, grow-out and reference sites at the Chelsea/Wang site. Silicate concentrations in pore water were variable across sites but very high at the Chelsea/Wang sites with little apparent relationship to geoduck culture. Elevated silica concentrations suggest that diatoms are dissolving in the geoduck beds. Both diatoms and phosphorus bound to inorganic particles would be focused by geoduck filter feeding from the water column into the sediment.

Nutrient data analyses are now complete, and data clearly show that nutrients (nitrogen and phosphorus) released from a typical commercial geoduck operation into Puget Sound are low — 40 $\mu mol\ L^{-1}$ dissolved inorganic nitrogen and less than 5 $\mu molL^{-1}$ SRP. The total release into Puget Sound during one tidal cycle in which two geoduck harvesters were at work was ~9 g phosphorus and 32 g nitrogen. 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.

Harvest effluent SRP concentrations were not high relative to pore water observations; however, SRP measurements suggest an imbalance in the regeneration of nitrogen and phosphorus in the sediment. The molar ratio of SRP to dissolved inorganic nitrogen (ammonium plus nitrate) was observed to be < 0.062, which is much lower than the expected ratio if nitrogen and phosphorus concentrations were derived solely from decomposing algae (0.10-0.71). One possible explanation for such an imbalance is the release of mineral-bound phosphorus.

The results of laboratory incubations of sediment cores from Thorndyke Bay under dark conditions, indicated generally low exchange of ammonium and SRP between the sediment and overlying water, but the SRP fluxes were significantly higher in geoduck culture areas than in control areas. Oxygen consumption also was significantly higher in geoduck culture areas than at the reference site. Increases in nitrogen and phosphorus release from the sediment, as well as the increased oxygen uptake by the sediment, are consistent with increased inputs of algal-derived organic material into geoduck culture areas.

Research Highlights

Ecological effects

- Infaunal communities at all three harvest study sites show high spatial and seasonal variability; such variability is common to benthic communities in Puget Sound.
- Results of the geoduck harvest study suggest that current practices have minimal impacts on benthic communities of infaunal invertebrates, with no observed "spillover effect" in habits adjacent to cultured plots. These results suggest that disturbance at the scale of current harvest practices is within the range of natural variation experienced by benthic communities in Puget Sound.
- Preliminary statistical analyses suggest significant differences in the structure of mobile macrofauna communities between planted areas with nets and tubes and nearby reference beaches. These differences do not persist once nets and tubes are removed from aquaculture areas during the grow-out culture phase.
- Fieldwork for the geoduck planting study is ongoing.
- Additional funding from the NOAA Aquaculture Program has been secured to conduct a separate but related study on the effects of geoduck aquaculture structures on trophic relationships in intertidal communities.

Geochemical effects

- Nutrients released from a typical commercial geoduck operation are low. Moderate concentrations of nitrogen and phosphorus found in sediments and released during harvest make a relatively small contribution to the overall nutrient discharges into Puget Sound. Localized effects are likely to be negligible.
- High densities of geoducks filter out algae and their constituent nitrogen and phosphorus in shallow intertidal areas, and the digested algae are incorporated into geoduck biomass or remineralized to inorganic nitrogen and phosphorus. In the absence of geoduck culture, algae may still be efficiently remineralized within the water column, processed in deeper water sediments or ingested by other organisms. The overall effect of aquaculture is to change the location of nutrient recycling from the water column to the sediment, rather than fundamentally change the overall rate of nutrient release.
- The results of this component of the project are being readied for a January 2012 submission to the peer-reviewed research journal *Aquaculture*.

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 provide information on possible pathogens and also provide insights into whether the initial outbreak or re-emergence of a disease is related to an endemic or recently introduced parasite.

In this three-year project, researchers have characterized parasites and other disease organisms associated with wild geoducks and determined their prevalence in three wild geoduck populations representing southern Puget Sound, Hood Canal and the Strait of Juan de Fuca. Geoducks were collected in summer and winter to facilitate detection of both warmwater and coldwater infectious organisms. The researchers are using multivariate statistical techniques to explore trends of parasite presence within geoduck populations and to identify the environmental factors (site distribution, sample depth, date/season) that influence the occurrence and diversity of parasite assemblages.

Figure 5. Map of sample sites. Source: soundwaves.usgs.gov/2005/01/puget-soundLG.jpg.
A — Freshwater Bay; B — Thorndyke Bay; C — Totten Inlet

Approach

For this project, three sites reflecting the geographic range of geoduck aquaculture in Washington were selected (Figure 5). 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.

Project Status

Examination of stained tissue sections from wild geoducks collected from Thorndyke Bay, Freshwater Bay and Totten Inlet revealed the presence of a microsporidian-like parasite resembling *Steinhausia* sp. The biology of *Steinhausia*-like parasites is poorly understood, but the existence of these organisms may impact reproductive success if present at high infection intensity. Although microsporidia have been reported in oysters, mussels and cockles from Europe, Australasia, California and the eastern United States, no molluscan microsporidia have been previously reported from Canada or Puget Sound. The most common abnormalities observed include: microsporidia-like protists in the siphon and intestine; a *Steinhausia*-like parasite in ova; a *Rickettsia*-like organisms in the gills; and nephrocalcinosis and inflammation in both the digestive gland and gills. Further analyses are needed to determine the taxonomy of these parasites. For example, it is unclear whether the microsporidian-like protists found in the geoduck ova, siphon and intestine are life-stages of a single microsporidian, three different species or a combination of the two possibilities. Researchers also observed a possible ciliate within gill tissues as well as numerous other parasites in association with the surface epithelium of the siphon. Several other parasites or diseases were also observed, including the presence of "warts" and a possible fungus associated with dark discoloration on the siphon and exposed mantle surface.

The most common parasites, their prevalence and seasonal occurrence are presented in Table 3.

Multivariate analyses of data indicated no distinct patterns as a function of site or sample depth. The presence of the *Rickettsia*-like organism is influenced by winter and summer seasons, with winter acting as a stronger driver than summer. The presence of protozoa in geoduck is more likely to occur during the spring season. Protozoa are not likely to appear during summer months. The remaining three parasites — microsporidia-like species in the siphon muscle, another microsporidia-like species in the intestine and the *Steinhausia*-like parasite in ova — all share similar community assemblages with no distinct environmental driver (season, collection depth or geographic location).

Table 3. Most commonly observed pathogens, their prevalence and seasonal occurrence.

Parasite	Tissue	Number of Samples	Prevalence	Seasonal Occurrence
Rickettsia-like organism	Gill	247	39.0%	Present in Winter and Summer
Protozoa	Siphon Epithelium	220	34.7%	Primarily in Spring
Microsporidia-like organism	Intestine	104	16.4%	No seasonal driver
Microsporidia-like organism	Siphon Muscle	27	4.3%	No seasonal driver
Steinhausia-like organism	Ova (egg)	99	15.6%	No seasonal driver
Bacteria	Intestinal Epithelium	3	0.5%	No seasonal driver

Molecular characterization of parasites will continue in 2012, to provide definitive identification and to assess parasite impact to wild geoduck health in the Northwest. Additional correlations of each parasite to individual drivers will be performed to supplement multivariate analyses.

Research Highights

- Analyses of disease data for wild geoduck indicate no distinct patterns in the distribution of disease organisms as a function of site or water depth. The occurrence of two organisms (*Rickettsia*-like and protozoans) show seasonal influences. Three remaining parasites — in the siphon muscle, intestine and ova — have no distinct environmental drivers (season, collection depth or geographic location).

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 geoducks offered a unique opportunity to study the effects of geoduck aquaculture on soft-sediment tideflat and eelgrass meadow habitats. This 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 in 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 4 and Figure 6. To determine the response of the local marine habitat to geoduck aquaculture practices, 15 surveys were conducted between April 2008 and July 2011, timed to coincide with geoduck harvest, planting, placement and removal of predator exclusion devices (PVC tubes and netting) (Figure 7).

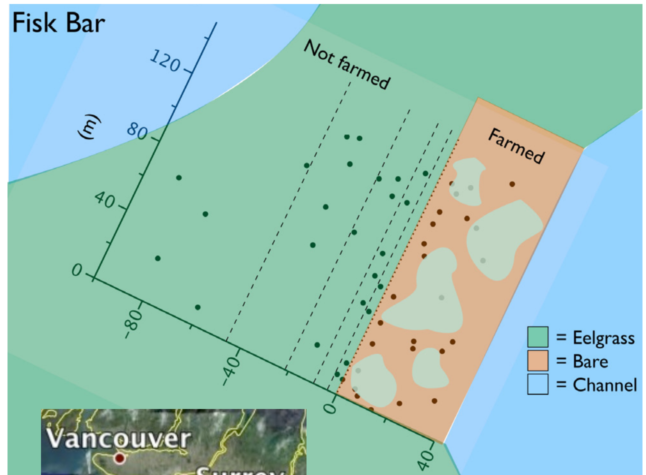

Figure 6. Fisk Bar, Samish Bay, WA (48°36'N, 122°26'W). Upper schematic represents a simplified birds-eye view of Fisk Bar on 4/9/2008, showing adjacent farmed and unfarmed areas. Points represent the placement of quadrats. The dotted line represents the harvest boundary, and dashed lines demarcate portions of the unfarmed area that are sampled equally through the stratified random design of quadrat placement. Left schematic represents the geographic location of Fisk Bar as a yellow star.

Table 4. Locations and characteristics of "Farmed" and "Unfarmed" 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 140 m x 36 m, 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/m^2. 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/m^2 in summer. This serves as the control site for the project.

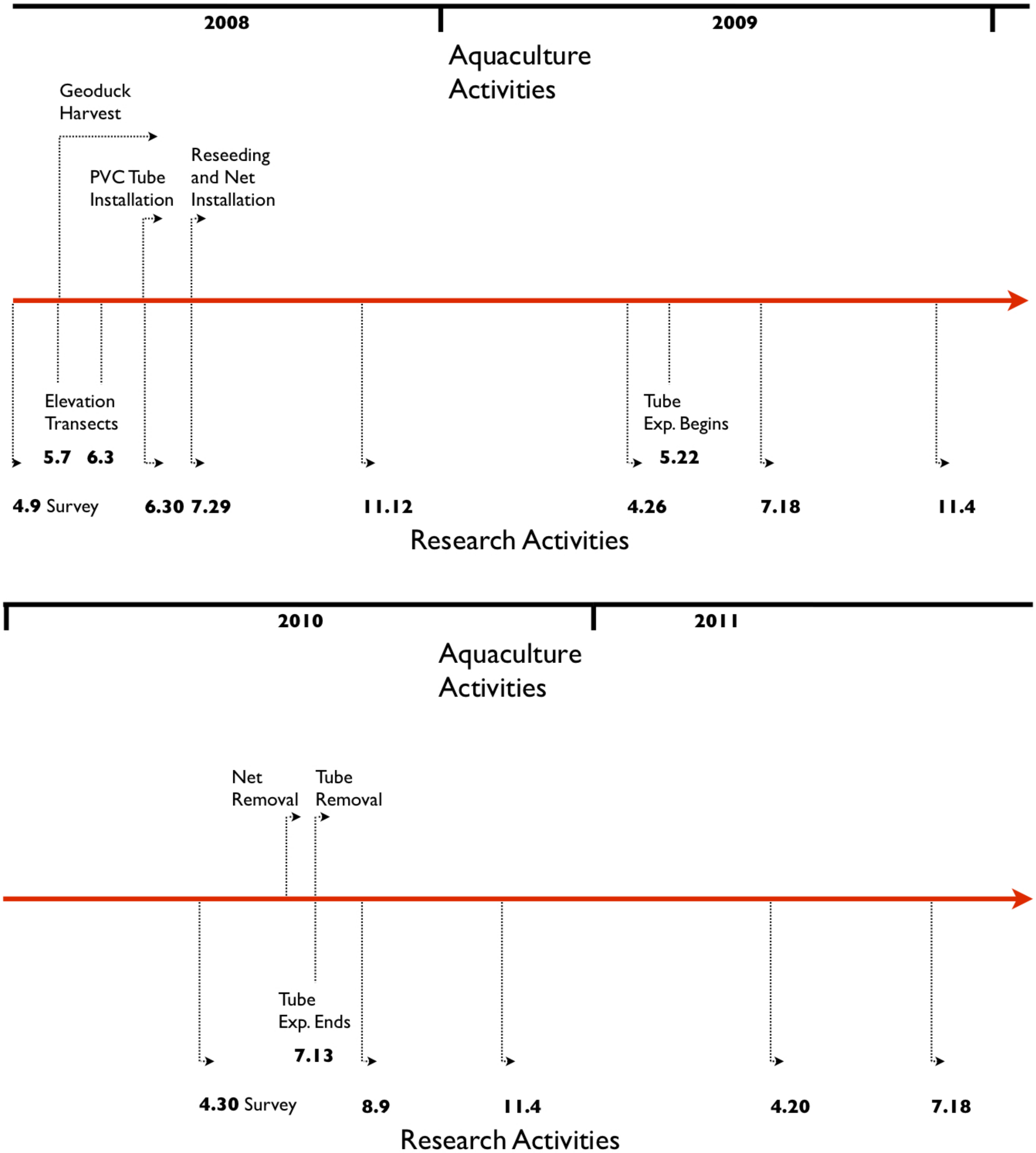

Figure 7. Timeline for aquaculture activities (above arrow) and research activities (below arrow) completed to date.

To determine the spatial extent of the habitat response to aquaculture practices, each plot was sampled during each survey using randomly positioned quadrats. The quadrats in the control plot were placed at set distances from the farm boundary. 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. Such change would indicate a loss or addition of sediment to the harvest location.

All fieldwork and full analyses of *Z. marina* and sediment samples (for organic content and grain size) have been completed. Analysis of infaunal samples is ongoing (Table 5).

In an accessory experiment conducted from May 2009 to July 2010 to determine the effect of installation of predator exclusion structures on sediment stability and eelgrass growth (Figure 8), four 10 x 5 m plots were selected outside the eelgrass meadow that mimicked conditions on Fisk Bar prior to geoduck planting in 2002. PVC tubes were installed over half of each plot (16 tubes per m2 in a 5 x 5 m area), while the other half was left bare. In each plot, 40 *Z. marina* seedlings were transplanted into the center of the area with tubes installed, and 40 seedlings were transplanted into the bare area. Changes in sediment elevation and seedling growth were assessed monthly during the summer of 2009 and in July 2010 when the PVC tubes were removed.

Table 5. A summary of surveys conducted and samples collected and processed to date.

Sample type	# Surveys	# Samples Collected	# Samples Processed
Quadrat: In-place assessment of # of *Z. marina* vegetative shoots, flowering shoots, seedlings, and *Z. japonica* shoots	12	580	N / A
Quadrat: Laboratory assessment of *Z. marina* size and branching rate	12	580 bags, 4,874 *Z. marina* shoots	580 bags, 4,874 *Z. marina* shoots
Quadrat: Laboratory assessment of sediment organic content	12	580	580
Quadrat: Laboratory assessment of infauna	12	580	80
Transect: In-place assessment of sediment elevation	5	360	N / A

Figure 8. Tube installation experiment, July 12, 2010. The farmed area of Fisk Bar is approximately 20 m to the right of the standing individual. (Photo credit: Micah Horwith).

Project status

The initial, pre-harvest survey in April 2008 found little difference between the farmed and control plots of Fisk Bar in sediment organic content, mean *Z. marina* size, reproductive activity of *Z. marina*, or *Z. marina* shoot density. However, eelgrass was patchily distributed in the farmed plot and uniformly distributed in the control plot. After geoduck harvest, reseeding and net installation (summer 2008), a range of effects on ecologically relevant aspects of Fisk Bar was detected. Within the farmed plot, an immediate and significant reduction in shoot density, rate of flowering and size of aboveground structures was observed for *Z. marina*, along with a delayed and significant reduction in belowground branching activity. *Z. marina* was lost from the farmed plot between April 26, 2009, and July 18, 2009, in part because of reduced light levels created by a thick covering of *Ulva* algae on the predator exclusion nets. After harvest, the farmed plot had a significantly lower sediment organic content than the control plot on every survey date. The farmed plot also demonstrated a significant post-harvest loss of elevation that was not evident in one subsequent survey, suggesting a quick recovery.

Preliminary analysis indicates some evidence of minor "spillover effects" of geoduck aquaculture on the adjacent eelgrass meadow. Effects included smaller, more densely packed *Z. marina* shoots and increased organic content of sediment nearer the farm. Together, these patterns may represent typical "edge effects," in which geoduck aquaculture has effectively formed a meadow edge where none existed before (Figure 9).

Figure 9. Fisk Bar on July 28, 2011. The standing individual is within the farmed area, with dense eelgrass in the unfarmed area. (Photo credit: Micah Horwith).

In the summer of 2011, there was preliminary evidence of recolonization of Fisk Bar by *Z. marina.* Although plant densities were low, small numbers of shoots were recorded across the farmed plot. Because these shoots were often too far from the control plot to be the product of vegetative propagation, it is likely that their recruitment was through seeds and seedlings (Figure 10).

Figure 10. Eelgrass growing within the farmed area of Fisk Bar on July 28, 2011, approximately 8 m from the unfarmed area. (Photo credit: Micah Horwith).

In the accessory PVC tube installation experiment, the transplanted seedlings perished within four months in all four plots, both experimental (with tubes) and control (no tubes). A higher rate of decline was observed in plots with tubes installed. These results indicate that this location was not favorable to eelgrass recruitment and growth. After 14 months, the plots with tubes demonstrated a significantly greater loss of sediment elevation, suggesting that tube installation and a lack of eelgrass may increase rates of scour on surrounding sediment. These results, however, are for the specific study area and may not be characteristic of all geoduck aquaculture locations.

Research Highlights

- 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 with limited "spillover effects" from the farmed site to adjacent reference ares. However in 2011, one year after the removal of tubes and nets from the new culture cycle, the first signs of eelgrass recovery were observed, indicating that current farming practices do not make sites unsuitable for later colonization by eelgrass.

V. Appendix

Program-Related Communications, October 1, 2010 to September 30, 2011.

Copies of representative presentations and publications are available on the WSG website at *www.wsg.washington.edu/research/geoduck/current_research.html.*

1. VanBlaricom et al.

Publications (not peer reviewed)

Smith, R. and McDonald, P.S. (2010) *Examining the effects of predator exclusion structures associated with geoduck aquaculture on mobile benthic macrofauna in South Puget Sound, Washington*. Northwestern Undergraduate Research Journal 5(2009-2010): 11-16.

Presentations

VanBlaricom, G.R. *Evaluation of ecological effects of geoduck aquaculture operations in intertidal communities of southern Puget Sound*. Invited presentation at the Environmental Science Seminar Series, Environmental Program, Interdisciplinary Arts and Sciences Program. University of Washington, Tacoma, WA. Feb. 7, 2011.

VanBlaricom, G.R. *Ecological effects of geoduck aquaculture operations in southern Puget Sound.* Invited presentation to the Panel on Aquaculture Research and Technical Support, Washington Sea Grant Program Site Review. Seattle, WA. Mar. 3, 2011.

Price, J.L., McDonald, P.S., Essington, T.E., Galloway, A.W.E., Dethier, M.N., Armstrong, D.A. and VanBlaricom, G.R. *Benthic community structure and response to harvest events at geoduck aquaculture sites in southern Puget Sound, Washington*. Invited presentation to the Joint Annual Meeting, Society for Northwestern Vertebrate Biology and Washington Chapter of The Wildlife Society, Gig Harbor, WA. Mar. 24, 2011.

Price, J.L., McDonald, P.S., VanBlaricom, G.R., Cordell, J.R., Essington, T.E., Galloway, A.W.E., Dethier, M.N. and Armstrong, D.A. *Benthic community structure and response to harvest events at geoduck (*Panopea generosa*) aquaculture sites in southern Puget Sound, Washington.* Oral presentation to the National Shellfisheries Association Annual Meeting. Baltimore, MD. Mar. 30, 2011.

Price, J.L. *Geoduck Harvest in Puget Sound: Is it an ecological problem?* Invited presentation to the State Capital Seminar Series, Washington Department of Fish and Wildlife. Olympia, WA. Jul. 13, 2011.

Price, J.L. *Quantifying the ecological impact of geoduck (*Panopea generosa*) aquaculture harvest practices on benthic infauna*. Master's Thesis Defense. School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. Aug. 8, 2011.

VanBlaricom, G.R. *Ecological disturbances associated with harvests of cultured geoduck clams in southern Puget Sound, with implications for sustainability*. Invited presentation to the Workshop on Washington State Environmental and Sustainability Learning Standards. Washington State Office of Public Instruction, Olympia, WA. Aug. 24, 2011.

Hurn, H., Eggers, J., McDonald, P.S. and VanBlaricom G.R. *Effects of geoduck aquaculture on predation and growth of non-target clams*. Oral presentation to the American Fisheries Society Annual Meeting. Seattle, WA. Sept. 6, 2011.

McDonald, P.S., Galloway, A.W.E., Price J.L., McPeek K., Armstrong D.A., VanBlaricom G.R. and Armintrout K. *Effects of geoduck aquaculture practices on habitat and trophic dynamics of nekton and macroinvertebrates in Puget Sound*. Oral presentation to the American Fisheries Society Annual Meeting. Seattle, WA. Sept. 6, 2011.

McDonald, P.S., Galloway A.W.E., Price J.L., McPeek K., Armstrong D.A., and VanBlaricom G.R. *Patterns in abundance of fish and macroinvertebrates associated with geoduck aquaculture*. Oral presentation to the 65nd Annual Meeting of the Pacific Coast Shellfish Growers Association and the National Shellfish Association – Pacific Coast Section. Salem, OR. Sept. 20, 2011.

Armintrout, K., McDonald, P.S., McPeek, K., Beauchamp, D., and VanBlaricom, G.R. *Trophic ecology within geoduck aquaculture habitat.* Oral presentation to the 65th Annual Meeting of the Pacific Coast Shellfish Growers Association and the National Shellfish Association – Pacific Coast Section. Salem, OR. Sept. 20, 2011.

VanBlaricom, G.R., Price J.L., McDonald, P.S., Cordell, J.R., Essington, T.E., Galloway A.W.E., Dethier, M.N. and Armstrong D.A. *Geoduck aquaculture harvest impacts: The results*. Oral presentation to the 65th Annual Meeting of the Pacific Coast Shellfish Growers Association and the National Shellfish Association – Pacific Coast Section. Salem, OR. Sept. 20, 2011.

Theses and dissertations

Price, J. (2011) *Quantifying the ecological impacts of geoduck (*Panopea generosa*) aquaculture harvest practices on benthic infauna*. Master's Thesis, University of Washington, Seattle, WA.

Media placements

Stang, John. *Economic benefits, ecological questions stall geoduck industry's growth*. The Kitsap Sun, Kitsap County, WA. Jul. 23, 2011

2. Friedman et al.

Presentations

Dorfmeier, E., Friedman, C., Frelier, P. and Elston, R. *Examining seasonal patterns of Pacific geoduck* (Panopea generosa) *disease using a multivariate approach*. Oral presentation to the 65th Annual Meeting of the Pacific Coast Shellfish Growers Association and the National Shellfish Association – Pacific Coast Section. Salem, OR. Sept. 20, 2011.

3. Ruesink and Horwith

Presentations

Ruesink, J. Resilience of eelgrass following multiple disturbances. Oral presentation to 65th Annual Meeting of the Pacific Coast Shellfish Growers Association and the National Shellfish Association – Pacific Coast Section. Salem, OR. Sept. 20, 2011.

Horwith, M. Ph.D. Dissertation Defense. Department of Biology, University of Washington, Seattle, WA. Jun. 23, 2011

Theses and dissertations

Horwith, M. (2011) *Plant behavior and patch-level resilience in the habitat-forming seagrass* Zostera marina. Ph.D. dissertation, University of Washington, Seattle, WA.

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