Interim Progress Report

July 1, 2007, through September 30, 2009

Geoduck Aquaculture Research Program

House Bill 2220

Report to the Washington State Legislature

House Committee on Ecology and Parks

House Committee on Agriculture and Natural Resources

House Committee on Environmental Health

Senate Committee on Natural Resources, Ocean and Recreation

Senate Committee on Environment, Water and Energy

December 2009

Sea Grant Washington

University of Washington • Seattle, Washington

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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Interim Progress Report:

House Bill 2220 Geoduck Aquaculture Research Program

I. Summary

At the direction of the State Legislature, the University of Washington's Washington Sea Grant established a geoduck aquaculture research program in 2007. Initial program activities included a review of existing scientific information and the commissioning of scientific research studies to assess possible effects of geoduck aquaculture on the Puget Sound and the Strait of Juan de Fuca environments. Top priority has been assigned to examining the effects of commercial harvesting.

Under Second Substitute House Bill 2220 (Chapter 216, Laws of 2007), Washington Sea Grant is tasked with completing the research studies and reporting the results to the Legislature by December 1, 2013. In 2007 and 2008, information on research activities was incorporated into the Washington State Department of Ecology's interim and final progress reports to the Legislature on the Shellfish Aquaculture Regulatory Committee (*www.ecy.wa.gov/programs/sea/shellfishcommittee/index.html*). This report includes information on the research program covered by those earlier reports and provides an update on research progress in 2009.

II. Program Progress

In 2007, the Washington State Legislature enacted Second Substitute House Bill 2220, directing Washington Sea Grant at the University of Washington to initiate a geoduck aquaculture research program. Program requirements included a review of existing scientific information and the commissioning of scientific research studies to assess possible effects of geoduck aquaculture on the Puget Sound and the Strait of Juan de Fuca environments. The purpose of the research is to examine key uncertainties related to geoduck aquaculture that could have implications for the health of the ecosystem and wild geoduck populations. Section 1 of SSHB 2220 (RCW 28B.20.475) identifies the following as priorities to measure and assess:

a) The effects of structures commonly used in the aquaculture industry to protect juvenile geoducks from predation;

b) 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;

c) 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;

d) 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;

e) Genetic interactions between cultured and wild geoducks, including measurement of differences between cultured and wild geoduck in term of genetics and reproductive status; and

f) The impact of the use of sterile triploid geoducks and whether tripoid 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 (Priority b above) and directed Washington Sea Grant to complete the research studies and report the results to the Legislature by December 1, 2013. The Shellfish Aquaculture Regulatory Committee (established by SSHB 2220) and the Department of Ecology were tasked with overseeing the research program. Their oversight is intended to ensure that funded research satisfies the planning, permitting and data management needs of the state. Washington Sea Grant has worked closely with both entities throughout the initial phase of the research program. Presentations were made to the Committee during 2007 and 2008 to provide updates and feedback on the research prioritization and selection process, and Department of Ecology staff served on the project selection panel.

Northwest Workshop on Bivalve Aquaculture and the Environment

To articulate a scientific baseline and encourage interest in the research program, Washington Sea Grant convened the ***Northwest Workshop on Bivalve Aquaculture and the Environment*** in Seattle in September 2007. Experts from the United States, Canada and Europe were invited to discuss recent findings and provide recommendations for research needed to support sustainable management of geoduck and other shellfish resources. A diverse range of attendees included state, federal and tribal resource managers, university researchers, shellfish farmers, conservation organizations and interested members of the public. All workshop materials, including video of scientific presentations and panel discussions, are available on the Washington Sea Grant Web site at *wsg.washington.edu/research/geoduck/shellfish_workshop.html*.

Review of Current Scientific Knowledge

SSHB 2220 required a review of all available scientific research that examines the effect of prevalent geoduck aquaculture practices on the natural environment. Washington Sea Grant contracted with experts at the University of Washington's School of Aquatic and Fishery Sciences to conduct an extensive literature review of current research findings pertaining to shellfish aquaculture. The researchers evaluated 358 primarily peer-reviewed sources and prepared a draft document for public comment in September 2007. WSG received four formal comment submissions, which were considered by the authors while editing the final document and responded to in writing. The final literature review, ***Effects of Geoduck Aquaculture on the Environment: A Synthesis of Current Knowledge***[1], was completed in January 2008 and is available on the WSG Web site at *wsg.washington.edu/research/geoduck/literature_review.html*. It was revised and updated to include recent findings in October 2009.

[1] Straus KM, Crosson LM, Vadopalas B (2008) Effects of Geoduck Aquaculture on the Environment: A Synthesis of Current Knowledge. Washington Sea Grant, Seattle, WA. 67p.

Commissioning of Initial Research Studies

Research priorities identified in SSHB 2220, at the Northwest Workshop and through the literature review were used to develop the request for scientific research projects (RFP) that Washington Sea Grant issued on October 9, 2007. Seven research teams responded to the RFP and submitted preliminary proposals for review and comment by an external panel of experts. A summary of the comments was provided to each team for guidance in developing a full project application for submission to Washington Sea Grant on December 10, 2007.

The seven completed applications underwent a rigorous peer review, based on four criteria: (1) project contribution to addressing research priorities and management needs; (2) technical and scientific merit; (3) qualifications of the applicants; and (4) project cost-effectiveness. Each project was evaluated by at least three independent scientific experts. On February 1, 2008, Washington Sea Grant convened a six-member geoduck research review panel to discuss the applications and peer reviews and develop recommendations for project funding. One of the panel members, a Department of Ecology ecologist, was responsible for providing agency and Shellfish Aquaculture Regulatory Committee perspectives.

The review panel recommended that four of the projects be funded during the initial phase of the program, and that two projects addressing harvesting and planting operations be combined to develop a more integrated and comprehensive study. Together, the recommended projects address six of the seven priorities identified in SSHB 2220 and the RFP. A study to evaluate the effects of geoduck aquaculture on overlying waters (Priority c) was deferred until later in the six-year research program, when additional resources were anticipated. In addition, while a study on triploidy was approved, fiscal constraints required that the project starting date be deferred until later in the research program.

Washington Sea Grant worked with principal investigators to finalize work plans, identify possible study areas and complete funding contracts by mid-May 2008. Project titles, principal investigators, research organizations and a brief description of the initial studies are as follows:

Geochemical and Ecological Consequences of Disturbances Associated with Geoduck Aquaculture Operations in Washington. (Glenn VanBlaricom, University of Washington; Jeffrey Cornwell, University of Maryland) This project assesses geoduck aquaculture effects on plant and animal communities, including important fish and shellfish, in and on Puget Sound beaches. It also assesses the physical and chemical properties of those beaches. All phases of the aquaculture process are being evaluated — geoduck harvest and planting, presence and removal of predator exclusion structures and ecosystem recovery.

Cultured-Wild Interactions: Disease Prevalence in Wild Geoduck Populations. (Carolyn Friedman, University of Washington) This study is developing baseline information on pathogens to improve understanding of geoduck health and the management of both wild and cultured stocks. Researchers are working and coordinating with Puget Sound tribes and state natural resource agencies to broaden the range of animals tested.

Resilience of Soft-Sediment Communities after Geoduck Harvest in Samish Bay, Washington. (Jennifer Ruesink, University of Washington) This study capitalizes on the colonization by eelgrass of an existing commercial geoduck bed to study the effects of geoduck aquaculture on soft-sediment tideflats and eelgrass meadow habitats.

Research Program Implementation

Research project time, effort and funding initially were devoted to the necessary start-up activities associated with a large-scale research activity. These activities included the selection of research sites, assembly of staff, coordination of research protocols and procedures, and refinement of sampling methods and experimental designs. Preliminary surveys were conducted and data analyzed to ensure collection of adequate data to support project conclusions.

In 2008 and 2009, research efforts focused on the conduct of extensive field activities. Analysis of field samples is currently underway and initial results provide some indication of environmental response to geoduck aquaculture activities. However, these results are very preliminary and must be confirmed by additional fieldwork and analyses of full sample sets before they can be used to guide management. Among the tentative observations at this early stage in the six-year program:

Preliminary data from one site suggest declines in some abundant worms and small crustaceans within the geoduck harvest zone and in adjacent areas immediately following harvest activity. There is evidence of recovery of these populations within six months.

Diver surveys conducted at planted sites suggest that the addition of structures associated with geoduck aquaculture may change the community of mobile organisms visiting the site during high tides. Populations of structure-associated rock crabs, sea stars and other animals may increase, while populations of flatfish and other sandy-bottom species may decrease when nets and tubes are added to intertidal beaches.

Initial results suggest that the release of nutrients due to prevalent harvest techniques is not significant.

Preliminary screening of wild geoduck populations in three locations in Puget Sound and the Strait of Juan de Fuca identified a microscopic parasite that has not been recorded in geoduck previously. Further analysis is required to determine the full extent and severity of infection.

Initial results indicate that eelgrass beds neighboring a geoduck farm are affected by aquaculture practices, although additional surveys are necessary to determine whether effects are short-lived or persistent.

Detailed project descriptions and overviews of research progress as of September 30, 2009, are presented in Section III of this report. Full technical progress reports are also available on the WSG Web site at *wsg.washington.edu/research/geoduck/current_research.html.* The appendix provides a list of media reports, publications and presentations generated by the program to date.

Schedule for Research Program Completion

The three selected projects represent the initial phase of the geoduck aquaculture research program. As indicated in Figure 1, these initial projects will continue into the second and third biennia of the program, contingent on the availability of funding. In addition, studies to address the use of triploid (sterile) geoducks and the influence of geoduck aquaculture practices on water quality were tentatively planned for initiation in 2010 to complete the scope of the research called for in SSHB 2200. The initiation of this second phase also will rely on the availability of funding.

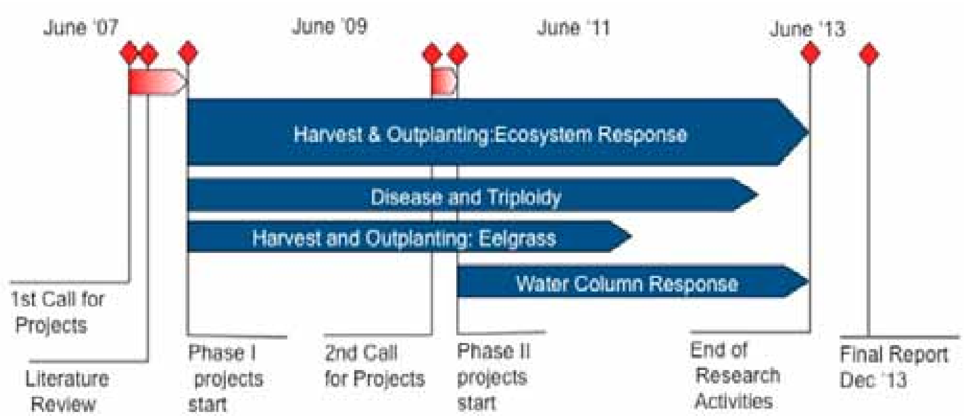

Figure 1. *Timeline for completion of geoduck aquaculture research program.*

III. Progress of Research Projects

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 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 disturbance

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 have been selected (Figure 2) that represent all stages of culture activity and have environmental conditions that allow meaningful comparisons among sites.

Figure 2. *Map of sites established in southern Puget Sound to study planting effects (red circles) and harvest effects (yellow circles). The Rogers site and Stratford site were out-planted in November 2008 and June 2009, respectively; planting at the Fisher site is ongoing. Harvest of mature geoducks at Foss/ Joemma (i.e., Foss) was completed in December 2008. Harvest at the Chelsea/Wang and Manke sites is underway and will be completed in 2010.*

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.

The Stratford and Rogers sites have been selected as "alpha sites," at which the entire culture cycle, from planting of juvenile geoducks to their commercial-scale harvest, will be monitored.

Initially, researchers conducted extensive sampling exercises and pilot studies to refine sampling techniques and data collection. Pilot work was completed in fall 2008 and has been critical for determining sampling methods that provide optimal measures of taxonomic abundance and species diversity. In addition, infaunal invertebrate samples from selected locations were analyzed and data have been used to determine requisite numbers of samples to detect patterns and trends with the desired level of resolution.

Subsequent research has primarily focused on communities of infauna and epifauna at planting and harvest sites, as well as fish, crabs and other mobile invertebrate predators that visit planting sites during high tides. Communities were sampled using sediment cores (Figure 3) 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 (Figure 4). All research sites were visited and sampled extensively between May 2008 and August 2009 (Table 1).

Figure 3. *A research assistant collects a sediment sample in a plot of mature geoducks at the Manke site on Hartstene Island, WA*

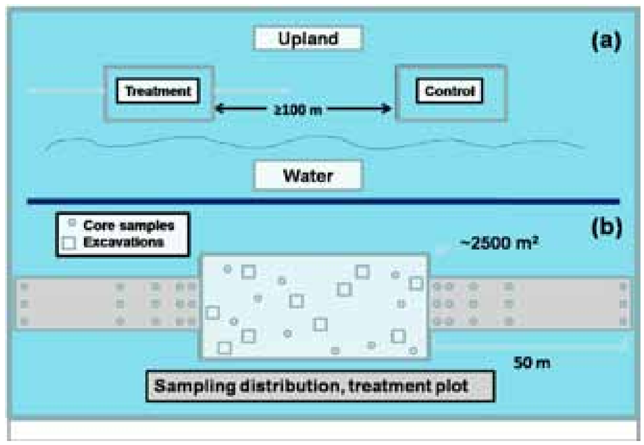

Figure 4. *Schematic diagram showing (a) site design and (b) the two categories of samples collected at each site: randomly distributed, within-plot samples and linear arrays that begin at the edge of a cultured plot and extend away from the plot parallel to the shoreline.*

Table 1. Summary of samples collected and processed through September 30, 2009.

Site	Type	# Collection Trips	# Samples Collected	# Samples Processed
Infaunal samples				
Chelsea/Wang	Harvest	6	300	91
Fisher	Planting	7	350	13
Foss/Joemma	Harvest	13	720	612
Manke	Harvest	8	440	101
Rogers	Planting	10	640	165
Stratford	Planting	5	175	0
Epifaunal samples				
Chelsea/Wang	Harvest	5	100	0
Fisher	Planting	6	120	0
Foss/Joemma	Harvest	9	180	40
Manke	Harvest	6	120	0
Rogers	Planting	8	160	122
Stratford	Planting	5	100	19
Photo quadrats				
Chelsea/Wang	Harvest	4	80	40
Fisher	Planting	6	100	100
Foss/Joemma	Harvest	8	150	140
Manke	Harvest	5	100	0
Rogers	Planting	8	160	160
Stratford	Planting	4	80	80

Mobile organisms were surveyed using three techniques. Shore-based observations monitor fine-scale use of shallow nearshore areas by juvenile salmonids. Surface-based snorkel surveys investigate the effects of predator exclusion structures on the shallow-water distributions of salmon. Diver surveys are conducted for bottom-dwelling fishes and small benthic invertebrates (Figure 5). To date, monthly surveys have been conducted at the three planted sites from April to September 2009, during weeks with neap tides. Surveys were conducted at planted and unplanted sites and, whenever possible, surveys were conducted prior to planting to obtain baseline data.

As an addition to the planned research, a pilot study was conducted to compare feeding behavior of a key mobile predator, the Pacific staghorn sculpin, in areas with aquaculture structures (PVC tubes and cover nets) to behavior at paired, unstructured reference sites.

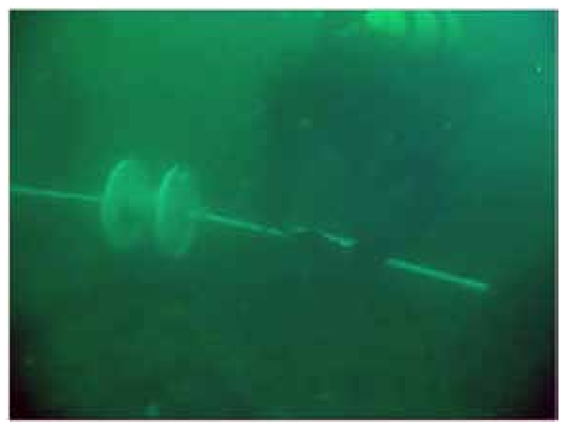

Figure 5. *Divers use a metric underwater transect tool (MUTT) to conduct surveys of fish and macroinvertebrates.*

Geochemical effects. This component of the research is designed to quantify the extent that 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 Thorndyke Bay, Foss-Joemma and Wang sites. 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 and incubated under laboratory-controlled conditions. Samples were collected four times at three-hour intervals and incubated and analyzed for concentrations of oxygen, nitrogen, silicate and soluble reactive phosphorus.

As an addition to original project scope, researchers took advantage of a benthic ecosystem tunnel (BEST) experimental set-up, installed at the Thorndyke Bay site by an independent research team. The BEST was installed over a dense population of eight-year-old geoducks in the extreme low intertidal zone, with the tunnel axis oriented parallel to tidal flow; water flushed through the tunnel was due solely to the action of tidal currents. The experimental design allowed measurement of nutrient exchange between the sediment and overlying water over a large area, with geoducks in place. Water was sampled at the entrance and exit ends of the tunnel over a period of three days to assess changes in concentrations of key nutrients (nitrogen, phosphorus, silicate), particulate matter and phytoplankton (Figure 6).

Figure 6. *BEST experimental set-up and sampling activities. Panel A: tunnel at low tide; Panels B and C: collecting cores for sediment-water exchange and benthic infauna; Panel D: measuring sizes of harvested geoducks.*

Project status

Ecological effects. To date, one of the harvest sites (Foss/Joemma) has been thoroughly sampled and processed. Work at the other sites is ongoing (Table 1). Preliminary observations of infauna at the Foss/Joemma site suggest interesting patterns in species richness and abundance across months coincident with harvest disturbance; there were observed declines in some abundant worms and small crustaceans within the harvest zone and adjacent areas immediately following the harvest of geoducks. There is evidence of recovery of these populations within six months. However, these patterns cannot be interpreted until sampling at all of the harvest sites is completed.

Preliminary analyses of snorkel data have not indicated differences in use of farmed and unfarmed habitats by salmon. However, these data are presently limited by low sample sizes. Early analyses of diver-collected data suggest a more pronounced seasonal response of large mobile invertebrates found within planted areas relative to reference beaches and increased use of planted areas by kelp crabs and red rock crab. Graceful crab, Pacific staghorn sculpin and speckled sanddab appear 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 but may displace other species. Additional data are necessary to distinguish the effect of geoduck aquaculture from seasonal patterns.

Geochemical effects. The results of research on geochemical effects will be completed in early 2010 and published in a peer-reviewed journal article in late 2010. Among the initial findings:

Pore Water Chemistry – Sediment biogeochemistry indicates the slow movement of water through sediments and little exchange of pore water associated with tidal rise and fall. Pore water results were consistent in 2008 and 2009, and most concentrations of key nutrients, nitrogen, sulphur, phosphorus and iron were relatively low.

Harvesting Water Efflux – Mean ammonium concentrations in water flowing from the active harvest sites were relatively low. Data also suggest that total releases of nitrogen are low and not ecologically significant.

Sediment-Water Exchange – Overall, metabolic activity in darkness was higher in areas populated by geoducks than in adjacent unfarmed areas. Denitrification rates were generally low. Under light conditions, nutrient and oxygen exchanges were consistent with the growth and photosynthetic activities of benthic algae. Changes in silicon release under illumination suggest that diatoms are an important part of the phytoplankton community.

BEST Studies – Nutrient and phytoplankton concentrations in and out of the tunnel were low, but complete analysis of physical flow data and continuous oxygen records are required to convert these concentrations to rates. Cores from the BEST and from unfarmed locations showed similar results. Additional analysis is required to determine the balance of material consumed by geoducks and release of nutrients into the water column.

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 the first two years of this five-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. Animals were collected during summer and winter to facilitate detection of both warmwater and coldwater infectious organisms.

Figure 7. Map showing location of wild geoduck sampling locations.

Approach

For this project, three sites reflecting the geographic range of geoduck aquaculture in Washington were selected (Figure 7, Table 2). Samples from each site were taken in summer and winter 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 and Lower Elwha Klallam Tribe.

All samples have been processed, slide-mounted and stained. Slides have been screened, but full analysis will not occur until late 2009 and early 2010.

Table 2. *Sampling dates, locations in Puget Sound and numbers of animals collected.*

Date	Location	Number of geoducks collected
July 30 2008	Totten Inlet	64
July 31 2008	Thorndyke Bay	55
August 7 2008	Freshwater Bay	60
February 5 and 24, 2009	Freshwater Bay	62
February 23, 2009	Totten Inlet	60
February 23 and 26, 2009	Thorndyke Bay	53

Project Status

All geoducks were examined for gross abnormalities. For Totten Inlet, one geoduck was recorded with a pustule and one with a discolored mantle; for Freshwater Bay and Thorndyke Bay no abnormalities were noted. Preliminary analysis of the slide-mounted samples revealed the presence of a microsporidian-like parasite previously unknown in geoducks (Figure 8). The parasite was observed in 30 percent of geoducks from Totten Inlet, although infection intensity was very low, and there was no evidence of parasite infections in Thordyke Bay or Freshwater Bay geoducks. The biology of this parasite is poorly understood. Although microsporidia have been reported in oysters, mussels and cockles from Europe, Australasia, California and the eastern United States, no molluscan microsporidia have been reported from Canada or Puget Sound. 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, but high-intensity infections could impact reproductive capacity.

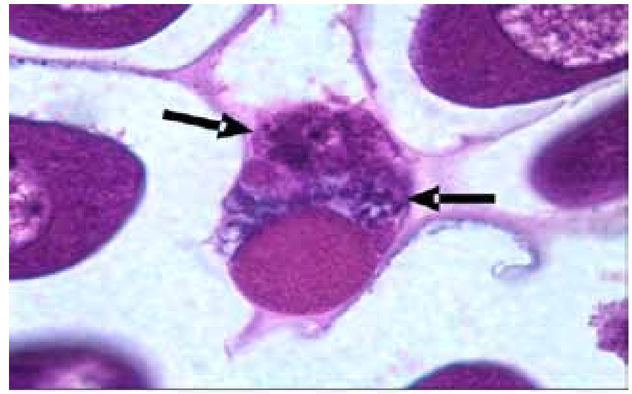

Figure 8. *Microsporidian-like parasites (arrows) in a geoduck egg.*

Several other parasites or diseases were observed in preliminary screening, including a possible fungus associated with dark discoloration on the siphon and exposed mantle surface and the single-celled parasite, *coccidia*, in the gills and digestive gland. Mantle discoloration and the presence of an external layer of material composed of debris, bacteria and phytoplankton have been noted in about 12 percent of screened geoducks from Totten Inlet, about 29 percent from Thorndyke Bay and about 40 percent from Freshwater Bay.

Full analysis to determine the suite of microscopic organisms associated with geoducks and to quantify the extent and severity of disease prevalence 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 at an adjacent unfarmed (control) site. The location and characteristics of the two sites are provided in Table 3. To determine the response of the local marine habitat to geoduck aquaculture practices, surveys were timed to coincide with geoduck harvest, PVC tube installation, reseeding and net installation, and net replacement (Figure 9). To date, five surveys have been completed. During each survey, each site was sampled using randomly positioned quadrats. Samples in the unfarmed plot were sampled at set distances from the harvest boundary to determine the spatial extent of the habitat response to aquaculture practices (Figure 10). 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 analysis of eelgrass and sediment samples has 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.

Table 3. *Location and characteristics of "Farmed" and "Control" study sites*

Site Name	Location	Site Description
Fisk Bar (Farmed)	Samish Bay, WA 48º36' N, 122º26' W	Taylor Shellfish geoduck farm, 145 m x 40 m, adjacent to a channel and colonized by eelgrass between summers of 2002 and 2008. Where eelgrass occurs, shoot densities average ~360/m^2 in summer.
Fisk Car (Control)	Samish Bay, WA 48º36' N, 122º26' W	Extensive low-intertidal eelgrass meadow, with shoot densities ~400/m^2 in summer

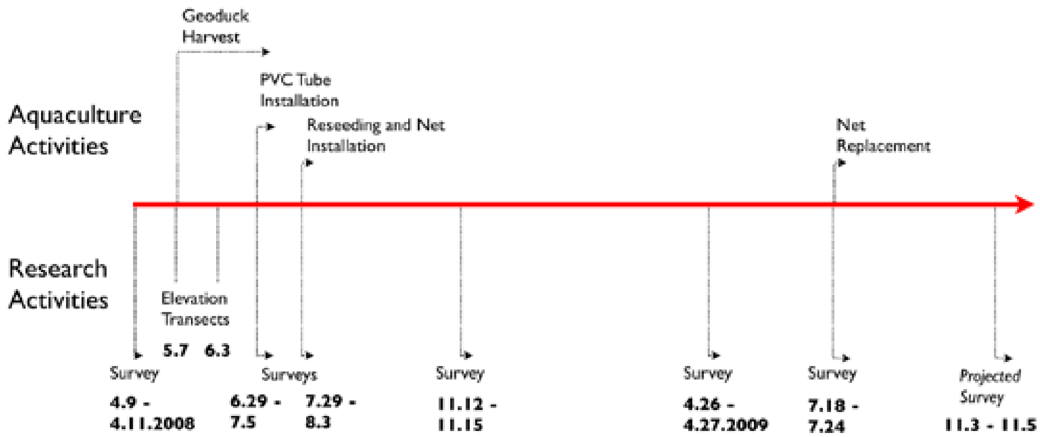

Figure 9. *Timeline of aquaculture and research activities at Fisk Bar from Apr. 9, 2008, to Nov. 5, 2009.*

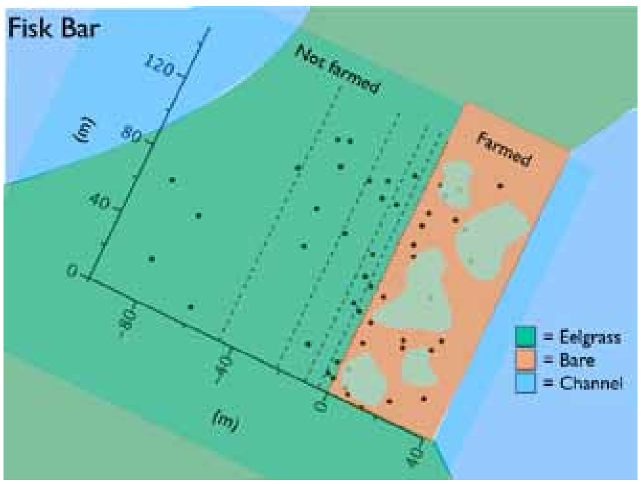

Figure 10: *Fisk Bar, Samish Bay, WA. Schematic representing a birds-eye view of Fisk Bar on 4/9/2008, showing adjacent control and impact plots. Points represent the placement of quadrats. The dotted line represents the harvest boundary and dashed lines demarcate areas of the control plot that were sampled equally through the stratified random design of quadrat placement to determine the spatial extent of habitat response to aquaculture practices.*

Project Status

The initial, pre-harvest survey found no significant differences in parameters between the farmed and control plots of Fisk Bar. After geoduck harvest, a range of effects on ecologically relevant aspects of Fisk Bar was detected. Within the harvest plot, eelgrass exhibited an immediate and significant reduction in shoot density, rate of flowering and size of aboveground structures, and a delayed and significant reduction in belowground branching activity. One year later, eelgrass within the harvest plot had declined, attributable to light limitation caused by the recruitment and growth of a thick mat of ulvoid algae on the predator exclusion nets. After harvest, the farmed plot had a significantly lower sediment organic content than the control plot on every sampled date. The farmed plot also demonstrated a significant post-harvest loss of elevation that was not evident in later surveys, suggesting a quick recovery. During the most recent survey, a "spillover effect" was detected in the control plot, with a measured decrease in size, density and biomass of plants closest to the harvest site boundary. The next two surveys will reveal whether this pattern of spillover is persistent.

Within the impact plot, for almost every measured parameter, results show that geoduck harvest activities produced effects on the biological and physical characteristics of Fisk Bar. 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, and the spillover effects of geoduck farming may emerge only after one year into the aquaculture cycle. The determination of rates and patterns of recovery may constitute the central contribution of this project to the planning and permitting needs of the state. Aspects of this determination are provided by these initial results, but further work is needed to establish the longer-term outcomes of geoduck aquaculture for infauna and eelgrass within and outside farmed areas.

Appendix

Program-Related Media, Publications and Presentations

Media

"Clam Wars", Deborah Wang, KUOW Puget Sound Public Radio News, Sept. 25, 2008.

"Skirmish continues over shellfish farming in Puget Sound", Michelle Ma. *The Seattle Times*, Seattle, Washington, Mar. 7, 2009.

"University of Washington Researchers Say Geoduck Funding in Jeopardy", Deborah Wang, KUOW Puget Sound Public Radio News, Apr. 15, 2009.

Publications

Welch, C. 2009. Geoducks: Happy as Clams. Smithsonian, March, 2009. – *Refers to disease research.*

Vadopalas, B, Pietsch, T.W., and C.S. Friedman, *in press*. The proper name for the geoduck: resurrection of P*anopea generosa* Gould, 1850, from the synonymy of *Panopea abrupta* (Conrad, 1849) (Bivalvia: Myoida: Hiatellidae). *Malacologia – Samples collected by Friedman and others contributed to a separate effort to correct the scientific name for the geoduck clam.*

Presentations

1. VanBlaricom et al.

P. Sean McDonald. *Effects of geoduck aquaculture on ecosystem structure and function: a progress report*. Presentation to the National Shellfisheries - Pacific Coast Section / Pacific Coast Shellfish Growers Association Annual Meeting, Chelan, Washington, Oct. 3, 2008.

Glenn VanBlaricom. Guest class lecture for class, Ocean 506: Writing about science and technology for general audiences, University of Washington, Seattle, Washington, Oct. 8, 2008.

Glenn VanBlaricom. *Geoduck clam aquaculture on the intertidal habitats of southern Puget Sound: Assessment of ecological impacts and mitigation of regional-scale cultural conflict*. Presentation to the Water Center Seminar Series, University of Washington. Seattle, Washington, Oct. 28, 2008.

Glenn VanBlaricom. *Ecological effects of geoduck aquaculture: The battle of southern Puget Sound*. Presentation to a Workshop entitled "Communicating Ocean and Marine Science". Centers for Ocean Sciences Education Excellence. University of Washington, Seattle, Washington, Nov. 22, 2008.

Glenn VanBlaricom. *Geoduck aquaculture investigations in Puget Sound: Digging deep for answers*. Presentation to the Sound Science Seminar Series, Washington Sea Grant. Union, Washington, Feb 26, 2009.

Glenn VanBlaricom. *Planting and harvest as disturbances in geoduck aquaculture: An overview and preliminary observations*. Presentation to the 17th Conference for Shellfish Growers, Washington Sea Grant. Union, Washington, Mar 3, 2009.

Glenn VanBlaricom. *Another resource collision? Projecting interactions of sea otters with geoduck clam populations and fisheries in Washington and British Columbia.* Presentation to Sea Otter Conservation Workshop VI. Seattle Aquarium, Seattle, Washington, Mar. 21, 2009.

Rachel Smith. *Examining the effects of predator exclusion structures associated with geoduck aquaculture on mobile benthic macrofauna in South Puget Sound, Washington*. Presentation to the 101st Annual meeting of the National Shellfisheries Association. Savannah, Georgia, Mar 24, 2009.

Glenn VanBlaricom. Planting and harvest as disturbances in geoduck aquaculture: An overview and preliminary observations. Presentation in the State Capitol Fish & Wildlife Seminar Series, Washington Department of Fish and Wildlife, Olympia, Washington, Jun. 9, 2009.

Kristin Larson. *Trophic implications of structure additions associated with intertidal geoduck aquaculture*. Presentation to the National Shellfisheries - Pacific Coast Section / Pacific Coast Shellfish Growers Association Annual Meeting, Portland, Oregon, Sept. 30, 2009.

Jenny Price. *Disturbance and recovery of a benthic community in response to geoduck aquaculture harvest.* Presentation to the National Shellfisheries - Pacific Coast Section / Pacific Coast Shellfish Growers Association Annual Meeting, Portland, Oregon, Sept. 30, 2009.

Glenn VanBlaricom. *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 National Shellfisheries - Pacific Coast Section / Pacific Coast Shellfish Growers Association Annual Meeting, Portland, Oregon, Sept. 30, 2009.

Aaron Galloway. *Effects of geoduck aquaculture planting practices on fish and macroinvertebrate communities in southern Puget Sound, WA*. Presentation to the National Shellfisheries - Pacific Coast Section / Pacific Coast Shellfish Growers Association Annual Meeting, Portland, Oregon, Sept. 30, 2009.

2. Freidman et al.

Santa Cruz, A, Vadopalas, B and Friedman CS. *Endosymbiotic, commensal, and parasitic organisms associated with wild geoduck clams* (Panopea abrupta). Presentation to the Pacific Coast Shellfish Growers Association joint conference with the Pacific Coast Section of the National Shellfisheries Association in Chelan, WA. Oct. 3, 2008.

Friedman, C.S., Santacruz, A. and B. Vadopalas. *Endosymbiotic, commensal, and parasitic organisms associated with wild geoduck clams*. Presentation to the 17th Conference for Shellfish Growers, Washington Sea Grant Program, Alderbrook Resort, Union, Washington. March 2-3, 2009.

3. Ruesink and Horwith

Micah Horwith. Presentation to the Annual Meeting of the Western Society of Naturalists, Vancouver, BC. Nov. 8, 2008.

Micah Horwith. Presentation at the Annual Graduate Student Symposium for the Department of Biology at the University of Washington. Dec. 6, 2008.

Micah Horwith. Presentation to the Sound Science Seminar Series, Washington Sea Grant. Union, Washington, Feb 26, 2009.

Micah Horwith. Presentation to the 17th Shellfish Growers' Conference, convened by Washington Sea Grant in cooperation with the Western Regional Aquaculture Center and the Pacific Coast Section of the National Shellfisheries Association, Union, WA. Mar. 3, 2009.

Micah Horwith. Presentation to the Aquatic Resources Program of the Washington State Department of Natural Resources. May 5, 2009.

Micah Horwith. Presentation to the Annual Meeting of the Ecological Society of America, Albuquerque, NM. Aug. 3, 2009.

Micah Horwith. Presentation to the Annual Meeting of the Pacific Coast Shellfish Growers Association, Portland, OR. Sept. 3, 2009.