Update Report

Period: 2/1/2014 - 1/31/2015

Project: R/SFA-5 - *An ecosystem modeling approach to investigate direct and indirect effects of geoduck aquaculture expansion in Washington State*

STUDENTS SUPPORTED

No Students Reported This Period

CONFERENCES / PRESENTATIONS

McDonald PS (2014) Honoring the data: A review of recent studies on ecological consequences of geoduck aquaculture in southern Puget Sound. Oral presentation at the Shellfish and the Environment Research Symposium, Lacey, WA, December 8., public/profession presentation, 300 attendees, 2014-12-08

Conference oral presentation: McDonald PS, Galloway AWE, Price JL, McPeek KC, Armstrong DA, Ryan C, VanBlaricom GR (2014) Shellfish aquaculture at the confluence of science, policy, and conflicting stakeholder interests: lessons learned from geoduck farming in the northeastern Pacific. Oral presentation at the ICES Annual Science Conference, A Coruña, Spain, September 15-19., public/profession presentation, 75 attendees, 2014-09-18

Conference oral presentation: McDonald PS, Ryan C (2014) Geoduck aquaculture in Puget Sound: next steps toward understanding social and policy dimensions. Oral presentation at the 68th Annual Shellfish Conference, Vancouver, WA, September 21-24., public/profession presentation, 200 attendees, 2014-09-21

ADDITIONAL METRICS

P-12 Students Reached:	0	**P-12 Educators Trained:**	0
Participants in Informal Education Programs:	0	**Volunteer Hours:**	0
Acres of coastal habitat protected, enhanced or restored:	0	**Resource Managers who use Ecosystem-Based Approaches to Management:**	0
Annual Clean Marina Program - certifications:	0	**HACCP - Number of people with new certifications:**	0

ECONOMIC IMPACTS

Description	Patents	Market Impact	Non-Market	Businesses Created	Businesses Retained	Jobs Created	Jobs Retained

		ts ($)	Impacts ($)				
none	0	0	0	0	0	0	0

SEA GRANT PRODUCTS

Description	Developed?	Used?	ELWD?	Number of Managers	Names of Managers
Ecopath with Ecosim food web model for central Puget Sound incorporating geoduck aquaculture	Yes	No	No	0	

HAZARD RESILIENCE IN COASTAL COMMUNITIES

Name of coastal community	County	Number of resiliency trainings / technical assistance services *provided*	Was community hazard resiliency improved (e.g., via changes in zoning ordinances) ?
		0	Yes

ADDITIONAL MEASURES

Number of stakeholders modifying practices: 0

Sustainable Coastal Development

# of coastal communities: 0

PARTNERS

Partner Name: Department of Ecology
Partner Name: Department of Natural Resources, type: Government, scale: State
Partner Name: NOAA Fisheries
Partner Name: Pacific Shellfish Institute
Partner Name: Point No Point Treaty Council

Partner Name: Shellfish Interagency Permitting Team, type: Other, scale: Regional

Partner Name: Taylor Shellfish Farms

IMPACTS AND ACCOMPLISHMENTS

Title: **Washington Sea Grant ecosystem modeling provides insight into the effects of geoduck aquaculture on the Puget Sound food web**
Type: impact
Relevance, Response, Results:
Relevance: From 2007 to 2013 Washington Sea Grant conducted a comprehensive state-funded study of the effects of geoduck aquaculture on the Puget Sound environment. This research provided the first scientific assessment of the ecosystem impacts of geoduck culture practices from planting through harvest. While the study substantially increased understanding, some stakeholders continued to express concern about broader ecosystem effects, particularly on iconic Northwest wildlife such as salmon, bald eagles, seabirds, and marine mammals.
Response: Partnering with the Northwest Fisheries Science Center, Washington Sea Grant-funded researchers investigated the effects of expanding intertidal geoduck culture on the Central Puget Sound ecosystem. They incorporated key predator–prey relationships quantified in previous research into a robust food-web model. Together with an inclusive working group of stakeholders, they identified management scenarios to submit to the model.
Results: Preliminary results suggest that culture practices that modify shoreline habitat can have consequences that are most pronounced at farm sites but ripple throughout the food web, and which may affect more mobile species such as eagles, herons, and shorebirds. Results also indicate that bottomfish, small crustaceans, and flatfish may be useful as indicator species. The model provides new information about the potential impacts of expanding geoduck aquaculture in Puget Sound and will help managers plan for future conditions.
Recap:
Recap: A Washington Sea Grant-supported ecosystem model examines the effects of continued and expanding geoduck aquaculture on the Puget Sound food web, with preliminary results suggesting some unexpected indirect implications for finfish, birds, and mammals.
Comments:
Primary Focus Area: SFA
Secondary Focus Areas: RCE, HCE
Associated Goals: Aquaculture operations and shellfish harvests are safe, environmentally sustainable and support economically prosperous businesses. (SFA)
Coastal communities engage in comprehensive planning and sustainable development. (RCE)
Ocean and coastal resources are managed using ecosystem-based approaches. (HCE)
Partners:
NOAA Northwest Fisheries Science Center

Pacific Shellfish Institute
Point No Point Treaty Council
Shellfish Interagency Permitting Team
Taylor Shellfish Farms
Washington State Department of Ecology
Washington State Department of Natural Resources
Related Partners: *none*

PUBLICATIONS

No Publications Reported This Period

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

No Leveraged Funds Reported This Period

UPDATE NARRATIVE

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WASHINGTON SEA GRANT PROGRESS REPORT

for the period 2/1/2014 - 1/31/2015

Project Title: R/SFA-5 - *An ecosystem modeling approach to investigate direct and indirect effects of geoduck aquaculture expansion in Washington State*

Principal Investigator(s) and Affiliation:

Glenn R. VanBlaricom School of Aquatic & Fishery Sciences, University of Washington

1. PROJECT OBJECTIVES (from original proposal)

We will synthesize five years of data collected at geoduck aquaculture sites and reference beaches to guide model simulations (see below). Our objectives are as follows: (1) to evaluate direct and indirect ecosystem effects in scenarios involving future increases in the extent of geoduck aquaculture; (2) to identify appropriate indicator species that reflect the broader status of ecosystem health in response to geoduck aquaculture expansion; (3) to determine gaps in data to guide future research; and 4) to provide a tool for managers to aid in screening policy options.

2. PROJECT PROGRESS

We have integrated empirical field data from studies carried out as part of the Sea Grant-sponsored Geoduck Aquaculture Research Program (McDonald et al. 2015, McPeek et al. 2014, VanBlaricom et al. 2015) into a food web model of central Puget Sound developed in the Ecopath with Ecosim (EwE) software by Harvey et al. (2010, 2012b). EwE simulates production, mortality, predator-prey interactions, habitat effects, and fishery effects in aquatic food webs (Christensen and Walters 2004).

Once the initial food web model had achieved mass balance (in the static Ecopath module of the program), we perturbed the system in the dynamic Ecosim module. Perturbations are simulations of changes in environmental conditions or human activities. Because functional groups are linked by predator-prey relationships, a perturbation in one group will ripple throughout the entire food web. The magnitudes of ripples depend on the strength of direct and indirect interactions, as determined in large part by the core parameters listed above.

In a management context, system perturbations allow the user to conduct experiments in which different policies can be applied; the outcomes of multiple model runs can then be compared to determine which policies best achieve desired goals and objectives, as well as the tradeoffs involved. For example, one scenario may result in increased yield in a fishery but also lead to reduction in some other

ecosystem service, such as the capacity for a species of concern to recover. This capability for strategy comparisons and tradeoff analysis is why ecosystem models like EwE are often employed as part of management strategy evaluation (Sainsbury et al. 2000) and integrated ecosystem management (Levin et al. 2009).

The original EwE model developed by Harvey et al (2010a, 2012b) has been modified in the following ways:

- We added a new geoduck group representing "cultured geoducks" whose biomass, harvest rates, and spatial distribution are based on aquaculture practices. Thus, the simulated interactions and management activities are focused on cultured geoducks, rather than on the diffuse population of wild geoducks that occur at a much broader range of depths and experience quite different management practices.
- We integrated the findings from field studies conducted by McDonald et al. (2015), McPeek et al. (2014), and VanBlaricom et al (2015). These data provide direct and indirect links between cultured geoducks (or geoduck aquaculture activity) and other functional groups in the nearshore community. Linkages include: direct consumption of phytoplankton by cultured geoducks; transition of available habitat from soft sediment tideflats to farmed plots; and shifts in diet due to "mediation functions" in Ecosim, as described by Espinosa-Romero et al. (2011). In essence, the biomass of a mediating group—here, cultured geoducks—indirectly facilitates or constrains ecological processes of other biota, in a manner consistent with the empirical data.

We integrated cultured geoducks into the model and conducted two series of model runs. First, we tested the sensitivity of the model to parameter inputs, so that we could include estimates of uncertainty in subsequent scenario exercises (Fig. 1). Second, we built scenarios that address potential geoduck aquaculture futures in central Puget Sound, based on discussions with stakeholder groups such as shellfish growers and managers (Table 1).

Once completed, our modeling work will contribute results as bases for making informed decisions and allow managers to move beyond the delicate matter of responding to public demands based solely on postulated aesthetic values and anticipated ecological effects. Previous funding by Washington State Legislature, DNR, and ECY, and our current NOAA NMAI grant has allowed us to establish study sites, foster working relationships with state regulatory agencies, tribal organizations, and private companies involved in geoduck aquaculture activities, and develop an infrastructure and data set necessary to evaluate ecological impacts of aquaculture activity. While completed work has focused on characterizing communities and trophic dynamics directly associated with geoduck operations (McDonald et al. 2105, McPeek et al. 2014, VanBlaricom et al. 2015), this project greatly expands our understanding of ecosystem responses in the region and provides a useful framework to evaluate policy options.

The present work also coordinates with other shellfish aquaculture research programs. Collaborator Dr. Dan Cheney of Pacific Shellfish Institute (PSI) has received a 2012 NMAI award to address ecological carrying capacity of South Puget Sound, in part, using

a similar modeling approach (*Planning for sustainable shellfish aquaculture in complex multiple use environments: Determining social and ecological carrying capacity for south Puget Sound, Washington*); that project is both regionally specific (i.e., focused on Mason, Pierce, and Thurston Counties) and generalized (i.e., lacks specific data for geoduck aquaculture). We are coordinating analyses among projects to provide opportunities to extend the applicability of our results by comparing and contrasting model architecture and parameters, as well as extending the spatial extent of the modeled area to other counties where geoduck aquaculture is occurring.

Our findings when complete will facilitate a more holistic view of the impacts of geoduck aquaculture and policy decisions regarding future expansion. This work contributes to Sea Grant's National Strategic Plan Focus Area of Safe and Sustainable Seafood Supply by supporting aquaculture with acceptable environmental impacts. Moreover, the work addresses goals of the Puget Sound Partnership's (PSP) Puget Sound Action Agenda (A.4.4.1 Implement best management practices for shellfish production; continue the work of the SARC and implement its recommendations). Building on previous efforts, including work funded by Washington Sea Grant and NOAA National marine Aquaculture Initiative, we have identified and engaged target audiences for outreach. To date, we have had one meeting of our model advisory group to develop initial model scenarios. We anticipate 1-2 additional meetings of the advisory group, which will focus on discussion of initial model results and reassessment of additional model scenarios to explore; and disseminating the results of the management strategy evaluation and developing recommendations for agency partners, including ECY and DNR.

References:

Christensen V., and C.J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172:109-139.

Espinosa-Romero M.J., E.J. Gregr, C. Walters, V. Christensen, and K.M.A. Chan. 2011. Representing mediating effects and species reintroductions in Ecopath with Ecosim. Ecological Modelling 222:1569-1579.

Harvey C.J., K.K. Bartz, J.R. Davies, T.B. Francis, T.P. Good, A.D. Guerry, M.B. Hanson, K.K Holsman, J. Miller, M. Plummer, J.C.P. Reum, L.D. Rhodes, C.A. Rice, J.F. Samhouri, G.D. Williams, N.J. Yoder, P.S. Levin, and M.H. Ruckelshaus. 2010. A mass-balance model for evaluating food web structure and community-scale indicators in the central basin of Puget Sound. NOAA Tech. Memo. NMFS-NWFSC-106.

Harvey C.J., T.P. Good, and S.F. Pearson. 2012a. Top-down influence of resident and overwintering bald eagles (*Haliaeetus leucocephalus*) in a model marine ecosystem. Canadian Journal of Zoology 90: 903-914.

Harvey C.J., G.D. Williams, and P.S. Levin. 2012b. Food web structure and trophic control in central Puget Sound. Estuaries and Coasts 35:821-838.

Levin P.S., M.J. Fogarty, S.A. Murawski, and D. Fluharty. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. PLoS Biology 7:23-28.

McDonald, P.S., A.W.E. Galloway, K.C. McPeek, and G.R. VanBlaricom. 2015. Effects of geoduck (*panopea generosa* Gould, 1850) aquaculture gear on resident and transient macrofauna communities of Puget Sound, Washington. Journal of Shellfish Research 34(1):189-202.

McPeek, KC, PS McDonald, and GR VanBlaricom. 2014. Aquaculture Disturbance Impacts the Diet but not Ecological Linkages of a Ubiquitous Predatory Fish. Estuaries and Coasts 10.1007/s12237-014-9909-z

Sainsbury K.J., A.E. Punt, and A.D.M. Smith. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science 57:731-741.

VanBlaricom, GR, J Price, J Olden, and PS McDonald. 2015. Ecological effects of the harvest phase of geoduck clam (*Panopea generosa* Gould, 1850) 1 aquaculture on infaunal communities in southern Puget Sound, Washington USA. Journal of Shellfish Research 34(1):171-187.

Table 1. Changes in biomass of functional groups due to increases in cultured geoduck biomass and landings (from 70% to 120%). Bold values represent biomass changes greater than 10% and gray highlight represents biomass changes greater than 20%. Biomass values are estimated in Ecosim, running the time series for each geoduck stanza and landings over 50 years.

		Increase in Cultured Geoduck Biomass and Landings					
Functional Group	**Start Biomass ($t \cdot km^{-2}$)**	**70%**	**80%**	**90%**	**100%**	**110%**	**120%**
Birds							
Resident birds	0.011	-9.9%	**-11.3%**	**-12.8%**	**-14.2%**	**-15.6%**	**-16.9%**
Great blue herons	0.003	**-11.8%**	**-13.5%**	**-15.2%**	**-16.8%**	**-18.5%**	**-20.1%**
Resident eagles	0.001	-9.3%	**-10.8%**	**-12.2%**	**-13.5%**	**-14.9%**	**-16.2%**
Migratory eagles	0.002	-8.8%	**-10.3%**	**-11.8%**	**-13.2%**	**-14.7%**	**-16.1%**
Pelagic fish							
S/a wild salmon	16.367	-5.5%	-6.4%	-7.3%	-8.3%	-9.2%	**-10.1%**
Surf perch	3.490	**18.3%**	**20.2%**	**22.0%**	**23.7%**	**25.2%**	**26.7%**
Demersal fish							
Walleye pollock	3.237	-5.8%	-6.9%	-7.9%	-8.9%	-9.9%	**-10.9%**
Pisc flatfish	1.155	-7.9%	-9.0%	**-10.1%**	**-11.3%**	**-12.4%**	**-13.5%**
Small mouth flatfish	7.962	**-18.5%**	**-20.8%**	**-23.1%**	**-25.4%**	**-27.5%**	**-29.6%**
Demersal fish	5.816	8.3%	9.0%	9.8%	**10.4%**	**11.0%**	**11.5%**
Demersal invertebrates							
Urchins	0.455	9.1%	**10.3%**	**11.4%**	**12.5%**	**13.6%**	**14.6%**
Small crustaceans	20.143	-8.1%	-9.6%	**-11.1%**	**-12.6%**	**-14.2%**	**-15.8%**
Small crabs	15.921	**11.1%**	**12.5%**	**13.9%**	**15.2%**	**16.4%**	**17.6%**
Pred gastropods	0.988	**-26.0%**	**-29.4%**	**-32.6%**	**-35.7%**	**-38.8%**	**-41.7%**
Suspension feeders	2.526	9.3%	**10.5%**	**11.6%**	**12.7%**	**13.7%**	**14.7%**

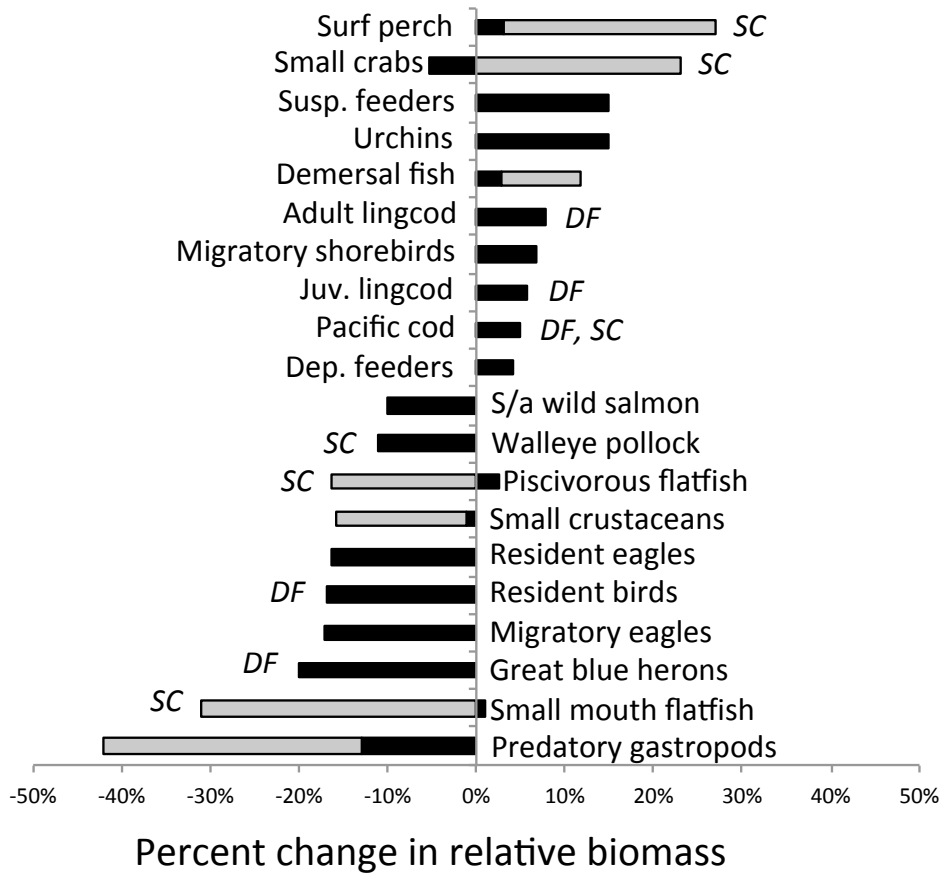

Figure 1. The functional groups whose biomasses are most affected (10 most positive and negative) due to the addition of geoduck mediation effects in the model. The changes in biomass due to indirect effects (black) and direct effects (gray) are additive (except for small crabs). A list of changes in biomass for all groups is in Table 3. Groups are assiged the label *DF* (Demersal fish) or *SC* (small crustaceans) if those are one of their top three prey (as defined by Ecosim). The biomass estimates are generated by increasing cultured geoduck biomass by 120% over 50 years. The magnitude of change in biomass estimates is relative to the biomass of cultured geoducks in the model and is less relevant than the general trends (positive or negative) and which species are most sensitive to these mediation effects.

3. ACCOMPLISHMENTS AND IMPACTS

Accomplishment Statement

Title: **Sea Grant-supported research helps elucidate direct and indirect effects of geoduck aquaculture on the food web**

Relevance: Despite increased understanding of the ecological effects of geoduck aquaculture at farm sites, some stakeholders have expressed concern about broader ecosystem effects of continued geoduck aquaculture expansion, particularly as it relates to iconic wildlife of the Pacific Northwest (e.g., salmon, bald eagles, seabirds, marine mammals).

Response: Sea Grant funding is enabling university researchers to investigate expansion of intertidal culture operations for Pacific geoduck clams (*Panopea generosa*) on the broader ecosystem of central Puget Sound. Investigators have built on results from previous Washington state-funded research by incorporating key relationships into a robust food web model. Working with stakeholders in an inclusive working group, they have identified management scenarios to test with the model.

Results: Model output indicates aquaculture practices that modify shoreline habitat can have direct consequences for plants and animals, with additional indirect effects rippling through the food web. Whereas impacts will be most dramatic at farm sites, more mobile species like eagles, herons, and shorebirds may be affected. The work also demonstrates the value of demersal fish, small crustaceans, and flatfish as possible indicator species. These results are providing new information as to the potential impacts of expanding geoduck aquaculture in the Puget Sound region, and will help managers plan for future conditions.

Recap: Washington Sea Grant-supported researchers are using an ecosystem model to examine the broad effects of continued and expanding geoduck aquaculture operations on the Puget Sound food web, with preliminary results suggesting unexpected indirect consequences with implications for finfish, birds and mammals.

Impact Statement

Not applicable. Results are preliminary and have not yet yielded significant economic, societal, and/or environmental benefits.