REPORT TO THE WASHINGTON STATE LEGISLATURE

Interim Progress Report (July 1, 2013 – November 30, 2014)

Ecology and Economics of Shellfish Aquaculture in Washington State

December 1, 2014

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Interim Progress Report

This report is available on the Washington Sea Grant website at wsg.washington.edu/shellfishresearchreport

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I SUMMARY

At the direction of the Washington State Legislature, Washington Sea Grant at the University of Washington (UW) initiated a shellfish aquaculture research program in 2013. The purpose of the program is to assess possible negative and positive effects, including cumulative and economic impacts, of evolving Washington shellfish aquaculture practices. A group of scientific experts was engaged to develop recommendations for program research components and to select team members to carry out the research.

A peer-reviewed scope of work was completed in early 2014, calling for the research team to use modeling approaches and available data to complete pilot studies for Willapa Bay and Central and South Puget Sound. Five program components are underway: spatial analysis, qualitative food web analyses, Puget Sound ecosystem and circulation models, and an economic synthesis. This interim report summarizes the progress of the program to date and provides detailed reports on research status through November 30, 2014.

II BACKGROUND

Shellfish and the Washington environment

Commercial shellfish cultivation has taken place in Washington waters for more than 160 years and evolved over time in terms of the species farmed, methods used, product markets and acreage under cultivation. Today Washington State is the nation's leading producer of farmed clams, oysters and mussels. The 2011 Washington Shellfish Initiative estimated that state shellfish growers directly and indirectly employ more than 3,200 people and provide an estimated total economic contribution of $270 million. Production includes hatcheries, nurseries, farms and processing, distributing, wholesale and retail operations. In addition to their commercial importance, shellfish are central to tribal cultures and economies and contribute to recreational opportunities and tourism.

Shellfish are an important component of marine ecosystems and environmental changes and stressors can affect aquaculture production. For example, the Washington coast is especially vulnerable to ocean acidification, a change in ocean chemistry that interferes with shell development in some marine organisms and has the potential to affect both cultured species and marine food-web dynamics. Harmful algal blooms and aquatic invasive species also continue to pose serious threats to shellfish resources and seafood product safety. Meanwhile, climate change has introduced additional variability in environmental parameters like water temperature, contributing to and interacting with other changes.

Shifts in Washington's coastal environment have been coupled with growing human populations that affect coastal water quality and put additional pressure on regional shellfish resources. About 65 percent of state residents live in coastal counties, and the Puget Sound region alone is expected to grow almost 35 percent, to five million people, by 2040. The region has lost 70 percent of its wetlands and the Puget Sound Partnership reports that installation of hardened shoreline structures currently is exceeding removals by a factor of five. Citing concerns that stormwater runoff carries millions of pounds in marine waters each year, the Partnership stresses the importance of public involvement in management. This complexity of challenges facing shellfish managers and growers has spurred interest in more comprehensive, ecosystem-based research that integrates environmental, social, economic and institutional information.

Shellfish aquaculture research program development

Housed in the UW College of the Environment, Washington Sea Grant is a federal–university partnership that conducts research, education and outreach to address Washington's coastal and marine issues and needs. In 2013, the Washington State Legislature directed Washington Sea Grant to conduct a two-year scientific research program specifically addressing state concerns related to shellfish aquaculture. The legislative language specified that the funding was provided:

> …to commission scientific research studies that examine possible negative and positive effects, including the cumulative effects and the economic contribution, of evolving shellfish aquaculture techniques and practices on Washington's economy and marine ecosystems. The research conducted for the studies is not intended to be a basis for an increase in the number of shellfish harvesting permits available and should be coordinated with any research efforts related to ocean acidification (Section 606, 3ESSB 5034).

As a first step, Washington Sea Grant convened a series of scoping sessions with researchers and faculty from the UW, Washington Ocean Acidification Center and National Oceanic and Atmospheric Administration (NOAA). Based on the recommendations of session participants, a research team was assembled to develop a scope of work for the program. Although shellfish are cultured throughout Washington State marine waters, neither the available time nor resources permitted a full state assessment. The research team therefore focused on areas of culture where some data existed and gaps and new information needs could be defined. In addition, efforts were made to maximize spatial overlap within program components. For these reasons, the proposed research concentrated on three pilot areas, the coastal estuary of Willapa Bay and Central and South Puget Sound (Figure 1). To build on completed and ongoing studies, the research team focused on program components that complemented those studies and had potential to leverage one another.

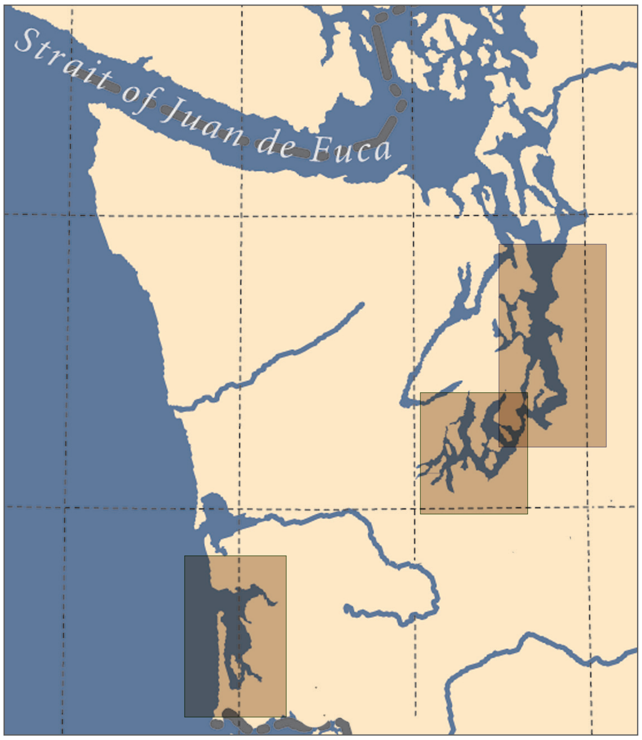

Figure 1. Study areas for shellfish research program components.

In March 2014, scientists with expertise in ecosystem function and ecology were asked to provide external peer reviews of the proposed research scope of work; the document was then revised in response to their comments and suggestions. Work on all five of the program's modeling and analysis components (Figure 2) commenced by May 2014. In August 2014, the research team held a workshop at The Evergreen State College with participants representing tribes, environmental groups, county planners, state and federal agencies, scientists, shellfish growers and legislative staff. The workshop provided a forum for the team to present the goals of the research and initial work products, and for participants to provide feedback that is informing the development of models and scenarios.

Research team members and a brief summary are provided below for each research program component:

1. Spatial planning and aquaculture data availability and needs

Dara Farrell, UW Applied Physics Lab; Jon Reum and Bridget Ferriss, Washington Sea Grant; Chris Harvey, NOAA Fisheries; P. Sean McDonald, UW Program on the Environment

Researchers are compiling and synthesizing spatially referenced information relevant to Washington shellfish aquaculture, focusing in particular on the physical extent of current practices, ecological sensitivity and other constraints.

2. Qualitative network model of shellfish aquaculture in the estuarine food webs of Willapa Bay and South Puget Sound

Jon Reum and Bridget Ferriss, Washington Sea Grant; P. Sean McDonald, UW Program on the Environment; Chris Harvey, NOAA Fisheries

The goal for this program component is to develop qualitative food web models for aquaculture–environment linkages in two study areas, Willapa Bay and South Puget Sound. Qualitative models generally require less data than quantitative models and are useful for organizing knowledge about ecosystem responses in order to identify data gaps and highlight candidate indicator species useful for monitoring ecological change.

3. A quantitative ecosystem approach to understanding the relationship between shellfish aquaculture and the Central Puget Sound food web

Bridget Ferriss and Jon Reum, Washington Sea Grant; Chris Harvey, NOAA Fisheries; P. Sean McDonald, UW Program on the Environment

Building on a tested ecosystem model for Central Puget Sound, researchers are examining the potential effects on species resulting from changes in aquaculture practices or the environment. By incorporating farm operations into the model, it can be used to evaluate management scenarios.

4. South Puget Sound ocean circulation model

Neil Banas and Wei Cheng, UW School of Oceanography

Researchers are creating a South Puget Sound ocean circulation model at a scale and resolution suitable for addressing biological, chemical and physical factors involved in shellfish aquaculture interactions with the surrounding environment. The model will also contribute to an early warning system for Puget Sound acidification developed in collaboration with the Washington Ocean Acidification Center.

5. Economic contribution of shellfish aquaculture to Washington State

Kevin Decker, Washington Sea Grant

Despite the limited quality of current economic information, this component will assess potential economic impacts of aquaculture growth, capturing direct, indirect and induced effects by evaluating jobs and labor income.

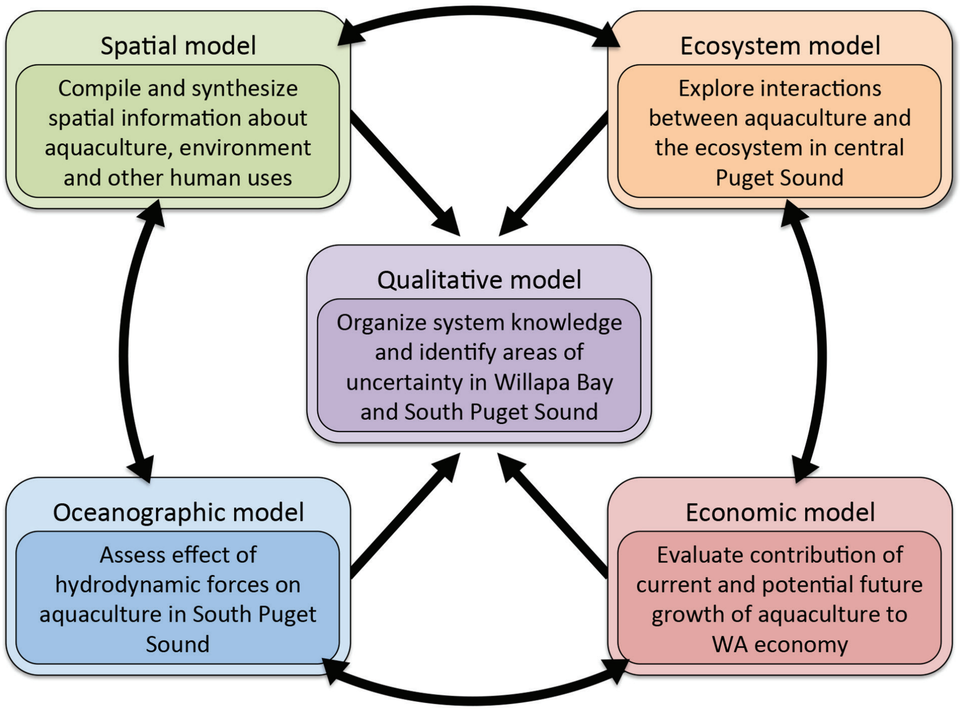

Figure 2. Conceptual diagram for shellfish aquaculture research program components. Each model is being developed individually as a tool for growers and managers and for use together to increase scientific understanding of shellfish aquaculture effects.

The current project schedule is summarized in the table below.

Table 1. Timeline and schedule for shellfish aquaculture research program.

YEAR	MONTH	PROJECT ACTIVITY
2013-14	August – January	WSG scoping sessions with experts and researchers
2014	February	Identification of core program research team
	March	Development of proposed research scope of work
	April	Peer review and revision of research scope of work
	May	Research team finalized and program components initiated
	June – July	Model conceptualization and literature review
	August	Interim review and workshop
	September – November	Model modification based on review and workshop input; continued model development
	December	Report to Legislature; continued model development
2015	January – March	Model refinement and validation
	April – June	Scenario execution, analysis and writing
	July – December	Final report review, completion and delivery to Legislature

III RESEARCH PROGRESS

1. Spatial planning and aquaculture data availability and needs

Dara Farrell, UW Applied Physics Lab; Jon Reum and Bridget Ferriss, Washington SeaGrant; Chris Harvey, NOAA Fisheries; P. Sean McDonald, UW Program on the Environment

Overview

Geographic information systems have become widely used tools in spatial planning and natural resource management. Application to aquaculture operations and management has been limited to date, but has potential to contribute to a fuller understanding of the interaction between aquaculture and the environment from local to regional scales. Spatial data are useful to: (1) minimize user conflict; (2) assess multi-scale environmental considerations for siting farms; and (3) identify and evaluate changes in areas under cultivation. This component also will highlight key data gaps based on potential spatial analyses and generate recommendations for future data acquisition and research.

Approach

Data layers were compiled initially to identify information sources that might be useful for application of spatial analysis tools to shellfish aquaculture. Through this initial collection, general data availability and needs were assessed to provide a starting point for aquaculture-relevant spatial analyses. Data were grouped into three types: (1) current spatial extent of locations certified for shellfish harvest; (2) ecological sensitivity, including critical habitat and ranges of protected or sensitive flora and fauna; and (3) other considerations such as water quality, physical constraints, and designated areas for other uses.

Project status

Researchers completed an initial overview of publicly available data resources, and identified emerging spatial tools that may be used to address specific shellfish questions. The work should complement ongoing marine spatial planning by providing an inventory of available aquaculture-related spatial data relevant to shellfish farmers, city and county planners, state and tribal managers and others. Data collection has focused primarily on two key regions, Willapa Bay and South Puget Sound, with available data classified by the types listed above (e.g., Figure 3). Collected data will be summarized with relevant metadata and access information in a format useful for future data collection and analysis. In addition, challenges in applying spatial planning to aquaculture will also be identified, generally involving data availability, accuracy and standardization.

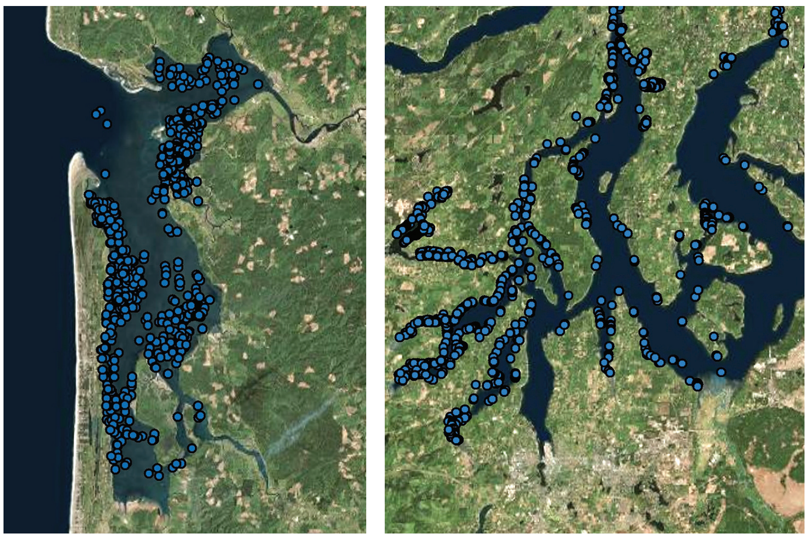

Figure. 3. Locations of shellfish beds certified for commercial harvest by the Washington Department of Health for Willapa Bay (left) and South Puget Sound (right) in 2010.

2. Qualitative network models of shellfish aquaculture in the estuarine food webs of Willapa Bay and South Puget Sound

Jon Reum and Bridget Ferriss, Washington Sea Grant; P. Sean McDonald, UW Program on the Environment; Chris Harvey, NOAA Fisheries

Overview

Complex ecosystem interactions challenge ecologists and resource managers who must identify the effects of shellfish aquaculture on estuarine food webs and the influence of environmental change on aquaculture. To address this challenge, researchers are developing qualitative food web models of aquaculture-environment linkages in Willapa Bay and South Puget Sound, two major shellfish aquaculture regions in Washington State. In contrast to quantitative food web models, which may require significant amounts of data to parameterize, qualitative network models require information only on the sign of an interaction between any pair of variables composing a system. The process of building and analyzing qualitative network models can highlight critical information gaps and help inform future research efforts.

At the same time, however, qualitative network models permit only a limited number of variables, thereby demanding conceptual clarity and an understanding of the causal connections between the source of disturbance and the ecosystem components of interest. The research team is employing qualitative models to accomplish the following:

1. develop a framework for organizing system knowledge in Willapa Bay and South Puget Sound;
2. identify uncertainty in key links within each system;
3. identify candidate species for ecological monitoring; and
4. evaluate qualitative predictions of system responses to changes in the abundance of component species including phytoplankton, cultured species and bivalve predators.

Approach

Qualitative networks correspond to conceptual models of species interactions and abiotic processes that influence system behavior. For each variable pair in the system, qualitative links (i.e., positive, negative and neutral interactions) are assigned (Figure 4). Drawing on published experiments and studies, ecological theory, and expert knowledge from farmers and regional scientists, researchers first sought to delineate the variables to include for the Willapa Bay and South Puget Sound networks.

In qualitative network analysis, all the separate pathways through the network that emanate from a variable are counted to determine the total number of feedback cycles. The effect of a feedback cycle is the sum of the qualitative links along each path. The effect of a sustained change in one variable on other components of the network can be predicted based on summations of the complementary feedback cycles for each variable. Responses in the sign direction are predicted for each variable, along with a measure of probability for the sign direction. The sign direction predicts how the abundance of a species will respond to a change in one variable and the weight of the prediction value measures the reliability of the prediction. Low-weighted prediction values result from an equal or nearly equal number of positive and negative effects contributing to a response prediction.

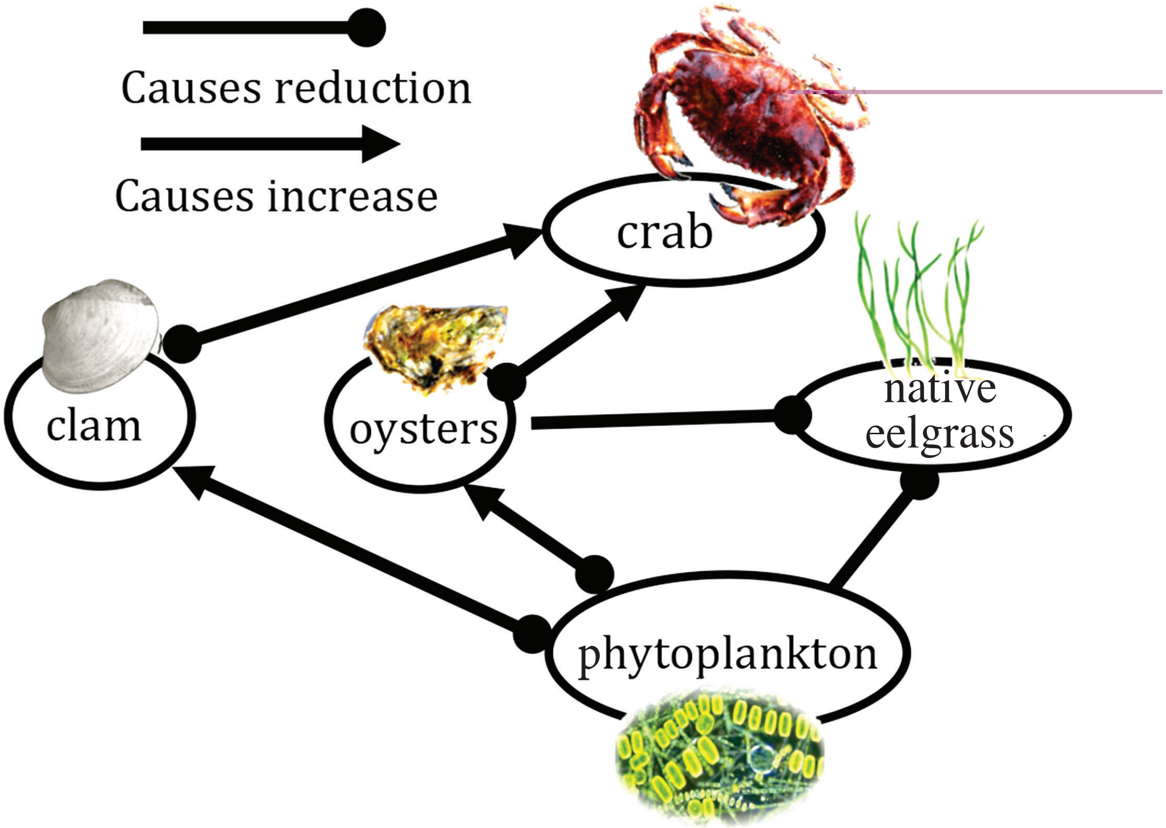

Figure 4. Example of a qualitative network model illustrating ecological interactions in an estuary with clams and oysters.

Project status

At the August 2014 workshop, research team members solicited input from participants on variables that should be incorporated into the qualitative models. In addition, the team completed a review of published literature on the ecology of shellfish aquaculture on the U.S. west coast. The researchers are currently in the initial stages of model construction and documentation. Once the model structure is finalized, they will evaluate scenarios of habitat change and predator abundance; identify uncertain linkages that have a strong impact on system behavior; compare system responses to shared scenarios between Willapa Bay and South Puget Sound models; and identify species that may be candidates for monitoring ecological change related to aquaculture.

3. A quantitative ecosystem approach to understanding the relationship between shellfish aquaculture and the Central Puget Sound food web

Bridget Ferriss and Jon Reum, Washington Sea Grant; Chris Harvey, NOAA Fisheries;
P. Sean McDonald, UW Program on the Environment

Overview

Better understanding of the relationships between shellfish aquaculture and the Puget Sound food web will inform management decisions, clarify tradeoffs in ecosystem functions and services and inform monitoring at an ecosystem scale. Quantitative ecosystem models account for direct and indirect interactions within food webs. They permit simulation of the potential magnitude of change in a species' biomass resulting from changes in aquaculture practices or environmental change. The approach also allows identification of data gaps related to species biomass, diet and life history characteristics that are relevant to the relationship between aquaculture and the surrounding food web.

The Puget Sound Central Basin (PSCB) has relatively little shellfish aquaculture. While the urban, eastern shoreline of the basin is unsuitable for shellfish harvest due to pollution and habitat modifications, the western shoreline is less developed and may be suitable for further expansion of shellfish aquaculture. This region provides a baseline system within which to identify indicators of food web health, and analyze the ecological impacts of shellfish aquaculture under various aquaculture growth scenarios.

This quantitative ecosystem modeling component will be used to accomplish the following:

1. identify key sets of species that may strongly influence shellfish productivity;
2. develop scenarios of environmental change and assess impacts on aquaculture; and
3. evaluate potential ecosystem-level indicators that are sensitive to aquaculture development.

Approach

Researchers modified an existing dynamic, mass balanced food web model of the PSCB developed within the Ecopath with Ecosim (EwE) modeling framework to accommodate aquaculture-related questions. The EwE model is well-documented, used widely and operates by modeling the flow of energy between predators and prey (Figure 5). Specifically, the model was expanded to include multiple nearshore species groups, such as cultured geoduck and Pacific oyster, migratory shorebirds, great blue herons, other bivalves, red rock crabs and small-bodied species of crab. It was also updated to incorporate information on shifts in distribution of nearshore species resulting from the presence of anti-predator structures on geoduck farms. Finally, researchers integrated intertidal habitat data into the model to determine spatially explicit ecosystem impacts of aquaculture. They developed model scenarios based on previously established research priorities and new information gathered during the August 2014 workshop (Figure 5).

Project status

The EwE model has been fully modified to address the questions in this study. Researchers incorporated the nearshore and cultured species groups, the interaction of farm structure on species' distributions, and the habitat data. They are currently validating the spatial component of the model.

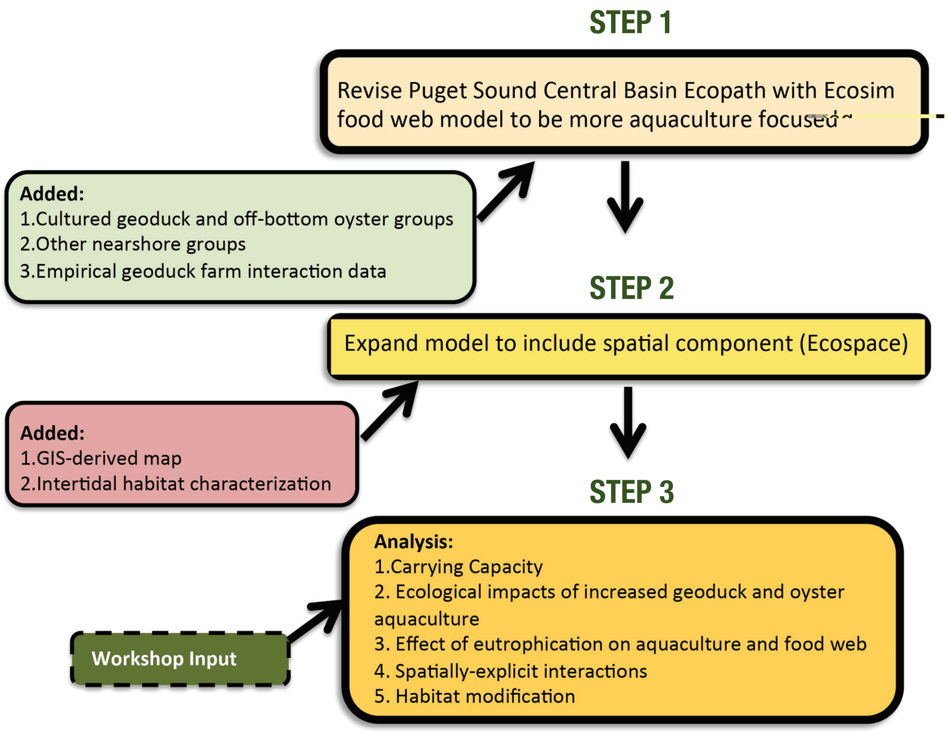

Figure 5. Overview of the conceptual framework used to develop and refine an existing ecosystem model of Central Puget Sound to accommodate shellfish aquaculture development scenarios.

Analysis scenarios have been selected from a list of workshop responses to the two following questions:

1. How does shellfish aquaculture interact with the PSCB food web?
    - Carrying capacity determination for PSCB aquaculture;
    - Ecological impacts of increased cultured geoduck; and
    - Ecological impacts of increased cultured, off-bottom oyster.
2. How does environmental change impact PSCB aquaculture?
    - Effects on aquaculture of systematic increases in phytoplankton; and
    - Effects on aquaculture of conversion of intertidal habitat.

Once the model is validated, analyses will be completed and applied in the broader context of improving our understanding of the relationships between shellfish aquaculture and the Puget Sound food web.

4. Ocean circulation model of South Puget Sound

Neil Banas and Wei Cheng, UW School of Oceanography

Overview

A multiple-scale biological, chemical and physical model of Puget Sound and adjacent coastal waters can be used to link stressors (e.g., land-use pressure, climate change, ocean acidification) to their impact on habitat for wild and cultured species. Using Puget Sound as a test case, this research component is developing the tools to nest high-resolution circulation submodels within a regional biophysical model previously developed by the UW Coastal Modeling Group (*http://faculty.washington.edu/pmacc/cmg/cmg.html*). Work is being coordinated with a parallel effort through the Washington Ocean Acidification Center to add carbon chemistry and short-term forecasting ability to the regional model. Together, these efforts will point the way toward an operational oxygen/pH early-warning system for Puget Sound and its surrounding waters.

In general, benthic filter feeders in shallow estuaries both limit and are limited by phytoplankton in the water column. The balance of local phytoplankton production, hydrodynamic import and export, shellfish consumption rates, and consumption and recycling by other grazers (such as zooplankton) collectively controls the carrying capacity of the system for shellfish production. Previous Sea Grant-sponsored work in Willapa Bay demonstrated that cultured shellfish and other benthic grazers appear to be controlling phytoplankton concentrations bay-wide. In systems where the concern is oversupply of phytoplankton rather than undersupply (i.e., systems vulnerable to eutrophication) calculations indicate that aquaculture has the potential to mitigate such water-quality concerns.

In this research component, an oceanographic model will be used to evaluate coupling between benthic grazers such as shellfish and their phytoplankton diet. This type of model has many other potential applications including analysis of pollution and sewage dispersal, larval supply and population connectivity.

Approach

Researchers are using high-resolution circulation models to integrate information on water residence time and flushing rates with estimates of the filtration capacity of cultured organisms in each sub-basin of South Puget Sound. The circulation models are part of the framework developed by the UW Coastal Modeling Group. Specifically, researchers have performed an intensive particle-tracking analysis of an existing, well-validated Puget Sound model (400 m resolution in South Sound, realistic river flow, no intertidal zone) and have repeated that analysis on a new model version. The new version currently under development has a higher resolution (200 m), a well-resolved intertidal zone and is nested in a Puget Sound model that is, in turn nested within a coastal model.

These two model versions that are broadly similar and differ only in technical details, are being used to estimate uncertainty in the results. This is a simple version of the "ensemble forecasting" methods used in climate science and weather prediction. The UW Coastal Modeling Group and the Puget Sound modeling team at the Washington Department of Ecology/ Pacific Northwest National Laboratory are working toward increased coordination of efforts and analysis, facilitated by the Puget Sound Ecosystem Monitoring Program's modeling working group.

Project status

Preliminary results indicate rapid flushing in the deep main channels of eastern South Sound, but long retention times in the narrow, shallow western inlets (Figure 6). Combining these results with data on the current density of cultured shellfish allows estimation of whether the potential reduction of phytoplankton by cultured filter feeders is faster or slower than the reduction via physical flushing in each sub-region of South Sound. Based on preliminary estimates in the western inlets of South Sound, such as Eld, Totten and upper Case Inlet, it appears that cultured grazers may have the potential to graze down a large portion of the standing stock of phytoplankton before circulation takes it away. However, the process appears to be localized and over most of South Sound, phytoplankton are controlled by circulation more than they are by cultured grazers. Researchers are continuing to refine these oceanographic models and will be conducting further analyses relevant to various scenarios.

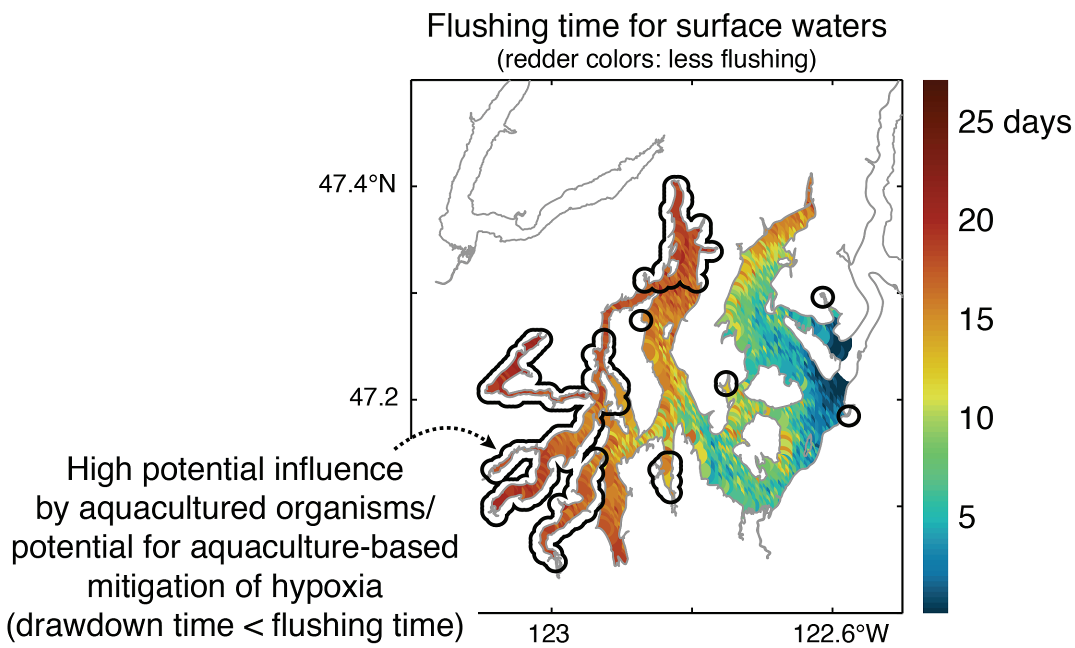

Figure 6. Average flushing time for surface waters in South Puget Sound in preliminary analyses.

5. Economic contribution of shellfish aquaculture

Kevin Decker, Washington Sea Grant

Overview

The shellfish aquaculture industry contributes significant economic value to the state, with Washington leading U.S. production of farmed bivalve shellfish. The objective of the economic component is to synthesize existing economic data of shellfish aquaculture in an easily understood and explicit way. The researcher also is working to incorporate outputs from the ecological studies directly into the economic impact assessment to investigate the potential positive and negative economic effects of changes to aquaculture production.

Approach

Determining the economic value of shellfish is often difficult because it is hidden within multiple complex reports, and is reliant on self-reporting. This program component will attempt to summarize the economic value of shellfish to the state of Washington, relying on secondary data provided by the most recent and accurate reports available. Data on production is available from the Washington Department of Fish and Wildlife. Shellfish production and value will be reported based on region, which has been separated as follows: South Puget Sound (including Hood Canal), Central Puget Sound, North Puget Sound, Willapa Bay, and Grays Harbor.

Data are limited on recreational harvest, tourism value and the value of ecosystem services of shellfish. Ecosystem services are the direct and indirect contributions of ecosystems to human well-being. Shellfish are a part of the ocean ecosystem and contribute multiple services that benefit people.

To assess the economic impact of potential increases in production based on ecological carrying capacity, an Input-Output (I-O) model will be generated using the IMPLAN™ software tool and 2012 data. The model measures how money circulates throughout the economy, capturing the direct, indirect and induced impacts on the economy as evaluated through jobs and labor income generated within the study area. The impact analysis will be used to assess how increasing shellfish aquaculture, based on the potential capacity, will affect the overall economy.

Project status

The researcher has completed the literature review and summarized the most relevant information from the reports. Experts external to the project are currently reviewing the data summary for validity and accuracy. The researcher is also in the process of determining the best method for presenting the information so that it is easily understood and referenced. The relevant economic data for completing an impact analysis are ready and waiting for proposed ecological scenarios, based on the quantitative ecosystem model, that will allow the researcher to determine opportunities for increased carrying capacity within the system and the potential economic benefits.

IV PROGRAM COMPLETION

Over the course of the shellfish research program, information from one component is intended to inform development and analysis of other components. For example, the oceanographic circulation model will be used to generate water residency times for use in spatial analyses. In addition, the quantitative ecosystem modeling will help inform scenarios of ecological change and aquaculture development for further analysis in the economic component. While the initial qualitative modeling effort will focus on ecological networks that include aquaculture, future iterations may include interdisciplinary models that incorporate findings and relationships identified in other research components.

The models themselves should serve as useful tools for a variety of purposes, including evaluation of management scenarios and testing hypotheses about how environmental changes could affect shellfish aquaculture. Moreover, component outputs will be useful for identifying gaps in scientific understanding to help direct future research.

While significant progress has been made, additional work remains. Analyses and model development for all program components will continue through mid 2015, with the research team continuing to finalize models and compile, process and summarize aquaculture-relevant spatial data layers and metadata. Once complete, models will be used to analyze aquaculture-related scenarios. Preliminary results from the South Puget Sound circulation model will be updated after the full high-resolution model is operational. Upon completion, the final report will undergo external scientific review before submission to the Legislature on or before December 1, 2015.

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