

# RESEARCH/PD ANNUAL REPORT - FINAL REPORT

2015 annual report - final

Dan Cheney

Planning for sustainable shellfish aquaculture in complex multiple use environments: Determining social and ecological carrying capacity for south Puget Sound, Washington

R/LME/N-5

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## METRICS & MEASURES

Metric/Measure	Value	Note
Acres of coastal habitat	0	This project is a modeling and analysis study and is not directed at habitat restoration or enhancement.
Fishermen and seafood industry personnel	0	The models developed and tested are not yet available for direct application by the seafood industry. These tools are available through the PSI modeling specialists.
Communities - economic and environmental development	0	The models developed and tested are not yet available for direct application by public agencies or private entities. These tools are available through the PSI modeling specialists.
Stakeholders - sustainable approaches	0	To be determined in followups with demonstrations of the modeling tools.
Informal education programs	0	
Stakeholders who receive information	550	Presentations were made at WAS 2016, PCSGA-NSA 2015, NSA 2015, etc.
Volunteer hours	200	Time provided by non-PSI personnel during stakeholder meetings, individual interviews, and for preparation and collection of field data. Includes WDOE time for assistance in EcoWin development, and time spent by growers and public resource managers.
P-12 students reached	0	No P-12 students were involved with this research.
P-12 educators	0	No P-12 educators participated in the project.

## REQUESTED INFORMATION

### Publications

**Ecological Carrying Capacity for South Puget Sound, Ecopath with Ecosim**

**Publication Type:** General Public and Advisory Reports, Fact Sheets, Posters, etc.

**Publication Year:** 2016

**Publication Authors:**

**Publisher Info:** Pacific Shellfish Institute, Olympia, WA

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, Ecopath, Ecosim, Puget Sound, Bivalve Shellfish, Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** NA

**Citation:** PSI. 2016. Ecological Carrying Capacity for South Puget Sound, Ecopath with Ecosim Pacific Shellfish Institute, Olympia, WA. 1 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [EwE\\_1pger\\_Jan2016.pdf](#)

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## **Ecosystem Models of Species Changes in South Puget Sound from 1970 to 2012 and Simulations of Species Changes From 2012 to 2054**

**Publication Type:** Technical Reports (non-peer-reviewed)

**Publication Year:** 2016

**Publication Authors:**

**Publisher Info:** Madrone Environmental Services, Duncan BC

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, Ecopath, Ecosim, Puget Sound, Bivalve Shellfish, Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** We used both mass balance and dynamics ecosystem models to represent historic, current and potential future ecosystem conditions in South Puget Sound. The forecast model examines the potential effects of different fisheries and aquaculture management policies on managed species in the South Puget Sound Ecosystem over the next 40 years. Our forecasts of future conditions involve simulating three potential future marine productivity regimes: - greater and more variable than that from 1970 to the present, - similar to that from 1970 to the present lower but with similar variability to that from 1970 to the present. In order to simulate likely marine production in the future we developed an Ecosim model of South Puget Sound from 1970 to the present in which we used time series of biomass, mortality and/or catches for managed shellfish, finfish, bird and marine mammal to estimate trophic dynamics and annual mean phytoplankton production. The historically estimated bottom-up and top-down dynamics were then used to initialise Ecosim forecast models from the present to 2054 driven by phytoplankton production time series reflective of the three potential marine production regimes. The mass balance models of South Puget Sound in 1970 and 2012 catalogue the changes that have occurred in the biomass of several marine species of biological, cultural and economic significance. Analyses of the mass balance models suggest that the rapid expansion of shellfish aquaculture would not likely have significantly influenced the biomasses of other species. The dynamic historic model reinforces the hypothesis that shellfish aquaculture had significant room to grow between 1970 and 2012 without interfering with the energetic dynamics of wild species in South Puget Sound. Forecast models show that in all scenarios of future marine production there are few, if any, effects on the South Puget Sound ecosystem from maintaining or doubling the production shellfish aquaculture production. In a scenario in which farmed Geoduck production was increased 10 times over that of 2012 small decreases in wild bivalves were observed by 2054. Forecast modelling also suggests that current fisheries and aquaculture policies generally have the effect of allowing for rebuilding biomasses in species that had declined from 1970 to the present. Sea lions appeared to attenuate the rebuilding of biomasses of some finfish in forecasts to 2054. However scenarios modelled with mandated reduction in Sea Lion biomasses showed significant rebuilding of rockfish, salmon and gadids.

**Citation:** Dave Preikshot, Bobbi Hudson, and Daniel Cheney, 2016. Ecosystem Models of Species Changes in South Puget Sound from 1970 to 2012 and Simulations of Species Changes From 2012 to 2054. Prepared for the Pacific Shellfish Institute, Olympia WA. by Madrone Environmental Services, Duncan BC. 102 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [SPS\\_EwE\\_model\\_07\\_Jan\\_2016.pdf](#)

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**Application of the Farm Aquaculture Resource Management (FARM) model to shellfish culture in South Puget Sound**

**Publication Type:** Technical Reports (non-peer-reviewed)

**Publication Year:** 2016

**Publication Authors:**

**Publisher Info:** Longline Environment Ltd

**Notes:** Draft Copy

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, FARM, EcoWin, Puget Sound, Bivalve Shellfish, Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** The Farm Aquaculture Resource Management (FARM) model was applied to examine the production and ecological outcomes of different cultivation strategies at the farm scale in South Puget Sound (SPS) inlets with significant existing production, and estimate the role of shellfish farms in nutrient removal. FARM combines physical, biogeochemical, bivalve growth, and economic tools to determine shellfish production, financial performance, and local eutrophication assessment. Utilizing economic data and ecosystem services valuation methodologies assembled with previous research, FARM was adapted to estimate the economic value of nitrogen removed by shellfish at various production levels.

**Citation:** Joao G. Ferreira, Alhambra Cubillo, Dan Cheney, Andrew Suhrbier and Bobbi Hudson. 2016. Application of the Farm Aquaculture Resource Management (FARM) model to shellfish culture in South Puget Sound. Prepared for Pacific Shellfish Institute, Olympia, WA by Longline Environment Ltd. 13 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [FARM\\_application\\_report\\_for\\_PESCA\\_final.pdf](#)

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### **Ecosystem goods and services of geoduck farming in South Puget Sound: A modelling analysis**

**Publication Type:** Technical Reports (non-peer-reviewed)

**Publication Year:** 2015

**Publication Authors:**

**Publisher Info:** Longline Environment

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, FARM, Puget Sound, Bivalve Shellfish, Geoduck Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** We have simulated the ecosystem goods and services of geoduck farming in Eld Inlet Farm, property of Chelsea Farms. These results were then scaled to the whole Puget Sound basin. An individual geoduck clam (*Panopea generosa*) growth model was developed, based on our previously developed generic framework for bivalves (AquaShell). Geoduck growth performance was then calibrated and validated for the commercial farm. For the most part, equations were taken or adapted from the literature and parameterised for the studied site. The geoduck individual model was incorporated into the Farm Aquaculture Resource Management (FARM) model to simulate the production cycle, economics, and environmental effects of intertidal culture. Both the individual and farm-scale models are built in C++ using object-oriented programming. The FARM model was also used to classify the farm area with respect to its eutrophication status, applying the Assessment of Estuarine Trophic Status (ASSETS) model. Farm production of 17.3 t of clams per 5-year culture cycle is well reproduced by the model (14.4 t). In the area of Eld Inlet Farm, at the current culture density of 21 animals per square meter, geoduck farming provide an annual ecosystem service equivalent to 45 Population-Equivalents (PEQ, i.e. loading from humans or equivalent loading from agriculture or industry) in reducing eutrophication symptoms. This represents a potential nutrient credit trading value of over US \$1,800 per year. The potential income would add 1.5% to the annual profit (US \$124,900) from clam sales. A scaling exercise to the whole of Puget Sound suggests that clams provide a significant ecosystem service, of the order of 1,840 PEQ per year (about US \$74,000) in removing primary symptoms of eutrophication.

**Citation:** Alhambra Cubillo and Joao G. Ferreira. 2015. Ecosystem goods and services of geoduck farming in South Puget Sound: A modelling analysis. Prepared for the Pacific Shellfish Institute by Longline Environment LTD. 19 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [Final\\_report\\_geoduck\\_model\\_LLE\\_2015.12.22.pdf](#)

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**EcoWin.NET model box division Stakeholder feedback and changes to model layout -- PESCA working document**

**Publication Type:** Technical Reports (non-peer-reviewed)

**Publication Year:** 2014

**Publication Authors:**

**Publisher Info:** Longline Environment

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, EcoWin, Puget Sound, Bivalve Shellfish, Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** Following a review of stakeholder inputs, we propose a box layout for the EcoWin.NET ecological model of 76 boxes, with 38 boxes in the upper water column layer and 38 boxes in the lower layer. The detailed analysis, results, and their justification, are presented in the text below.

**Citation:** Vazquez, F., C. Saurel, and J. G. Ferreira. 2014. EcoWin.NET model box division Stakeholder feedback and changes to model layout -- PESCA working document. Prepared for the Pacific Shellfish Institute by Longline Environment Ltd. 22 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [Stakeholders\\_summary\\_final.pdf](#)

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**Ecosystem goods and services of geoduck farming in South Puget Sound: A modelling analysis**

**Publication Type:** Presentations (non-peer-reviewed)

**Publication Year:** 2015

**Publication Authors:**

**Publisher Info:** Longline Environment Ltd.

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, FARM, Puget Sound, Bivalve Shellfish, Geoduck, Aquaculture

**Publication URLs:** [ecowin.org/geoduck](http://ecowin.org/geoduck)

**Abstract:** Local-scale models such as FARM are a good tool to assess the environmental services of cultivated animals, and are easily applied, without requiring large volumes of data

- Results from the FARM model indicate that geoduck and Manila clam aquaculture in Puget Sound provide a combined ecosystem service corresponding to 90,000 population-equivalents (3.6 million USD) in reducing eutrophication
- To the economic and social value of shellfish we have to add the ecosystem services they provide
- Filter-feeders such as geoducks are not only a valuable product, but can be used as nutrient bioextractors, in a bioremediation role

**Citation:** Cubillo, Alhambra M., Joao G. Ferreira, Robert Marshall, Chris M. Pearce, Daniel Cheney, Bobbi Hudson, Andrew D. Suhrbier, William F. Dewey, Peter Becker, Shina Wysocki. 2015. Ecosystem goods and services of geoduck farming in South Puget Sound: A modelling analysis. Prepared for the Pacific Shellfish Institute by Longline Environment Ltd. 19 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [EAS\\_Geoduck\\_Alhambra\\_Cubillo\\_2015.10.08.pdf](#)

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**Application of the EcoWin model to shellfish culture in South Puget Sound**

**Publication Type:** Technical Reports (non-peer-reviewed)

**Publication Year:** 2014

**Publication Authors:**

**Publisher Info:**

**Notes:**

**Related URLs:**

**Keywords:** Carrying Capacity, Ecosystem Modeling, FARM, EcoWin, Puget Sound, Bivalve

Shellfish, Aquaculture

**Publication URLs:** [pacshell.org](http://pacshell.org)

**Abstract:** The implementation of EcoWin with (i) adaptation and if necessary development of biogeochemical and physiological process equations; (ii) spatial definition of the modeling domain; and (iii) coupling to hydrological and hydrodynamic models. Challenges and future directions.

**Citation:** Ferreira, Joao G. 2016. Application of the EcoWin model to shellfish culture in South Puget Sound. Prepared for Pacific Shellfish Institute, Olympia, WA by Longline Environment Ltd. 3 p.

**Citation for Coverage:**

**SG can post PDF online?:** Yes

**Uploaded File:** [EcoSim\\_application\\_for\\_SPS\\_Ferreira.pdf](#)

## Students Supported

No **Students Supported** information reported

## Narratives

**Planning for sustainable shellfish aquaculture in complex multiple use environments: Determining social and ecological carrying**

**Uploaded File:** [WSG\\_Carrying\\_Capacity\\_Narrative\\_PSI\\_4-2016.pdf](#)

## Partners This Period

### Madrone Environmental Services

**Types:** Other

**Scale:** REGIONAL

**Notes:**

### Longline Environment, LLC

**Types:** Other

**Scale:** INTERNATIONAL

**Notes:**

### Washington Department of Ecology

**Types:** Government

**Scale:** STATE

**Notes:**

### Washington State University Social & Economic Sciences Research Center

**Types:** Academic Institution

**Scale:** STATE

**Notes:**

### Calm Cove Oyster Co.

**Types:** Industry/Business

**Scale:** REGIONAL

**Notes:**

### Chelsea Farms

**Types:** Industry/Business

**Scale:** LOCAL

**Notes:**

### Nisqually Indian Tribe

**Types:** Other

**Scale:** LOCAL

**Notes:**

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**Taylor Shellfish Farms**

**Types:** Industry/Business

**Scale:** REGIONAL

**Notes:**

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**Baywater Shellfish Farm**

**Types:** Industry/Business

**Scale:** LOCAL

**Notes:**

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**Arcadia Point Shellfish Co.**

**Types:** Industry/Business

**Scale:** LOCAL

**Notes:**

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**Fisheries and Oceans Canada (DFO)**

**Types:** Government

**Scale:** INTERNATIONAL

**Notes:**

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**National Marine Fisheries Service (US DOC, NOAA, NMFS)**

**Types:** Government

**Scale:** FEDERAL or NATIONAL

**Notes:**

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**Washington Sea Grant**

**Types:** Sea Grant Program

**Scale:** STATE

**Notes:**

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**STANDARD QUESTIONS**

**Community Hazard Resilience**

No **Community Hazard Resilience** information reported

**Economic Impacts**

No **Economic Impacts** information reported

**Impacts and Accomplishments**

(1)

Type	impact
Title	Environmental remediation and room to grow: National Sea Grant-supported models assess the impacts of expanding shellfish aquaculture in South Puget Sound
	Washington produces a quarter of all U.S. farmed shellfish and wants to produce much more. But just how much can it grow sustainably? Determining

<b>Relevance</b>	carrying capacity would aid growers, facilitate dialog, and inform management and production decisions. Gauging shellfish's remediation role in removing nitrogen would also be valuable in South Puget Sound, the prime growing region, which suffers from increasing nutrient loads and low oxygen in some embayments.
<b>Response</b>	National Sea Grant-funded researchers considered physical, ecological, social and production capacities in determining South Puget Sound's shellfish carrying capacity. They incorporated farm production records, shellfish species metrics, water resource data, policy and regulation assessments, and stakeholder information. Ecopath modeling was used to create past and recent biomass snapshots of multiple plant and animal species and Ecosim modeling forecast changes out to the year 2054 according to various production and management scenarios. Researchers used Farm Aquaculture Resource Management (FARM) modeling to simulate shellfish growth, harvests, and algae and detritus removal.
<b>Results</b>	FARM modeling accurately predicted actual harvests. Ecopath modeling indicated current growing practices had neutral or beneficial effects on most key species' biomass. Doubling bivalve production, even increasing it 10 times in most cases, had little impact. Model results for South Puget Sound suggest shellfish harvest removed as much nitrogen as 40,000 humans produce, saving \$1.6 million a year in waste treatment. The results helped researchers calculate the ecosystem services aquaculture provides, particularly in controlling eutrophication.
<b>Recap</b>	National Sea Grant-supported modeling in South Puget Sound suggests expanded shellfish production could help control eutrophication without adverse impacts on key marine species.
<b>Comments</b>	
<b>Primary Focus Area</b>	Sustainable Fisheries and Aquaculture
<b>Secondary Focus Areas</b>	Resilient Communities and Economies
<b>Goals</b>	Coastal communities and economies are vibrant and resilient.
<b>Partners</b>	Arcadia Point Shellfish Co. Baywater Shellfish Company Calm Cove Oyster Company Chelsea Farms Fisheries and Oceans Canada (DFO) Longline Environment, Ltd Madrone Environmental Services National Marine Fisheries Service (US DOC, NOAA, NMFS) Nisqually Tribe Taylor Shellfish Company Washington State Department of Ecology Washington State University Social & Economic

Type accomplishment \* Title Washington Sea Grant investigates social and ecological carrying capacity for shellfish aquaculture \* Relevance Washington is the nation's leading producer of bivalve shellfish, with harvests of about 40,000 metric tons annually, and South Puget Sound is a major growing area. The region also is experiencing rapid development, which has at times created conflicts between shoreline users and shellfish growers and illustrated the need for tools and information to inform regional planning and management of sustainable shellfish culture. \* Response Funded through a national strategic initiative, Washington Sea Grant-supported researchers conducted an evaluation of South Puget Sound's shellfish production and ecological and social carrying capacity. The research team applied comprehensive farm- and ecosystem scale models (e.g., FARM, EcoPath) to help shellfish farmers and harvesters, resource managers, and other interested parties identify, evaluate, and account for social and environmental considerations in shellfish aquaculture development. \* Results Researchers analyzed farm production records, shellfish species metrics, and aquaculture related policies and regulations, and they completed a detailed review of regional industry constraints and incentives. They also examined nitrogen removal and natural shellfish recruitment. Information from a variety of sources was compiled and incorporated into the models, which also built upon and complement ongoing and recently completed efforts elsewhere in the region. Model outputs simulated and predicted future biomass and nutrient conditions for a wide range of farming and harvest scenarios. All findings were presented to stakeholders as reporting was completed. \* Recap Washington Sea Grant-supported research investigated ecosystem conditions and perspectives—including human dimensions—that determine South Puget Sound's carrying capacity for shellfish aquaculture. Comments Support conservation and sustainable use of living marine resources through effective and responsible approaches, tools, models and information for harvesting wild and cultured stocks and preserving protected species. Assist coastal communities and marine-dependent businesses in planning and making decisions that provide local and regional economic benefits, increase resilience and foster stewardship of social, economic and natural resources. Match priorities and goals of state and national shellfish initiatives. Primary Focus Area Healthy Coastal Ecosystems Secondary Focus Areas Resilient Communities and Economies Goals Ocean and coastal resources are managed using ecosystem-based approaches., Coastal communities engage in comprehensive planning and sustainable



development. Partners Baywater Shellfish Farm  
Calm Cove Oyster Co. Chelsea Farms Longline  
Environment, LLC Madrone Environmental Services  
Nisqually Indian Tribe Little Skookum Shellfish  
Farms Taylor Shellfish Farms Washington  
Department of Ecology Washington State University  
Social & Economic Sciences Research Center -----

----- Type accomplishment \* Title  
Application of the Farm Aquaculture Resource  
Management (FARM) model to shellfish culture in  
South Puget Sound \* Relevance The application of  
models for local-scale simulation of production and  
environmental effects assists managers and industry  
in promoting sustainable aquaculture, and facilitates  
stakeholder dialog. \* Response The Farm  
Aquaculture Resource Management (FARM) model  
was applied to shellfish farms in Puget Sound to  
simulate growth, harvest potential, and removal of  
algae and detrital organics by filter-feeders. The  
results were used to calculate the environmental and  
economic contribution of the industry in Puget Sound  
with respect to ecosystem services, particularly with  
respect to the top-down control of eutrophication. \*  
Results With respect to provisioning services, the  
model outputs were in general a good match to  
declared production. The value of regulatory services  
to the entire Sound is estimated to be in excess of  
three million dollars per year, or the nitrogen loading  
of 84,000 Population-Equivalents. \* Recap  
Washington Sea Grant support enabled the  
application of state-of-the-art modeling tools to  
shellfish culture in South Puget Sound, and  
promoted stakeholder access to these tools. Farmers  
now understand better how mathematical models  
can be used to support the industry and help with  
sustainable growth. Comments Primary Focus Area  
Sustainable Fisheries and Aquaculture Secondary  
Focus Areas Healthy Coastal Ecosystems Goals  
Ocean and coastal resources are managed using  
ecosystem-based approaches.,Aquaculture  
operations and shellfish harvests are safe,  
environmentally sustainable and support  
economically prosperous businesses.,The future  
workforce is skilled in disciplines critical to coastal and  
ocean economies and ecosystem health. Partners  
Longline Environment, Ltd Washington Department  
of Ecology Chelsea Farms Taylor Shellfish Farms  
Fisheries and Oceans Canada (DFO) -----

--- Type accomplishment \* Title Ecological Carrying  
Capacity for South Puget Sound Ecopath with  
Ecosim \* Relevance This work focused on several  
lower trophic level components of the South Puget  
Sound (SPS) food web. A key aspect of this  
approach was the unique application to multi-species  
and commercially important aspects shellfish  
aquaculture and harvest. Simulations forecasted  
potential future ecosystem configurations under a  
variety of population changes and fishing and

PI Draft

aquaculture management policies. \* Response The Ecopath with Ecosim (EwE) modeling framework provided a way to visualize the biomass of a suite of species groups over time, using mortality rates or 'production' of species groups, food intake and diet composition. The SPS EwE model simulated known historic changes for 1970-2012, and forecasted potential changes through 2054 for 12 key species of marine mammals, marine birds, salmon, game fish and bivalves. \* Results Analyses of the 1970 and 2012 mass balance models suggested that the rapid expansion of shellfish aquaculture would not likely have significantly influenced the biomasses of other species. In all scenarios of future marine production, there were few trophic effects on the South Puget Sound ecosystem when maintaining or significantly increasing shellfish aquaculture production. \* Recap Washington Sea Grant-supported research applying existing ecosystem models to shellfish aquaculture production in South Puget Sound, and an in-depth examination of the current and future effects of production/harvest changes on critical marine organisms. Comments See: Central Puget Sound Ecopath/Ecosim model biological parameters - Developing food web models for ecosystem-based management applications in Puget Sound (NMFS, <http://www.nwfsc.noaa.gov>) for an earlier modeling study in Puget Sound. Primary Focus Area Sustainable Fisheries and Aquaculture Secondary Focus Areas Healthy Coastal Ecosystems Goals Ocean and coastal resources are managed using ecosystem-based approaches., Ocean and coastal habitats are protected, enhanced and restored., Aquaculture operations and shellfish harests are safe, environmentally sustainable and support economically prosperous businesses., Fisheries are safe, responsibly managed and economically and culturally vibrant. Partners Madrone Environmental Services Washington Department of Ecology Taylor Shellfish Farms Fisheries and Oceans Canada (DFO) National Marine Fisheries Service (US DOC, NOAA, NMFS) Washington Sea Grant ----- Type impact \* Title Washington Sea Grant investigates the production and ecological carrying capacities for shellfish aquaculture in south Puget Sound \* Relevance Washington State is the largest producer of hatchery-reared and farmed shellfish in the U.S, accounting for 25% of the total domestic production by weight, with an annual value exceeding \$107 million. To address questions regarding sustaining and increasing shellfish production in the state we applied an expanded definition of carrying capacity to integrate interrelated elements of 1) physical, 2) production, 3) ecological and 4) social carrying capacities. This Sea Grant funded research applied an interdisciplinary approach to simulate shellfish production and environmental effects to assist

growers, facilitate public dialog and inform management and production decisions. \* Response Farm production records and shellfish species metrics, water resource data, assessments of aquaculture-related policies and regulations, and information from stakeholder groups were incorporated in ecosystem and farm-scale models to assist in simulating future carrying capacities for bivalve shellfish farming and harvest scenarios in the south Puget Sound area of Washington state. “Ecopath” with “Ecosim” modeling provided a way to visualize the biomass of a suite of species in south Puget Sound. Ecopath created biomass balanced snapshots for 1970 and 2012 of multiple plant and animal species. Ecosim was then used to forecast to 2054 future changes in selected plants and animals relative to various aspects of shellfish aquaculture production and natural resource management. The “FARM” model was applied to simulate shellfish growth, harvest potential, and removal of algae and detrital material at the farm-scale. The results were used to calculate the environmental and economic contribution of the industry in south Puget Sound with respect to ecosystem services, particularly with respect to the top-down control of eutrophication by shellfish. An Assessment of Estuarine Trophic Status (ASSETS) model was used to update the eutrophication status in south Puget Sound, including the factors influencing development of eutrophication, and nutrient related water quality conditions. \* Results Ecopath modeling indicated current shellfish production and management practices were beneficial or not harmful to biomass changes of almost all key species in south Puget Sound. Fisheries and aquaculture policies generally had the effect of allowing for rebuilding biomasses in species that had declined from 1970 to the present. In all scenarios of future marine production, trophic effects on the south Puget Sound ecosystem were largely driven by changes in phytoplankton production. Increasing overall south Puget Sound bivalve aquaculture by a factor of 2 (in most cases to 10) had little effect on the other key species modeled. The FARM model forecasted shellfish production of 3,700 to 47,300 kg valued at \$23,000 to \$122,000 per culture cycle from four small to medium sized oyster and Manila clam farms in south Puget Sound. The harvest from a similarly sized geoduck farm was forecasted to be 14,600 kg with a farmgate value of \$608,000. A larger raft-culture mussel farm had a modeled output of 814,800 kg valued at \$2,171,000. In general, these model outputs were in close agreement with declared harvest figures. Shellfish harvest also reduces nutrient enrichment through consumption of phytoplankton and detrital material. Harvest at the six modeled south Puget Sound farms removed about 40 tons of nitrogen per year. The reported south

Puget Sound shellfish harvest (2013 data) was estimated to remove over 130 tons of nitrogen per year, which is equivalent to the nitrogen loading of nearly 40,000 humans. The value of waste treatment plant cost savings to the entire south Puget Sound was estimated to be 1.6 million dollars per year. ASSETS modeling for 2007 and 2015 showed south Puget Sound continues to experience an increasing level of nutrient loading. This is indicated by current chlorophyll and macroalgal observations, as well as the occurrence of toxic algae blooms. On the other hand, dissolved oxygen depletion does not appear to be a south Sound-wide problem, although it does occur in some embayments. The combined indicators suggest that nutrient management measures should continue, including innovative measures such as the use of shellfish aquaculture, to remediate continued worsening conditions. \* Recap Washington Sea Grant-supported research applying existing ecosystem models to shellfish aquaculture production in south Puget Sound, and an in-depth examination of the current and future effects of production/harvest changes on critical marine organisms. These products will help shellfish farmers and harvesters, resource managers, and other interested parties identify, evaluate, and account for social and environmental considerations in shellfish aquaculture development. Comments 1) Support conservation and sustainable use of living marine resources through effective and responsible approaches, tools, models and information for harvesting wild and cultured stocks and preserving protected species. 2) Assist coastal communities and marine-dependent businesses in planning and making decisions that provide local and regional economic benefits, increase resilience and foster stewardship of social, economic and natural resources. 3) Match priorities and goals of state and national shellfish initiatives. Primary Focus Area Healthy Coastal Ecosystems Secondary Focus Areas Goals Partners

### Leveraged Funds

No **Leveraged Funds** information reported

### Meetings, Workshops, Presentations

(1)

<b>Type of Event</b>	Public or professional presentation
<b>Description</b>	PCSGA 2015 -- What Effect Does Shellfish Culture Really Have on the South Puget Sound Ecosystem? Bobbi Hudson, David Preikshot, Daniel Cheney and Teri King. PCSGA/NSA-PCS Annual Meeting, Hood River, OR.

<b>Event Date</b>	09-29-2015
<b>Number of Attendees</b>	150

(2)

<b>Type of Event</b>	Public or professional presentation
<b>Description</b>	NSA 2015 -- Shellfish Farming in the Pacific NW Public and Stakeholder Perceptions. Bobbi Hudson, Thom Allen and Danna Moore. NSA Annual Conference, Monterey, CA.
<b>Event Date</b>	03-27-2015
<b>Number of Attendees</b>	100

(3)

<b>Type of Event</b>	Public or professional presentation
<b>Description</b>	WAS/NSA 2016 -- Physical and Social Dimensions of Shellfish Aquaculture on the U.S. West Coast. Bobbi Hudson, Thom Allen, Danna Moore, Andrew Suhrbier and Hannah Faulkner. WAS 2016, Las Vegas, NV.
<b>Event Date</b>	02-24-2016
<b>Number of Attendees</b>	100

(4)

<b>Type of Event</b>	Public or professional presentation
<b>Description</b>	European Aquaculture Society 2015 -- ECOSYSTEM GOODS AND SERVICES OF PACIFIC GEODUCK FARMING IN SOUTH PUGET SOUND? A MODELLING ANALYSIS. Alhambra M. Cubillo, Joao G. Ferreira*, Robert Marshall, Chris M. Pearce, Daniel Cheney, Bobbi Hudson, Andrew D. Suhrbier, William F. Dewey, Peter Becker, Shina Wysocki. EAS 2015. Rotterdam, Netherlands.
<b>Event Date</b>	10-23-2015
<b>Number of Attendees</b>	150

(5)

<b>Type of Event</b>	Sea Grant-sponsored/organized event
<b>Description</b>	EcoPath Workshop -- Visualizing Ecological Interactions of South Puget Sound Research Overview. Bobbi Hudson, David Preikshot, Daniel Cheney and Teri King. LOTT Clean Water Alliance, Olympia, WA.

<b>Event Date</b>	01-27-2016
<b>Number of Attendees</b>	50

**Tools, Technologies, Information Services / Sea Grant Products**

No **Tools, Technologies, Information Services / Sea Grant Products** information reported







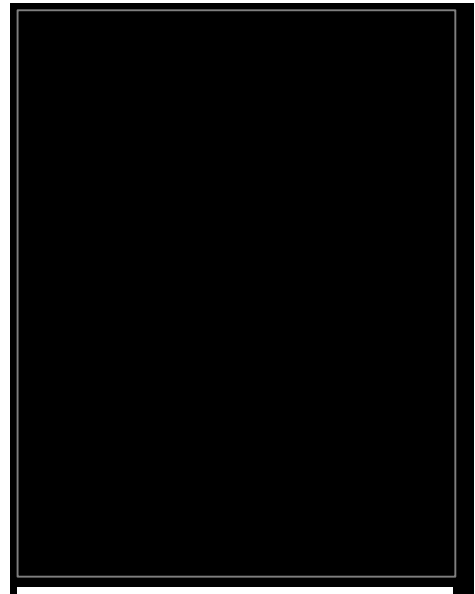




information was updated in Year 2 to conform to the latest shoreline management guidance currently being finalized for south Puget Sound counties.

Three stakeholder meetings were completed as part of informational data collection sessions (meetings 1 and 2), and presentation of project findings for EWE modeling. All meetings were facilitated by Teri King, University of Washington Sea Grant.

A survey was designed to assess perceptions and behaviors related to shellfish and shellfish farming, and to examine what influences social attitudes toward these activities. An Advisory Committee comprised of local, state, and federal resource managers, planners, and industry representatives was assembled by PSI to guide survey development. The survey was implemented by Washington State University's Social and Economic Research Center, along with a companion stakeholder survey for a separate but related NOAA Sea Grant Aquaculture Research Program project. For this project, the survey "Shellfish Farming and Your Community" (**Figure 2**) was implemented in six Washington counties: Skagit, Kitsap, Pacific, Thurston, Pierce, Mason. (Under PSI's companion project, four additional counties were surveyed, within Oregon and California.) Survey questions were designed to gauge:



**Figure 2.** Stakeholder survey cover.

- ✎ How do these communities understand, value, and respond to shellfish farming?
- ✎ What factors and sources of information influence these social attitudes and values?
- ✎ What kinds of outreach might be most effective at improving public awareness of shellfish farming?

The population for the survey consisted of all residential households within the 10 county study area. A total of 862,187 residential households were identified by Genesys Sampling Inc., and a random sample of 4,000 households were selected. Residents were first asked to complete the survey online, but those who did not respond to the web survey were later sent a paper version of the questionnaire.

## Results and Discussion

### Farm Aquaculture Resource Management model (FARM)

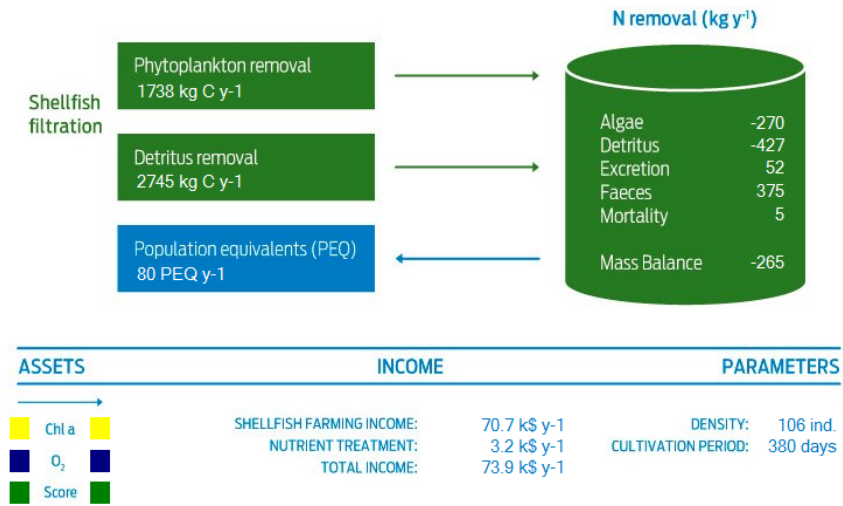
The simulated outputs for Pacific oyster culture at the two farm sites showed a relatively good match to the declared harvest (**Table 1**). The role of the Totten Inlet oyster farm in nutrient removal is shown in **Figure 3**, which represents the annualized mass balance of the culture. There was a net removal of 265 kg of nitrogen, which equated to 0.7% of the total live weight biomass produced.

Considerably different results were obtained from a large Mediterranean mussel farm in Totten Inlet. Both the area and the stocking density were an order of magnitude higher than the oyster and clam farms, and this is reflected in the food depletion simulations. FARM indicates a significant reduction in chlorophyll of over 12%, which means that farm plays an important role in mitigating eutrophication.

**Table 1.** Production effects of two Pacific oyster farms in SPS (per production cycle)

Variable	Eld Inlet	Totten Inlet
<i>Model inputs:</i> Seeding (kg)	800	1,000
<i>Model outputs:</i> Total harvest (kg)	23,000	38,723
<i>Actual outputs:</i> Declared harvest (kg)	19,395	47,343
<i>ASSETS:</i> eutrophication model score (in to out)	4-no change	4-no change

An assessment of the role of the three species of bivalves in mitigating eutrophication is shown in **Table 2**. The numbers can be combined with simulations executed for Manila clam in North Puget Sound, geoducks in SPS, and extended to other shellfish harvesting areas of the United States. This would for the first time allow a budget to be made of the role of bivalve shellfish in controlling eutrophication at a national scale.



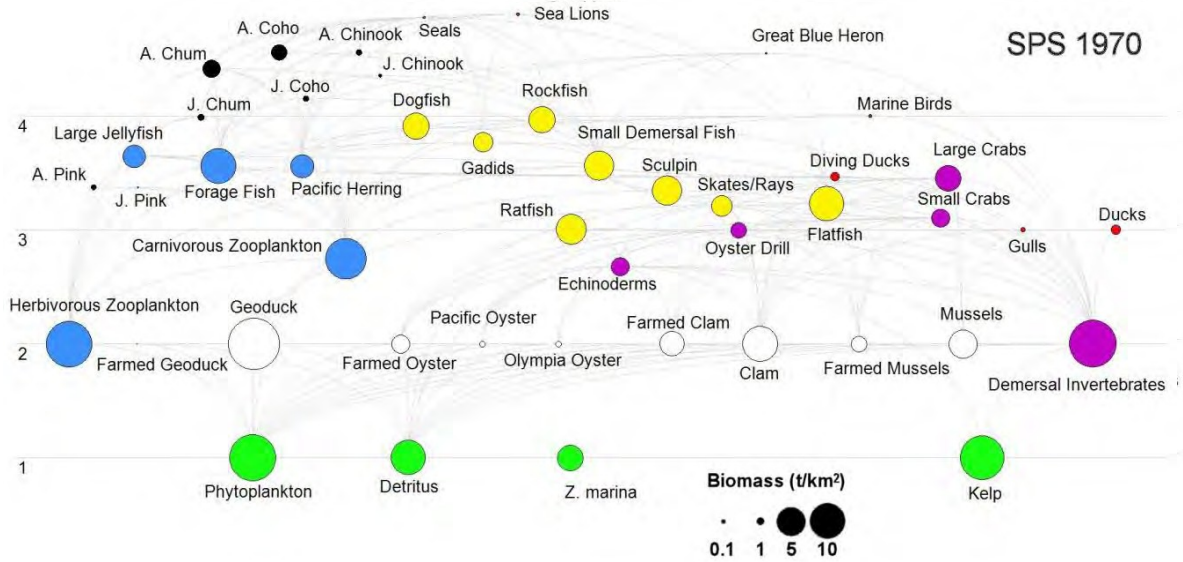
**Figure 3.** Mass balance for culture of Pacific oysters in Totten Inlet.

**Table 2.** Environmental externalities from bivalve culture in SPS (FARM case study outputs)

	Pacific oyster		Manila clam		Mediterranean mussel
	Eld Inlet	Totten Inlet	Eld Inlet	Little Skookum	Totten Inlet
Culture cycle (days)	365	380	1240	840	400
Production (kg cycle-1)	22999.72	38723.10	3449.68	18484.74	868570.29
Annualized production (kg y-1)	22999.72	37194.56	1015.43	8032.06	792570.39
Net nitrogen removal (kg N y-1)	167	265	94	380	38900
Percentage N / live weight (%)	0.73	0.71	9.26	4.73	4.91
Population-Equivalents	51	80	29	115	11788
Potential nutrient credits (USD)	2040	3200	1160	4600	471500

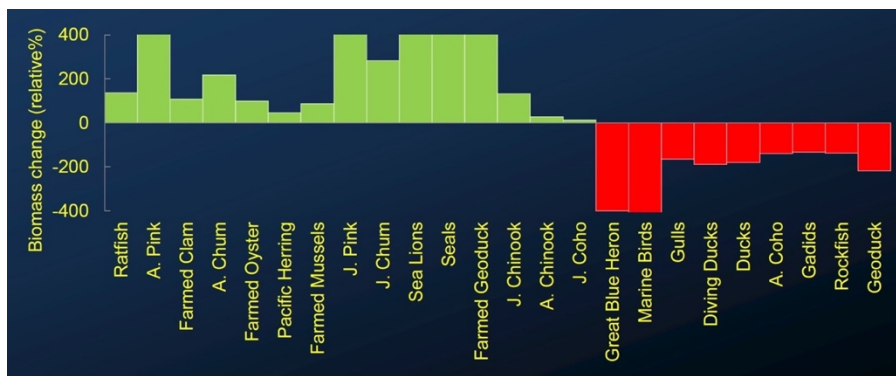
**EcoPath / EcoSim (EWE) Model**

*Mass balance and MTI modeling:* The mass balance models of South Puget Sound in 1970 and 2012 catalogued the changes that occurred in the biomass of several marine species of biological, cultural and economic significance. Diagrams of the biomasses and trophic links simulated by the 2012 Ecopath model can be seen in **Figure 4**. Not all species are known to have exhibited significant biomass changes in SPS between 1970 and 2012. In the case of relative biomass change within species groups between 2012 and 1970, the largest gain was seen in farmed geoduck clams, sea lions, harbor seals, pink salmon, and chum salmon, **Figure 5**. The dynamic historic model reinforces the assumption that shellfish aquaculture had significant room to grow between 1970 and 2012 without interfering with the energetic dynamics of wild species in South Puget Sound.



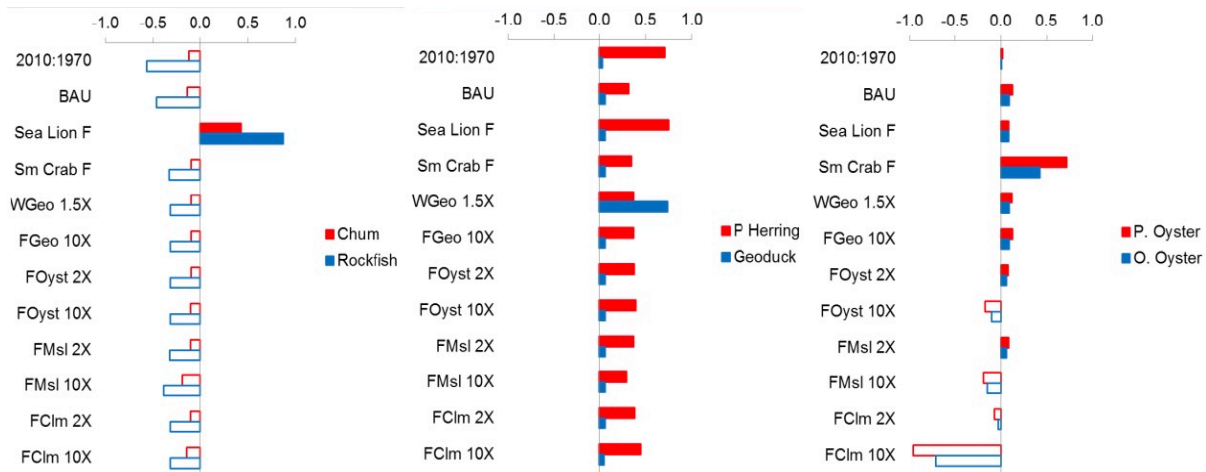
**Figure 4:** Trophic web of the SPS ecosystem in 1970. Circle area is proportional to the logarithm of biomass, grey lines show predator/prey linkages. Trophic level is labelled on the left. Groups are color coded to indicate niche similarities: red=marine mammals and birds, black=Pacific salmon, yellow=demersal fish, blue=forage fish and zooplankton, white=bivalves, purple=benthic invertebrates and green= primary producers.

A mixed trophic interactions (MTI) subroutine was employed to assess the effects that increasing the biomass of a given species, or magnitude of a fishery or harvest, will have on other groups in the model. When considering the effect of bivalve aquaculture operations on other groups in the model, it is interesting to note that there appears to be few negative feedbacks, the exception being some of the wild bivalve species groups. A detailed discussion of the MTI model results is provided in the full research report.



**Figure 5.** Modeled relative biomass change within species groups: 1970-2012.

*Ecosim modeling:* Ecosim scenarios were run in a module of Ecosim called Multisim. Multisim allowed us to run iterative simulations of the future to generate a probability distribution of future outcomes in several Ecopath parameters. An example of relative biomass changes for 100 simulations for 12 scenarios of management policy changes for 6 of 12 key species groups is shown in **Figure 6**.



**Figure 6.** Relative change in biomass for 6 of the 12 focal species for 12 scenarios of management and production changes between 2012 and 2054 in which future phytoplankton production and variation is similar to that modelled for 1970-2010. Baseline Ecosim changes from 1970-2010 are also shown for comparison. Bars show average value from 100 simulations of each scenario.

Multisim modelling suggests bivalve aquaculture is generally benevolent at the scale of SPS as a whole. However, this does not mean that within some of the bays and inlets where aquaculture is concentrated there will be no effects on some species. Such meso-scale effects may be modelled more effectively with a spatial modelling tool like Ecospace. The observation that increasing clam aquaculture by an order of magnitude could result in decrease biomass of wild oysters may suggest the kinds of effects that may be seen at smaller scales within SPS.

Having established a biological modelling baseline, it would be invaluable to invoke the economic modelling capacity of Ecosim to examine potential trade-offs not only between different fisheries but also between the cost of a given management policy versus its benefit in species biomass. Such questions could be of particular value when examining the value of increases to wild geoduck clam biomass or whether or not to devote economic and social capital to expanding extant kelp and eelgrass habitat.

Finally, the business as usual or ‘BAU’ scenario, was beneficial or not harmful to biomass changes of almost all key species, and current fisheries and aquaculture policies generally have the effect of allowing for rebuilding biomasses in species that had declined from 1970 to the present.

### Stakeholder Surveys

During the study period, 652 surveys were collected online and another 598 were mailed in, resulting in a 34% response rate (**Table 3**). Sampling error, or the degree to which the randomly selected sample of respondents represents the population from which it is drawn, was calculated at  $\pm 3\%$ . At the time of the survey U.S. Census data estimates 1,519,653 adults lived in the ten county study area.

Results of the survey were detailed in “Public Opinion of Shellfish Farming: A report on the public perception of shellfish aquaculture in select counties in Washington, Oregon and California” and distributed to stakeholders across the three states and available on the PSI website ([www.pacshell.org](http://www.pacshell.org)). Overall, the survey revealed limited knowledge of shellfish aquaculture, but a considerable level of support for policies supporting shellfish aquaculture and increased domestic seafood production. When

questioned if nearshore aquaculture production in their state should be increased, decreased, or stay the same, a preference for increased production outnumbered decreased production by a factor of nearly 5 to 1. Survey respondents also recognize the benefits of shellfish aquaculture, especially for providing locally produced seafood, creation of jobs, improving the local and state economy, and relieving pressure on wild fisheries.

**Table 3.** Summary statistics for the survey’s ten county study region. Washington counties were the focus for this project, while Oregon and California counties were conducted under a companion PSI project funded by NOAA Sea Grant Aquaculture Research Program.

Study Area	Sample Size	Completed Surveys	Response Rate	Sample Error	Households in Area
<b>Total Study Area</b>	4,000	1,250	34%	±3%	862,187
<i>Washington Study Area</i>	2,400	770	35%	±4%	640,462
Skagit	400	129	34%	±9%	51,473
Kitsap	400	131	36%	±9%	107,367
Pacific	400	150	42%	±9%	15,547
Thurston	400	125	33%	±9%	108,182
Pierce	400	109	29%	±9%	325,375
Mason	400	126	35%	±9%	32,518
<i>Oregon Study Area</i>	800	282	38%	±6%	48,952
Tillamook	400	145	39%	±9%	18,359
Coos	400	137	37%	±9%	30,593
<i>California Study Area</i>	800	198	26%	±7%	172,773
Humboldt	400	103	27%	±9%	61,559
Marin	400	95	24%	±9%	111,214

This research indicated there was great potential for increased education and outreach regarding shellfish related activities. Survey responses suggested that the most effective means to share information will be television, newspapers and websites, as well as booths at public events.

### Summary of Outreach and Information / Technology Transfer

Project results were transferred to a broad range of audiences, including local, state and federal agencies, academia, and shellfish growers. The tools developed by this project were presented to those in the aquaculture industry and to researchers and others interested in applying these tools. Stakeholders were engaged from the beginning of ecosystem carrying capacity modeling, and workshops presenting findings were extended to additional stakeholders, including local government, shellfish growers and environmental groups. Technical reports as well as presentations at local, regional, national and international meetings [including but not limited to informational sessions at WSG’s annual Shellfish Growers Conference, the joint Pacific Coast Shellfish Growers Association (PCSGA)/National Shellfisheries Association (NSA) annual meeting, the NSA annual meeting, and the World Aquaculture Society (WAS) annual meeting] were developed for distributing the information to the scientific and aquaculture communities.

The following short, medium and long term outcomes are predicted to result from this project:

**Short-term outcomes:** Optimization of aquaculture operations based on model outputs and stronger community and local government awareness of trade-offs and environmental effects; increased awareness among resource managers of the potential application of models and scenario development; and increased public understanding of and engagement in modeling process and ecosystem interactions.

**Medium-term outcomes:** Scientists use study results and guidance materials to support promote sustainable aquaculture practices that also improve water quality; enhanced capacity among decision-makers to plan for and support sustainable shellfish aquaculture; baseline results are used as fisheries reference to manage coastal resources; and politicians pass legislation to include aquaculture as acceptable water quality management measure, potential nutrient trading component.

**Long-term outcomes:** Increased public support for shellfish aquaculture; and expanded sustainable shellfish aquaculture and improved water quality in South Puget Sound and throughout the region.

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