NATIONAL SEA GRANT FINAL REPORT

Project Number: NA08OAR4170822
Project Title: Washington State Shellfish Production and Restoration - Environmental and Economic Benefits and Costs

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OBJECTIVES:
The objectives of this project are three-fold:

1. Identify and quantify the environmental costs and benefits of commercial shellfish harvest strategies and shellfish restoration in Washington State, and quantify these costs and benefits in economic terms where possible.

2. Inform and educate local, regional and federal policy makers, industry representatives, tribal members, and other stakeholders of the outcome of this research and make recommendations to regulators and managers as to how best use this information in decision making to enhance economic and environmentally sustainable shellfish production and restoration.

3. Provide a framework for other geographic locales to evaluate the environmental benefits and costs of their aquaculture and shellfish based economies.

RATIONALE:
Resource managers at the state and national level have called for the integration of environmental and economic systems to assist in making trade-off decisions about future management options as they relate to shellfish production, water quality, habitat protection and multi-user issues. This research aimed to integrate environmental and economic systems to evaluate Washington State shellfish production and restoration. As such, this final report summarizes research incorporating a wide range of project team member expertise, including various social, biological and applied mathematical sciences. Project objectives were achieved

through a uniform, interdisciplinary, case-study approach. Throughout this report, supplementary project materials in the form of numerous technical memorandums prepared for the Pacific Shellfish Institute are referenced. These technical memorandums are listed at the end of this report and are submitted as project deliverables. Although this final report[1] was created in an attempt to simplify dissemination of key findings, under most circumstances the technical memorandums should be consulted directly and cited accordingly.

FINAL REPORT:

1. Literature Review

Although literature review was an ongoing component of any research, the defined elements of this project's literature review were completed during the first year of the project. Northern Economics finalized a report, titled: "*Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature*." The document is a valuable summary of current literature related to the ecosystem services of shellfish, and in order to orient non-economists to economic valuation, the review also describes the economic concepts and methods that have been applied in the literature. The emphasis of the literature review is on socioeconomic and biological studies of the shellfish resources of the Pacific Northwest; however, studies of the shellfish resources of many other areas are also discussed. The report has been widely shared with interested individuals and organization, and is available in PDF format on the Pacific Shellfish Institute (PSI) website: www.pacshell.org.

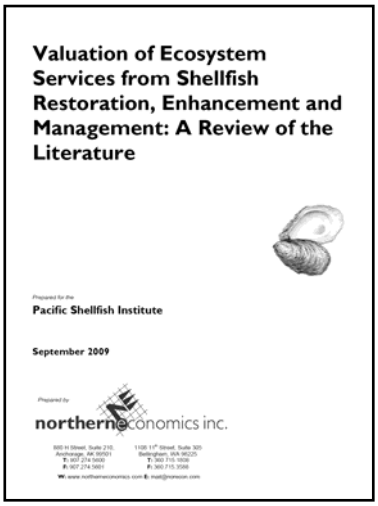

Figure 1. Literature review of ecosystem services of shellfish.

Section headings of the report include:

- Description of Ecosystem Services
- Economic Valuation of Ecosystem Services
- Costs of Shellfish Restoration
- Enhancement and Management
- Economic Valuation Issues and Considerations
- Economic Impact Analysis

2. Economic Concepts and Methods behind Valuation

Central to Northern Economics' discussion of the literature is economic valuation. Economic valuation of ecosystem services can be defined as the process of expressing a value for these services in monetary terms. Estimating the economic value of resources is frequently an important element in the formation and institution of efforts to prevent the twin problems of under-provision and overexploitation of public goods (Isaacs et al 2004). Today, the identification and quantification of ecosystem values is not only possible, it is increasingly seen as essential for the efficient and rational allocation of environmental resources among competing social and political demands (National Research Council 2004). While most of the ecosystem

[1] For the purpose of NA08OAR4170822 progress reports, numbered tasks were referenced. In contrast, for this final report task numbers have been eliminated and replaced with descriptive section headings.

services provided by shellfish are not sold in markets and, therefore, not priced, there are exceptions, the principal one being the commercial harvest of shellfish for food. However, in the absence of information on the value of un-priced ecosystem services, the default measure of project success tends to be fisheries-based metrics such as harvest of market-sized oysters. The results are often disappointing due, in part, to a mismatch between the scale of restoration and measured outcomes. So although there is increasing recognition that shellfish provide multiple ecosystem services, management of shellfish and their habitats for objectives beyond recreational and commercial harvest has not yet become widespread (Brumbaugh and Toropova 2008).

Specific ecosystem and cultural services of shellfish are described, including provisioning services, regulating services, water quality maintenance, protection of shorelines and sediment stabilization, carbon sequestration, supporting services, cycling of nutrients, and nursery habitats (Table 1).

Table 1. Ecosystem Services Provided by Shellfish

Provisioning	Commercial, recreational and subsistence fisheries Aquaculture Fertilizer and building materials (lime) Jewelry and other decoration (shells)
Regulating	Water quality maintenance Protection of coastlines from storm surges and waves Reduction of marsh shoreline erosion Stabilization of submerged land by trapping sediments
Supporting	Cycling of nutrients Nursery habitats
Cultural	Tourism and recreation Symbolic of coastal heritage

3. Economic Impacts

Shellfish production provides revenues, jobs and income to local and regional economic systems. However, the database for Washington's shellfish production volume has significant limitations, as discussed in Section 3 of this report. Northern Economics attempted to address this data gap by conducting a preliminary revenue and expenditure analysis of commercial shellfish farms in Little Skookum (Manila clams) and Totten Inlet (mussels and oysters). The analysis is a step toward developing a more comprehensive cross-sectional economic survey of shellfish growers to estimate a production function and build an input-output model for the Washington shellfish industry. Determining the production function for the Washington shellfish industry is a significant undertaking, largely because so little data is currently collected or available for the industry. Northern Economics worked closely with PSI and Little Skookum Shellfish Growers to design a test survey and conduct the survey among south Puget Sound shellfish growers. The survey explicitly queried shellfish producers about their production volumes, revenues, and expenses.

Northern Economics analyzed the survey responses (confidentially) to both summarize findings and to assess necessary changes that would ensure the effectiveness of a full survey. Summary findings are reported in Northern Economics technical memorandum to PSI, titled "*Puget Sound Shellfish Revenue and Expenditure Survey*." The goal was to acquire additional resources in order to conduct a more comprehensive survey of shellfish growers. At present, additional

resources have been secured with NOAA Grant #NA10OAR4170057 "West Coast Shellfish Aquaculture – Economic Impacts, Barriers to Entry and Opportunities for Expanded Production" and full economic impact analysis of Washington, Oregon and California's shellfish aquaculture industry is underway. Based on findings summarized in Northern Economics "*Puget Sound Shellfish Revenue and Expenditure Survey*" a revised survey is being utilized for NOAA Grant #NA10OAR4170057, which will enable Northern Economics economists complete IMPLAN® modeling (Figure 2).

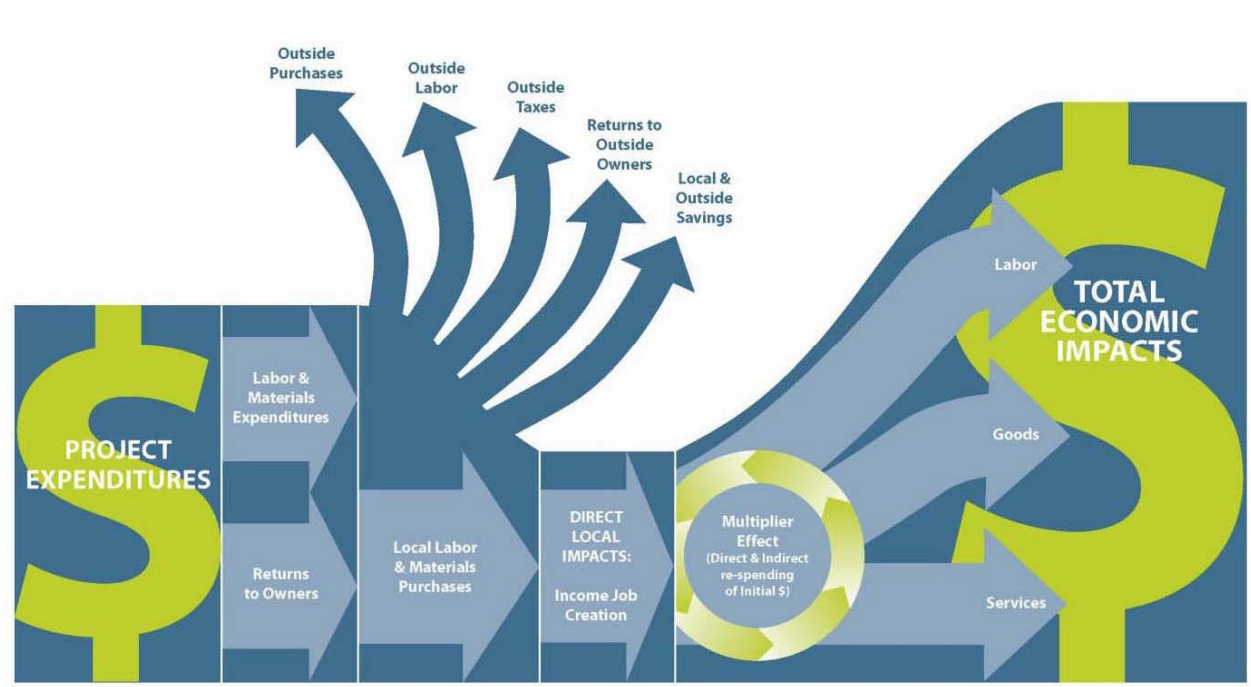

Figure 2. How IMPLAN® measures economic impacts. (Graphic by Northern Economics.)

To examine to potential negative economic impacts of shellfish production in Washington State, residential property values were examined. Northern Economics recommends hedonic analysis as the preferred method to investigate the question of whether the negative externalities created by commercial shellfish harvesting activities have a detrimental effect on property values, but limited resources made the development of such a model for the South Puget Sound Region impractical. The hedonic method attempts to find the price effect associated with the characteristics that affect the home or property sales price. Therefore, hedonic method provides the price impacts that commercial shellfish harvesting has on property values.

Northern Economics "*Property Value Study*" memorandum to PSI indicates that the potential for discernable quantitative effect on property values exists, but the effect may be so specific to individual buyers or sellers that it is not discernable in a qualitative interview. The fact that so few of interviewees of Northern Economics' survey noted a market effect could mean that there is no discernable broad-based market effect and that buyers who are turned off by commercial shellfish operations are replaced by willing buyers willing to tolerate or take advantage of these operations. Table 2 outlines a non-inclusive list of variables that could be used to explain the sales price of properties in the South Puget Sound Region. The list is based on information collected from the key informant interviews and research on studies that used hedonic property valuation models.

Table 2. List of Hedonic Variables compiled by Northern Economics for future analysis.

- Specific location of residential properties
- Number of bedrooms
- Number of bathrooms
- Lot size
- Garage
- Age and condition of building
- Square footage of the home
- Property taxes
- Shore/beach access
- View (e.g. sound, river, lake, etc.)
- Waterfront or non-waterfront property
- Bank height
- Distance to major highways
- Distance to major employment centers
- Proximity to tidelands used for commercial shellfish harvesting activities
- Existence of shellfish culture contracts providing income to the property

4. Oakland Bay Case Study

The purpose of this case study was to quantify nitrogen removal services provided by shellfish in Oakland Bay, southern Puget Sound. Since nitrogen is the nutrient that most likely limits phytoplankton productivity, and phytoplankton productivity partially determines dissolved oxygen depletion, most research has focused on estimating the magnitude of nitrogen sources. Our research, lead by Herrera Environmental Consultants, Inc. summarizes nitrogen loads in Puget Sound, but also assesses the potential of nitrogen removal via shellfish harvest. Herrera's report indicates that shellfish harvest in Oakland Bay removes 11.7 MT/year of nitrogen, and Puget Sound commercial aquaculture harvest removes an average of 62 MT/year. Average annual harvests were determined by averaging the most recent (2000-2008) years of data in metric tons (MT) wet weight, and shellfish nitrogen concentration was assumed to be 1 percent of the total wet weight, a value well supported by the literature (Rice 2001, Ojea et al. 2004, Linehan et al. 1999) and previously compiled data for two shellfish species widely farmed in south Puget (Table 2). The Table 2 shellfish nitrogen concentrations were determined by collecting ten shellfish (whole animals) from two locations, Henderson Inlet and Oakland Bay, both in south Puget Sound, on ten different occasions. Samples were then analyzed by EXOVA, a materials testing laboratory in Portland Oregon, using the Kjeldahl Method for determination of total nitrogen content in a tissue.

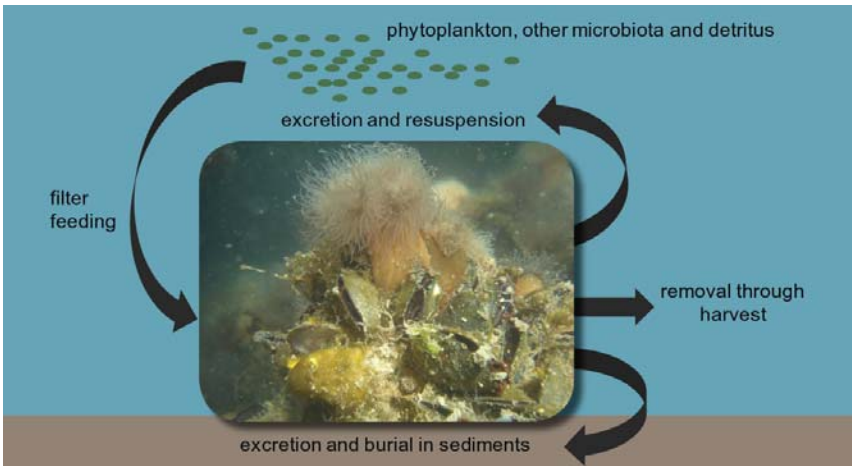

Figure 3. Simplified depiction of nitrogen cycling by shellfish.

Table 2. Average nitrogen (N) concentration, as a percentage of live weight, in two shellfish species widely farmed in south Puget Sound, Washington. (SD = 0.08 for both mean N concentrations.)

Shellfish species	Location	N concentration
Pacific oyster (*Crassostrea gigas*)	Henderson Inlet	0.95%
Manila clam (*Venerupis philippinarum*)	Oakland Bay	0.96%

However, the overall values for Oakland Bay and Puget Sound most likely vastly underestimate N removed by farmed shellfish because a complete record of shellfish production does not exist for Washington State. Harvest records utilized for Herrera's estimate were provided by the Washington State Department of Fish and Wildlife in association with their management of Aquatic Farm leases. However, harvest reporting associated with Aquatic Farm leases was previously voluntary, and compliance remains incomplete at best, due to a number of factors. Foremost, the Department's data collection method is to mail paper surveys to Aquatic Farm leasees quarterly, to collect shellfish production volume and value. Units of measure are up to the individual completing the survey, as well as reported value. Data collected is periodically entered into a database when completed surveys are received by the Washington Department of Fish and Wildlife. Discussion with Department staff indicated that some follow-up is conducted when surveys are not received, but little, if any, data quality control is performed.

5. Liberty Bay Case Study

Liberty Bay, in central Puget Sound, provides an ideal case study site for an examination of the benefits of native oyster restoration. Between 2005-2008, the Puget Sound Restoration Fund (PSRF) and Baywater, Inc assessed the costs and benefits of several years of enhancement activity in Liberty Bay using Pacific oyster (*Crassostrea gigas*) shell as a basement layer to increase the availability of emergent hard structure for native oyster settlement and subsequent recruitment. Findings were reported by PSRF in the memorandum titled "*Liberty Bay Case Study, Subtast 8a.*" In short, increasing the quantity of emergent shell material in Liberty Bay had the overall effect of increasing native oyster density. Results showed that the complex habitat associated with the creation of emergent substrate for settlement of native oysters can increase oyster abundance. Significant increases in abundance and species diversity of associated invertebrates, particularly epibenthic organisms (mainly harpacticoids), were also observed on emergent shell material.

To examine long term effects, 18+ year control plots were analyzed to assess the availability of settlement substrate relative to oyster abundance. Results demonstrate a positive (but weak) statistical relationship with total oyster abundance. Plots established in 2005, 2007 and 2008 show no statistical relationship for these parameters. What this suggests are three things: First, it is increasingly clear that multiple recruitment events over a period of years are necessary to populate an enhanced native oyster bed at this site. Second, the volume of cutch material may exceed the recruitment potential, at least over the period of study. Loss of shell due to submergence into underlying muddy substrates will likely occur over time, so there is a significant benefit to adding more rather than less shell material to support oyster recruitment. Third, the existence of significant populations of oysters on remnant Pacific oyster shell in Liberty Bay indicates that Pacific oyster shell is both effective in the short run and provides long lasting recruitment benefits. Overall, this site demonstrates a restoration potential for reestablishing significant populations of native oysters.

PSRF's memorandum to PSI also summarized the economic investment applied to Liberty Bay oyster restoration. Resources dedicated to enhancing mudflats in Liberty Bay with hard substrate ($294,000 total) demonstrated that that cost of establishing enhancement plots is roughly $50,000 per acre when Pacific oyster shell is deposited on mudflats or other substrates without significant amounts of emergent substrate. The 2,180 cubic yards of shell distributed on tideflats over the course of the project increased the native oyster population by 50% (from 691,884 oysters to 1,030,000 oysters) and provided a basement layer of shell that will be available for recruitment in future years.

Native shellfish restoration efforts also affect water quality issues, though unlike shellfish aquaculture where shellfish are removed from the watershed at harvest the removal of nutrients at harvest is not a prime consideration for such activities. As native oyster beds increase in size and ecological complexity, however, a suite of other benefits will likely emerge. Foremost is the potential through benthic pelagic coupling for native oysters to help facilitate nitrification and denitrification processes. Recent work suggests that complex habitats associated with oyster beds may significantly enhance ecosystem services related to nitrogen sequestration in estuaries subject to high nutrient loading (Cornwall et al., 2011). These processes have not been demonstrated in native oyster beds and remain a prime focus with renewed interest to better define and characterize.

Figure 4. Remnant Pacific oyster (*Crassostrea gigas*) shell, native clamshell at Liberty Bay Scandia with native oysters of several size classes indicated by arrows.

6. Drayton Harbor Case Study

The benefits and costs of a community shellfish farm in Drayton Harbor, north Puget Sound, was thoroughly examined and reported by Dr. Susan Burke in "*Drayton Harbor Oyster Farm Community and Ecosystem Benefits.*" Benefits of developing and operating the Drayton Harbor Community Oyster Farm (DHCOF) to both the ecosystem, and the community of Drayton Harbor and surrounding Whatcom County, Washington are documented. Dr. Burke's extensive report, which drew largely from information provided by the farm's manager, Geoff Menzies, presents a methodology to identify, describe and categorize the myriad of benefits provided by the farm. Detailed appendices are also included with the report. A brief summation the benefit categories, and how they can be valued, are presented in Table 3.

Historically, over 100 acres of the Drayton Harbor was utilized for shellfish production. If water quality in Drayton Harbor improved to a level that those 100 acres could be re-opened to unconstrained commercial operations the economic impact could be as high as $1,235,000 annually. That estimate is based on the per-acre revenue generated by the DHCOF, resulting in an estimate of $700,000 in annual production value and $535,000 in economic 'ripple' effects

throughout the region. The public investment necessary to improve water quality also yields a variety of direct and indirect benefits available to the City of Blaine and Whatcom County from continued investment in water quality. Furthermore, the creation of social capital that has occurred over the decade of volunteerism in the DHCOF is challenging to quantify however likely of greater value to the community. Public investment in volunteerism activities like the DHCOF buys more than shellfish production, habitat and human health benefits; it provides social capital necessary for effective government.

Table 3. Benefits of the Drayton Harbor Community Shellfish Farm (DHCOF) in northern Puget Sound, Washington, and the valuation method utilized for benefit determination.

			Quantified Value or Quantification	
Benefit Category	***Benefit Description***	***Valuation Method***	***Project Benefit***	***Ancillary Benefit***
Provisioning	Oyster Harvest	Market value & econ. impacts	$25K max year	Tribal estimated (30K-50K lbs) valued at $86K
Regulating	Water quality improvements	Willingness-to-pay	$53K	
	N removal	Replacement	TBD $31.62mg/L -$1.65 mg/L	Biofiltration
Cultural	Regional planning	Replacement	Volunteers time $24K-$41K	Social capital
	"Farmers of the Tideflats"	Qualified	Volunteers' value "keeps me young"	Inspirational, Recreational, Educational, Spiritual
Supporting	Aquaculture	Replacement	No direct benefit to the DHCOF	Nutrient cycling, habitat structure and quality

7. Comparisons of Water Quality Benefits

Cost data collected from regional waste water treatment facilities, along with similar national data summarized in earlier investigations, are used to estimate the benefit- in dollars- of nitrogen removal services provided by shellfish. This effort appears to be the first of its kind in the U.S. to put a price on shellfish nutrient removal services. Findings are reported in: "*Estimating Water Quality Benefits from Shellfish Harvesting: a Case Study in Oakland Bay, Washington*." Compared to the cost of traditional waste water treatment processes, the 11.7 MT (25,787 lbs) annual N removal by shellfish in Oakland Bay can be viewed as $77,100- $650,863 annual water quality benefit. These values were derived by employing replacement cost method to the estimates of average nitrogen removed by shellfish harvest calculated in section 4 of this report, the Oakland Bay Case Study. The most relevant monetary data sets for the Oakland Bay case

study are the City of Shelton waste water treatment facility, which discharges into the bay, and a nearby facility in Olympia, Washington. The City of Shelton facility is currently investing in improved nitrogen removal technology, which will increase nitrogen removed from 10.0 mg/L to 4.0 mg/L. The City of Shelton facility treats an average of 3.3 million gallons per day and the upgrade would remove approximately 365,000 lbs of nitrogen. Similarly, the nearby LOTT wastewater treatment facility (which serves Lacey, Olympia, Tumwater and Thurston County, hence "LOTT") is planning a 2017 upgrade to increase its nitrogen removal capacity from 4.0 mg/L to 2.25 mg/L. The LOTT facility currently treats an average of 18 million gallons per day and the upgrade would remove approximately 86,356 lbs of nitrogen.

Shellfish N removal value based on City of Shelton 2010 upgrade:
25,787 lbs N/year x $2.99 life cycle cost of N removal technology =
$77,100 annual water quality benefit

Shellfish N removal value based on LOTT 2017 upgrade:
25,787 lbs N/year x $25.24 life cycle cost of N removal technology =
$650,863 annual water quality benefit

The life cycle costs for both calculations are based on capital costs only, annualized and assuming a 6% discount rate of a 20 year life. The annualized capital was divided by the lbs of nitrogen removed to obtain the per unit capital. Life cycle costs would normally include operation and maintenance costs as well, which would increase the annual water quality benefit figure, but these costs are not yet available for these two upgrades.

8. Stakeholder Input

Stakeholder input of significant perceptions, concerns, and values related to shellfish production and restoration were gathered as part of this research, with additional funding provided by Washington Sea Grant. There were several different stakeholder groups with an interest in shellfish harvest and restoration practices, ranging from groups that benefit directly from shellfish production (e.g., industry, recreational shellfish harvesters, tribes) to those with competing uses for the areas where shellfish production occurs (e.g., near shore property owners and NGOs such as Audubon). With assistance from the project team, Northern Economics invited participants to four stakeholder feedback sessions. The sessions were held during evening hours on four separate dates, in four Puget Sound locations: Oakland Bay (Shelton), Liberty Bay (Poulsbo), Drayton Harbor (Blaine), and Totten Inlet (Olympia). The locations were chosen because of their association with case-study areas used in other areas of this project's research. The object of the stakeholder feedback sessions was to learn more about stakeholder objectives, perspectives, and values related to shellfish production and restoration in Puget Sound. All sessions were held in neutral locations and moderated by a professional facilitator. Participation was good and covered a range of stakeholder groups including NGOs, the Tribes, shellfish growers and commercial harvesters, recreation shellfishers, shoreland property owners, non-shoreland residents, and state, local and federal agency representatives.

The outcome of the sessions was summarized by Katherine Wellman of Northern Economics, in her report titled: "*Perceptions and Values of Shellfish Stakeholders*." Results from the four focus groups indicate some degree of consistency across geographic locations in terms of perspectives of benefits and costs of shellfish production and restoration (Table 4). Generally, participants

expressed the view that there are significant economic, social, and environmental costs and benefits, though social benefits stood out as a dominant factor across the four focus groups. The desire to resolve multiuse conflicts was explicitly stated as a future goal, along with a healthy shellfish industry that does not adversely impact the carrying capacity of the ecosystem. However, there are recognized limitations to the work. Worth mentioning is that while focus group participants were invited from a wide set of stakeholders, those that chose to attend a focus group were, for the most part, proponents of shellfish production and restoration. As a result, output from the focus groups is most likely biased.

Table 4. Summary of stakeholder feedback provided during four facilitated sessions in north, central and south Puget Sound, Washington.

Benefits consistently raised in all sessions:	**Costs consistently raised in all sessions:**
• Traditional and cultural value • Source of tribal subsistence • Commercial food source • Iconic association to the Pacific Northwest and generation of sense of place • Fostering of environmental stewardship • Educational opportunities • Provision of habitat and structure for other species • Provision of ecosystem services such as nutrient uptake and nitrogen removal • Indicator of health of ecosystem • Positive economic impacts to local communities	• Greater impacts to landowners from water quality regulations and waste treatment requirements • Land use conflicts • Litter and waste material from commercial aquaculture • Property rights and equality concerns

Dr. Wellman's report also includes the results and discussion of a survey of Suquamish Tribe members in March 2009. One hundred thirty-five of the approximately 1,000 Suquamish tribal members described their perceptions of native oyster recovery efforts in Liberty Bay. The bay is part of the Tribe's Usual and Accustomed Fishing Ground, and the Tribe has been an active and willing partner in native oyster rebuilding since 1999. A survey of tribal members was intended to reach beyond tribal staff and tribal council members to ascertain the importance of native oyster recovery to other tribal members and to engage them in restoring a resource of cultural and historic significance. The event on March 15th, at which tribal members elected the new tribal council members, provided an opportunity to solicit broader input and at the same time impart information about the multiple dimensions of native oyster recovery—encompassing ecological, economic, social, and cultural benefits. Among the survey respondents, 65 percent felt that native oyster filtration was a valuable service provided to the ecosystem; 48 percent stated nitrogen removal; 59 percent said habitat; 38 percent said other or did not know. When asked if native oysters provide services that they would be willing to pay for, 75 percent of respondents circled cultural services, 47 percent recreational, 50 percent ecological, 42 percent economic, 39 percent social, 13 percent other. However, when asked if they would be willing to pay for a septic operation and maintenance program to improve water quality for recreational, tribal and commercial shellfish harvest, only 51 percent said yes.

9. Qualitative Discussion of Benefits and Costs

Placing a statistically significant or robust quantitative value on the benefits and costs of Washington shellfish is not possible, therefore qualitative discussion was used to balance areas in which a quantitative assessment of the monetary value is possible. This project generated a report describing the suite of economic, social, and environmental benefits and costs associated with shellfish production and restoration in Washington State. That report, "*Assessment of Benefits and Costs Associated with Shellfish Production and Restoration in Puget Sound*" was prepared by Northern Economics, using information derived from the literature review, stakeholder focus groups and all other areas of this project's research.

Economic benefits are the most easily identifiable. Washington is the leading producer of farmed bivalve shellfish in the United States. Farmed shellfish harvest in the state (Puget Sound and Coastal Washington) has increased from 5.6 million pounds in 1970 to 7.6 million pounds in 2008 with an estimated 2006 ex-vessel value of $107 million. Commercial enterprises generate revenue for the state through licensing and lease fees and contribute direct employment, secondary employment (e.g. shucking and packing houses, transport, manufacture of prepared oyster products and retail sales), and a number of other local economic impacts.

Research suggests that shellfish also provide several environmental benefits or ecosystem services (in addition to the commercial and recreation harvest), by enhancing water quality and providing essential habitat structure. Shellfish enhance water quality through increased biodeposition of organic matter in sediments leads to increased bacterial denitrification, which when harvested, can help to remove nitrogen from estuarine systems. Decreases in concentrations of particulate matter from water increases water transparency and primary productivity and decreases bacteria and pathogen concentration in water. Shellfish may also play a role in sequestering carbon in the calcium carbonate of shells, thereby reducing concentration of a greenhouse gas. Shellfish production and restoration can contribute to increasing abundance of natives species such as geoduck (commercial) and native oysters (restoration). Reintroduction of native shellfish species may also reduce the establishment of non-native shellfish species in Washington.

Figure 5. "Farmers of the Tideflats" with their 1st hard won bushel of oysters in 2004, after the harbor was reopened. Photo by: Jack Kintner, Chapter Two Communications

In addition to benefits to water quality, shellfish also function as natural breakwaters that protect the shoreline against the erosive force of wind- and boat-generated waves, thereby reducing bank erosion, protecting fringing salt marsh, and decreasing loss of aquatic vegetation beds, such as eelgrass. As ecosystem engineers, shellfish can create conditions that allow many other plant and animal species in estuaries and coastal bays to thrive, including other commercially or recreationally important species. Bivalve shellfish can help to structure benthic communities in

other ways even when they do not provide the dominant physical structure, providing nursery and nesting sites for fish and attachment points for macroalgae and a variety of invertebrates. The Liberty Bay case study showed that the complex habitat associated with the creation of emergent substrate for settlement of native oysters can increase oyster abundance. Significant increases in abundance and species diversity of associated invertebrates, particularly epibenthic organisms (mainly harpacticoids), were also observed on emergent shell material.

Shellfish also provide significant social and cultural benefits. Commercial production provides a sustainable, high protein food source for local communities. Indeed, shellfish culture has a long and vibrant history in Washington, and represent significant cultural heritage for communities and tribes alike. The iconic value and abundance of shellfish in Washington also create environmental education and stewardship opportunities, brining environmental problems to the attention of nearby communities. Community support and involvement in shellfish restoration and enhancement projects has been particularly effective in heightening public awareness of the need to rehabilitate and conserve marine and estuarine ecosystems. The Drayton Harbor Community Oyster Farm case study demonstrated that in addition to economic and environmental benefits, public investment in volunteerism has also provided the social capital necessary for effective government in the area.

While there are numerous benefits to shellfish cultivation and restoration, there are also economic, environmental, and social costs associated with these activities. In examining the fixed and variable operations and maintenance costs of commercial aquaculture operations, it was discovered that the cost structure and primary product among of Puget Sound shellfish producers differs greatly. These differences resulted in impressive variation across expense categories. The largest average expense for shellfish producers was for growing and harvesting crews, followed by managers and executives, tideland leases, and growing/harvest supervisors.

Memorandums generated under Project Number NA08OAR4170822:

- Northern Economics, Inc. *Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature*. Prepared for Pacific Shellfish Institute. September 2009.
- Northern Economics, Inc. *Assessment of Benefits and Cost Associated with Shellfish Production and Restoration in Puget Sound*. Prepared for Pacific Shellfish Institute. April 2010.
- Northern Economics, Inc. *Perceptions and Values of Shellfish Stakeholders*. Prepared for Washington Sea Grant and Pacific Shellfish Institute. June 2009.
- Northern Economics, Inc. Technical Memorandum "*Puget Sound Shellfish Revenue and Expenditure Survey*" April 16, 2010.
- Northern Economics, Inc. Technical Memorandum "*Property Value Study*" January 24, 2010.
- Entrix, Inc. Technical Memorandum "*Estimating Water Quality Benefits From Shellfish Harvesting: A Case Study in Oakland Bay*" September 25, 2009.
- Entrix, Inc. Technical Memorandum "*Task 8b Drayton Harbor Community Oyster Farm Community and Ecosystem Benefits*" July 2010.
- Puget Sound Restoration Fund. Technical Memorandum "*Liberty Bay Case Study, Subtast 8a*" April 12, 2011.
- Herrera Environmental Consultants, Inc. Technical Memorandum "*Nitrogen Removal with Shellfish Harvest in Oakland Bay and Puget Sound*" February 15, 2010.

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