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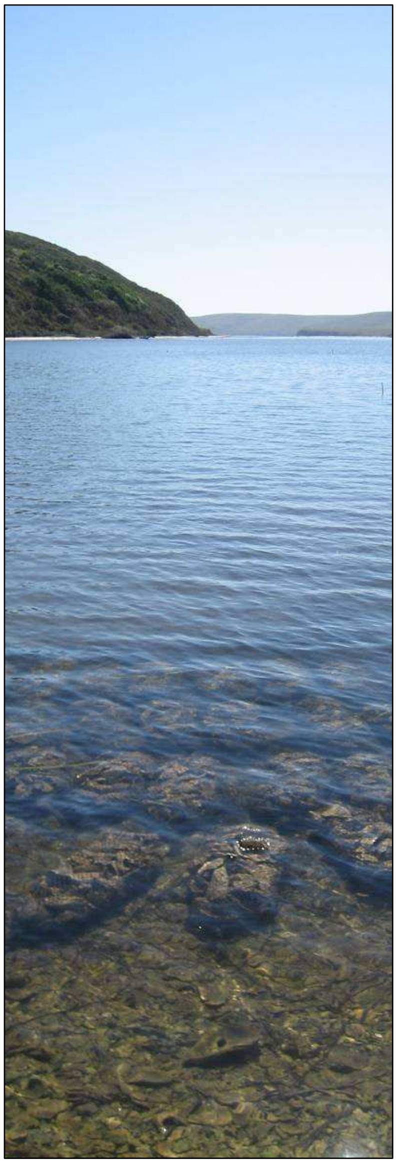

# Developing Aquaculture to Support Restoration of the Native Oyster, *Ostrea conchaphila*, in California

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Donald Bren School of Environmental Science and Management

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DONALD BREN SCHOOL OF
ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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## Table of Contents

## List of Figures

## List of Tables

## List of Equations

## Abstract

California's only native oyster, the Olympia oyster (*Ostrea conchaphila*), is an ecosystem engineer that creates biogenic reef habitat, stabilizes estuarine substrate, and improves water quality through biofiltration. However, the species is now ecologically extinct due to habitat degradation, reduced water quality, and a history of overfishing. Recently, California State and Federal agencies recognized this oyster as a priority for restoration. Oyster restoration projects are costly and have historically relied heavily on government appropriations. Our research addressed the question of whether it is feasible to initiate a commercial Olympia oyster aquaculture operation, currently non-existent in California, as a market-based source of support for restoration projects. We hypothesized that a commercial Olympia oyster aquaculture business is financially feasible and could be used to offset high restoration costs through oyster seed and shell donations, technical support, advanced research, and funding. Our market analysis revealed non-monetary purchasing preferences (e.g., taste and 'green' image) and strong demand for Olympia oysters in California. Our production analysis revealed that a public-private partnership between a commercial aquaculture facility and a public organization was the most cost-effective means of production. We integrated our findings into an innovative business model that supports restoration goals while generating a profit. Our work indicates that Olympia oyster aquaculture is feasible and could provide significant support to restoration projects in California.

## Executive Summary

### Background and Significance

The Olympia oyster (the "Native oyster"), *Ostrea conchaphila*, is an ecosystem engineer that creates reef habitat, stabilizes estuarine substrata, improves water quality through filtration, recycles nutrients, and potentially occupies a critical position in California's coastal marine food webs (Lenihan 1999; Ruesink et al. 2005; Lotze et al. 2006). Due to overharvesting, degraded water quality, habitat loss, exotic competitors, invasive predators, and probable interaction among these factors, Olympia oyster populations declined significantly in California during the early 20th century (Barrett 1963). By the 1970s, only remnant populations of Olympia oysters remained in select California bays and estuaries (Baker 1995). Given the Olympia oysters' ecological significance, the California Ocean Protection Council and the National Oceanic and Atmospheric Administration (NOAA) recently identified them as a priority species for restoration in California (NOAA 2003; California Ocean Protection Council 2006). In 2007, NOAA's Community-Based Restoration Program (CRP) allocated approximately $900,000 in federal funding to several small-scale (one acre or less) Olympia oyster restoration projects in central and northern California (NOAA Restoration Center 2007). While these restoration projects continue to provide critical guidance on Olympia oyster restoration techniques, the federally-funded restoration programs are limited in their scale and scope. The high costs of restoration limit the ability of federal and state governments, municipalities, environmental organizations, and private individuals to expand the network of Olympia oyster restoration projects.

Commercial Olympia oyster aquaculture represents an alternative means of support for expensive restoration projects. Through culturing and selling oysters, an oyster aquaculture business could provide oyster seed, shell substrate, or funding to restoration projects. Furthermore, commercial aquaculture could provide invaluable technical expertise to restoration programs and increase public awareness of this ecosystem engineer's significance through marketing the Olympia oyster product. Thus, oyster aquaculture may represent a potential market-based pathway to support restoration projects. A profitable Olympia oyster aquaculture business that incorporates restoration objectives could align public and private incentives, resulting in a new aquaculture product for the market, enhanced restoration programs, and better stewardship of coastal marine resources.

Currently, the only commercial production of Olympia oysters is in Washington State, but genetic differences amongst Olympia oyster populations limit these producers from supporting restoration projects in California. Restoration projects generally adhere to the precautionary principle and, therefore, avoid importing different genetic populations of oysters. Further, Washington-produced Olympia oysters rarely reach the California oyster market due to the significant transportation costs. Thus, there is a unique market opportunity to commercially produce Olympia oysters and provide critical support to California's restoration efforts.

**Purpose and Research Questions**

The purpose of our research was to evaluate the feasibility of integrating Olympia oyster restoration goals into a commercial aquaculture business model in California. Our client, The Nature Conservancy (TNC), sought guidance on the potential for a market-driven business model to enhance the scale and scope of Olympia oyster restoration projects. Therefore, our objective was to answer the following research questions:

1. Is commercial Olympia oyster aquaculture feasible in California?
2. Can a commercial aquaculture operation support Olympia oyster restoration in California?

**Approach**

Our analysis evaluated the feasibility of an Olympia oyster aquaculture business through an investigation of Olympia oyster market demand and aquaculture production costs. We combined these two elements and developed a profitability projection model to determine the overall feasibility of an Olympia oyster aquaculture business. Through extensive research on Olympia oyster restoration, we identified specific ways that an aquaculture business could contribute to restoration projects. Finally, we integrated our Olympia oyster restoration research findings into the profitability projection model to quantify the potential restoration benefits from the business. The following section will briefly outline the methodology of each step in our analysis.

The initial step in our feasibility analysis was to evaluate the demand for Olympia oysters in California. To evaluate the demand, we conducted a telephone survey of the target market: raw bars and high-end seafood restaurants. We selected these restaurant types as our target market through an analysis of market consumption trends and interviews with seafood distributors and other experts in the field. We focused our demand analysis on the largest seafood markets in California: San Francisco, Los Angeles, and San Diego. The goal of the survey was to identify the revenue-maximizing price for wholesale Olympia oysters and the key factors restaurants consider when adding oysters to their menu.

Following the market demand analysis, we identified Olympia oyster aquaculture production costs in California. This analysis required extensive research into the biological constraints, aquaculture techniques, site-selection, legal requirements, and costs of Olympia oyster aquaculture in California. Based on this analysis, we narrowed the number of aquaculture sites to those that met biological and legal constraints. Additionally, we identified appropriate production techniques for Olympia oyster aquaculture in California. Given these findings, we developed and compared several Olympia oyster production cost scenarios that outlined the specific costs of the two phases of oyster production: hatchery (seed production) and growout (near-shore development). We then paired the most cost-effective hatchery scenario with the most cost-effective growout scenario to form the foundation of our profitability projection model.

With our profitability projection model, we used results from the market demand analysis and the production cost scenarios to project the cumulative profitability of the Olympia oyster aquaculture business over a designated time horizon. The profitability projection model provided the final results of our feasibility analysis.

Next, we researched the status of scientific knowledge on Olympia oyster restoration and outlined how aquaculture could support restoration in California. We quantified the direct benefits of Olympia oyster aquaculture to restoration with the profitability projection model. Finally, we integrated all of our findings into an Olympia oyster aquaculture conceptual business model.

**Key Findings**

Our market survey revealed a significant demand for Olympia oysters at raw bars and high-end seafood restaurants in California. The survey showed that, on average, restaurants would purchase 31 dozen Olympia oysters per week from an aquaculture business if they were sold at the wholesale price of Pacific oysters (*Crassostrea gigas*) (the most common oyster in the West Coast seafood market, currently sold at about $0.60 per oyster). As expected, restaurants demanded fewer Olympia oysters as the price increased from $0.60 to $1.50 per Olympia oyster. Our analysis showed that the $1.20 price per oyster maximized revenue from Olympia oyster sales to the aquaculture business. However, we concluded that $0.90 per Olympia oyster, which resulted in only $5 less revenue per restaurant, was the best price for our target market because it was competitive with the current market price for specialty oysters in California. At $0.90 per oyster, restaurants demand an average of 21 dozen Olympia oysters per week.

In addition to revealing the target price and estimated weekly demand, our survey results revealed that the flavor of the oyster was the most important factor that respondents consider when they decide whether to add a new variety of oyster to their menu. In order of importance, the flavor factor was followed by sustainable production, a ‘green’ marketing story, and the fact that Olympia oysters would be locally produced. Out of nine potential factors, price ranked seventh in relative importance. This low rank suggested restaurants are willing to add a new oyster, even at a high price, as long as it satisfies the other criteria. Additionally, respondents expressed an interest in being able to market their participation in an Olympia oyster shell recycling program as part of their advertising. The shell recycling program would allow restaurants to directly contribute to Olympia oyster restoration projects.

Our evaluation of hatchery and growout production cost scenarios revealed that a public-private partnership between the University of California, Santa Barbara, and Drakes Bay Family Farms was the most cost-effective way to start a commercial Olympia oyster aquaculture operation in California. Drakes Bay Family Farms is located in relatively pristine Drakes Estero, which has a resident population of Olympia oysters that could be collected as broodstock for seed production. As an established Pacific oyster aquaculture business, Drakes Bay Family Farms has existing infrastructure and leased tidelands that would significantly reduce Olympia oyster aquaculture start-up costs. In addition, Drakes Bay Family Farms has an established clientele and distribution network throughout the metro San Francisco region, California's largest seafood market.

Next, we developed a profitability projection model to evaluate the financial feasibility of an Olympia oyster aquaculture business. The public-private partnership hatchery and growout production cost scenarios provided the foundation for our profitability projection model. The profitability projection model parameterized key variables, such as Olympia oyster mortality, price per oyster, and growth rate, to estimate revenue and production costs over an eight-year time horizon. With our best estimates of the model parameters, the profitability projection model revealed that the public-private partnership made a modest profit over the time horizon. However, our sensitivity analysis demonstrated that profitability was highly sensitive to the mortality parameter. Further investigation revealed that Olympia oyster mortality must be kept at or below 60% to turn a profit.

As a public-private partnership, an Olympia oyster aquaculture venture can remain profitable while supporting restoration efforts through a variety of avenues. We quantified two means of direct support from an aquaculture operation in the profitability projection model: funding and shell donations to restoration projects. The profitability projection model calculated that the public-private partnership had only modest restoration funding potential. Although restoration projects would receive financial support from the public-private partnership, the non-monetary benefits are likely to be more significant. The model predicted that significant quantities of Olympia oyster shell would be available for substrate-limited restoration projects, but the range of values depended on the number of restaurant participants in a shell recycling program.

Beyond funding and shell donations, our research suggests that a public-private partnership will provide invaluable restoration support that cannot be measured in a quantitative analysis. One of the most important benefits from the public-private partnership is the pairing of research, conducted by the University of California, Santa Barbara, with a private aquaculture business. Both parties will work together to solve some of the critical technical uncertainties in Olympia oyster production. These technical uncertainties have direct corollaries to the problems faced by restoration practitioners. Thus, this partnership is likely to provide substantial benefits to both parties. The private aquaculture operation will benefit through increased profits and access to the University's research findings that improve site-specific Olympia oyster aquaculture techniques. Sharing technical expertise and collaboration is likely to strengthen restoration efforts and increase private profit margins. Further, the public-private partnership has the potential to provide a range of in-kind donations to restoration projects. For example, the aquaculture operator could provide oyster seed, aquaculture equipment, or local expertise to restoration projects. Additionally, we expect increased public support of oyster restoration projects as a result of the Olympia oysters' 'green' marketing in restaurants. This marketing strategy may improve public awareness of Olympia oysters and their role as an ecosystem engineer in California's marine ecosystem.

**Conclusions and Recommendations**

The results of our market, production, and profitability analyses indicate that an Olympia oyster aquaculture business is financially feasible in California and could provide support for Olympia oyster restoration projects. Although the efficiency of our production techniques includes some uncertainty, our analyses point to the likelihood of modest, long-term profitability in conjunction with aid to restoration efforts.

Our market analysis showed that restaurants want to buy this oyster and support local restoration efforts. Restaurants' stated preference of the 'green' story and sustainable production over price shows the significant potential for marketing this oyster as a sustainable, local product. Ultimately, our research suggests that restaurants and their customers are willing to support an innovative approach to restoring California's coastal estuaries.

Our profitability findings present a strong case for the adoption of public-private partnerships. Olympia oyster aquaculture represents a unique opportunity for the aquaculture industry to pair with municipal and community restoration projects to enhance California's coastal estuaries. Our study indicates that a public-private partnership is likely to benefit all participating parties and the coastal ecosystem. Establishing an Olympia oyster aquaculture public-private partnership would bolster restoration efforts in California while producing local, sustainable seafood. Further, our business model has the potential to enhance public awareness of the significance of native species restoration projects in California. Finally, our conceptual business model and public-private partnership prototype could develop into a network of Olympia oyster aquaculture and restoration partnerships that could directly improve the ecological integrity of California's coastal ecosystems.

## 1.0 Problem Statement

Full-bodied and sweet with a slightly coppery finish, the Olympia oyster, *Ostrea conchaphila*, has long been revered by oyster connoisseurs as the premier specialty oyster (Taylor Shellfish Farms 1998). The Olympia oyster, also known as the West Coast native oyster, the California oyster, and more commonly as 'Olys', is the only indigenous oyster to the West Coast. Once a profitable commercial commodity, overharvesting decimated Olympia oyster populations throughout West Coast estuaries in the late 1800s and early 1900s (Barrett 1963). Since then, degraded water quality, habitat loss, exotic competitors, and invasive predator pressures further suppressed Olympia oyster populations. In California, a recent survey revealed that Olympia oyster populations still exist in select bays and estuaries, but only at a fraction of their historic abundance (Polson et al. 2006).

With the decline of Olympia oysters, California's estuaries lost an important ecosystem engineer. Olympia oysters create loose reef habitat, stabilize the benthos, improve water quality through filtering, recycle nutrients, enhance benthic biological diversity and occupy a critical position in California's coastal marine food webs (Gordon et al. 2001; Ruesink et al. 2005; Kimbro et al. 2006; Lotze et al. 2006). Over the last decade, the scientific research community recognized that restoring this once-common benthic species could return critical biological, physical, and ecological structure and function to West Coast estuaries detrimentally impacted by anthropogenic change (Peter-Contess et al. 2005).

Given their role as an ecosystem engineer, the California Ocean Protection Council (OPC) and the National Oceanic and Atmospheric Administration's (NOAA) Community-based Restoration Program (CRP) recently identified the Olympia oyster as a priority species for restoration in California (NOAA 2003; California Ocean Protection Council 2006; NOAA Restoration Center 2007). In 2007, NOAA CRP allocated approximately $900,000 in federal funding to several small-scale (one acre or less) Olympia oyster restoration projects in central and northern California (NOAA Restoration Center 2007). While these restoration projects continue to provide critical guidance on Olympia oyster restoration techniques, the federally-funded restoration programs are limited in their scale and scope. A potential alternative restoration approach could include commercial aquaculture, which would capitalize on the Olympia oysters' distinguished taste.

Commercial Olympia oyster aquaculture in California represents an alternative means of support for expensive restoration projects. Commercially-cultivated Olympia oysters could be sold to generate revenue. At the same time, this commercial aquaculture operation could support Olympia oyster restoration programs through funding, technical collaboration, in-kind donations, and donations of oyster seed or shell substrate. Thus, Olympia oyster aquaculture may provide a market-based solution to enhance the scale and scope of Olympia oyster restoration projects in California. Currently, Washington State aquaculture operators produce a limited supply of Olympia oysters each year, which represents the only commercial production on the West Coast. Our research evaluates the feasibility of starting an Olympia oyster aquaculture business in California and quantifies the potential restoration benefits from that venture.

## 2.0 Purpose

The purpose of this group project was to evaluate the feasibility of merging marine restoration goals into a commercial aquaculture business model. Our client, The Nature Conservancy (TNC), sought guidance on the potential for a market-driven business model to enhance the scale and scope of Olympia oyster restoration projects in California.

## 3.0 Research Questions

1. Is commercial Olympia oyster aquaculture feasible in California?
2. Can a commercial aquaculture operation support Olympia oyster restoration in California?

## 4.0 Objectives and Approach

Our research employed a diverse approach, including quantitative and qualitative analyses, to determine the feasibility and restoration potential of a commercial Olympia oyster aquaculture business in California. Our approach examined demand, supply, and restoration objectives independently and then combined these feasibility components into a profitability model. We projected the profitability of the Olympia oyster aquaculture business under different scenarios to determine the venture's overall feasibility. Our three objectives and approach are described briefly below.

**Conduct a market analysis to evaluate demand for Olympia oysters in California**
Our research began with a market analysis of the Olympia oyster product. We researched current global and local oyster consumption trends. Our initial investigation revealed scant information on oyster demand in California. Therefore, we interviewed experts, including aquaculture operators, seafood distributors, and restaurant owners to gauge the market for the Olympia oyster in California. These interviews provided direction on the potential target market and marketing strategies for the Olympia oyster product. Next, we conducted a formal market survey and quantified the demand and consumer preferences for Olympia oysters in California. Finally, we examined market trends and volatility in specialty oyster markets to assess the potential variability in Olympia oyster demand.

**Evaluate the feasibility of an Olympia oyster aquaculture operation in California**
To understand the supply-side feasibility of an Olympia oyster aquaculture business, we researched Olympia oyster biology, disease, predation, legal considerations, site-specific requirements, and aquaculture techniques. Next, we interviewed aquaculture operators, hatchery experts, seafood distributors, restaurant owners, community restoration groups, and the academic research community to estimate costs and evaluate strategies to establish commercial production of Olympia oysters in California. Through research and interviews, we recognized the risks to commercial Olympia oyster production and

developed potential aquaculture technology alternatives. After we identified production costs for potential aquaculture sites, we developed multiple aquaculture production scenarios. We analyzed theses scenarios to determine the most efficient, cost-effective means of producing Olympia oysters.

**Assess whether aquaculture can support Olympia oyster restoration in California and develop a business model that supports restoration objectives**

We first summarized the status of scientific knowledge on Olympia oyster restoration. Participation in the 2007 West Coast Native Oyster (Olympia oyster) Restoration Workshop in Shelton, WA provided detailed assessments of current restoration strategies. Interviews with restoration experts yielded critical insights into restoration bottlenecks. With this information, we identified specific contributions that commercial aquaculture could make to Olympia oyster restoration projects.

We combined our supply, demand and restoration findings into a conceptual business model that generates a specialty Olympia oyster product and incorporates restoration goals. Finally, we developed a profitability projection model to analyze the feasibility of our conceptual business model. This analysis identified the variables that were most important for profitability, estimated the restoration benefits from the Olympia oyster aquaculture business, and evaluated the overall feasibility of the venture.

## 5.0 Significance

An Olympia oyster aquaculture business in California represents an important source of sustainable seafood that could also generate resources for estuarine habitat restoration. A profitable Olympia oyster aquaculture operation has the potential to support restoration on an unprecedented scale through donations of funds, technical expertise, oyster shell, oyster seed, and in-kind donations to a variety of West Coast oyster restoration projects. This market-based solution could impact a large number of restoration projects without being affected by cyclical changes in political power and appropriations cutbacks. For example, community members in Drayton Harbor, WA, created a community oyster farm in the hopes of restoring local shellfish populations through commercial production. Their aquaculture farm successfully restored harvestable oyster populations in the bay. In fact, they harvested and processed more than 50 tons of oysters for local sales and international export in 2004 (EPA 2006).

Through commercial production and sales of Olympia oysters as a "specialty oyster" in California, the aquaculture business could be economically self-sufficient, with the ability to support restoration efforts indefinitely into the future. This market-based solution would privatize public restoration goals, aligning public and private incentives to promote better monitoring, restoration, and stewardship of coastal resources. Since California's demand for oyster products far exceeds the state's production level (Conte 1996), Olympia oyster aquaculture represents a sustainable means to enhance the state's supply of fresh oysters while also providing important ecosystem services.

In addition to the restoration benefits, an Olympia oyster aquaculture operation would also provide locally-grown, sustainable seafood. Unlike all other forms of marine aquaculture, commercially-grown bivalves, particularly oysters, have been identified as the only sustainable form of aquaculture (Naylor et al. 2000). Traditional finfish aquaculture operations contribute to the global depletion of fish stocks because they require significant fish-based feed supplements (Pauly et al. 2002). In addition, finfish aquaculture operations are also a major source of nutrient pollution from fish waste (Naylor et al. 2000; Pauly et al. 2002). Conversely, oysters feed on phytoplankton and suspended organic matter in the water column. Thus, oyster aquaculture operations are generally presumed to have few negative impacts on the local environment (Barrett 1963; Naylor et al. 2000; Shumway et al. 2003).

Oyster aquaculture operations have the potential to improve local water quality conditions by filtering out pollutants, sediments, seston, and phytoplankton from the water column (Naylor et al. 2000; Shumway et al. 2003). For example, estimates by Newell (1988) and Dame (1981) indicate that populations of oysters can improve water quality through biofiltration. This filtering activity is predicted to have a positive impact on important native seagrasses and benthic primary producers (Newell 1988; Newell et al. 2004; Ruesink et al. 2005). Thus, oysters not only represent a critical component of marine food webs, they can also systematically improve water quality, enhance benthic biodiversity through the creation of loose reef habitat, and influence the survivorship of native communities.

The significance of the role of oysters in native marine ecosystems has been closely examined over the past decade. A growing body of research illustrates the significant risks associated with large-scale removal of benthic primary producers (Jackson et al. 2001; Lotze et al. 2006). In Chesapeake Bay, overfishing and poor water quality decimated Eastern oyster (*Crassostrea virginica*) populations, reduced the water filtration capacity of oysters, removed an important constituent of the food web, and shifted marine communities toward algal-dominated systems plagued by eutrophication (Ruesink et al. 2005; Lotze et al. 2006). Without baseline data, it is difficult to assess the impact of the removal of Olympia oyster populations on California's native marine ecosystem.

Considerable political momentum to restore California's Olympia oyster populations surfaced in 2006. Governor Arnold Schwarzenegger's Ocean Protection Council identified habitat restoration of native oyster habitat, wetlands, eelgrass, and kelp as the top priorities for improving the physical processes of California's coast (California Ocean Protection Council 2006). Similarly, NOAA's Community-based Restoration Program (CRP) partnered with academic and non-profit groups to expand the number of Olympia oyster restoration projects in California to include restoration sites in Tomales Bay and San Francisco Bay. Meanwhile, efforts to restore Olympia oysters in Washington and Oregon have already achieved some success, including greater than expected reestablishment rates in areas that have been extirpated for decades (NOAA 2003) . Recent evidence of small, surviving Olympia oyster populations in many Southern California estuaries (Polson et al. 2006) and the increasing political momentum indicates that restoration efforts in California are poised for unprecedented success.

## 6.0 Market Analysis

A detailed market analysis is vital to accurately assess the feasibility of a new business venture for business owners and investors. In fact, insufficient market research is cited as one of the top reasons for the failure of new businesses (Laumer et al. 2007). The goal of our market analysis was to quantify the current demand for the Olympia oyster product, identify target consumers, determine the geographic target market, establish the consumers' willingness to pay for the product and identify existing competitors. Currently, there is no established market for Olympia oysters in California because there is no commercial production of the species. Therefore, it is especially important to understand past, current, and future trends of oyster consumption. We researched historic global and domestic oyster consumption trends to gauge the volatility of the market and to predict the future of the Olympia oyster market. Next, we identified specific characteristics that set the Olympia oyster apart from other oyster products. Finally, we designed a market survey to determine the demand for Olympia oysters in California.

### 6.1 Seafood and Oyster Consumption Patterns

Oyster consumption trends indicate that seafood consumption is on the rise globally and domestically. Increased demand is being met by a growing number of aquaculture seafood producers. As the supply of seafood shifts further toward commercial aquaculture species, we expect that demand for oysters will increase. U.S. demographic trends indicate that there will be more oyster consumers by 2020 and that California demand will be stable or will increase, particularly if oysters are consistently available. See Appendix A for supporting documents.

### 6.2 Marketability of the Olympia oyster

In the process of a market assessment, it is important to recognize the key characteristics that make a product unique. Olympia oysters vary considerably from other commercially-produced oysters because of their small size and distinct taste. Therefore, Olympia oysters occupy a specific market niche and have significant marketing potential. The key characteristics that set Olympia oysters apart from other oyster products include their taste and their 'green' story.

*Taste/Specialty Oyster*

For true oyster aficionados, the Olympia oyster is recognized as one of the best tasting oysters, if not the best. In the 1950's, naturalist William Cooper described the taste as a 'peculiar coppery flavor' while others highlight a subtle cucumber or melon flavor (Apple Jr. 2004). In general, Olympia oysters are marketed as a specialty 'cocktail oyster' (an appetizer), served fresh on the half shell (Finger 2007). Since Olympia oysters are significantly smaller and more expensive than the larger Pacific oysters (average size between 35 and 45 mm), seafood restaurants and oyster bars generally only serve

Olympia oysters if they have a selection of oysters on their menu (Finger 2007). Customers of these restaurants are likely to be familiar with the different types of oysters and are more likely to purchase specialty oyster products (Finger 2007).

*Marketing: Green Story*
Marketing Olympia oysters within California could capitalize on the Olympia oysters' unique 'green story'. A green story is a marketing campaign that emphasizes the environmentally-friendly aspects of the product. The Olympia oysters' green story includes local and sustainable production, few negative environmental impacts, and the potential to directly contribute to restoration projects. These unique attributes could provide aquaculture producers and restaurants with a powerful marketing tool which may appeal to a variety of consumers. The components of the green story are described in Appendix A.

### 6.3 Substitute Markets

Our research on current oyster products sold in California revealed that there were two substitute products, the Kumamoto oyster (*Crassostrea sikamea*) and the European (flat) oyster (*Ostrea edulis*) that could compete with the Olympia oyster for the "specialty oyster" market niche. Like the Olympia oyster, the Kumamoto oyster is a smaller specialty oyster approximately three to four inches in length, usually served as an appetizer or cocktail oyster. Only a handful of growers produce Kumamoto oysters on the West Coast, so production is limited. Kumamoto oysters command a high price due to the high cost of production and the slow growth of the oyster (three years to market size) (Finger 2007). European oysters are produced in even smaller quantities and represent a very small portion of the oyster market (Finger 2007). Typically, Olympia oysters would command the highest price, followed by European (Flat) and Kumamoto oysters. However, many California oyster bars can not obtain consistent supplies of Olympia oysters, so the Kumamoto oyster is generally the highest priced oyster on the menu (Seafood Choices Alliance 2006). Over the last decade, the popularity and price of Kumamoto oysters has grown quickly, making it the most popular cocktail oyster in California (Finger 2007). Strong demand for Kumamoto oysters suggests that there is great potential for other specialty oysters to also occupy this unique market niche.

### 6.4 Demand Risk Analysis

Conducting a demand risk analysis is an important component of a market analysis because it can help explain past market fluctuations and provide insights to predict the future stability of the market. The market demand for Olympia oysters may be somewhat volatile and subject to fluctuation due to the health of the U.S. economy, consumer perceptions of the health risk associated with consuming oysters, and the specific taste of Olympia oysters produced in California. See Appendix A for a complete discussion of the volatility of the oyster market in California.

### 6.5 Market Survey

We conducted a market survey to assess the potential Olympia oyster market in California. Our initial market research (above) provided clues to the potential target market, marketability and consumer preferences for the Olympia oyster. However, a detailed survey represented the best means to quantify California's Olympia oyster market. The following sections outline our market survey objectives, methods, results, and analysis.

*Survey Objectives*
Quantifying the size of the Olympia oyster market in California represents one of the most important steps in our market analysis because it determines if there are enough buyers for the product. Without sufficient demand, an Olympia oyster aquaculture business would not generate enough revenue to avoid bankruptcy. For the Olympia oyster, the market has to be willing to buy the oyster at a price premium[1]. Our initial research indicated that oyster bars and high-end seafood restaurants would be the target market. In addition, we hypothesized that there would be significant demand for the Olympia oyster if it was priced similarly with other specialty oyster products. Finally, we wanted to distinguish between different marketing strategies to determine which Olympia oyster characteristics are most appealing to target restaurants. With these questions in mind, we established the following objectives for our market survey:

- Confirm the Olympia oyster target market in California
- Estimate the demand of the target market for this oyster
- Elicit the willingness to pay for the Olympia oyster half shell product[2]
- Quantify the importance of factors influencing purchasing decisions in the target market, such as price, sustainability, and green marketing.

*Market Survey Methods*
We collected market data through a telephone survey, which we identified as the survey technique most likely to return the highest response rate. The survey targeted individuals responsible for food product decisions, usually the executive chef, manager, or restaurant owner. Typically, these individuals have limited "down time" on the job, so we developed a short survey (3 to 4 minutes) to increase the likelihood that this target group would be willing to participate in our survey.

*Assumptions*
Based on our initial research, we assumed that oyster bars and high-end seafood restaurants would be our target market. Our goal was to do a complete census survey of this target market in California. However, we were unable to find a complete list of California seafood restaurants, due in part to the high turnover in the industry. So, we

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[1] In general, specialty oysters, including Olympia oysters, have a higher cost of production and take more time to produce. This difference in cost of production results in a higher cost to the consumers.
[2] The definition of 'willingness to pay' is: the maximum amount that a buyer will pay for a good (Mankiw 2001).

used the *Zagat* restaurant guide as a proxy for a complete list of restaurants in California. Using *Zagat : Los Angeles/Southern California Restaurants*, *Zagat : San Francisco Bay Area Restaurants*, and *Zagat: San Diego Restaurants* , we compiled a list of 75 oyster bars from the 'raw bar' category (see Appendix B for complete definition and justification). We chose these three Zagat guides because they represent the major seafood markets in California (Worthington 2007).

*Line of Questioning*

We randomly assigned our list of target restaurants to the interviewers, with restaurant names coded for anonymity. Prior to the survey, we contacted (or attempted to contact) each restaurant to determine who was the most appropriate staff member to survey. Following a standardized script, we identified the correct individual and introduced the survey so that each respondent would receive the exact same information. We designed the survey to avoid bias by paying particular attention to the ordering of questions, the amount of information presented, and other variables that might bias the respondent. After the respondent agreed to participate in the survey, we briefly described background information on the Olympia oyster to confirm that every respondent was clear on which species of oyster we proposed to produce (Olympia oysters). The complete survey script is included in Appendix C.

We gathered basic statistics on the demographics of the surveyed restaurants, which are described in detail in Appendix B, using a series of 'yes'/'no' and open-ended questions. Next, we asked respondents to rate the level of importance of nine factors they consider when deciding whether to add oyster products to their menus. Respondents were asked to rate importance on a 5-point scale, with 1 being not important and 5 being very important, of the following factors: price, seasonal availability, year-round availability, flavor, local production, sustainable production, unique menu item, expansion of current oyster selection, and the 'green story'[3] aspect for marketing. We chose these factors based on our initial research and interviews.

Finally, we questioned each respondent to determine how much they would pay for the Olympia oyster product. First, we asked respondents: "Setting price aside, if the Olympia oyster were available, would you consider adding it to the menu?" Next we asked "If Olympia oysters were the same price per dozen as Pacific oysters, how many dozen would you buy for an average week?" This question determined how many Olympia oysters the respondent would purchase with no price premium[4].

To develop a willingness-to-pay curve, we asked: "If Olympia oysters were _____ each, how many dozen would you buy for an average week?" The wholesale price per oyster was randomly assigned from the following distribution: $0.30, $0.60, $0.90, $1.20, $1.50.

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[3] A brief description of how shells from restaurants could be recycled for restoration was given before asking the importance of the "green story" as a marketing angle.

[4] A price premium is the amount that a buyer is willing to pay for a good above the normal price of that good (Mankiw 2001).

We created this distribution by choosing a range of wholesale prices centered around the average cost of other specialty oysters similar to the Olympia oyster. Restaurants typically mark up food items up 250% from the wholesale price (Worthington 2007).

*Survey Analysis Methodology*

We divided surveyed restaurants into four subcategories for analysis to gather demographic data and to further tease out the specific target market. These categories were (see Appendix B for definitions):

- oyster bars
- seafood restaurants
- generic restaurants (high-end restaurants that did not specialize in seafood)
- other (included international cuisine and sushi restaurants)

We analyzed the restaurant preference data with one-tailed paired t-tests. When respondents gave a range of values (e.g. 3 to 4) for a given factor, we entered these responses as an average (3.5 for the example given). We analyzed the demand data with multiple regression analysis and percent change calculations. Again, when respondents answered open-ended demand questions with a range instead of a single value, we used the average of the range in our analysis.

### 6.6 Market Survey Results

We received responses from 59 of the 75 restaurants, giving us a 79% rate of response. Each restaurant type responded at a similar rate. Oyster bar respondents were most familiar with Olympia oysters, with 83% of the respondents already familiar with the product. This compared to 76% familiarity for seafood restaurants, 75% for generic restaurants, and only 57% for other restaurants. For complete survey results, see Appendix B.

Our survey results indicated that oyster bars and seafood restaurants are an appropriate target market for the Olympia oyster product. All but three of the surveyed restaurants currently serve oysters, and all of those serving oysters offer them on the half-shell. The fact that restaurants already offer oysters on the half-shell indicates that they fall in the target market for Olympia oysters, which are also sold on the half-shell. On average, the restaurants offer 3.35 varieties[5] of oysters. Multiple varieties of oysters served also indicated the correct market for the Olympia oyster. Restaurants that feature multiple oysters on their menu are more likely to purchase an additional specialty oyster, such as the Olympia oyster.

The willingness to pay line of questioning quantified demand for the Olympia oyster in California. Of the 75 respondents, 52 said they would be interested in purchasing

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5 The variety of oysters at each restaurant represents the number of different oysters on the menu. However, this does not necessarily mean that the restaurant serves different species because often times the same species is marketed differently based on where that oyster was grown out.

Olympia oysters if they were priced the same as Pacific oysters (no price premium). The average weekly demand (per restaurant) for Olympia oysters at no price premium was 49 dozen, with a range from 0 to 666. No price premium means the Olympia oysters cost the same as Pacific oysters, about $0.60 per oyster (based on the respondent's reported average cost data). We removed two outliers resulting in the weekly demand being narrowed to 0 to 105 dozen per week, with an average demand of 31 dozen (see Appendix B for complete results).

Demand for Olympia oysters fluctuated depending on the price. Results indicated that demand increased by 25% when Olympia oysters were less expensive than Pacific oysters (at $0.30 each). However, as the price increased beyond $0.30 per oyster, the demand decreased. The smallest percent change was at $0.60, only a 5% decrease, which confirms that $0.60 corresponds to a no price premium level. At $0.90, $1.20, and $1.50 per oyster demand decreased 36%, 49%, and 65% respectively.

Our regression analysis of the price range data showed a downward sloping demand curve, as expected, and gave us the following equation:

**Equation 1**: Olympia oyster demand

$$y = -1.2681x + 33.318$$

See Appendix B for complete results of weekly demand depending on price (R2 = 0.107, p = 0.025).

By multiplying the average number of oysters bought per restaurant (the y-value calculated using
Equation **1**) by the cost of oysters at each price level, we calculated the potential revenues from the market. The highest weekly revenues from one restaurant were at oyster prices of $1.20/each and $0.90/each, which resulted in $217 and $212 respectively. These revenues were compared to potential revenues calculated from the percent change data with Equation 2.

**Equation 2**: Weekly revenue to aquaculture operator

Weekly Revenue = 31 dozen/week * (1+percent change) * price per dozen

This function revealed the projected weekly revenues that could be expected per restaurant. For example, at an oyster price of $1.20 each, the aquaculture operator can expect $228 per week per restaurant. At $0.90 each, the aquaculture operator can expect $214 per week per restaurant (Figure 1).

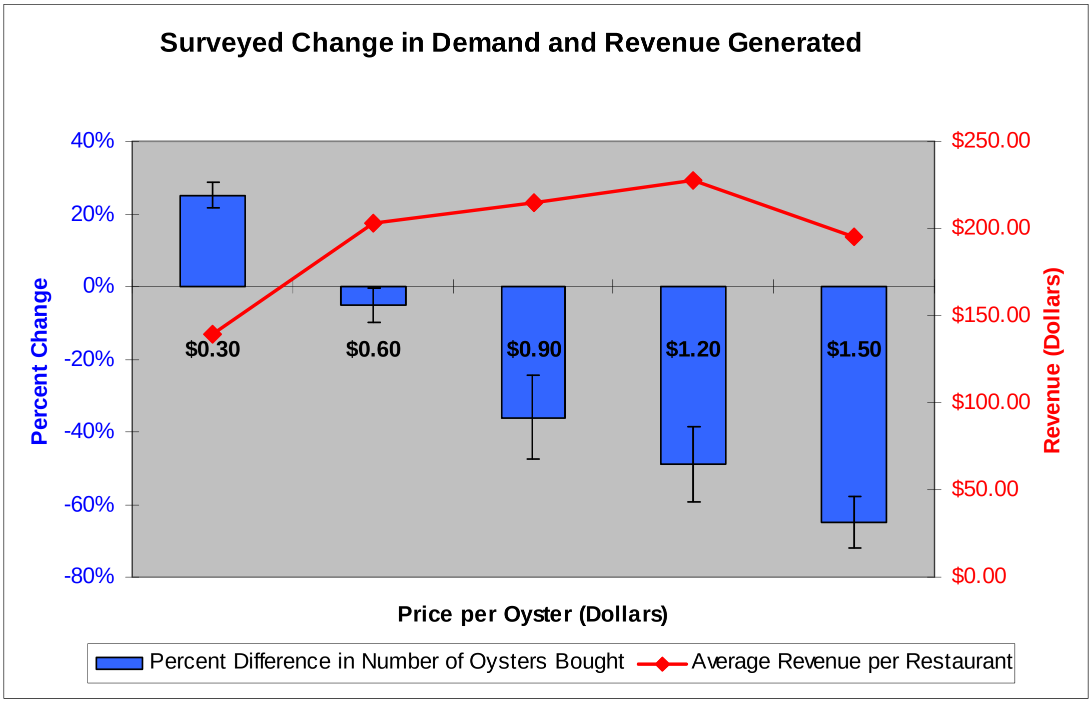


**Figure 1**. Surveyed change in demand and revenue generated. The bar graph shows the estimated percent change in demand from no price premium to the randomly assigned survey price. Blue bars above the 0% change indicate an increase in demand while blue bars below the 0% change indicate a decrease in demand. The red line shows the weekly revenue from one restaurant based on the change in demand from the average demand of 31 dozen oysters per week. The prices per oyster are wholesale prices.

The preference line of questioning results provided several statistically significant findings. The averaged factor importance data showed that respondents gave 'flavor' the highest ranking, followed by 'sustainably produced', 'green story', and 'locally produced' (Figure 2). These four factors ranked higher than price, which is counter to the commonly-held assumption that product price is the most important factor when deciding whether to add an oyster to the menu. The four factors ('sustainably-produced', 'green story', 'locally-produced', and 'flavor') had p-values <.005 in paired two sample t-tests for means when compared to price data. 'Year-round availability' and 'in-season availability' had the lowest rankings, followed by product price.

Seventy-three percent of the respondents ranked 'flavor' higher than 'price'. Only one respondent ranked price over 'flavor', while the remainder of respondents ranked them equally. Seventy percent of respondents also ranked 'sustainably produced' over 'price'.

The mode value for 'flavor', 'sustainably-produced', and 'locally produced' was five. The mode value for 'green story' for respondents who would consider adding the Olympia oyster if it were available was also five (see Appendix B for the complete statistical results). Three respondents said they would not consider adding the Olympia oyster to their menu regardless of availability.

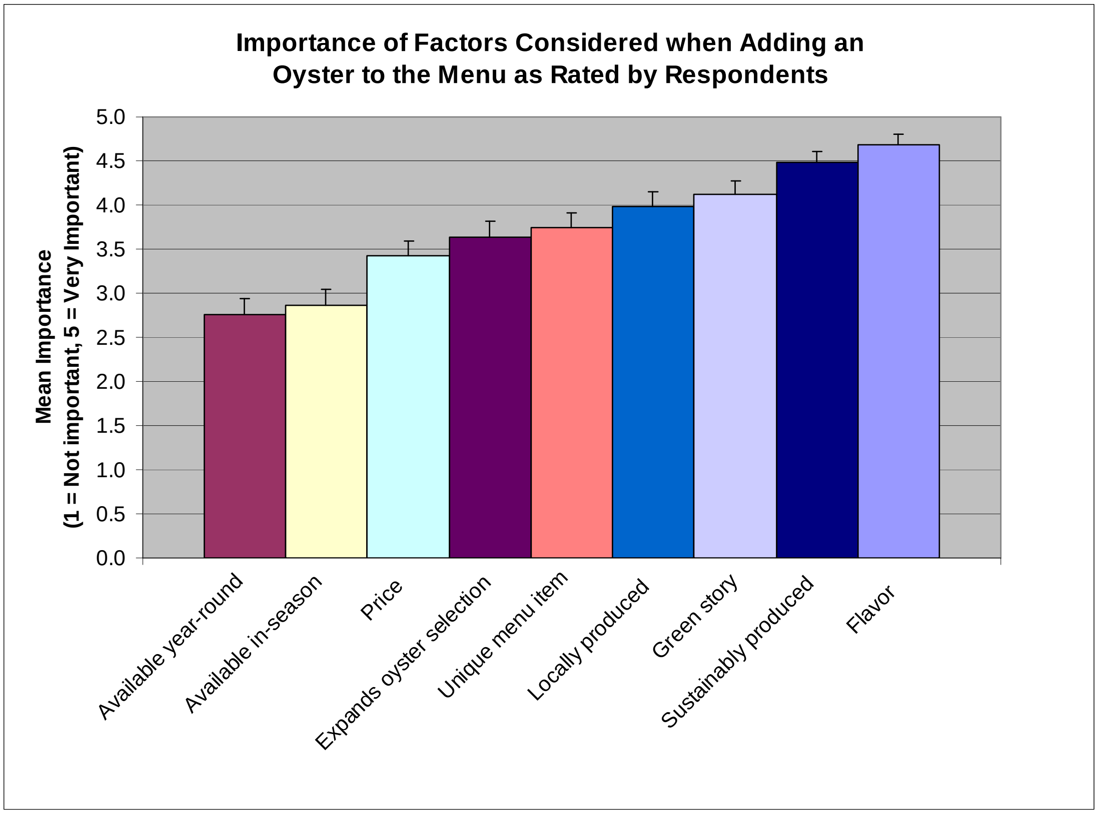


**Figure 2**. Importance of decision factors. Importance of various factors respondents might consider when adding a new oyster to the menu. They rated importance on a 5 point scale, with 1 being not important and 5 being very important. These nine factors were considered the most important to the Olympia oyster market and do not represent an exhaustive list of all the factors that respondents might consider. The error bars represent 95% confidence interval for each factor.

*Market Survey Results Discussion*

Based on our survey results, we conclude that there is a strong market for Olympia oysters in California's restaurant industry. Our results suggest the following conclusions:

- *Oyster bars are the target market for this product.* Based on our response rate and the percent of respondents at oyster bars who are already familiar with Olympia oysters, we confirmed our initial assumption that oyster bars are the target market for this product. However, the market is not limited solely to oyster bars.
- *Familiarity with this oyster will likely increase a restaurant's willingness to buy this product.* The majority of respondents already familiar with the Olympia oyster had positive comments about its flavor and marketability. The high importance rating given to flavor indicates that executive chefs who are already familiar with the Olympia oyster product are more likely to purchase it. Furthermore, familiarity with the Olympia oyster in the restaurant industry may allow the aquaculture operator to initially sell the oyster at a higher cost (e.g. $0.90 per oyster) rather than an artificially-low low cost (to increase demand), as is often done with new products.

- *The target price for an Olympia oyster is $0.90 to $1.20 per oyster.* At these prices, demand decreases slightly but the increase in revenue offsets the decline in demand. The current price range of substitute specialty oysters, such as the Kumamoto oyster, is $0.90 to $1.10, which supports our results.
- *Price is not as important as the flavor and unique story behind the oyster.* The clientele frequenting high-end restaurants and oyster bars are probably not concerned with costs of individual menu items. The clientele's insensitivity to price may be one reason that survey respondents did not rank price as the most important factor they consider when adding an oyster to the menu. Additionally, this clientele can afford to be more concerned with the environmental impact of their meals, making the 'green story' marketing more important to restaurants. The importance of the 'green story' is encouraging because it increases the likelihood that restaurants would participate in an Olympia oyster shell recycling program.

### 6.7 Market Analysis Discussion

Our market analysis indicates a strong market demand for Olympia oysters in California. According to global and domestic consumption trends, demand for seafood and shellfish will continue to increase. U.S. demographic data and trends in food consumption also indicate increasing demand for oysters. Increasing imports of oyster products and limited production of specialty oysters highlight the opportunity for industry growth.

Compared with other forms of commercial aquaculture, Olympia oyster aquaculture boasts many unique selling points. Olympia oysters can be produced with relatively few negative environmental impacts, can enhance local water quality, are a native species to California, and offer aquaculture operators and restaurants an opportunity to contribute to local restoration projects. These unique attributes can provide aquaculture producers and restaurants with a powerful green image marketing strategy, capitalizing on the current purchasing trend toward local, sustainable products.

The market survey confirmed that the target market for the Olympia oyster product is oyster bars and restaurants featuring a variety of oysters. This restaurant segment featured a high level of familiarity with the Olympia oyster and already had strong positive opinions about its flavor. California has seen an increase in the number of seafood restaurants (that serve a variety of oysters) and oyster bars. Their popularity continues to grow in urban areas, particularly in California's largest oyster markets, San Francisco and Los Angeles (Worthington 2007). Currently, most of the target restaurants do not feature Olympia oysters on their menus. However, in a highly competitive industry, unique specialty items such as Olympia oysters may give restaurants a competitive edge. Based on our survey analysis, we suggest pricing oysters at $0.90 per oyster to stay competitive with other Olympia oyster producers and substitute products. This price represents a conservative estimate that could be increased once the market has been established. The predicted average demand per restaurant for Olympia oysters at $0.90 per oyster is about 20 dozen oysters per week. At $0.90 per oyster, the average quantity demanded would generate a weekly revenue of $214 per restaurant.

The majority of survey respondents indicated that flavor, sustainable production, local production and the 'green story' of the Olympia oyster were most important to them when purchasing a new oyster product. Marketing the Olympia oyster should highlight these aspects and emphasize the benefits of Olympia oyster aquaculture to restoration projects and local water quality. The market survey indicated the high value that restaurants placed on local products, suggesting that it would be best to specifically target restaurants within a close proximity to the aquaculture facility. A risk analysis revealed that the oyster market is subject to volatility, primarily due to the Olympia oysters' specialty status and high prices. Negative media attention on the health threats to consumers of shellfish could impact sales, but probably less than other oysters due to the demographic of the typical specialty oyster consumer.

## 7.0 Production Analysis

Although oyster aquaculture has the potential to be profitable, there are some substantial financial risks associated with starting a new venture. An Olympia oyster aquaculture venture may have additional risk due to the oysters' specific biological limitations. As such, Olympia oyster aquaculture will require a unique blend of traditional and experimental aquaculture techniques to be successful. This section first discusses the biological requirements that are unique for Olympia oyster aquaculture in California. Secondly, it identifies specific hatchery and growout techniques that may enhance Olympia oyster aquaculture in California. These techniques are combined into a recommended Olympia oyster aquaculture production model. Finally, this section discusses the assumptions and limitations of our aquaculture model.

### 7.1 Requirements for Olympia Oyster Aquaculture

Olympia oyster aquaculture differs from other types of oyster aquaculture because Olympia oysters are one of the slowest-growing oyster species. Therefore, the aquaculture strategy needs to resemble that of other slow-growers, such as Kumamoto oysters. Olympia oysters also require more maintenance during production than faster-growing species, especially in terms of defouling the oysters and equipment. If an aquaculture facility plans to grow more than one type of oyster, then the Olympia oysters need to be grown separately from the faster-growing species, such as Pacific oysters. Fast-growing Pacific oysters can out-compete Olympia oysters for space during growout, thereby increasing Olympia mortality. The remainder of this section summarizes the biological factors that need particular consideration when designing an aquaculture growout system for Olympia oysters. Additional details are provided in Appendix D.

*Biological Requirements for Production*
In designing a commercial aquaculture facility for Olympia oysters, the following factors must be addressed for successful production: ambient environmental conditions, water quality, predation, and disease.

Olympia oysters flourish in protected estuarine waters with high salinity, moderate temperatures, and varied hard substrates. Environmental conditions strongly dictate where Olympia oysters can be successfully grown for commercial aquaculture.

Olympia oysters generally do not occur more than 1 or 2 feet above the mean lower low water (MLLW) and have been found at depths as great as 65 feet (Grosholz et al. 2006). This range illustrates Olympia oysters' high sensitivity to air exposure. Olympia oysters cannot survive temperature extremes, such as freezing temperatures (-1° to 5° C) or excessive heat (>30° C) (Baker 1995; Conte 1996). Due to their preference for a stable temperature, larger populations of Olympia oysters occur in low intertidal or subtidal areas that are better protected from prolonged hot summer surface temperatures and colder winter water temperatures (Conte et al. 2001). Olympia oysters also thrive in stable saline conditions (above 25 ppt), but can survive in low salinity waters (15 ppt) (Korringa 1976; Couch et al. 1989).

*Water quality*

Water quality presents a major consideration for aquaculture businesses that sell their oysters on the public market. While historically Olympia oysters were most affected by industrial effluents, tighter regulation of point sources with the Clean Water Act (1977) resulted in a shift toward non-point source pollution as the primary pollution threat to Olympia oyster populations (Cook et al. 1998).

One non-point source pollutant with major implications for Olympia oysters is sedimentation. Total dissolved solids can smother oysters and make it difficult for them to set on the available substrate. Mr. John Finger, the manager of Hog Island Oyster Company in Tomales Bay, has observed increasing sedimentation at his aquaculture facility over the years due to local land management practices. Mr. Finger noted a correlation between the increase in sedimentation and a decrease in Olympia oyster sets. Similarly, a study in San Francisco Bay between 2001 and 2003 concluded that fine sediments have a negative effect on Olympia oyster populations (McGowan et al. 2006).

*Disease*

According to research, Olympia oysters are not disease-prone compared to other commercially grown oysters (Moore 2007). However, three possible threats to Olympia oyster populations exist: Denman Island disease (*Mikrocytos mackini*), redworm (*Mytilicola orientalis*), and disseminated neoplasia. Of these diseases, disseminated neoplasia is the greatest potential threat.

Between 2004 and 2006, Moore et al. (2006) conducted a California-wide oyster health survey, which included eight populations of Olympia oysters. The sample locations ranged from Humboldt Bay to Elkhorn Slough. Ultimately, disseminated neoplasia was found in four of the eight locations: Tomales Bay (north end), Drakes Estero, Fort Mason Marina (San Francisco Bay), and Candlestick Park (San Francisco Bay). The results varied widely among individuals and populations in terms of the intensity and incidence of disease. The greatest incidence of disease (i.e. number of diseased individuals per number sampled) occurred in Drakes Estero and Candlestick Park. Meanwhile, the intensities among individuals varied broadly from a few cells to greater than 90% of cells in circulation (Moore et al. 2006). While this disease does not appear to induce mass mortality in Olympia oyster populations at present, the movement of oysters from one area where the disease occurs to another should be restricted.

*Predators*

Off-bottom culture is a preferable means for growing Olympia oysters because it excludes many types of predators. Ducks, crabs, bat rays, and leopard sharks, for example, are not expected to significantly affect Olympia oyster mortality when off-bottom culture techniques are employed. However, Olympia oysters may still be vulnerable to some predatory species, namely oyster drills. The Pacific coast supports two particularly voracious invasive predators, the Japanese oyster drill (*Ceratostoma inornatum*) and the Eastern oyster drill (*Urosalpinx cinerea*). However, the effect of oyster drills on Olympia oysters can be significantly reduced by proper maintenance. Regularly cleaning the oyster bags of drills, tunicates, and sponges will reduce oyster mortality and reduce the proliferation of these predatory species.

### 7.2 Olympia Oyster Aquaculture Techniques

Destructive oyster harvesting methods, such as raking and other bottom culture techniques, can cause significant ecosystem damage and have been prohibited by California state law. Therefore, Olympia oyster aquaculture in California must utilize an off-bottom growout technique. Currently, little is known about the most effective method for raising Olympia oysters using off-bottom culture (Adams 2007; Finger 2007). The only existing commercial Olympia oyster aquaculture operators are located in Washington and utilize bottom culture techniques. Therefore, arriving at the most effective off-bottom growout method for Olympia oysters will require trial-and-error experimentation. Based on our interviews with aquaculture and restoration experts and our review of existing literature, we formulated a culture method that we anticipate will yield successful results in California. The general framework is shown in Figure 3. The detailed steps involved in commercial oyster aquaculture are explained in more detail in Appendix E.

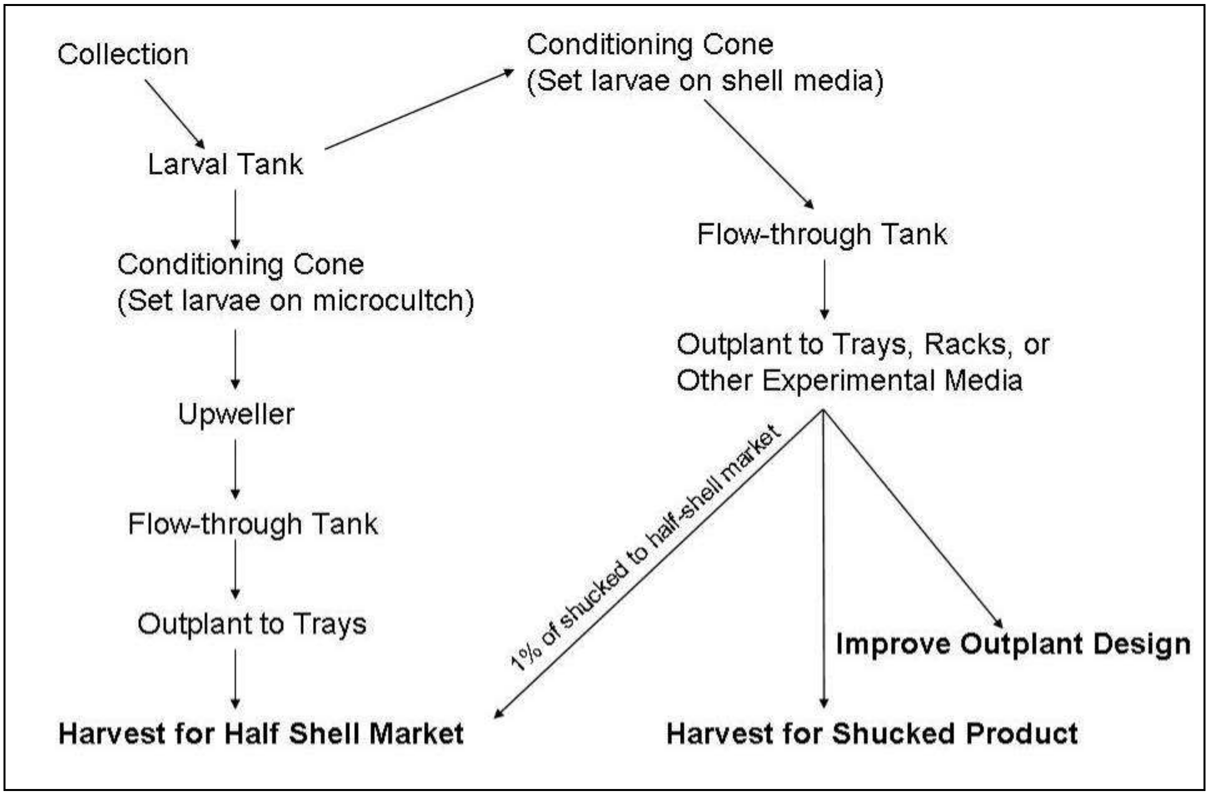


**Figure 3**. General steps in the recommended aquaculture process for producing Olympia oysters in California.

*Recommended Olympia Oyster Hatchery Operations*

The hatchery process for Olympia oysters will not differ significantly from that of other varieties of oysters. The hatchery process includes broodstock conditioning, larval production (spawning), and spat production (seeded oyster shell) (Robert et al. 1999). As shown in Figure 3, production of oysters for the respective half-shell and shucked markets diverges early in the process. In the larval tank, the brood oysters are immersed for one week in water at a temperature of 13 to 16° C to initiate spawning. After the brood oysters successfully spawn, their larvae are concentrated in small conditioning tanks. At this point, the half-shell and shucked oysters are placed into separate tanks to settle onto cultch. For oysters intended for the half-shell market, the larvae settle onto microcultch to produce individual oysters. For oysters intended for the shucked market, the larvae settle onto cultch (i.e. regular-sized oyster shell) to produce clustered oysters.

Hatchery production is generally reliable with large larval production (millions of larvae per 100 oysters spawned) (Newman 2007). Survivorship is more uncertain during the juvenile stage, which typically occurs during growout in the local estuary. A study by McKernan et al. (1949) (in Baker 1995) found 34% juvenile mortality in laboratory experiments. However, natural (non-aquacultured) populations can suffer significantly higher mortality, varying from 60% to 100% in a recent experiment by Trimble et al. (2007). Under optimal growing conditions (using the recommended growout method) and in an optimal growing location, we predict mortality rates of 30% to 60% for the juvenile through the adult stage as a median range between the aforementioned research findings. Typically, aquaculture operators assume a 50% mortality rate during growout for most oyster species (Finger 2007). As such, our estimate of a 30 to 60% mortality rate seems reasonable. Site-specific conditions will ultimately have the greatest impact on the oyster mortality rate.

*Recommended Olympia Oyster Growout Technique*

After considering all of the Olympia oysters' biological constraints, we determined the most feasible method for growout in a typical California estuary. The following discussion explains our recommended Olympia oyster growout technique for California.

Half-shell and shucked oysters will have different methods for outplanting, but both methods will require an off-bottom technique that has a high degree of stability. Experiments and restoration efforts have shown that currents, wave action, and other natural disturbances can have detrimental effects on Olympia survivorship (Trimble et al. 2007). Therefore, the off-bottom growout method requires a very stable media anchored to the substrate.

Our recommended growout method for half-shell oysters is a stacked tray system that is anchored to the bottom substrate, as shown in Figure 4. The tray system would consist of 10 standard plastic Nestier trays (each approximately 3 feet square) that are connected to each other by a heavy steel chain running through their centers. The trays are stacked vertically in the water column with one end of the chain anchored to the bottom and the other tied to a floating buoy. Therefore, the trays will consistently remain submerged. Each tray has a cover to protect the oysters and is flanked by sections of buoyant Styrofoam to keep it upright in the water column. Overall, the tray system will provide space for the oysters to grow, yet provide the stability and protection from predators to minimize mortality.

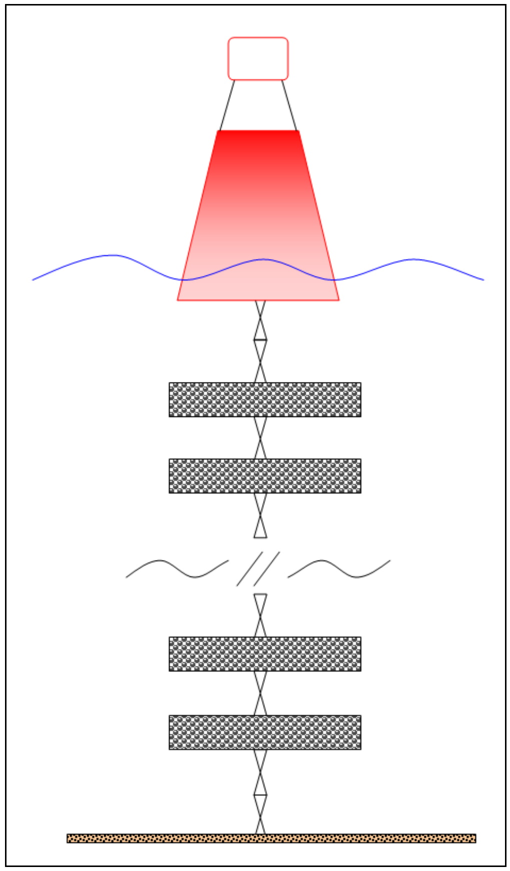

**Figure 4**. Schematic of tray system for half-shell oyster growout.

**Figure 5**. Photo of Nestier trays proposed for the half-shell oyster growout method.

The growout method for shucked oysters requires more experimentation before determining the best method. Our research indicates that the most promising off-bottom technique is a form of rack and bag culture called "bag-bottom" culture. This technique is described in more detail in Appendix E.

Existing literature states that Olympia oysters take three to four years to mature to a harvestable size (35 to 40 mm) under natural growth conditions (Couch et al. 1989; Baker 1995). However, several studies suggest that Olympia oysters can grow much faster, especially in warmer waters. For example, a study by Coe et al. (1937) showed that Olympia oysters suspended off of the Scripps Institution of Oceanography pier (San Diego, CA) grew to 50 mm in only 10 weeks. A more recent study by Trimble et al. (2007) showed that Olympia oysters in Willapa Bay, WA grew to at least 30 mm in 1 year. Trimble's study is the most comprehensive and provides the most robust data for Olympia oyster growth under conditions that are similar to conditions in Northern California estuaries.

Based on these observations, we predict that Olympia oysters are capable of growing at a much faster pace in aquaculture than under natural conditions. Using Trimble et al.'s (2007) analysis, we estimate that Olympia oysters would reach market size in 1.5 to 2 years under our aquaculture scenario, which includes reducing natural threats and optimizing growth conditions to decrease mortality.

### 7.3 Olympia Oyster Site Selection in California

Whether building a new aquaculture business or starting a restoration project, site selection is crucial to success. Aquaculture sites require some amount of land for processing, storing equipment, retail space, and office duties. Legal issues surrounding aquaculture will also play a role in site selection. Prime locations along the California coast already host several shellfish aquaculture operations. The following section discusses existing California aquaculture operations and site-specific considerations for an Olympia oyster aquaculture operation in California.

*California Aquaculture Operations*

Currently, at least 25 shellfish aquaculture businesses operate in California, 16 of which culture oysters (California Department of Fish and Game 2004; Moore 2008). The public inventory of California aquaculture businesses available from the California Department of Fish & Game (DFG) lists six locations with oyster aquaculture: Humboldt Bay, Tomales Bay, Drakes Estero, Morro Bay, Santa Barbara, and Carlsbad (California Department of Fish and Game 2004). Production statistics for these existing aquaculture businesses are provided in Appendix F.

As shown in Table 1, the most common species of oyster produced is the Pacific oyster. In fact, all 16 oyster producers in California culture Pacific oysters. Eight of these businesses also culture "specialty" oysters: three aquaculture operators culture Kumamoto oysters, six culture Eastern oysters and seven culture European flat oysters.

No one in California is currently growing Olympia oysters for retail purposes[6]. The DFG aquaculture registration application does not even list Olympia oysters as an option, though there is an 'other' option that would apply.

Kumamoto oysters, the closest substitute to Olympia oysters, are produced in Humboldt Bay, which is over 200 miles from the nearest major seafood market (San Francisco). This lopsided distribution provides evidence of a gap in the specialty oyster market, thus little competition, near the largest California oyster markets.

**Table 1**. Commercial oyster aquaculture businesses in California and types of oysters produced (California Department of Fish and Game 2002; 2004; 2007; Moore 2008).

| **Business Name** | **Location** | **Species of Oyster Produced** |
|---|---|---|
| Aqua-Rodeo Farms | Humboldt Bay | Pacific, Eastern, European |
| Carlsbad Aquafarm | Carlsbad | Pacific |
| Charles Friend (Brothers Bernal) | Tomales Bay | Pacific |
| Coast Seafoods Co. | Humboldt Bay | Pacific, Kumamoto |
| Cove Mussel Co. | Tomales Bay | Pacific |
| Drake's Bay Family Farms | Drakes Estero | Pacific |
| Emerald Pacific Seafoods | Humboldt Bay | Pacific, European, Kumamoto |
| Hog Island Oyster Co. | Tomales Bay | Pacific, Eastern, European |
| Humboldt Bay Oyster Co. | Humboldt Bay | Pacific, Eastern, European |
| Kuiper Mariculture, Inc. | Humboldt Bay | Pacific |
| Marin Oyster Co. | Tomales Bay | Pacific |
| North Bay Shellfish | Humboldt Bay | Pacific, Eastern, European, Kumamoto |
| Point Reyes Oyster Co. | Tomales Bay | Pacific, Eastern, European |
| Santa Barbara Mariculture Co. | Santa Barbara (offshore) | Pacific |
| Tomales Bay Shellfish Farms, Inc. | Tomales Bay, Morro Bay | Pacific, Eastern, European |
| Williams Shellfish Farms | Morro Bay | Pacific |

[6] The 2004 California Department of Fish & Game (DFG) public list of aquaculture operators in California cite Kuiper Mariculture, Inc. of Humboldt Bay as licensed to grow Olympia oysters. However, further investigation into this record did not indicate that Kuiper ever produced Olympia oysters and the record was absent from DFG's revised list of California aquaculturists released on December 12, 2007.


**Figure 6**. Geographic distribution of existing oyster aquaculture businesses in California.

*Potential sites for Olympia oyster aquaculture*

To minimize start-up costs, the most effective method for establishing a site for Olympia oyster aquaculture is to partner with, or sub-lease from, an existing aquaculture operator (Finger 2007). The next most important consideration is whether there is a viable natural Olympia oyster population inhabiting the water body. As described in Section 8.0, the movement of native populations between water bodies is discouraged due to the risks of transferring diseases, predators, and genetic mutations to new areas. Therefore, the presence of a local Olympia oyster population to provide local broodstock is an absolute requirement for potential sites. Other important considerations include the distance to the major seafood markets (to minimize transport of a perishable product), existing local competition, and water quality. Within these constraints, we evaluated four potential aquaculture sites in California: Humboldt, Marin County; the Central Coast, and Southern California. The major advantages and disadvantages of each site are discussed in Appendix G. Our research indicated that sites in Marin County and the Central Coast represented the best potential regions for an Olympia oyster aquaculture operation. Ultimately, we chose Drakes Estero in Marin County and Elkhorn Slough on the Central Coast as the estuaries within these regions with the best prospects for supporting Olympia oyster aquaculture.

### 7.4 Legal Issues

Starting a new aquaculture operation requires a substantial financial investment, a hurdle closely tied to finding a site. Much of this initial investment must be used to cover the costs of the many required state and federal permits. Federal and state governments also regulate aquaculture property rights and monitor aquaculture facilities and products. Federal involvement in aquaculture ensures product safety and monitors quality, both of which allow consumers to buy local aquaculture products with confidence. Financial backing will depend on this anticipated market for the product and also the stability of the business based on its property rights (DeVoe et al. 1989; Duff et al. 2003). Property rights include exclusive culturing and harvesting rights, possible exclusive entrance rights, and the right to a certain level of water quality. The right to water quality means that the aquaculture operator knows that neighboring areas will not detrimentally affect the water quality of the aquaculture site (DeVoe et al. 1989).

The Department of Fish and Game acts as the lead agency for aquaculture in California and is responsible for awarding tideland leases. Competing uses of the coast pose a serious challenge to obtaining a lease. California has a very large tourist economy that is based on coastal activities and coastal development. Not only does this make it difficult to find accessible sites for aquaculture, but the heavy coastal usage causes poor water quality in many areas. The permitting process for tideland leases and aquaculture can take years to complete (McCormick 2007) and can be very expensive. The cost of getting any new activity approved in tidelands is so prohibitive that there have been no new leases since 1993 (Moore 2008). Once a lease is established, aquaculture operators still face legal obligations every year such as renewing their annual aquaculture registration. Meanwhile, water quality must be monitored continually. The Department of Fish and Game also levies a privilege tax on oyster aquaculture for every 100 oysters produced (1933). (See Appendix H for full Federal and State involvement in aquaculture activities.)

### 7.5 Supply Risk Analysis

The production model specified in this report depends upon a number of indeterminate factors. As such, we needed to make a few key assumptions because Olympia oyster aquaculture is a new concept in California, and the data was nonexistent for several elements of the model. Furthermore, natural variability and uncertainty can alter the outcome of production; therefore, we acknowledged certain uncontrollable factors that can affect production. More details for the supply risk analysis are provided in Appendix I. The key assumptions include:

- Olympia oyster broodstock is healthy (i.e., it has enough genetic variability to maintain and perpetuate the viability of the stock)
- Our estimate of the Olympia oyster growth rate is accurate (i.e., Olympia oysters will grow faster in warmer California waters)

- Our estimate of the Olympia oyster mortality rate is accurate (i.e., oyster mortality will be reduced if certain biological and physical considerations are accounted for in the growout technique).

The natural variability and uncertainties associated with production include:

- Variation in environmental factors (e.g., dissolved oxygen concentration, water temperature, turbidity)
- Catastrophic events (e.g., an oil spill).

Until off-bottom culture for Olympia oysters is actually implemented, these assumptions and variables can only be estimated. Existing bottom culture of Olympia oysters in Washington has shown extreme variability in yield from year to year. The exact causes of this variability are uncertain due to a lack of scientific research, but may be due to a property of the species, the culture technique, or certain environmental factors.

### 7.6 Production Conclusions

We believe that implementing a pilot study would be the most effective way to identify the best growout technique for Olympia oysters in California. This pilot study would also verify the accuracy of other assumptions in the model, thereby reducing the level of uncertainty surrounding certain environmental factors. Most importantly, it would provide technique-specific information about actual growth and mortality rates in California.

Specifically, the pilot study would:

- Identify the minimum shell size for larvae settlement that will maximize survivorship in the hatchery
- Identify the best media[7] to maximize Olympia oyster growth rates during the growout stage
- Monitor environmental variables to determine their influence on survivorship
- Determine the most efficient use of products with fixed and variable costs.

Overall, the results of the pilot study would identify the most successful hatchery and growout techniques and provide a foundation for cost-effective and efficient production methods. The results would allow the aquaculture operation to adjust to annual environmental stochasticity thereby improving the quality and stability of the product.

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[7] In this case, "media" refers to the type of physical mechanism used for oyster growout. This media can be the trays, racks, or other apparata.

## 8.0 Restoration

Though some restoration practitioners suggest that the focus for the Olympia oyster should be on restoration rather than commercial production (Peter-Contess et al. 2005), we argue that commercial aquaculture of Olympia oysters will provide incomparable support to restoration projects. The 2007 West Coast Native Oyster Restoration Workshop in Shelton, WA provided a forum for the synthesis of critical information regarding the state of scientific knowledge on Olympia oyster restoration. Research results and recent findings presented support our idea that restoration and aquaculture of Olympia oysters need not be exclusive activities. Specifically, the findings support the argument that aquaculture may directly contribute to restoration projects by 1) improving post-recruitment survivorship through growout method experiments, 2) providing funding, and 3) producing Olympia oyster shell to enhance substrate-limited populations. Additionally, there are many potential indirect benefits to restoration, such as larval spillover in production bays, advancing the scientific knowledge of Olympia oysters, and public education. See Appendix J for a complete description of considerations, alternative techniques, and recent research findings for Olympia oyster restoration.

If the commercial aquaculture operation proves successful and the product demand is strong (as expected), there is likely to be renewed interest in the species, partly as a result of the desire to produce the species more effectively. For example, after the importation of Eastern oysters (and later Pacific oysters) to the West Coast, research on Olympia oysters reduced to only a handful of studies from approximately 1930 through 1990 (J. Madeira, pers. obs.). Instead of researching the Olympia oyster, scientists worked to maximize production of Eastern and Pacific oysters to satisfy the market demand for West Coast-produced oysters (Gordon et al. 2001). An Olympia oyster aquaculture operation could refocus attention on this critical native species and generate new research efforts throughout the West Coast to meet the market demand for this specialty oysters.

Beyond encouraging research, an Olympia oyster aquaculture operation is likely to provide unparalleled support for local, regional, and West Coast Olympia oyster restoration projects in the following six ways:

- Enhanced post-recruitment survivorship due to research on commercial Olympia oyster growout methods. Regular maintenance and monitoring by a commercial aquaculture operation will provide critical insights on how to improve post-recruitment survivorship with more effective growout techniques. In recent academic research on this topic, Trimble et al. (2007) described their experimental growout techniques as "less than satisfactory", but identified that stable, low density rosettes[8] had the highest growth. Due to the necessity of

[8] A rosette is a rack system that Trimble et al. (2007) used to simulate a low-density, highly stable media for Olympia oyster growout.

maximizing growth and survivorship to maximize the quantity of commercial product delivered to market, an Olympia oyster aquaculture operation has an inherent incentive to develop the best growout strategies, which would be directly applicable to all restoration projects.

- Advancement of Olympia oyster hatchery techniques and genetic knowledge of the species. Additionally, there is the potential to use hatchery-produced Olympia oyster seed at restoration sites. An Olympia oyster aquaculture operation would enhance and propagate local, genetically-unique Olympia oyster populations in individual bays in California. Thousands of fecund individuals (hatchery-spawned Olympia oysters growing out in a floating tray system) may interact and reproduce with natural populations, resulting in larger natural recruitment. Meanwhile, hatchery production would ensure that samples of local broodstock are collected, identified, and maintained despite environmental stochasticity in the local estuary. Adhering to the precautionary approach, an Olympia oyster aquaculture operation in California should only culture and grow Olympia oysters from broodstock within their (growout) estuary. Additionally, the aquaculture operation could also directly outplant hatchery-reared individual oysters into the local (growout) estuary[9] (Camara 2007).

- Financial support through annual donations based on the profit margin of the aquaculture operation.

- Provision of Olympia oyster shell on a large-scale for restoration programs dealing with substrate-limited populations. An Olympia oyster aquaculture operation would produce vast quantities of Olympia oyster shell. Following inspection procedures outlined by Cohen et al. (2007), the Olympia oyster shells could be dried in piles and inspected for disease and exotic species. After passing inspection, the Olympia oyster shell could be used for restoration. To our knowledge, only White et al. (2005) quantitatively compared recruitment with different shell substrates, finding that Olympia shell was the preferred substrate[10]. Additional observations at restoration sites in Washington and California suggest that Olympia oysters appear to preferentially recruit in the highest abundances to Olympia shell (Couch 2007; Davis 2007). Given Trimble et al.'s (2007) evidence of the significance of placement of suitable substrate, Olympia oyster shell could be used to enhance substrate to maximize restoration success in appropriate estuaries. However, the key to this solution lies in the availability of Olympia

[9] Using hatchery-reared individuals for outplanting as a restoration strategy carries a risk of increasing the probability of inbreeding as a result of increased mating between relatives (Camara 2007). However, general protocols exist that can deal with these problems and avoid the possibility of allee effects (Camara 2007).

[10] White et al. (2005) reported that Olympia oysters recruited to Olympia oyster shell more than all other shell substrates, but the differences were not statistically significant. Further research is required to differentiate more accurately between these substrate types.

oyster shell for restoration. An Olympia oyster aquaculture operation would be the first and only aquaculture operation to provide Olympia oyster shell substrate to West Coast restoration projects.

- In-kind support. In addition to providing shell substrate, an Olympia oyster aquaculture operation will develop species-specific techniques and tools that can be donated to support restoration projects. The ability of the commercial operation to provide technical and in-kind goods donations is likely to significantly enhance restoration projects. Further, aquaculture operators can lend their extensive local knowledge of estuaries and bays to research and restoration projects.

- Educational outreach opportunities through marketing. Adding the Olympia oyster to the market will enhance public awareness of this local, native oyster. A marketing campaign designed to capitalize on the restoration component of the aquaculture business will provide an excellent platform to market the product, enhance public restoration support and educate the public about the significance of the species. See Section 9.1 (below) for further description of the marketing strategy.

Restoration and commercial aquaculture do share many of the same goals. Improved water quality and reducing invasive species are just two of the many instances where restoration and commercial aquaculture are working toward the same goals. For Olympia oysters, the symbiotic goals go further. Both parties have an interest in restoring robust natural populations that can self-seed the local estuary and enhance broodstock viability. Similarly, both aquaculture and restoration success are likely to flourish only if they can identify the best techniques to enhance post-recruitment survivorship. Thus, an Olympia oyster aquaculture operation and restoration projects are trying to solve many of the same technical problems.

The fundamental difference between the commercial operation and the restoration project exists in their bottom lines. Federal and private grants supply the lifeline to most West Coast restoration projects, while an Olympia oyster aquaculture operation has the potential to raise revenue and support restoration in a variety of ways. Therefore, creating an Olympia oyster aquaculture operation in California may be an important step toward establishing long-term, financially-sustainable restoration projects while making immediate contributions to Olympia oyster restoration research.

## 9.0 Olympia Oyster Aquaculture Business Model Design

After completing the demand analysis, defining production techniques, and establishing specific restoration goals, we developed a conceptual framework for an Olympia oyster aquaculture business in California. Although the ultimate objective of our business model is to enhance Olympia oyster restoration, research, and education, it is unrealistic to construct a business model that does not include profitability as a primary goal (Libecap 2007). As such, we designed a conceptual business model that attempts to balance profitability with restoration goals.

### 9.1 Conceptual Design

The conceptual design for the Olympia oyster aquaculture business model includes the production and sale of oysters to target-market restaurants, and the additional potential restoration benefits. Figure 7 illustrates the business model's conceptual design. The model begins with the production of half-shell Olympia oysters. The aquaculture operator sells the half-shell oysters to oyster bars and seafood restaurants, generating revenue. The oyster bar or restaurant markets the Olympia oyster to consumers as a sustainable and locally-grown specialty oyster that is native to California. Further, the restaurant can choose to market the species as a 'restoration oyster' and recycle the (empty) oyster shells back to the aquaculture farm. A shell recycling program of this nature would allow consumers to make a direct contribution to restoration projects. More importantly, these marketing strategies will encourage target market oyster bars and restaurants to explain the Olympia oyster restoration story. As a result of this marketing campaign, we expect increased public education and awareness of the species' significance to the local marine ecosystem.

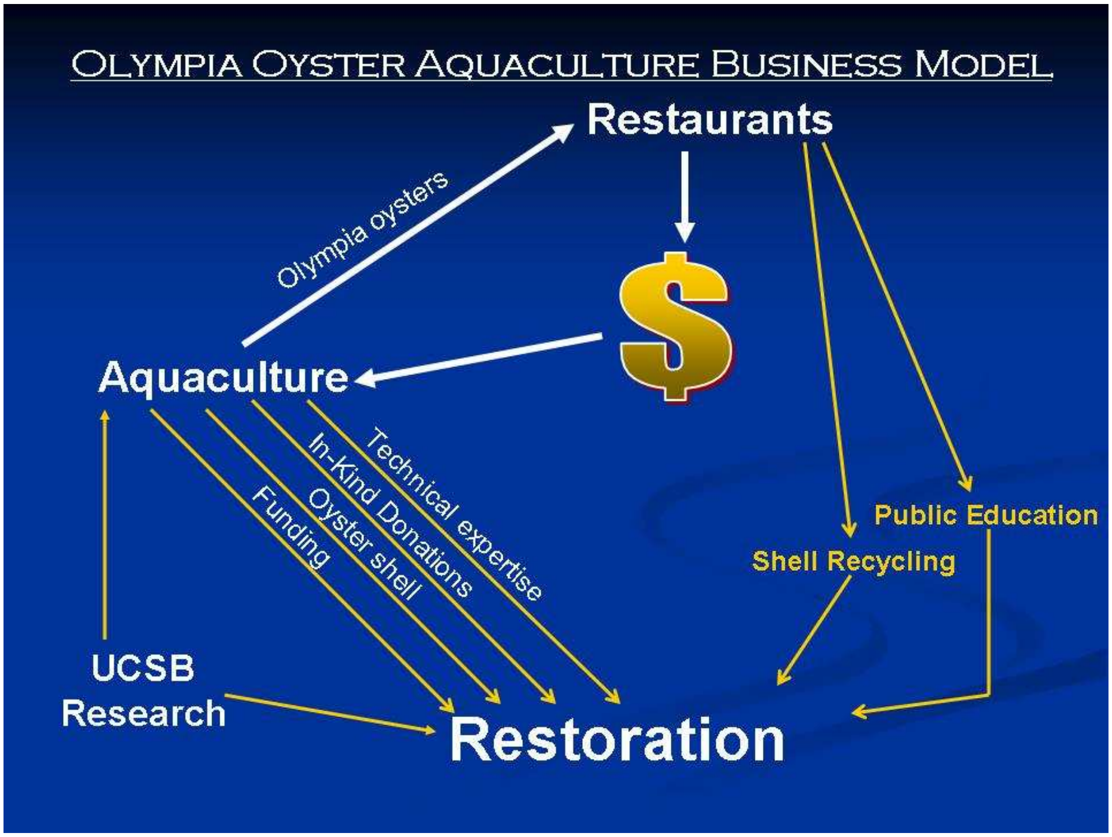


**Figure 7**. Conceptual Olympia oyster aquaculture business model.

As outlined in Section 8.0, an Olympia oyster aquaculture operation could also provide significant benefits to restoration. The first benefit of this conceptual business model would be a new collaborative research campaign with the University of California, Santa Barbara (UCSB). The UCSB research team would work with selected aquaculture operator(s) to assess site-specific limitations to local Olympia oyster populations. In addition, the UCSB research team would examine post-recruitment survivorship at the aquaculture site (growout site) to develop more efficient growout and restoration techniques. After two to three years of research, the commercial aquaculture business would be operational and would be able to provide other direct benefits to restoration, including the provision of Olympia oyster shell, improvements to hatchery techniques, in-kind donations, and funding. It is important to note that the actual benefits from the Olympia oyster aquaculture business will vary depending on the operation's profitability, scale, and the physical constraints of the hatchery and production estuary.

### 9.2 Applying the Business Model: Alternative Production Cost Scenarios

After completion of the Olympia oyster aquaculture conceptual business model, we investigated specific applications of our business model to real-world alternative cost scenarios. Through alternative cost scenarios, we evaluated the efficiency of the conceptual business model at specific locations, involving actual aquaculture operators and hatchery professionals. Within each scenario, we identified the costs associated with that business operation, including permitting, hatchery operations, growout operations, fixed costs, marketing, shipping costs, and taxes (see Appendix K for the complete list of costs for each scenario). Aquaculture literature provided some information on costs, but a majority of cost estimates came from interviews with hatchery professionals, academic research institutions, aquaculture operators, and seafood distributors.

After tabulation of all the costs, we evaluated the relative cost-effectiveness of each hatchery and growout scenario. A sensitivity analysis identified the specific cost categories that had the most impact on cost-effectiveness.

*Limitations of Hatchery and Growout Cost Scenarios*
Due to financial and time limitations of our research, it was impossible to include all of the site-specific costs for each hatchery and growout scenario. Additionally, some site-specific information was proprietary or not publicly available, and therefore further limited the scope of the scenarios. As a result, we included specific categories of information, including the costs of permitting, hatchery operations, growout operations, distribution, marketing, and taxes that could be compared across the alternative scenarios. To prevent undue complexity, we priced out all hatchery and growout operations to utilize identical hatchery and growout techniques. By pricing each scenario to construct the same hatchery and growout capabilities, all operations produce the same quantity of product with the same techniques. Therefore, the key differences in cost-effectiveness amongst the scenarios lie within each scenario's fixed and variable costs. For a complete discussion of the assumptions of this model, see Appendix L.

## 9.3 Hatchery Scenarios

With the help of our Group Project Technical Advisor, Tom McCormick, we evaluated the cost-effectiveness of three separate hatchery scenarios. Together, we defined the general criteria to construct and operate an Olympia oyster hatchery operation. In addition, we consulted with hatcheries currently producing Olympia oysters, including the Quilcene Hatchery (Taylor Shellfish Farms, WA) and the Bodega Marine Laboratory (University of California, Davis), to gather specific Olympia oyster culture instructions and data to parameterize our hatchery operation. With this information, we divided the costs of an Olympia oyster hatchery operation into six categories:

- Pre-hatchery broodstock collection
- Tanks and tank accessories
- Algae
- Pumps, filtration, and supplies
- Microcultch system and settlement media
- Fixed costs

After discussions with our Group Project advisors, we selected three hatchery scenarios for evaluation. Using the six cost categories (listed above), we evaluated three hatchery scenarios:

1. Subcontract a professional hatchery, Proteus SeaFarms International, Inc.
2. Operate an Olympia oyster aquaculture hatchery at UCSB
3. Develop a public-private partnership between UCSB and Drakes Bay Family Farms

These alternative hatchery scenarios represent an array of options that might be available to Olympia oyster aquaculture entrepreneurs. See Appendix K for a complete description of each of these hatchery scenarios and the rationale for their selection.

Of these scenarios, Hatchery Scenario 3 is unique due to the formation of a public-private partnership. A public-private partnership (PPP) between UCSB and Drakes Bay Family Farms (DBFF) signifies a collaborative relationship between a public organization (UCSB) and a private corporation (DBFF) that would jointly operate the Olympia oyster hatchery at Drakes Bay Family Farms, Inverness, CA. The rationale for a public-private partnership scenario stems from the recent trend toward community-based oyster restoration projects pairing with agencies, municipalities, and local aquaculture operations to enhance restoration and marine conservation (Beck et al. 2004; Udelhoven et al. 2005; Beck 2007). Partnerships between public organizations and private industries can facilitate technical assistance and funding to restoration, while the private industry receives positive community support and a 'green' image. For a complete description of these mutually-beneficial partnerships, see Appendix M.

Under the PPP, DBFF would be the primary responsible party for funding, installing, and maintaining the hatchery. However, UCSB research funding would support a portion of the initial capital investment and provide a salaried graduate student to conduct the hatchery operations. DBFF was selected over the other aquaculture operations as the site for the hatchery operation for several reasons. First, DBFF is located in Drakes Estero, which has abundant, consistent Olympia oyster recruitment (Lunny 2007). Second, DBFF is the only aquaculture farm in the region with a hatchery on site, giving it a comparative advantage over other aquaculture operations. Third, DBFF is committed to, and has a history of, contributing to Olympia oyster restoration programs.

### 9.4 Hatchery Scenario Results and Analysis

A quick look at the projected costs associated with the three different hatchery scenarios illustrated that the UCSB/DBFF PPP (Hatchery Scenario 3) is the most cost effective means to culture Olympia oysters in California, followed by the UCSB hatchery. Conversely, subcontracting the hatchery production to a professional hatchery, such as Proteus SeaFarms International, Inc., is significantly more costly. Figure 8 illustrates the different hatchery cost scenarios projected over a five-year time horizon. All three hatchery operations feature high initial (Year 1) costs because they must purchase expensive capital infrastructure, including tanks, filters, the microcultch system, lab equipment, etc. However, after the initial year of expense, hatchery production is significantly less expensive for all three scenarios.

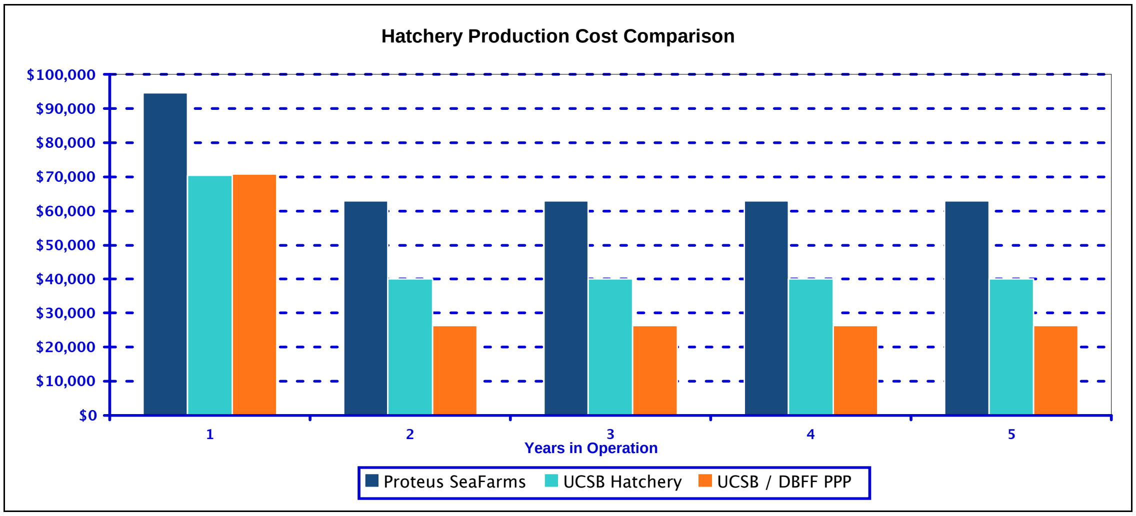


**Figure 8**. Hatchery Cost Projections over five-year time horizon.

Labor is the most critical factor separating the professional hatchery, Proteus SeaFarms, Int., Inc., from the other two hatchery scenarios. After Year 1 of the operation, labor accounts for 91 to 98% of the cost of the annual hatchery operations in all three scenarios (Figure 9). As such, the UCSB hatchery scenarios (UCSB and UCSB/DBFF PPP) are significantly more cost-effective because they utilize graduate student labor rather than professional staff. See Appendix K for further analysis of the significance of labor in the hatchery cost projections.

Based on his expertise in aquaculture and hatchery science, Mr. McCormick recommended that we include a 20% uncertainty factor to all of our cost estimates. The UCSB/DBFF PPP proved to be most cost-effective given the 20% uncertainty factor.

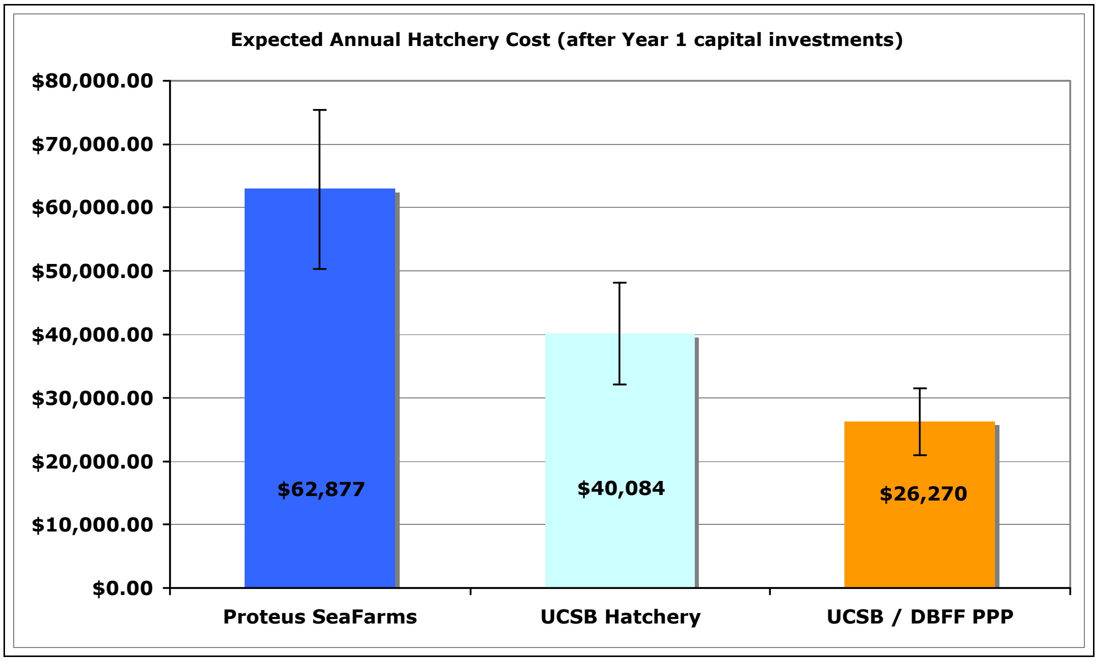


**Figure 9**. Annual Hatchery Cost for three alternative scenarios. Values represent the calculated mean cost of that hatchery operation. Error bars represent a 20% uncertainty factor.

### 9.5 Growout Scenarios

Next, we identified different growout scenarios to pair with the chosen hatchery scenarios. Hatchery Scenario 1 (Proteus SeaFarms International, Inc.) was significantly more costly than the other hatcheries, so our research group eliminated it from consideration for a growout pairing. This left two alternative hatcheries (the UCSB hatchery and the UCSB/DBFF PPP hatchery) to be paired with growout sites and/or aquaculture operators.

Through discussions with aquaculture operators, seafood distributors, and our Group Project advisors, we identified six categories of costs to evaluate the growout scenarios:

- Tray growout costs
- Experimental growout costs
- Fixed costs
- Marketing costs
- Legal costs
- Shipping costs

With these criteria, we evaluated two growout scenarios:

1. UCSB "start-up" aquaculture operation at Elkhorn Slough (UCSB/Elk)
2. UCSB/Drakes Bay Family Farms Public-Private Partnership (UCSB/DBFF PPP)

These two scenarios represent two potential means to initiate an Olympia oyster aquaculture operation: as an entrepreneur or as a public-private partnership. First, the UCSB/Elk scenario explored the possibility of starting an Olympia oyster aquaculture (growout) operation from scratch. In this scenario, UCSB would act as an entrepreneur and operate the aquaculture operation at Elkhorn Slough. The cost estimates in the scenario reflect typical costs that could be expected from a start-up aquaculture operation that does not have any existing capital[11] (no processing equipment, boat, distribution network, etc.) at the start of the business. An alternative to the entrepreneurial approach is to partner with an existing aquaculture operator for growout production. We selected DBFF as a partner in the public-private partnership because they had the most available growout acreage, favorable estuarine conditions in Drakes Estero and other comparative advantages over rival aquaculture operators in California. See Appendix K for a complete description of the selection rationale for these growout scenarios.

### 9.6 Growout Scenario Results and Analysis

Results of the growout cost scenarios revealed that the UCSB/DBFF PPP was more cost-effective than the UCSB/Elk aquaculture operation. Figure 10 illustrates the projected costs for each growout scenario over an eight-year time horizon. Though cost projections for both scenarios follow the same general trends, the UCSB/Elk scenario has significantly higher initial and average annual costs than the UCSB/DBFF PPP. Ignoring the initial year cost difference, the UCSB/Elk scenario is approximately $25,000 more expensive at each year of the time horizon.

[11] See Appendix J for a complete list of the assumptions regarding these cost scenarios.

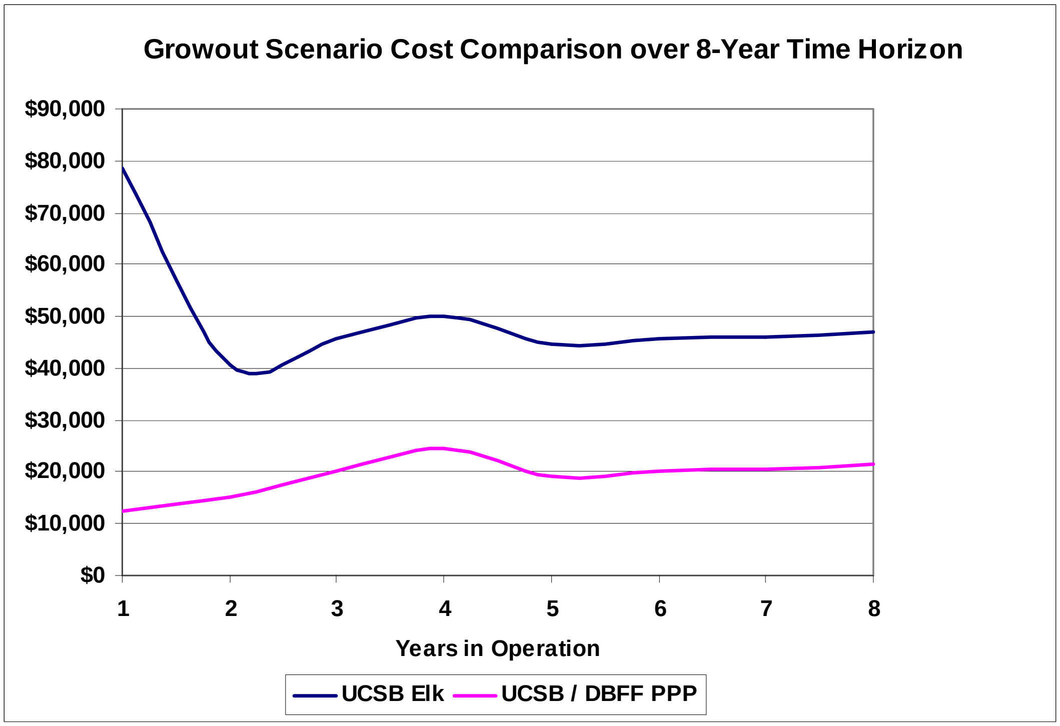


**Figure 10**. Cost Comparison of different growout scenarios over an eight-year time horizon.

Unlike the hatchery scenarios, labor does not represent the significant cost differential between the growout operations[12]. A closer look at the results illustrates that most of the costs are nearly identical for the two operations. However, fixed costs differ significantly because of three extra expenses incurred by the UCSB/Elk scenario:

- Rent
- Vessel purchase
- Shellfish processing equipment purchase

While the vessel and shellfish processing equipment are one-time purchases (approximately $20,000 each), rent is estimated to cost $2,000 per month or $24,000 per year. Even setting aside the Year 1 production costs, the UCSB/DBFF PPP is more cost-effective than the UCSB/Elk scenario. Growout production costs (not including Year 1 capital costs) for the UCSB/Elk scenario averaged approximately $46,000, while the UCSB/DBFF PPP scenario averaged approximately $21,000. The addition of a 20% uncertainty factor[13] to these values does not change this conclusion because the error bars (between the UCSB/Elk and UCSB/DBFF PPP scenarios) do not overlap. The UCSB/DBFF PPP does not incur vessel or processing equipment costs because the

[12] Growout labor costs are identical in both scenarios because both scenarios are based on the same technical growout design. These labor costs do not include management personnel salaries, because those costs are already included in the hatchery labor costs.

[13] Group Project Technical Advisor Tom McCormick recommended a 20% uncertainty factor on all scenario cost values.

operation already has this capital. Similarly, there is no rent payment because DBFF has rights to the land. These costs have a significant impact on the comparative cost-effectiveness between the scenarios. See Appendix K for complete growout scenario results and analysis.

### 9.7 Total Production Costs

The total costs of production[14] (combined hatchery and growout costs) illustrate that the UCSB/DBFF PPP is significantly more cost effective than the UCSB/Elk production scenario (Figure 11). In addition to producing Olympia oysters at a lower total cost per oyster, the UCSB/DBFF PPP presents significant opportunities for immediate collaboration on restoration projects due to the willingness of the Drakes Bay Family Farms ownership. In the UCSB/Elk scenario, several uncertainties remain, particularly regarding the ownership of submerged lands leases. There are many more uncertainties associated with the UCSB/Elk scenario than the UCSB/DBFF PPP. Given these findings, our research group selected the UCSB/DBFF PPP hatchery and growout production cost values as inputs for our profitability projection model.

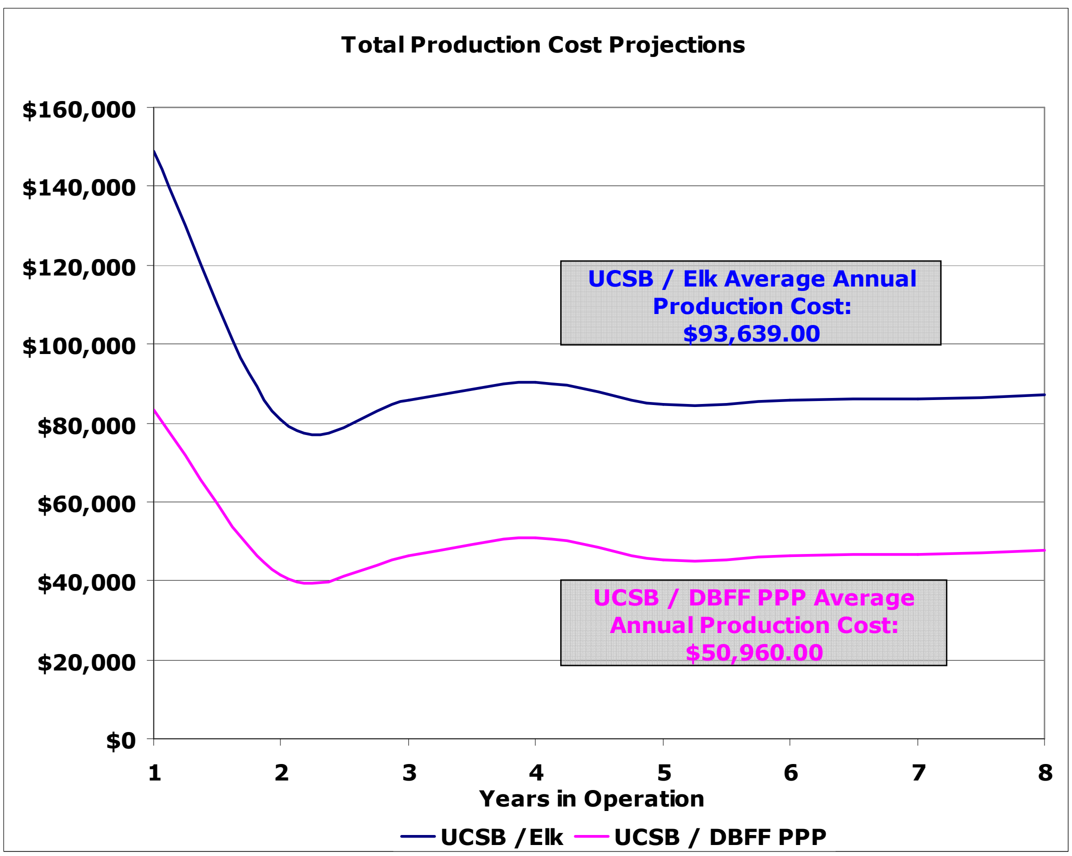


**Figure 11**. Total production cost projections for two Olympia oyster aquaculture operations.

[14] See Appendix J for a description of the combined hatchery and growout scenarios.

## 10.0 Olympia Oyster Aquaculture Feasibility

We designed a profitability projection model to assess the feasibility of an Olympia oyster aquaculture operation in California. The profitability projection model calculates annual profit based on the aquaculture business's costs and revenues over a designated time horizon. Profitability projection models are used to evaluate the economic feasibility, viability, and potential of the business. We designed our profitability projection model, hereafter referred to as the 'profitability model', to project the costs and revenue of an Olympia oyster aquaculture business over an eight-year time horizon[15]. The model output reveals positive or negative annual profits for the Olympia oyster aquaculture business and assesses the venture's cumulative profitability.

### 10.1 Methods

The results of the market demand analysis and the production cost analysis provided the critical inputs required for the profitability model. The market analysis confirmed the Olympia oyster target market, optimal price, marketability and demand in California. The production cost scenarios identified the most cost-effective hatchery and growout combination, the UCSB/DBFF PPP. These two elements provide the critical framework for the profitability model. The basic equation in the profitability model is:

**Equation 3**: Profitability Calculation

$$profitability = \sum [R - C]$$

where R= annual revenue

C= annual production costs (UCSB/DBFF PPP)

However, for this profitability model to produce an output (a profit projection), additional parameters must be added to both independent variables, R and C.

**Equation 4**: Annual Revenue Calculations.

$$R = [(oysters_{x-2} * M) * p] + [grant]$$

where $oysters_{x-2}$ = # of oysters produced in hatchery in Year ($x - 2$)

M = mortality rate

p = price per oyster

grant = education/ research funding

[15] An eight-year time horizon is appropriate for this profitability model because the standard time horizon (five-years) was too short to show the trends in profitability when we adjusted model parameters (during our sensitivity analysis). Since an Olympia oyster aquaculture operation has an initial lag time until the first cohort of oysters are delivered to market (~2 years), the time horizon needs to be extended clarify the overall trends in profitability.

**Equation 5**: Annual Cost Calculations

$$C = [hatchery_x] + [growout_x] + [distribution_x] + [taxes_x]$$

where $\text{hatchery}_x$ = hatchery production costs in Year *x*
$\text{Growout}_x$ = aquaculture growout costs in Year *x*
$\text{Distribution}_x$ = distribution costs in Year *x*
$\text{Taxes}_x$ = California state taxes in Year *x*

Each of these parameters influences the projected profitability of the UCSB/DBFF PPP. Appendix L describes the rationale and specific values assigned to each parameter.

### 10.2 Profitability Model Results & Analysis

Results from the profitability model illustrate that the UCSB/DBFF PPP is profitable over an eight-year time horizon (Figure 12). This prediction represents our best estimate of cumulative profitability based on a price of $0.90 per oyster and a 50% mortality rate. To be consistent with our production cost scenarios, we applied a 20% uncertainty factor to all model output values. The feasibility model shows that the UCSB/DBFF PPP is initially in debt because of expensive capital purchases and the two-year lag time until the first Olympia oysters mature to harvestable size. After year three, the venture becomes profitable as the operation continues to produce excess revenues over costs. At the end of eight years, the model predicts that the UCSB/DBFF PPP will have cumulative profits totaling approximately $350,000. While this margin of cumulative profitability may not be a recipe for a "Fortune 500" company, it does suggest that an Olympia oyster aquaculture operation is feasible in California.

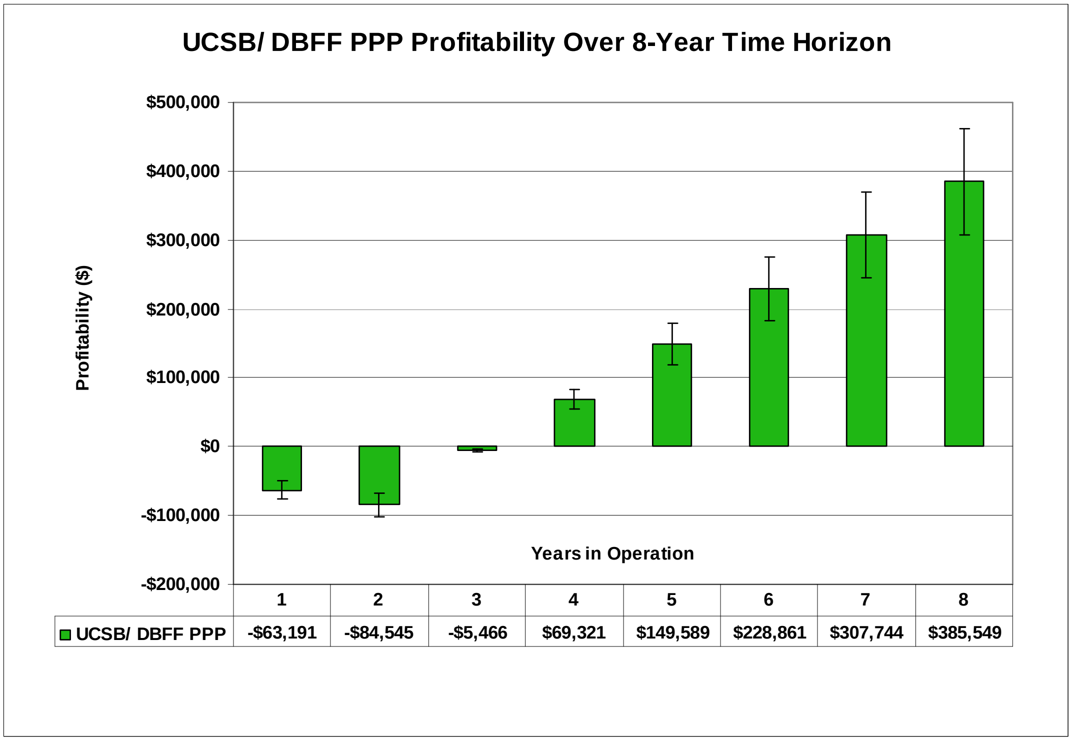


**Figure 12**. Expected cumulative profits of the UCSB/ DBFF PPP over an 8-year time horizon. Feasibility model included a mortality rate of 50% and a price of $0.90 per oyster. Error bars represent a 20% uncertainty factor.

A sensitivity analysis revealed that two parameters, the mortality rate and the price per oyster, had the most impact on the profitability projection. See Appendix L for the complete sensitivity analysis results. Comparatively, the mortality parameter caused more variation in profitability than the price per oyster parameter. In relative terms, a 10% increase in the mortality rate was equivalent to a 33% decrease in price. Therefore, the significance of the mortality parameter must be emphasized.

The extreme variability in cumulative profitability due to changes in mortality signifies that mortality is the most important parameter in the feasibility model. These results indicate that enhancing the survivorship of the oysters from the hatchery through their growout period will significantly influence the profitability of the business venture.
We examined mortality rates to identify a specific mortality rate that, on average, will ensure that the business is profitable (or at least breaks even). This analysis revealed that the UCSB/DBFF PPP must keep mortality levels at 60% or less to ensure that the business will remain profitable (Figure 13). Therefore, the 60% mortality rate represents a critical threshold to evaluate profitability and feasibility.

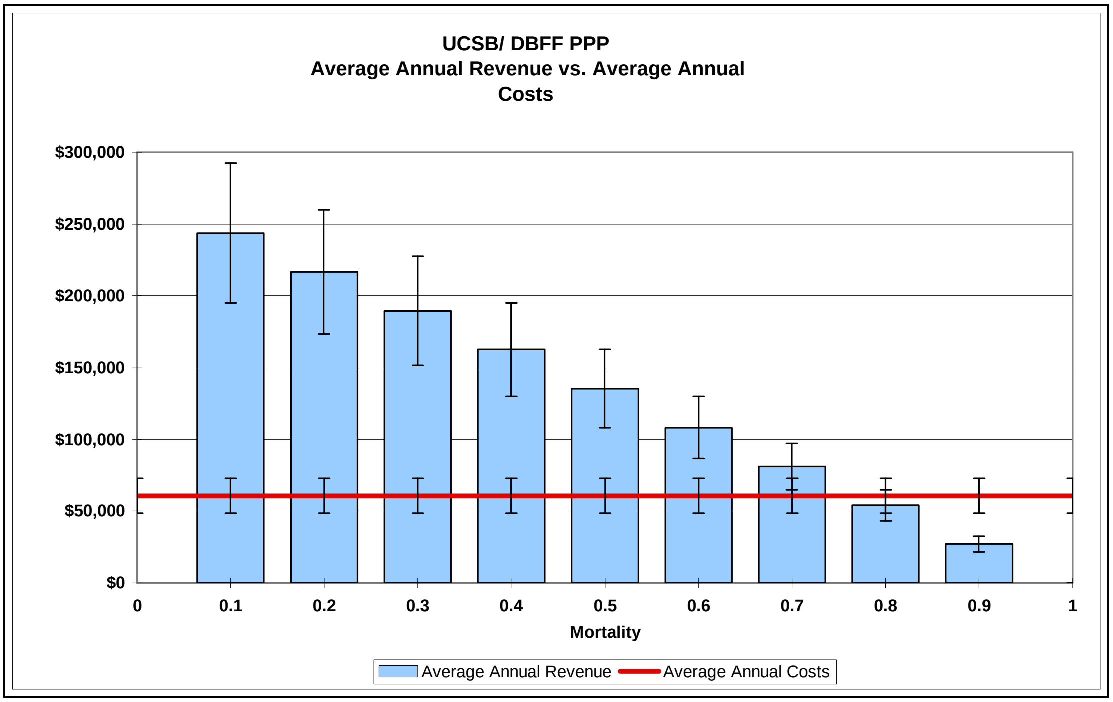


**Figure 13**. UCB/DBFF PPP average annual revenue compared to average annual cost at different levels of mortality. The red line represents the average annual cost of the aquaculture operation, while the blue bars represent the projected revenue at that level of mortality. As long as the blue bar exceeds the red line (including the error bars), the business will break even or generate profits. Error bars represent a 20% uncertainty factor for all cost projections.

These findings illustrate the importance of the research component of the UCSB/DBFF PPP. Research efforts will attempt to identify specific growout techniques to enhance Olympia oyster post-recruitment survivorship in Drakes Estero. This research will benefit restoration efforts and the technical design of the growout media to enhance survivorship of cultured oysters. As growout techniques improve, the mortality rate will decrease, resulting in greater profit margins.

*Restoration Benefits*
In addition to providing profitability projections, the feasibility model also gauged the potential restoration benefits of the UCSB/DBFF PPP. Two primary restoration benefits were quantified:

- Olympia oyster shell for restoration projects
- Funding for restoration projects

We calculated the number of Olympia oyster shells available for restoration programs by adding the number of shells from shucked oysters (all oyster shells are already collected in the process of shucking and packing) and a percent of the total half-shell oysters sold. Figure 14 illustrates the potential shell quantities available for restoration projects. A 50% recovery rate from restaurants would result in approximately 200,000 shells available for restoration projects annually.

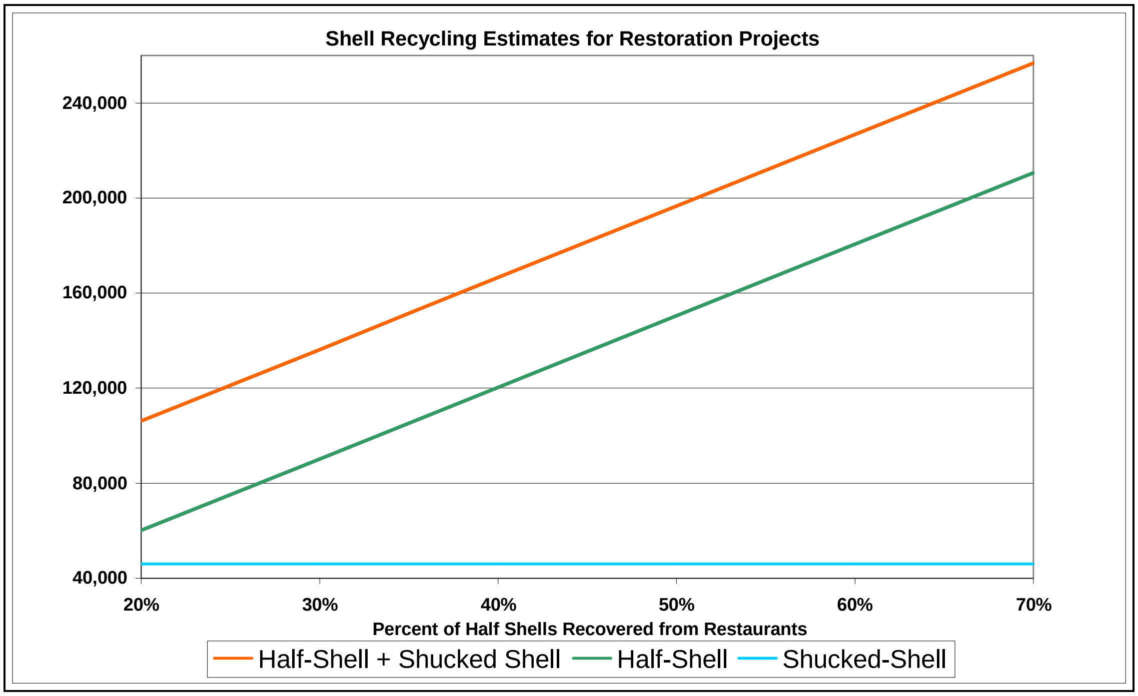


**Figure 14**. A range of potential shell contributions to Olympia oyster restoration projects as a function of shucked shells and half-shells recovered from restaurants. As the percentage of half-shells that are recovered from restaurants increases, the number of Olympia oyster shells available for restoration increases linearly.

In addition to shell contributions, the UCSB/DBFF PPP could also contribute funding to Olympia oyster restoration projects. The feasibility model projected potential funding as a percentage of the total revenue of the UCSB/DBFF PPP. As Table 2 illustrates, the UCSB/DBFF PPP has modest funding potential. If UCSB and DBFF established the public-private partnership as a non-profit company, then the percentage of total revenue for restoration donations could be increased to a much larger percent, yielding more substantial funding to restoration projects.

**Table 2**. Projected Olympia oyster restoration funding at different percentages of total revenue. These figures are based on the UCSB/ DBFF PPP with a $0.90 price per oyster and a 50% mortality rate throughout the eight-year time horizon.

| % of Total Revenue Donated to Restoration | Total Donation After Eight-Year Time Horizon |
|---|---|
| 0.2% | $1,625 |
| 0.5% | $4,062 |
| 1.0% | $8,125 |
| 1.5% | $12,187 |
| 2.0% | $16,250 |
| 2.5% | $20,312 |
| 3.0% | $24,375 |

*UCSB/DBFF PPP Competitive Advantages*
The UCSB/DBFF PPP takes advantage of many of the unique facets of the Drakes Bay Family Farm to enhance its profitability. Specifically, DBFF has the largest acreage of any aquaculture farm in California, excellent water quality, a relatively abundant natural population of Olympia oysters, extensive capital infrastructure, an established distribution/client network, and the only licensed shucking plant in California. These advantages filter down into production cost savings at the hatchery, in the growout process, and in distribution. The result is that the UCSB/DBFF PPP has significant potential for success as long as the UCSB research team can identify techniques to enhance growout survivorship and keep growout mortality below the 60% threshold.

Although these profitability model projections suggest that the UCSB/DBFF PPP could be lucrative, our results do not guarantee that an Olympia oyster aquaculture start-up business will produce the same margin of profitability. Without all of the competitive advantages listed above, the hatchery, production and distribution costs tend to be significantly higher, which reduces the profitability of the operation (see Appendix L for a comparison of the projected profitability difference between the UCSB/DBFF PPP and the UCSB Elk operation).

Our findings suggest that an entrepreneurial Olympia oyster aquaculture start-up business is not feasible, but it does not preclude the possibility of other successful public-private partnerships. The UCSB/DBFF PPP's positive profitability projections suggest that our conceptual business model is feasible. Further, these results indicate the great potential of public-private partnerships to support Olympia oyster restoration projects. Thus, the UCSB/DBFF PPP represents a potential prototype for other Olympia oyster aquaculture public-private partnerships.

### 10.3 Profitability Model Conclusions

The results of the feasibility analysis indicate that an Olympia oyster aquaculture business is feasible in California. The following list summarizes the key findings from the feasibility analysis.

- Controlling the oyster mortality rate during growout is the key to the profitability in an Olympia oyster aquaculture business and is likely to be more important than the wholesale price (per oyster).
- Critical research is required to enhance post-recruitment survivorship and growout techniques.
- The UCSB/DBFF PPP will be profitable if the Olympia oyster mortality rate is maintained at, or below 60%.
- The UCSB/DBFF PPP is expected to provide direct benefits to restoration projects including considerable quantities of Olympia oyster shell and modest funding.

- A public-private partnership is more feasible and profitable than an entrepreneurial Olympia oyster start-up company.
- The UCSB/DBFF PPP could act as a prototype for other Olympia oyster aquaculture public-private partnerships.

This analysis provides extensive evidence that the UCSB/DBFF PPP has significant potential as a business venture and as a tool to support Olympia oyster restoration in California. The profitability model identified the critical factors that will maximize profits and provided a quantitative analysis of the restoration potential of the aquaculture operation. Despite the positive feasibility results, this analysis is primarily limited by the accuracy of the mortality rate during the growout operation. Without site-specific research to identify techniques that will enhance post-recruitment survivorship, it is impossible to estimate profitability with high accuracy.

## 11.0 Conclusions

Through our extensive market, production, and profitability analyses, we believe that an Olympia oyster aquaculture business is feasible in California, and that the venture could provide support for Olympia oyster restoration efforts. Although the efficiency of our production techniques includes some uncertainty, our analyses point to the likelihood of modest, long-term profitability in conjunction with significant non-monetary aid to restoration projects. Given our findings, it is important to consider the broader implications of this research.

As a public-private partnership, an Olympia oyster aquaculture venture can remain profitable while supporting restoration efforts. Our research quantified two direct sources of oyster restoration support: funding and shell donations. These quantifiable sources of support proved to be less critical than other forms of support, particularly research, collaboration, and in-kind donations. Commercial Olympia oyster aquaculture and Olympia oyster restoration face many of the same technological gaps. Technical collaboration between public and private interests could enhance restoration success throughout California while increasing private aquaculture profit margins.

Marketing and sales of the Olympia oyster are likely to enhance public support of restoration projects and educate the public about the significance of the species. Our market analysis revealed a high demand for the Olympia oyster, with particular interest in the 'green' story marketing potential. Marketing the Olympia oysters' 'green' story will set this product ahead of substitute products.

Aligning private and community incentives will advance scientific knowledge of the Olympia oyster and enhance restoration success in California. Further, we expect ecosystem benefits from this public-private partnership, including improved water quality, more robust natural populations, and more abundant native oyster habitat. Our research suggests that the 'green' marketing will enhance public awareness and restoration support for this ecosystem engineer. The business model set forth in this report represents one form of a public-private partnership between aquaculture and restoration. However, our business model and public-private partnership prototype could be expanded and developed into a network of Olympia oyster aquaculture and restoration partnerships. A network of Olympia oyster public-private partnerships would provide unified local, municipal, and private support for oyster restoration throughout California, while supplying a sustainable source of local seafood.

## 12.0 Recommendations for Future Research

Our work showed that Olympia oyster aquaculture has the potential to fill a currently unmet market demand in California and make important contributions to restoration. Throughout our analysis we made several important assumptions about Olympia oyster aquaculture. Future research should investigate these assumptions, particularly questions about growout technology and site-specific restoration bottlenecks in California. In addition, further research should investigate other public-private partnerships and changes to legal statues to favor sustainable shellfish aquaculture. Each of these areas of future research is further described below.

*Growout methods and post-recruitment survivorship success:*
Our Olympia oyster aquaculture production model, prescribed that a certain number of hatchery-produced Olympia oysters would be used for experimental research each year. These oysters would be used to identify more efficient grow-out techniques for half-shell oyster production. Improvements to grow-out techniques will lead to a better understanding of post-recruitment survivorship that is directly applicable to restoration. Recent research by Trimble et al. (2007) improved our understanding of the biological constraints facing Olympia oyster populations and aquaculture production, but these conclusions must be tested within California. This research is vital to making an Olympia oyster aquaculture business a reality in California.

Another important line of research must identify the exact time required to produce Olympia oysters with the tray grow-out technique in California. The California coast exhibits a wide range of physical conditions, such as water temperature, which will have a significant impact on the growth rate of Olympia oysters.

*Public-Private Partnerships*
Our analysis outlined several positive benefits of developing a public-private partnership between UCSB, a public entity, and Drakes Bay Family Farms, a private oyster farm. Future research should explore other public-private partnerships that link restoration efforts with private enterprise. Our research showed that public-private partnerships can provide substantial benefits to both parties and provide positive environmental externalities. Given these results, other public-private partnerships should be explored. For example, some cities or counties own rights to tidelands, often within and around their harbors. These municipal governments could work with private aquaculture operators to develop their own public-private partnerships, thereby providing a new source of employment, locally-produced sustainable seafood, and improved water quality.

*Legal Structure*
Shellfish aquaculture is not recognized independently from other forms of aquaculture that have more significant environmental impacts. Throughout our analysis, we highlighted many of the studies that illustrate the biofiltration capacity of oysters. However, legal and policy mandates typically regulate all types of aquaculture in the same

manner. For oyster aquaculture, particularly Olympia oyster aquaculture, the potential benefits of aquaculture should be taken into consideration when awarding bottom leases and determining appropriate uses of state tidelands. Further, the law does not include any legal or political incentives to encourage aquaculture operators to grow native species over exotics. Although the State of California is currently working on a new process environmental impact report (PEIR) for aquaculture in state waters (Moore, 2008), future research should explore new policies that will favor aquaculture businesses that produce environmentally-friendly, native species. Alternatively, new policies could focus specifically on growing the native oyster or mitigation measures could include public-private partnerships to aid restoration efforts. Providing a streamlined process to aquaculture operators that grow native species may encourage Olympia oyster production in California. We have shown that native oyster aquaculture can produce a profit, but the state should explore ways to help current operations offset the costs of expanding those operations to include other native species.

## Appendix A: Market Demand Analysis

This appendix includes further discussion on global and domestic seafood and oyster consumption patterns, marketing of the Olympia oyster and a market demand risk analysis.

### Seafood and Oyster Consumption Patterns

*Global Seafood and Oyster Consumption*
Global per capita fish consumption, including shellfish, increased approximately 80% from 1960 to 2000 (FAO 2007). Total catch from capture fisheries has not exhibited this same level of increase, and is unlikely to do so considering that 75% of the monitored stocks have reached or exceeded their maximum sustainable catch limits (Figure 15). Demand for seafood will continue to increase, with projections of a global seafood demand of 130 million tons by 2020 (FAO 2006). As a result, global seafood supply has shifted towards more aquaculture production.

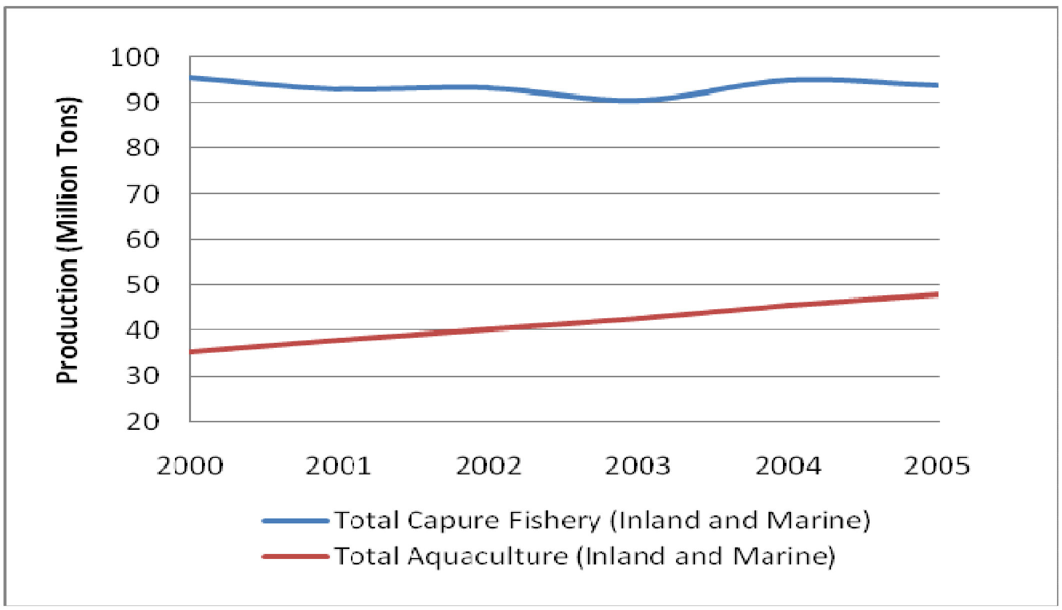


**Figure 15**. Total world capture fisheries and total aquaculture production from 2000 to 2005 in million tons. (Reproduced (FAO 2006).

Aquaculture's contribution to the total global supply of fish and shellfish has increased over the last three decades, with the most rapid growth in the last ten years. In 2004, aquaculture contributed approximately 43% of the total fish available for consumption (FAO 2006). Oyster production accounts for a significant portion of the increased global aquaculture production. Total mollusk production has increased by 7.7% in the last thirty years, a trend that is likely to continue in the future due to the increasing demand for seafood (Figure 16) (FAO 2006).

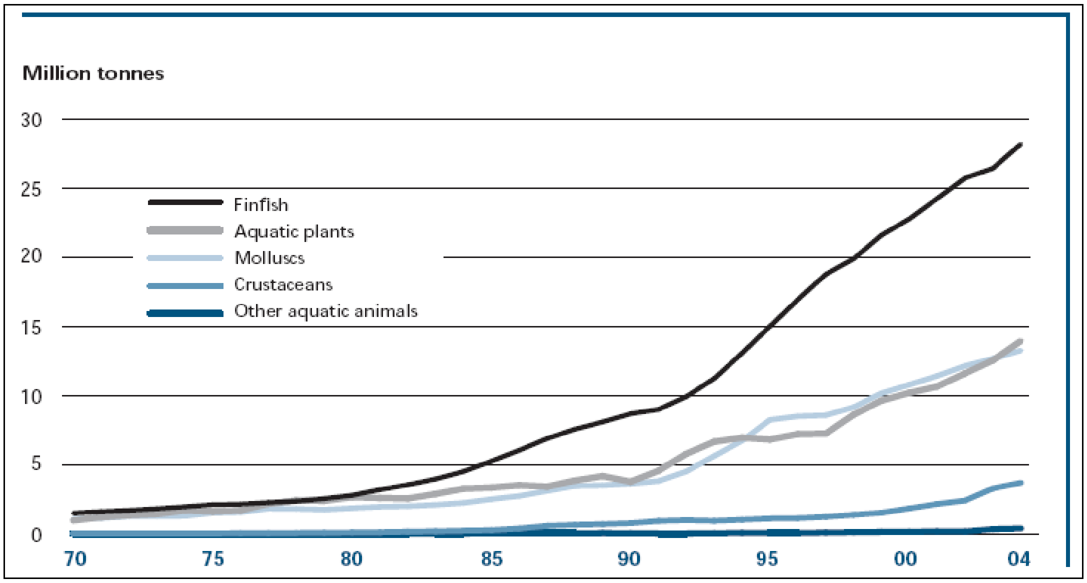


**Figure 16**. Trends of major species in global aquaculture production from 1970 to 2004, shown in million tons. (Reproduced from FAO 2006).

*Domestic Seafood and Oyster Consumption Trends*

U.S. aquaculture production has shown an 11% increase over the last ten years (USDA National Agriculture Statistics Service 2005). Of this production, mollusks (abalone, clams, oysters, and mussels) made up 19% of sales in 2005. With a very strong demand for seafood, the U.S. ranks as the third largest seafood consumer in the world (USDA National Agriculture Statistics Service 2005). However, domestic production of seafood ranks eleventh (by volume), creating a large gap in demand versus supply that is currently filled by seafood imports (USDA National Agriculture Statistics Service 2005). Similarly, U.S. commercial landings of oysters consistently fall below domestic demand, resulting in a steady increase in foreign imports of live oysters over the past decade (Figure 17) (NMFS 2007). The current oyster production deficit in the U.S. indicates a market opportunity for new domestic aquaculture businesses.

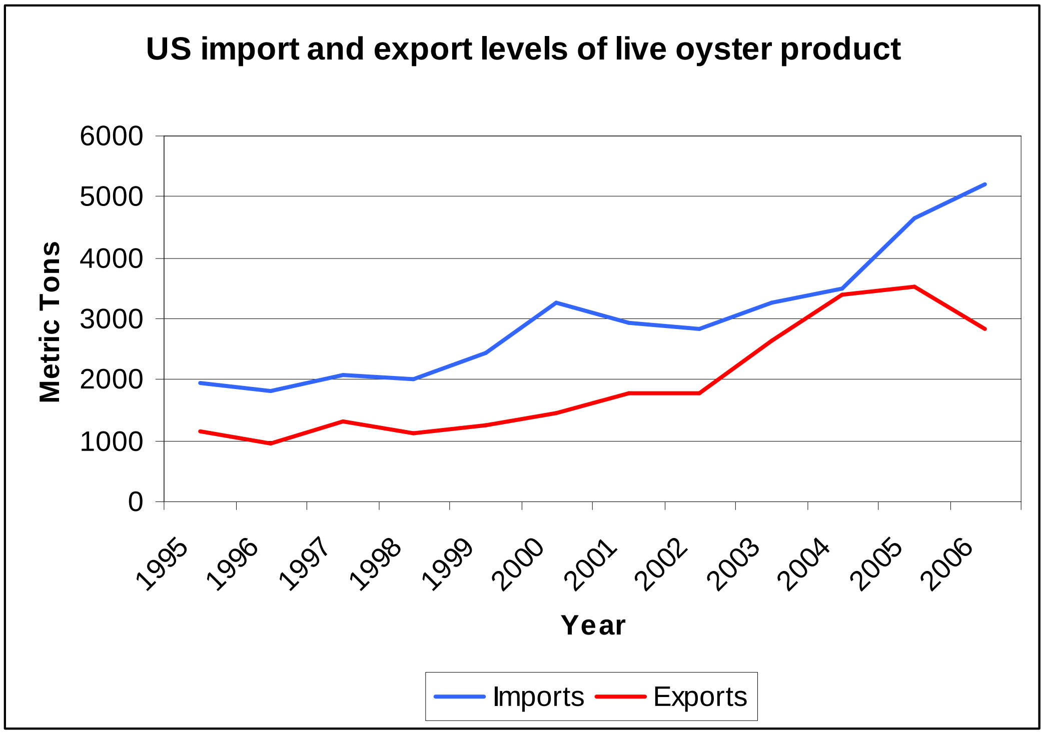


**Figure 17**. US import and export levels of live oyster product in metric tons. Canned (shucked) oyster products are not included in these estimates (NMFS 2007).

*Domestic Seafood Trends: Sustainable seafood*
Increased demand for "sustainable seafood" suggests that consumer demand for oysters will continue to intensify. Institutions that rate seafood species and production methods on scales of sustainability, such as the Monterey Bay Aquarium (the Seafood Watch Program), rank oysters produced from aquaculture as one of the most "sustainable" seafood species because there is virtually no environmental impact from oyster aquaculture production (see *Marketing: Green Story* below for a detailed explanation of the limited environmental impact of oyster aquaculture) (Monterey Bay Aquarium 2008). As public education on seafood sustainability increases, we expect that more consumers will demand oysters due to their highly "sustainable" production.

*Domestic Seafood Trends: Demographics*
National demographic research also indicates that oyster consumption will continue to rise. Market research showed that consumers, ages 35 and older, eat greater amounts of seafood as well as a higher proportion of shellfish (Johnson et al. 2004). Further, this research found that a majority of seafood consumers fall in the 50 to 65-age range (Johnson et al. 2004). By 2020, a larger proportion of Americans will be over the age of 60, leading to a higher total consumption of shellfish (Johnson et al. 2004). A study targeting oyster consumer demographics in California specifically found that fifty-five percent of respondents reported stable oyster consumption over the past five years, while 10% of respondents said their oyster consumption increased (Flattery et al. 2003).

Respondents that reported decreased oyster consumption cited a lack of product availability as the primary reason for reduced consumption (34%), followed by health concerns (30%), taste (11%), and cost (10%). This survey may suggest that there is an unmet demand for oysters in California and, furthermore, room for growth in the oyster market.

**Marketability of the Olympia oyster**

In the process of a market assessment, it is important to recognize the key characteristics that make your product unique. Olympia oysters vary considerably from other commercially-produced oysters because of their small size and distinct taste. Therefore, Olympia oysters occupy a specific market niche and have significant marketing potential. The key characteristics that set Olympia oysters apart from other oyster products include their taste and their 'green' story.

*Taste/Specialty Oyster*

For true oyster aficionados, the Olympia oyster is recognized as one of the best tasting oysters, if not the best. In the 1950's, naturalist William Cooper described the taste as a 'peculiar coppery flavor' while others highlight a subtle cucumber or melon flavor (Apple Jr. 2004). In general, Olympia oysters are marketed as a specialty "cocktail oyster" (an appetizer), served fresh on the half shell (Finger 2007). Since Olympia oysters are significantly smaller and more expensive than the larger Pacific oysters (average size between 35-45 mm), seafood restaurants and oyster bars generally only serve Olympia oysters if they have a selection of oysters on their menu (Finger 2007). Customers of these restaurants are likely to be familiar with the different oyster types and are more likely to purchase specialty oyster products (Finger 2007).

*Marketing: Green Story*

The Olympia oyster has several unique attributes and production methods that could be marketed as a 'green story'. These production characteristic includes local and sustainable production, few negative environmental impacts, and interesting restoration potential. The following is a brief discussion of each marketing component.

The restaurant industry has seen a movement in the last five to ten years that emphasizes the use of local, sustainable ingredients. Alice Waters, the founder of the famous Chez Panisse Restaurant in Berkeley, California, originally developed this emphasis on the use of local, sustainable ingredients. A recent culinary trends survey stated that since 2005, there has been a "…15% growth in the number of chefs who focus on locally grown, seasonal ingredients" (Agricultural Marketing Resource Center 2006). Industry experts forecast continued growth in the future. While choosing sustainably produced ingredients can increase a restaurant's total costs, most consumers are willing to pay more for locally cultivated seasonal meats and produce (Agricultural Marketing Resource Center 2006).

Shellfish aquaculture is one of the few forms of commercial aquaculture that can be produced with relatively few negative environmental impacts. The major environmental impacts associated with intensive commercial aquaculture operations include effluent discharge, local eutrophication, changes to the benthic community structure, and inefficient feed conversion rates. Effluent discharge from open net pen aquaculture contains nutrients, chemicals, and pharmaceuticals, which can have negative impacts on surrounding coastal environments (Naylor et al. 2000). Excess feed and fish feces can cause eutrophication and significant stress to marine communities due to poor water quality conditions (Naylor et al. 2000). Escaped exotic farmed species can disrupt established predator prey interactions of wild species. Fish pens used in traditional commercial aquaculture can also obstruct navigation and mar viewsheds.

Compared to other forms of aquaculture, oyster aquaculture features filter-feeding bivalves with virtually no environmental impact on the surrounding environment. Once oysters are outplanted to estuaries, no additional feed is required, eliminating eutrophication and effluent discharge issues. Through filter-feeding, oysters can actually improve local water quality (NOAA 2003). As a result, Olympia oysters can reduce turbidity and phytoplankton abundance, which is likely to decrease the probability of problematic algal blooms. Clear (non-turbid) water is also likely to improve the probability of survivorship of other important native marine communities, particularly eelgrass. Maintaining pristine water quality is also in the best interest of the oyster aquaculture business because it enhances the health and quality of their product. Since oyster products (produced in California) are eaten raw, oyster growing areas are closely monitored by the aquaculture operators, the California Department of Health Services (CDHS) and the National Shellfish Sanitation Program (NSSP) (California Department of Fish and Game 2001). Aquaculture operators test the waters regularly to ensure that the oysters meet the highest standards of safety.

Olympia oyster restoration represents another aspect of the 'green story' marketing. An Olympia oyster aquaculture operation could recycle used oyster shells (from participating restaurants) for use in oyster restoration efforts. Suitable substrate is limited at many restoration sites, so recycled shells could enhance the success of restoration projects. In turn, participating restaurants could advertise their direct support of Olympia oyster restoration, emphasizing a green image and a supporting role in the community.

**Demand Risk Analysis**

The market demand for Olympia oysters may be somewhat volatile and subject to fluctuation. The first reason for possible market fluctuation is that oysters are a luxury item, and as such, consumption and sales are closely tied to the health of the economy as a whole. If consumer spending in the US declines, restaurant sales and the subsequent purchase of the Olympia oyster product are likely to decline. Furthermore, Olympia oysters are subject to greater volatility because they are a specialty oyster with a higher price than other oyster varieties (Kallen et al. 2001).

Another factor influencing market fluctuation is the consumer perception of health risks associated with the consumption of oysters. Filter feeders, such as oysters, can harbor bacterium that can be harmful to particular demographic groups, such as pregnant woman, children, and the elderly. For example, *Vibrio vulnificus*, is a naturally occurring marine bacterium which can flourish in warm seawater. In general, healthy humans are not at risk from *V. vulnificus* infection after the consumption of raw oysters. However, in individuals with pre-existing health conditions which impair immune defense systems *V. vulnificus* infection can be fatal. Olympia oysters are not typically associated with *V. vulnificus* because of the cold water temperatures along the West Coast (Kaspar et al. 1993).

In actuality, the threat of a fatal shellfish bacteria poisoning is minimal and typically related to the physical condition of the consumer. Public perceptions of these risks are quite different however. Mass media coverage of severe cases of infection have led the public to perceive all shellfish as carrying some level of potential health risk, and these perceptions influence consumer demand for the product (Lin et al. 1993). Several studies identified factors that influence consumer seafood safety perceptions. In general, consumer perceptions are determined by past experiences with seafood, frequency of consumption, media attention, and risk-taking behavior (Wessels et al. 1995).

The target market for the Olympia oyster consists primarily of oyster connoisseurs, who frequently consume different species of oyster. Frequent consumers of seafood perceived seafood as safer than individuals who do not consume seafood and, subsequently, these consumers were less swayed by media attention (Lin et al. 1991; Levy 1995). Eating raw oysters is an informed choice; oyster consumers view the consumption of raw oysters as an acceptable risk given their fondness for oysters (Levy 1995). Based on these studies, consumers of Olympia oysters may be less influenced by media attention or health scares than consumers of Pacific oysters.

Oyster flavor is dependent on several local environmental conditions including the water quality of the growout site and the mineral content of the surrounding substrate and water (Barrett 1963). Given the subtle nuances in flavor (amongst the same species of oyster) imparted by location, dozens of varieties are recognized. Some of the most commonly found oysters in California oyster bars include Hood Canal (Pacific oyster), Miyagi (Pacific oyster), Hog Island Sweetwaters (Pacific oyster), and Blue Points (Eastern oyster). Olympia oysters raised in California could have a slightly different flavor than the Washington stock. There is a risk that the taste of California Olympia oysters will not be as well received as Olympia oysters from Washington State. Regardless of the growout location chosen for the business model, Olympia oysters produced in California will have their own unique flavor, which will need to be evaluated by each potential restaurant.

## Appendix B: Market Survey

This appendix provides additional information on the methods and results from our market survey.

### Methods

*Creating the census list of restaurants for our survey*
We chose *Zagat* because of its comprehensive restaurant list, solid reputation[16], and convenient restaurant classification system. The Zagat guides categorized all restaurants that serve raw shellfish as "raw bars" for each city or area. This categorization included restaurants that specifically had oyster bars (restaurants that specialize in serving multiple varieties of raw oysters), as well as restaurants that included an oyster product on their menu but did not necessarily specialize in oysters. Our survey included all the listings under this raw bar heading in the three guides, which we assumed to be the established population of oyster bars in California.

*Dividing census list into four subcategories*
Though all the restaurants surveyed listed 'raw bar' as one of their features and were therefore included under that subheading in the Zagat Guide, they did not all have the same level of focus on oysters. An oyster bar describes a restaurant that either calls itself an oyster bar or has a raw bar with a focus on oysters. Seafood restaurants differ in that they focus on seafood without the oyster bar component (though many did sell more than one type of oyster). Generic restaurants are high-end restaurants that serve seafood. High-end restaurants were more expensive restaurants, generally with a ranking of four to five stars (the *Zagat* rating system). Other restaurants include international cuisine and sushi restaurants that served, or had served oysters in the past.

*Removing outliers in the data*
To improve the accuracy of our demand data, we removed outlier data points. Two data entries were removed as outliers because the quantity demanded was so much greater than the other data points it dramatically skewed the data. The two points we removed were weekly demands of 333 and 666 dozen oysters per week. The next highest oyster demand was 105 dozen oysters per week. We removed these two data points to show a more conservative, realistic view of the market.

[16] According to a recent New York Times article, "Zagat is considered the nation's pre-eminent populist printed restaurant guide" (http://www.nytimes.com/2008/01/14/business/14deal.html?_r=1&oref=slogin).

## Results

*Respondent Demographics*

**Table 3**. Restaurant surveyed and their response rate by restaurant type. Oyster bar describes any oyster bar or restaurant with a significant oyster component. Seafood restaurants are those focused on seafood but without a raw bar. Generic restaurants are high-end restaurants with a seafood component, and the 'Other' category includes sushi and international restaurants.

| Restaurant Type | No Contact | Contacted | Total | Response Rate |
|---|---|---|---|---|
| **Oyster bar** | **5** | **23** | 28 | 82.14% |
| **Seafood** | **5** | **21** | 26 | 80.77% |
| **Generic** | **3** | **8** | 11 | 72.73% |
| **Other** | **3** | **7** | 10 | 70.00% |
| **Total** | **16** | **59** | **75** | 78.67% |

**Table 4**. Respondent familiarity with Olympia oysters by restaurant type.

| Restaurant Type | Frequency | Percent |
|---|---|---|
| **Oyster bar** | | |
| Not Familiar | 4 | 17.39% |
| Familiar | 19 | 82.61% |
| **Seafood** | | |
| Not Familiar | 5 | 23.81% |
| Familiar | 16 | 76.19% |
| **Generic** | | |
| Not Familiar | 2 | 25.00% |
| Familiar | 6 | 75.00% |
| **Other** | | |
| Not Familiar | 3 | 42.86% |
| Familiar | 4 | 57.14% |
| **Total** | | |
| **Not Familiar** | **14** | **24%** |
| **Familiar** | **45** | **76%** |

**Table 5**. Restaurants surveyed that have considered adding the Olympia oyster to their menu.

| | Frequency | Percent |
|---|---|---|
| **Have Not Considered** | 21 | 36% |
| **Have Considered** | 38 | 64% |

**Table 6**. Restaurants surveyed that currently have some type of oyster on their menu. The average number of oysters for restaurants that have oysters on the menu is 3.35 varieties.

| | Frequency | Percent |
|---|---|---|
| **No** | 3 | 5% |
| **Yes** | 56 | 95% |

**Table 7**. All restaurants surveyed that had oysters on the menu offered oysters on the half shell. This table shows the number of restaurants where oysters on the half shell were their most popular dish. Restaurants not currently serving oysters are recorded as not applicable (N/A).

| | Frequency | Percent |
|---|---|---|
| **No** | 2 | 3.39% |
| **Yes** | 54 | 91.53% |
| **N/A** | 3 | 5.08% |

**Table 8**. Frequency of specialty oysters offered by restaurants surveyed.

| Type of Oyster | Frequency | Percent |
|---|---|---|
| **Olympia** | | |
| No | 43 | 74.14% |
| Yes | 1 | 1.72% |
| Sometimes | 14 | 24.14% |
| **Kumomoto** | | |
| No | 18 | 31.03% |
| Yes | 20 | 34.48% |
| Sometimes | 20 | 34.48% |
| **Eastern** | | |
| No | 12 | 20.69% |
| Yes | 29 | 50.00% |
| Sometimes | 17 | 29.31% |

*Market Demand Curve*

We created a basic demand curve, not normalized for restaurant size or type, from the data on how may oysters restaurants would buy at a randomly assigned price. Each restaurant was asked what their average demand would be at one price. The range of prices was \$0.30, \$0.60, \$0.90, \$1.20, \$1.50. We regressed quantity demanded on price (Figure 18). Normalizing for restaurant size and/or type did not considerably increase the $R^2$ value. The equation from this regression was used to determine potential revenues and demands for the Olympia oyster market.

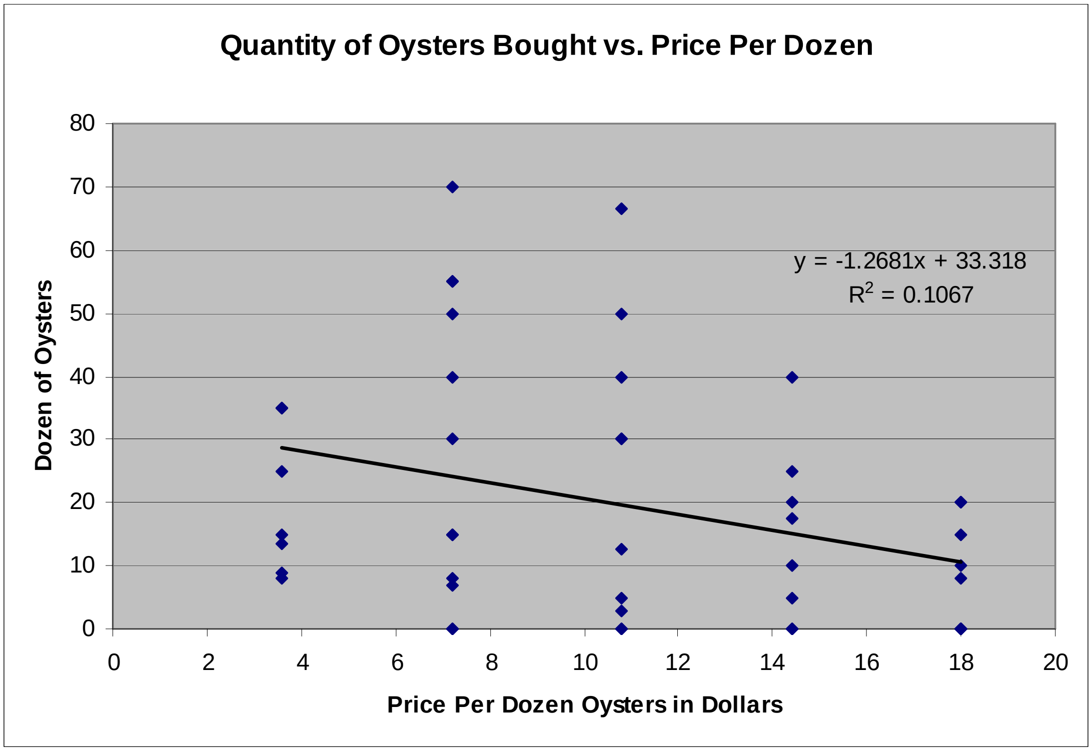


**Figure 18**. Respondents were asked how many oysters they would purchase for an average week of business at one of five prices per dozen. The price per dozen was randomly assigned to each respondent prior to the start of the survey. This graph does not include two outliers that were likely representative of special events and not average weeks. While the $R^2$ value is very low, we do see a general trend of fewer oysters being purchased as price increases. That the $R^2$ value is not good may reflect the fact that price is not an important factor when considering adding an oyster to the menu. The p-value was significant at 0.025.

**Table 9**. Number of restaurants who would consider adding the Olympia oyster to their menu if they cost the same as Pacific oysters.

| | Frequency | Percent |
|---|---|---|
| **No** | 4 | 7% |
| **Yes** | 52 | 88% |
| **Don't know** | 3 | 5% |

**Table 10**. The average demand, including the two outliers excluded from the demand curve, for Olympia oysters, if they were priced the same as Pacific oysters (no price premium) shows that restaurants are interested in selling this oyster.

| *Number of Dozen Oysters Bought Disregarding Price (With Outliers)* | |
|---|---|
| Mean | 49.08 |
| Standard Error | 13.89 |
| Median | 25 |
| Mode | 30 |
| Standard Deviation | 100.15 |
| Sample Variance | 10029.47 |
| Kurtosis | 30.02 |
| Skewness | 5.21 |
| Range | 666 |
| Minimum | 0 |
| Maximum | 666 |
| Sum | 2552 |
| Count | 52 |

**Table 11**. The average demand for Olympia oysters, if they were priced the same as Pacific oysters (no price premium) shows that restaurants are interested in selling this oyster. This average does not include the two outliers that were excluded from the demand curve.

| *Number of Dozen Oysters Bought Disregarding Price (Without Outliers)* | |
|---|---|
| Mean | 31.06 |
| Standard Error | 3.73 |
| Median | 24.5 |
| Mode | 30 |
| Standard Deviation | 26.37 |
| Sample Variance | 695.23 |
| Kurtosis | 1.13 |
| Skewness | 1.24 |
| Range | 105 |
| Minimum | 0 |
| Maximum | 105 |
| Sum | 1553 |
| Count | 50 |

**Table 12.** Descriptive statistics for the importance of decision-influencing factors

**Table 12.** Descriptive statistics for the importance of decision-influencing factors. Respondents were asked to rate the importance of the following factors that influence a decision to add an oyster to the menu on a 5 point scale, where 1 was not important at all, and 5 was very important.

| | | Importance of price | Importance of flavor | Importance of availability year round | Importance of availability in season only | Importance of being a unique menu item | Importance of being sustainably produced | Importance of being locally produced | Importance of expanding your oyster selection | Importance of marketing restoration story |
|---|---|---|---|---|---|---|---|---|---|---|
| N | Valid | 56 | 56 | 55 | 54 | 55 | 56 | 56 | 56 | 56 |
| | Missing | 19 | 19 | 20 | 21 | 20 | 19 | 19 | 19 | 19 |
| Mean | | 3.491 | 4.768 | 2.855 | 3.019 | 3.873 | 4.571 | 4.063 | 3.705 | 4.188 |
| Median | | 4.000 | 5.000 | 3.000 | 3.000 | 4.000 | 5.000 | 4.000 | 4.000 | 4.000 |
| Mode | | 4.0 | 5.0 | 3.0 | 3.0 | 5.0 | 5.0 | 5.0 | 4.0(a) | 5.0 |
| Variance | | 1.286 | .363 | 1.793 | 1.528 | 1.187 | .468 | 1.128 | 1.589 | 1.023 |
| Percentiles | 25 | 3.000 | 5.000 | 2.000 | 2.000 | 3.000 | 4.000 | 3.000 | 3.000 | 4.000 |
| | 50 | 4.000 | 5.000 | 3.000 | 3.000 | 4.000 | 5.000 | 4.000 | 4.000 | 4.000 |
| | 75 | 4.000 | 5.000 | 4.000 | 4.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |

a Multiple modes exist. The smallest value is shown

## Appendix C: Market Survey Script

This appendix provides scripts used for the interviewers for initial contact and the market survey. The scripts were used to be sure each respondent had the same information and to avoid bias in who chose to respond to the survey and how they answered questions.

**Oyster GP Phone Survey Protocol**

When Host/ Hostess answers your call:
Hi, I'm a graduate student at UC Santa Barbara doing some research on oysters. Do you know who would be the best person to talk to about the taste and marketability of oysters? I'm not sure if that would be the manager, chef, or the owner….
OR: Hi, I was wondering if your manager was available- I had a few questions for them….

Yes. Go to *Part I or Part II* as appropriate
No. Is there a better time to call back?

*Part I- Get past the Manager*
Hi, I'm a graduate student at UC Santa Barbara doing some research on oysters. My research involves oyster restoration in California and I'm looking for feedback from specialty high-end seafood restaurants like ___________ on the taste and marketability of certain oysters. I am hoping to tap into the expertise of your restaurant to answer a few questions. Would you be the best person to talk to, or maybe your chef, for a three to four minute survey?

Yes. Great- It's just a 3-4 minute survey. (START SURVEY)
No. Ok, is there a better time? Can I schedule something with you?
No: Ok could you tell me why you are unwilling to participate?

A. Too busy
B. Not interested
C. Other:____________________________________________________

(Record survey as UNWILLING TO PARTICIPATE at the top of the survey)

*Part II- Respondent (Chef, Owner, Manager)*
Hi, my name is ____________. I'm sure that you are really busy so I really appreciate you taking this call. I am a graduate student at UC Santa Barbara researching oysters. I'm trying to find out what high-end seafood chefs think about the taste and marketability of certain oysters. I was wondering if I could tap into your expertise to answer a 3 to 4 minute survey. Would it be possible to steal three to four minutes of your time or is there another time that is better for you?

Yes. START SURVEY
No. Ok, is there a better time? Can I schedule something with you?
No. Ok could you tell me why you are unwilling to participate?

A. Too busy

B. Not interested

C. Other: ______________________________________________

(Record survey as UNWILLING TO PARTICIPATE at the top of the survey)

**Native Oyster GP Survey**

Respondent Information: Business ID#:______________

Name of business:_______________________________________________

Name and Title of respondent:________________________________________

Date/time:________________________________

Number of contact attempts:__________________

Survey code:______________________________

GP interviewer:____________________________

Check here if UNWILLING TO PARTICIPATE (from Oyster GP Phone Protocol)

Unwilling to participate b/c:

A. Too busy

B. Not interested

C. Other: _______________________________________________

*Start Survey:*

Our research project is trying to determine whether aquaculture of the native oyster could help restoration efforts in the state. The key question is: IF the aquaculture industry could provide a local, sustainable source of seafood, would restaurants be interested in this product? Would you be willing to participate in a study on restaurant preferences- the survey will take 3 to 4 minutes, and your identity will be kept confidential?

Q1. Yes (Go to Q2)

Q2. Are you familiar with the Olympia oyster- it's also known as the "Oly" or the native California oyster?

No (Go to Intro A)

Yes (Go to Intro B)

Intro A. The Olympia oyster is a small, tender oyster with robust flavor and a slightly coppery finish. They are also an important species in the coastal marine ecosystem because they build loose reefs that other organisms inhabit, and they clean the water through their filtering activity. They can be harvested sustainably, but Olympia oysters were decimated in the early 1900s by pollution and over-harvesting. So efforts are now underway to restore the species. One sustainable means to do this may be through aquaculture. Our idea is that aquaculture could generate a product to sell to restaurants like yours and also help to restore the species for the benefit of our marine ecosystems.

(Go to Q3)

Intro B. Great. So you know that the Olympia oyster is a small, tender oyster with robust flavor and a slightly coppery finish. They are also an important species in the coastal marine ecosystem because they build loose reefs that other organisms inhabit, and they clean the water through their filtering activity. They can be harvested sustainably, but Olympia oysters were decimated in the early 1900s by pollution and over-harvesting. So efforts are now underway to restore the species. One sustainable means to do this may be through aquaculture. Our idea is that aquaculture could generate a product to sell to restaurants like yours and also help to restore the species for the benefit of our marine ecosystems.

(Go to Q3)

Q3. Have you ever considered adding Olympia oysters to your menu?

No (Go to Q3a)
Yes (Go to Q3a)

Q3a. What was your reason for [adding / not adding] the Olympia oyster to your menu?

______________________________________________

(Go to Q4)

Q4. Does your restaurant currently serve any type of oyster?

No (Go to Q5)
Yes (Go to Q4a)

Q4a. Does your restaurant serve oysters on the half-shell?

No (Go to Q4c)
Yes (Go to Q4b)

Q4b. Are oysters on the half shell your most popular oyster dish?

No (Go to Q4c)
Yes (Go to Q6)

Q4c. What is your most popular oyster dish and do the oysters come from whole fresh oysters or shucked and jarred oysters?

______________________________________________

(Go to Q6)

Q5. Did you ever serve oysters in the past?

No (Go to Q7)
Yes (Go to Q5a)

Q5a. Why did you stop serving them?

______________________________________________

Q6. On the average night, how many types of oysters does your restaurant serve?

____________________ (write down # of varieties)

(Go to Q6a)

Q6a. Is one of the types you serve the Olympia?

No (Go to Q6b)

Yes (Go to Q6b)
Sometimes (Go to Q6b)

Q6b. Is one of the types you serve the Kumamoto?
No (Go to Q6c)
Yes (Go to Q6c)
Sometimes (Go to Q6c)

Q6c. Is one of the types you serve the Eastern?
No (Go to Q7)
Yes (Go to Q7)
Sometimes (Go to Q7)

Q7. Setting price aside, if the Olympia oyster were available, would you consider adding it to the menu?
No (Go to Q11)
Yes (Go to Q8)
Don't know (Go to Q8)

Q8. How important are the following factors when thinking about adding a new oyster to the menu (1 being not important at all, 5 being very important)?

| | |
|---|---|
| Q8a. Price? | 1 2 3 4 5 |
| Q8b. Flavor? | 1 2 3 4 5 |
| Q8c. The oyster is available year-round? | 1 2 3 4 5 |
| Q8d. The oyster is only available "in season"? | 1 2 3 4 5 |
| Q8e. The fact that it is a unique menu item? | 1 2 3 4 5 |
| Q8f. It's sustainably produced? | 1 2 3 4 5 |
| Q8g. It's locally produced? | 1 2 3 4 5 |
| Q8h. It expands your oyster selection? | 1 2 3 4 5 |

Q8i. What are the other factors that you consider when adding a new oyster to your menu?

________________________________________

(Go to Q8j)

Q8j. Olympia oyster aquaculture would provide a new local, sustainable product in California and help with restoration. By purchasing this new product, you would be directly supporting restoration efforts. On top of that, there would be an opportunity to recycle consumed shells to build reefs at restoration sites. Creating new oyster reefs will help restore local estuaries and bring back native fish, birds, otters, and other native California species.

How important is marketing this restoration story when considering whether to add this oyster to the menu (1 being not important at all, 5 being very important)?

1 2 3 4 5

(Go to Q9)

Q9. If Olympia oysters were the same price per dozen as Pacific oysters, how many dozen would you buy for an average week?

Don't know

_______________ dozen (Go to Q10)

_______________ bushels (Go to Q9a)

Q9a. Just to clarify, 1 bushel = 208 dozen? Is your estimate of ____________ bushels correct?

Yes

No: Intended quantity= ____________ bushels or ___________ dozen

(Go to Q10)

Q10. If Olympia oysters were ___[insert random #]__ each, how many dozen would you buy for an average week?

_______________ dozen

(END OF SURVEY)

That's it! Thanks so much for your time.

Do you have any further comments or questions about the survey? (Record in comments section)

Q11. What is your reason for not considering this oyster for your menu?

________________________________________

(Go to Q11a)

Q11a. Olympia oyster aquaculture would provide a new local, sustainable product in California and help with restoration. By purchasing this new product, you would be directly supporting restoration efforts. On top of that, there would be an opportunity to recycle consumed shells to build reefs at restoration sites. Creating new oyster reefs will help restore local estuaries and bring back fish, birds, otters, and other native California species.

How important is marketing this restoration story when considering whether to add this oyster to the menu (1 being not important at all, 5 being very important)?

1 2 3 4 5

(END OF SURVEY)

That's it! Thanks so much for your time.
Do you have any further comments or questions about the survey?

Notes/Comments:

## Appendix D: Biological Requirements

This appendix provides additional information on the biological requirements for growing Olympia oysters through aquaculture. Specifically addressed are disease, water quality, and predators.

*Disease*

According to research, Olympia oysters are not disease-prone compared to other commercially-grown oysters. However, three possible threats to Olympia oyster populations exist: Denman Island disease (*Mikrocytos mackini*), redworm (*Mytilicola orientalis*), and disseminated neoplasia. In 2002, two wild Pacific oysters from Washington were found to be infected with the pathogen *M. mackini*, which is the causative agent for Denman Island Disease (Moore 2004). Though there are no human health impacts from *M. mackini*, it causes yellow or green pustules to form on the oysters, denuding the oysters of any commercial value (Moore 2004). Previous studies showed that *M. mackini* caused significant mortalities in Pacific and European (*O. edulis*) oysters in British Columbia, with only intermittent mortalities of Olympia oysters in Yaquina Bay, OR (Farley 1988 in Baker 1995).

Since California receives all oyster seed from approved facilities in Washington, Oregon, and Hawaii, there was concern that *M. mackini* had established itself within California aquaculture operations (Moore 2004). A comprehensive survey of oyster disease conducted in 2005 in California did not reveal any evidence of *M. mackini* (Moore 2004). However, Moore (2005) cautioned that other pathogens, such as *Haplosporidium nelsoni* (the causative agent of Delaware Bay disease), have been found in isolated incidents, illustrating the risk of introduced pathogens.

Redworm is a common internal macroparasite caused by an intestinal copepod, *M. orientalis*, that was introduced with shipments of Pacific oyster seed from Japan (Odlaug 1946; Couch et al. 1989). The copepod lives in the anus of oysters, resulting in an infection that causes poor oyster health (Odlaug 1946; Couch et al. 1989). However, the incidence of infection is low, ranging from 0 to 3% in San Francisco Bay (Bradley and Seibert 1978 in Baker 1995). Experiments in Puget Sound revealed an infection rate of 0 to 16% with a corresponding decreased body weight in infected oysters (Odlaug 1946). Further research on the distribution of these diseases in California is required.

Disseminated neoplasia is a disease that affects many species of bivalves and is not limited to oysters. It is characterized by the uncontrolled proliferation of cells throughout the bivalve's circulatory system, which results in emaciation and eventually death. The disease is often compared to leukemia in mammals, however, unlike leukemia, neoplasia is an infectious disease that can be readily transmitted to other oysters (and other organisms). Early research (1969) on disseminated neoplasia in Olympia oysters indicated that it was found in 7% of the population in Yaquina Bay in Oregon. Later studies of the disease in the 1970s indicated that it was reduced to less than 1% of the population in Yaquina Bay. Until recently, there has been little investigation into the species in Olympia oysters.

Between 2004 and 2006, Moore et al. conducted a California-wide oyster health survey, which included eight populations of Olympia oysters. The sample locations ranged from Humboldt Bay to Elkhorn Slough. Ultimately, disseminated neoplasia was found in four of the eight locations: Tomales Bay (north end), Drakes Estero, Fort Mason Marina (San Francisco Bay), and Candlestick Park (San Francisco Bay). The results varied widely among individuals and populations in terms of the intensity and incidence of disease. The greatest incidence of disease (i.e. number of diseased individuals per number sampled) occurred in Drakes Estero and Candlestick Park. Meanwhile, the intensities among individuals varied broadly from a few cells to greater than 90% of cells in circulation. Despite these results, it is still unclear what implications this disease has on the Olympia oyster populations. Among different bivalve species and different locations, the disease is known to have caused mass mortality or limited individual mortality. As such, it is speculated that physical, biological, and temporal factors also play important roles in disease expression (Moore et al. 2006). While this disease does not appear to induce mass mortality in Olympia oyster populations at present, the movement of oysters from one area where the disease occurs to another should be restricted.

*Water quality*

As described in Appendix H, California enforces rigorous water quality standards to protect the public from contaminated shellfish. Historically, industrial chemical effluents caused the most significant Olympia oyster mortality rates, especially sulfite waste liquor from pulp mills (Odlaug 1949; Korringa 1976). Additionally, sewage was blamed for the loss of Olympia oysters in Puget Sound (Galtsoff 1929 in Baker 1995) and Yaquina Bay (Fasten 1931).

Recent field experiments revealed that Olympia oysters show strong recruitment, even in areas that fall below local water quality standards for dissolved oxygen, turbidity, chlorine (from sewage outfalls), fecal coliform, nutrients, and temperature (Shaffer 2004). With the exception of sulfite waste liquor, toxic wastes, and waters with high concentrations of cadmium or zinc, Olympia oysters showed the strongest growth and lowest mortality in areas that featured the worst water quality conditions (Barrett 1963; Shaffer 2004). Therefore, as long as water quality standards meet state requirements, Olympia oysters should thrive in an aquaculture operation.

*Predators*

Oyster drills are the most likely predatory threat to Olympia oyster aquaculture. Oyster drills have plagued oyster aquaculture operations in the Pacific Northwest since their accidental introductions sometime in the mid-twentieth century (Gordon et al. 2001). Oyster drills preferentially feed on young oysters and can cause major mortalities within aquaculture operations (Buhle et al. 2003). Studies show that one *C. inoratum* can consume at least one adult Olympia oyster per week by boring through the oyster shell (Chew 1960 in Baker 1995). *U. cinerea* can cause 10 to 20% of juvenile mortalities (Elsey

1933 in Baker 1995). In Tomales Bay, *U. cinerea* was found to significantly influence Olympia oyster survival (Trimble et al. 2006).

Mueller and Hoffman (1999) showed that mortality in outplanted Pacific oyster beds increased by at least 25% because of oyster drill predation during the first six months after planting, decreasing net aquaculture profits by 55%. Recent field experiments have shown that both species of oyster drills preferentially feed on Pacific oysters over Olympia oysters (Buhle et al. 2003). While *U. cinerea* is abundant throughout California's coast (Carlton 1979; Carlton 1992), *C. inoratum* has only been observed as far south as Morro Bay (Carlton 1979; Carlton 1992; Baker 1995).

## Appendix E: Commercial Oyster Aquaculture

This appendix provides information on the steps in the production process typically followed when culturing oysters for commercial sale. The final section discusses existing practices for Olympia oyster production in Washington State.

### Procedure for Commercial Oyster Aquaculture

Oyster aquaculture has four distinct phases: broodstock spawning, larvae culture/settlement, seed cultivation, and growout (National Research Council 2004). These phases require three types of facilities: a hatchery, a nursery, and a growout location.

The initial steps in oyster production, broodstock conditioning and larvae settlement, occur in the hatchery. For broodstock conditioning, the hatchery simulates spawning conditions so that adult oysters produce larvae. The larvae swim in the tank for a few days before they settle and attach to hard substrate that is introduced to the hatchery tank. The type of substrate, however, depends on the variety of oysters that will be produced. Oysters can be sold in two varieties: half-shell or shucked. For half-shell oysters, the larvae settle on fine grains of oyster shell. The oyster then matures as an individual, which allows it to develop an attractive shell so it can be easily served on the half shell in restaurants. These settled larvae are known as "cultchless" oyster seed. For shucked oysters, multiple larvae settle onto full-sized oyster shells and grow to maturity in a cluster, so that the oyster meats must be "shucked" from each oyster shell in a cluster of attached shells. The settled larvae in this case are known as "cultched" oyster seed. Oysters produced for sale on the half shell generally attain the highest price per unit and are the most popular oyster dish at restaurants.

Figure 19 (below) depicts the basic steps for oyster aquaculture. Steps 3a and 3b produce half-shell oysters whereas step 3c produces shucked oysters.

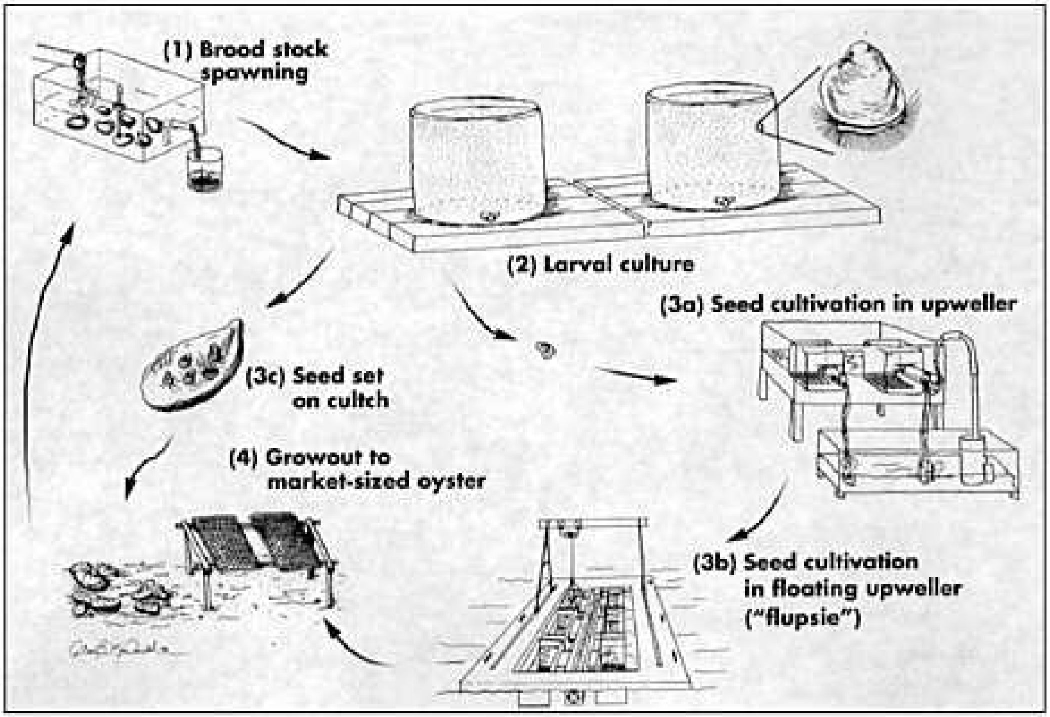


**Figure 19**. Basic steps involved in oyster aquaculture (reproduced from National Research Council 2004).

After the hatchery stage, the oyster seed are transitioned to a nursery for development. An oyster nursery usually consists of an upweller system that pumps seawater to the oysters to maximize growth potential. The upweller can either be located indoors or in the environment. The objective of the nursery is to protect the vulnerable seed oysters from predation and adverse environmental conditions, and to prime the juveniles for outdoor life (Toba 2002). The nursery also maximizes growth by providing oysters with the highest quantity of nutrients possible (Bishop 1996). The main feed for oysters is microalgae (phytoplankton). Microalgae can be cultured in-house or purchased as a concentrated formula (Robert et al. 1999).

The oyster seed are generally held in the nursery for several months. Cultchless seed need more care in the nursery than cultched seed. Cultchless seed oysters are usually kept in containers to prevent scattering. One of the newer technologies for nurseries located in the environment is the floating upweller system (FLUPSY). In a FLUPSY, the seed are placed in a container where a pump forces nutrient-rich water from the bottom to the top to maximize nutrient intake (Bishop 1996).

The growout phase involves transplanting the oysters to an area where they can mature to harvestable size. The seed oysters are ready for planting when they are approximately the size of a pencil eraser (usually within three months of settling) (Peter-Contess et al. 2005). There are two types of growout, or "culture", methods for oysters: bottom culture and off-bottom culture. Bottom culture involves simply spreading the oysters over the substrate and leaving them alone until they are mature enough to collect and sell.

Off-bottom culture techniques are often used in areas where substrate is too hard, too soft, or otherwise not ideal for bed culture. Besides utilizing areas not suitable for bed culture, the other advantages of off-bottom culture include reduced predation, higher yields because of increased survival, growth, and reduced environmental harm associated with bottom culture harvests. Disadvantages include potential damage from storms, fouling, increased visibility, and higher capital and maintenance costs. Table 13 below summarizes the various types of off-bottom culture techniques (Toba 2002).

**Table 13**. Description of types of off-bottom culture techniques and methodology for techniques.

| Off-bottom culture technique | Description of methodology |
|---|---|
| Suspended bag or net culture | Cultch suspended in bags or nets from docks, longlines, or other floating structures. |
| Longline culture | Cultch spaced at equal distances (6 to 10 inches) on a length of rope or wire. May be suspended on stakes, anchored to bottom, submerged from dock, or hanging from rack. |
| Stake culture | Cultch hung from precut stakes (up to 3 feet tall) that are driven into bottom. Cultch are nailed to stakes. |
| Floating culture | Cultch placed in growout trays or polyethylene cages stacked on the floor of a sink float or suspended from a raft or floating longline system. |
| Rack and bag culture | Single oysters placed in polyethylene growout bags or cages that are clipped to rebar racks. (In areas of hard substrate, racks are optional). |

To prepare the oysters for sale, the oysters must be thoroughly washed to remove mud, barnacles, and other fouling organisms. While this process may be done manually, several mechanical devices may be used for efficiency. An oyster tumbler grader uses a high-pressure wash and drum rotation to remove fouling settlement and prune shell shape (Fukui North America 2004). An oyster washer-grading table is composed of a conveyor belt and discharge boxes. The oysters are loaded onto the belt and carried under a high-pressure water wash to remove sediment. The oysters then pass by an area where they are visually graded and placed onto a divided belt to discharge into boxes at the discharge end (Fukui North America 2004).

The techniques described previously are widely used to cultivate all commercial oysters, particularly Pacific and Eastern oysters. These methods are common in California and throughout the West Coast. However, each aquaculture operator must assess their local growout site to maximize oyster harvests. In addition, different oysters require different types of growth techniques, so particular care is required to optimize aquaculture production.

## Existing Olympia Oyster Aquaculture Techniques

Currently, the only commercial Olympia oyster aquaculture operations in existence are located in Washington State. The most prominent commercial harvesters are Taylor Shellfish Farms and the Olympia Oyster Company, both of which are based in Shelton, WA (Olympia Oyster Company 2007; Taylor Shellfish Farms 2007). These companies raise their Olympia oysters in estuaries on the southern end of Puget Sound using dike culture, a form of bottom culture developed at the turn of the century (Gordon et al. 2001). Dike culture involves the construction of watertight walls, or "oyster terraces", to maintain a consistent water level suitable for Olympia oyster growth and to avoid temperature fluctuations (Gordon et al. 2001). However, dike culture is a form of bottom culture and is prohibited in California. Therefore, a method of off-bottom culture, such as those described in Table 13, must be implemented in California.

According to Olympia oyster expert Betsy Peabody, the most promising method of off-bottom culture for Olympia oysters is a form of rack and bag culture called "bag-bottom" culture. Bag-bottom culture involves filling 1/8- to 1/4-inch mesh bags will seed, placing them on rebar racks, and staking them on the substrate. Rebar keeps the bags in place and prevents physical disturbance. The bags protect against predators, but require some maintenance. This system requires periodic flipping of the bags to minimize the impacts of siltation and the potential for smothering oysters on the bottom of the bags. Bag-bottom culture is not considered bottom culture because the oysters are not technically settled in the substrate and it is minimally invasive (i.e., does not require raking for collection). This method is often used as a growout technique for Pacific oysters in California.

## Appendix F: Aquaculture Production Statistics

This appendix provides additional information on aquaculture production on the West Coast.

*West Coast Aquaculture Production*

West Coast states produce about half of all domestic shellfish[17], with annual production of approximately 47,000 tons (PACAQUA (Pacific Aquaculture Caucus, 2004). Oysters represent roughly 80% (~38,000 tons annually) of West Coast shellfish production (PSGA website). Four major oyster species, including Pacific, Kumamoto, European (Flat) and Eastern oysters, are commercially produced on the West Coast (Conte, 1996). Olympia oysters are also produced on a small scale in Oregon and Washington, though Olympia oyster production represents only a fraction of the total oyster sales in the United States (Conte, 1996; Dave DeAndre, pers. comm.). Figure 20 illustrates the total U.S. Olympia oyster production from 1950 to 2006. As the figure illustrates, Olympia oyster production and price has been highly variable. California makes up only 10% of the commercial oyster aquaculture market on the West Coast (PSGA).

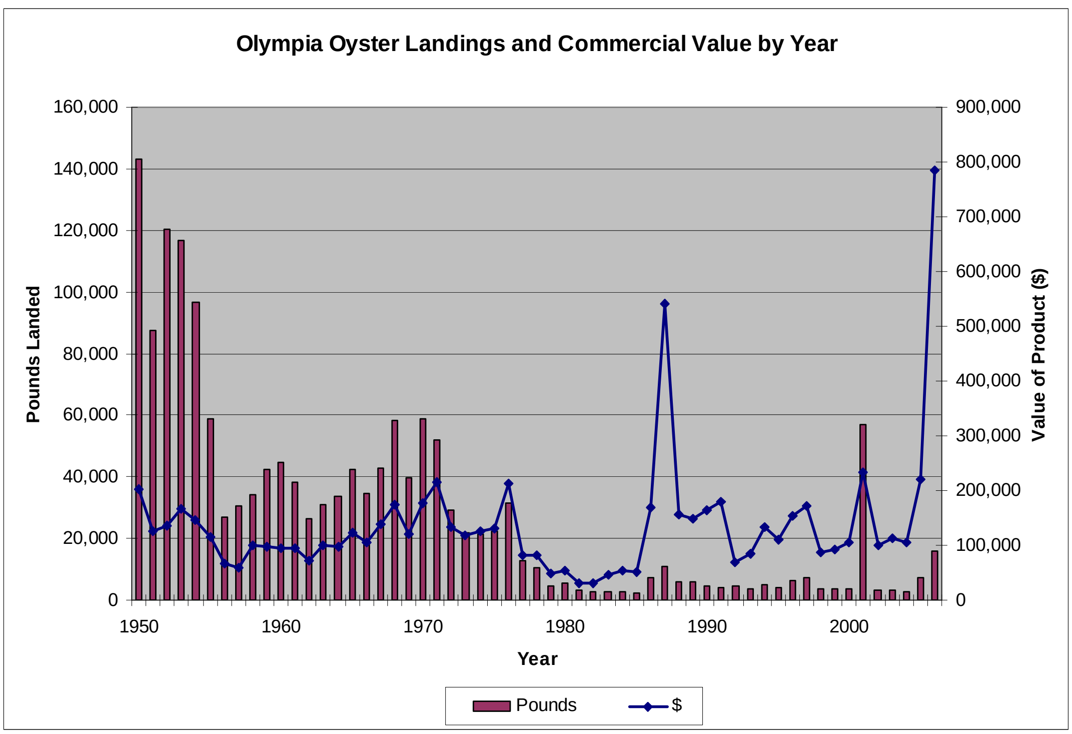


**Figure 20**. National Marine Fisheries Service landings statistics and commercial value of Olympia oysters, 1950- 2006 (NMFS, 2008).

[17] Shellfish production includes all species grown in aquaculture and from wild harvests.

## Appendix G: Site Selection for Olympia Oyster Aquaculture

This appendix summarizes the selection criteria and associated advantages and disadvantages of potential site for Olympia oyster aquaculture within California.

**Site Selection for Olympia Oyster Aquaculture**

To minimize start-up costs, the most effective method for establishing a site for Olympia oyster aquaculture is to partner with, or sub-lease from, an existing aquaculture operator (John Finger, pers. comm.). The next most important consideration is whether there is a viable natural Olympia oyster population inhabiting the water body. As described in Section 8.0, the movement of native populations between water bodies is discouraged due to the risks of transferring diseases, predators, and genetic mutations to new areas. Therefore, the presence of a local Olympia oyster population to provide local broodstock is an absolute requirement for potential sites. Other important considerations include the distance to the major seafood markets (to minimize transport of a perishable product), existing local competition, and water quality. Within these constraints, we evaluated four potential aquaculture sites in California: Humboldt, Marin County, the Central Coast, and Southern California. The major advantages and disadvantages of each site are discussed in the following sections.

*Humboldt*

Humboldt Bay, one of California's northernmost estuaries, is a historically successful location for growing oysters and the site of six existing commercial oyster producers. Humboldt Bay also hosts a thriving population of wild Olympia oysters (Couch 2007). However, Humboldt Bay's major disadvantage is its distance from major seafood markets. Distribution costs to San Francisco and Los Angeles would be extremely high from this rural location. Additionally, with so many existing specialty oyster producers, the local market is already saturated. Therefore, we recommend siting an Olympia oyster aquaculture business further south to more easily tap into the larger seafood markets and establish distance from other specialty oyster competitors.

*Marin County*

Marin County is the site of two major estuaries: Tomales Bay and Drakes Estero. Tomales Bay supports six existing oyster aquaculture businesses and Drakes Estero supports one. Despite the relatively large number of existing producers, Marin County is located just a short distance north of California's largest seafood market, San Francisco. As such, distribution costs to reach this market would be minimal and there is little risk of entering a saturated market. Furthermore, no one in Tomales Bay or Drakes Estero is currently producing the Olympia oysters' prime rival in the specialty oyster market: Kumamoto oysters. Both Tomales Bay and Drakes Estero are well-protected estuaries with established records of high water quality, particularly Drakes Estero. Both bays currently support native populations of wild Olympia oysters. Therefore, Marin County satisfies the major criteria for establishing a successful Olympia oyster aquaculture business. We recommend Drakes Estero as a potential site for Olympia oyster aquaculture, given its historically pristine water quality and healthy native population of Olympia oysters.

*Central Coast*
The central coast of California has a number of estuaries that meet the criteria to support Olympia oyster aquaculture. A study by Polson and Zacherl in 2006, which investigated the current geographic range of Olympia oysters, found that all bays and estuaries south of Morro Bay support intertidal populations of native oysters (Polson et al. 2006). Elkhorn Slough, located on the coast between Santa Cruz and Monterey, was home to several mollusk aquaculture businesses (although aquaculture is no longer performed there), suggesting that it is a suitable site for aquaculture (Conte 1996; Moore 2008). Another attractive characteristic of Elkhorn Slough is its central location between San Francisco and Los Angeles. Thus, distribution costs to both of these target markets would be minimized. Also, local competition is minimal because no other oyster aquaculture businesses exist in the vicinity. For these reasons, we recommend Elkhorn Slough as a potential site for cultivating Olympia oysters.

*Southern California*
Southern California supports one major oyster aquaculture business: Carlsbad Aquafarm. The farm is located just north of San Diego in Agua Hedionda Lagoon, adjacent to the Encina Power Station. Currently, Carlsbad Aquafarm produces a variety of shellfish but only one type of oyster (Pacific). Water quality issues are a major challenge in Southern California. While Carlsbad Aquafarm could potentially work as a site for growing Olympia oysters, its proximity to an industrial outfall would raise water quality issues. Olympia oysters are sensitive to environmental conditions, so extensive investigation into the water quality and siltation in the Agua Hedionda Lagoon would need to be performed before deciding whether or not it could support Olympia oyster aquaculture. Furthermore, while the managers of the farm were interested in the Olympia oyster aquaculture idea, they were not willing to share with us specific information about their business practices or suggest how native aquaculture could be integrated into their existing operations. As such, Carlsbad was eliminated from our recommendations for this feasibility study.

## Appendix H: Legal Framework

This appendix provides additional information on federal and state involvement in the legal framework surrounding aquaculture.

**Federal Involvement**

The National Aquaculture Act of 1980 as amended by the National Aquaculture Improvement Act of 1985 declares a national aquaculture policy that encourages growth in aquaculture activities public and private but does not address the wide variety of forms aquaculture can take. The Act created the Joint Subcommittee on Aquaculture (JSA) within the Office of Science and Technology Policy to assess national needs in regard to aquaculture, the adequacy of the government to address those needs, and coordinate among agencies to meet those needs and disseminate information. The Aquaculture Act made the U.S. Department of Agriculture the lead agency for aquaculture by appointing the JSA chair position to the Secretary of Agriculture. The JSA also includes the Secretaries of Commerce, Interior, Energy, and Health and Human Services, the Administrators of the EPA, the Agency for International Development, and the Small Business Association, the Chief of Engineers, the Chairman of the Tennessee Valley Authority, the Director of the National Science Foundation, the Governor of the Farm Credit Administration, and other federal agency heads as the Director of the Office of Science and Technology Policy deems appropriate (16 U.S.C. §2801 (6)(a)).

The range of agencies represented in the JSA gives an idea of the overlapping interests in aquaculture at the federal level. Many of these agencies are also involved in the regulation of aquaculture in state waters (Table 14). Regulation at the federal level focuses mainly on human health and safety issues, but also includes regulations protecting natural resources and the environment (Buck et al. 1993). In addition to regulations, the federal government also has programs that support and promote growth in the aquaculture industry through research and development and funding opportunities. These programs allow for advances in aquaculture technology that private companies don't have the funds to research themselves.

**Table 14**. Federal agencies that have regulatory programs affecting aquaculture in state waters (adapted from DeVoe 1997).

| Agency | Regulatory Responsibility |
|---|---|
| U.S. Army Corps of Engineers (COE) | Issues permits for structures and work in or affecting navigable waters or for discharge of dredge or fill material into waters and affecting water quality. |
| U.S. Environmental Protection Agency (EPA) | Prohibits point source pollutant discharge into waters, and limits use and application of pesticides. Prohibits the take of any threatened or endangered species and protects migratory birds. |
| U.S. Fish & Wildlife Service (FWS) | Issues licenses for importing or exporting animals (for sale or propagation) with a value of more than $25,000 a year. |
| U.S. Food & Drug Administration (FDA) | Regulates use of drugs and chemicals in feed and for treatment of ailments. Their National Shellfish Sanitation Program regulates growing, harvesting, handling, processing, and distribution of shellfish. |
| U.S. Department of Agriculture (USDA) | Chairs the JSA and approves vaccines. |
| U.S. Coast Guard (USCG) | Requires all structure located in navigable waters to be appropriately marked. |

Federal involvement in aquaculture ensures product safety and monitors quality, both of which allow consumers to buy local aquaculture products with confidence (Table 14 and Table 15). So, while federal involvement may overlap state regulations and make aquaculture permitting more cumbersome, the industry benefits from the assurance consumers have that their products meet known food standards. Federal involvement also guarantees a minimum level of habitat protection, water quality (which can be very important near state boundaries where pollution from one state may affect another state), and species protection (Table 15).

**Table 15.** Federal Regulations Affecting Nearshore Aquaculture (adapted from(Johnson et al. 2004) and DeVoe 2000).

| | |
|---|---|
| Clean Water Act of 1977 and the Water Quality Act of 1987 | regulates the discharge of dredge or fill material into waters which could come from an aquaculture system |
| Federal Coastal Zone Management Act of 1972 | deals with proposed federal activity within state waters which could include federally funded aquaculture endeavor |
| Rivers and Harbors Act of 1899 | any structure in navigable waters must be permitted by the COE |
| Endangered Species Act of 1973 | prohibits activities that may cause harm to threatened or endangered species, such as endangered marine species that may be predators of an aquaculture species |
| Lacey Act amendments of 1981 | import/export of fish, wildlife, or plants taken in way that violates state, tribal or federal law is unlawful |
| Migratory Bird Treaty Act | regulates lethal control methods on migratory birds which may be causing aquaculture crop losses |
| Wild and Scenic Rivers Act | issues permits to control land use along river corridors which may overlap with shellfish aquaculture in estuaries |
| Federal Food, Drug, and Cosmetic Act | regulates additives to aquaculture to protect the safety and health of future consumers |

To ensure the longevity of the business, an aquaculturist needs assurance that water quality will remain high (DeVoe et al. 1989). Aquaculture also requires a substantial financial investment, another hurdle closely tied to finding a site. Financial backing will depend on the anticipated stability of the business defined by its property rights (DeVoe et al. 1989; Duff et al. 2003). These property rights include exclusive culturing and harvesting rights, possibly exclusive entrance rights, and the right to a certain level of water quality. The right to water quality means the aquaculturist knows neighboring areas will not detrimentally affect the water quality of the aquaculture site (DeVoe et al. 1989). Investors want to see a consistent supply and stable business with a future. A consistent supply means water quality must remain at high enough levels to allow for harvesting for human consumption. In addition, poorly enforced water quality standards can lead to increased conflicts among competing users (Duff et al. 2003). If human consumption is not the goal of the aquaculture as is the case with restoration aquaculture, water quality becomes less important possibly making this type of aquaculture more compatible with multiple uses.

**State Involvement**

The Department of Fish and Game acts as the lead agency for aquaculture in California and is responsible for awarding tideland leases. Competing uses of the coast pose a serious challenge to obtaining a lease. California has a very large tourist economy that is based on coastal activities and coastal development. Not only does this make it difficult to find accessible sites for aquaculture, but the heavy coastal usage causes poor water quality in many areas. Aquaculture usually takes place in sheltered coastal bays, which means that most of the California coast is somewhat inhospitable to aquaculture (Conte 2005). In addition, coastal landowners or communities may not want to see aquaculture activities in their viewshed, and therefore, may challenge aquaculture permits or submerged lands leases. Additionally, aquaculture may conflict with other uses of the submerged lands, such as recreational fishing or boating. In many coastal communities, these activities and other coastal tourism activities support local business and play a large role in the local economy. Thus, opposition to new aquaculture could be strong.

The initial application for an aquaculture lease in California costs $624, but the lease goes to the highest bidder for annual rents (CFGC §15403)(1933). Minimum bids are $2/acre for plots greater than 10 acres and $10/acre for plots less than ten acres (CFGC §15406.5). The lease does not give exclusive access to the lessee, or water quality rights (meaning the water quality is not guaranteed against outside pollution), but it does protect against theft (CFGC §15402, §15411, §15413). If the lessee wants to exclude the public, they can apply for restricted entry. Awarding of leases is carried out in public meetings, giving the public a chance to voice opposition to an aquaculture lease. The lease term is for 25 years, with an option to renew for an additional 25 years. This allows operators ample time to establish their aquaculture operations. However, operators that grow oysters have to meet a quota to keep their lease.

The permitting process takes years to complete (McCormick 2007) and can be very expensive. The cost of getting any new activity approved in tidelands is so prohibitive that there have been no new leases since 1993 (Moore 2008). The California Environmental Quality Act (CEQA) (1970) requires documentation that there will be no adverse environmental effects from the proposed activity (CEQA §21000(g)). If there is a possibility of negative environmental effects then an Environmental Impact Report (EIR) must be completed to show significant effects, alternatives, and potential mitigation (CEQA §21002.1(a)). Both processes are time intensive and expensive. Completing an EIR involves many hours of surveying, developing alternatives, and public input, which can set a project back several years. The cost of an EIR can be in the tens of thousands of dollars and may result in a tideland lease not being approved if the adverse effects are significant and cannot be mitigated, or the public has made a strong case against the proposed aquaculture. Furthermore, certain local interest groups are trying to cut back on some of the leases in California (Cox 2007).

In addition to the CEQA documents, many other permits must be obtained. An aquaculture operator could need as many as 17 different permits from as many agencies (Maryland Department of Agriculture (MDA) and National Association of State Aquaculture Coordinators 1995). Once a lease is established, aquaculture operators still face legal obligations every year such as renewing their annual aquaculture registration. Meanwhile, water quality must be monitored continually. The Department of Fish and Game also levies a privilege tax on oyster aquaculture for every 100 oysters produced (Moore 2008).

## Appendix I: Supply Risk Analysis

This appendix provides additional information on natural variability and uncertainty in the production model factors.

### Supply Risk Analysis

*Assumptions*
We made a few key assumptions to create the production model. The assumptions were necessary because Olympia oyster aquaculture is a new concept in California, and the data was nonexistent for several elements of the model. Even though the assumptions introduce a certain level of uncertainty, they are based on the best available data gathered from interviews with existing shellfish producers and the available literature.

The first assumption is that the Olympia oyster broodstock is healthy. Specifically, we assumed that the broodstock collected for the hatchery operations has enough genetic variability to maintain and perpetuate the viability of the stock. The population of Olympia oysters declined to critical levels in some bays, so it is possible that a degree of inbreeding occurred that hindered the species (i.e. allee effects). Furthermore, studies have shown that the genetics of Olympia oyster populations vary between their native bays. See Appendix J for a complete description of Olympia oyster genetics and the impacts on aquaculture production.

Two other major assumptions are that our estimates of the Olympia oysters' growth and mortality rates are accurate for California. Studies have shown that Olympia oysters will grow faster in warmer California waters (Coe et al. 1937) and that oyster mortality will be reduced if certain bio-physical considerations are accounted for in the growout technique (see Section 7.2 for further description of maximizing Olympia oyster survivorship.) While demonstrated experimentally, none of these hypotheses have been proven in a commercial aquaculture business.

*Identification of critical 'unanswered' supply components*
The total production at all shellfish aquaculture facilities varies from year to year. Natural variation in environmental factors, most of which cannot be controlled, results in varied annual total production at all shellfish aquaculture facilities. Influential environmental factors include dissolved oxygen (DO) level, water temperature, and siltation, none of which can be directly controlled (at least on a short term scale). Catastrophic events can also harm production output. For instance, an oil spill near a bay can close an aquaculture facility indefinitely until the hazard has been fully mitigated.

Until off-bottom culture for Olympia oysters is actually implemented, these assumptions and variables can only be estimated. Existing bottom culture of Olympia oysters in Washington has shown extreme variability in yield from year to year. The exact causes of this variability are uncertain due to a lack of scientific research, but may be due to a property of the species, the culture technique, or certain environmental factors.

## Appendix J. Restoration

This appendix provides detailed information on restoration gathered from the literature, interviews, and participation at the 2007 West Coast Native Oyster Restoration Workshop in Shelton, WA.

**Recent critical findings in Olympia oyster restoration**

Finding: *Populations of Olympia oysters exist throughout their historical range, but only at a fraction of their historic abundance. Estuaries in California, particularly Southern California, include natural populations and regular recruitment at a majority of historical locations suggesting that these sites are favorable for future restoration projects.*

Polson et al. (2006) conducted the first quantitative intertidal survey of Olympia oyster populations along their entire known range, from Baja California, Mexico, to Southeast Alaska. In California, Polson et al. (2006) discovered (relatively) dense natural populations in Humboldt Bay, Tomales Bay and Point San Quentin (San Francisco Bay). Point San Quentin and Tomales Bay recorded the second and third highest average rank[18] (Bahia San Quentin, Baja, Mexico, reported the highest rank), signifying the relatively high natural abundances of Olympia oysters in Northern California estuaries as compared to the rest of the species' geographic range (Polson et al. 2006). Unfortunately, there was no estimate of abundance in Drakes Estero, a site that is reported to have dense natural populations (Lunny 2007). These findings are consistent with the historical record of significant populations of Olympia oysters in Northern California estuaries (Barrett 1963; Baker 1995).

Though one might assume that Southern California would have little to no Olympia oyster populations due to heavy development pressures within its coastal estuaries, Polson et al. (2006) discovered low oyster densities at most sites. Importantly, the study found intertidal populations in all surveyed bays and estuaries south of Morro Bay and multiple size classes of oysters, which indicates regular recruitment (Polson et al. 2006). In comparison to historically abundant sites in the northern end of the species' range (such as Netarts Bay, OR; Willapa Bay, WA; and Grays Harbor, WA), the sites in Southern California featured a greater number of size classes per site, more frequent intertidal populations and relatively higher intertidal densities (Polson et al. 2006). The data presented by Polson et al. (2006) suggests that Olympia oyster restoration efforts in California, particularly Southern California, are positioned for restoration success. The presence of small, but surviving, Olympia oyster populations indicates that the species is resilient in California estuaries and there is significant potential to enhance local populations. Locating an Olympia oyster aquaculture operation in California (rather than Washington or Oregon) will maximize the benefits to California restoration projects due to the proximity to the restoration sites, genetic limitations (discussed below), and the

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[18] Average rank is a normalized measure of density (Polson et al., 2006).

general notion that people are more likely to participate in restoration programs if it directly affects their community (or state).

<u>Finding</u>*: Initial analysis of extant Olympia oyster populations revealed that approximately 86% of genetic variance was explained by region, signifying the potential for strong spatially-distinct genetic structure amongst populations (Stick et al. 2007).*

Research conducted by Stick et al. (2007) used microsatellite DNA markers to analyze genetic variation among extant populations ranging from Vancouver Island, British Columbia, to San Francisco Bay, CA. Results of the study indicate that different genetic populations of Olympia oysters are geographically stratified from north to south (Stick et al. 2007). Approximately 86% of the variation in genetic structure of the oysters was explained by geographic region (Stick et al. 2007). While this research is not yet complete, Stick et al. (2007) indicated that populations of Olympia oysters appear to have a distinct genetic composition based on their geographic location. This research supports a commonly held assumption that Olympia oyster populations have limited larval transport and are unlikely to export larvae beyond the local estuary or bay (Baker 1995). The finding by Stick et al. (2007) has significant implications because it reinforces the use of the precautionary principle in Olympia oyster restoration projects. Specifically, it highlights the importance of maintaining the local/regional genetic composition of Olympia oyster populations. Outplanting Olympia oysters from other regions as a restoration technique may have serious unintended consequences because it could dilute local genetic integrity (Trimble 2007). Therefore, it is critical to preserve and propagate local Olympia oyster populations, particularly populations that have not had Olympia oyster introductions from other regions.

In terms of supporting restoration, an Olympia oyster aquaculture operation would enhance and propagate local, genetically-unique Olympia oyster populations in individual bays in California. Thousands of fecund individuals (hatchery-spawned Olympia oysters growing out in a floating tray system) may interact and reproduce with natural populations, resulting in a larger natural recruitment. Meanwhile, hatchery production would ensure that samples of local broodstock are collected, identified, and maintained despite environmental stochasticity in the local estuary. Adhering to the precautionary approach, an Olympia oyster aquaculture operation in California should only culture and grow Olympia oysters from broodstock within their (growout) estuary. Additionally, the aquaculture operation could also directly outplant hatchery-reared individual oysters into the local (growout) estuary[19] (Camara 2007).

Different estuaries, even within the same region, may have different levels of genetic mixing from introduced Olympia oysters. Stick et al. (2007) suggest that populations in

[19] Using hatchery-reared individuals for outplanting as a restoration strategy carries a risk of increasing the probability of inbreeding as a result of increased mating between relatives (Camara 2007). However, general protocols exist that can deal with these problems and avoid the possibility of allee effects (Camara 2007).

San Francisco Bay and Tomales Bay include genetically-mixed populations, which is probably due to extensive introductions of Olympia oysters from Washington and Oregon during the late 1800's (Barrett 1963; Trimble et al. 2007). Conversely, Drakes Estero is reported to have a genetically-unique and untainted population of Olympia oysters with no record of Olympia oyster introductions[20] (Lunny 2007). In addition, Drakes Estero is reported to contain a large (but unquantified) natural population of Olympia oysters. As such, Drakes Estero is likely to yield significant quantities of 'genetically- pure' Olympia oyster broodstock (Lunny 2007).

The potentially unaltered genetic strain in Drakes Estero is significant because it may be one of the only representative native populations in the region (a population that has not been genetically diluted by introduced Olympia oysters). As such, the Olympia oyster population in Drakes Estero may be a windfall for Olympia oyster restoration projects in the region. Currently, the movement of oysters between estuaries is not recommended because of the risk of mixing genetic populations (see the previous discussion on the precautionary principle). However, if further research confirms that 1) the genetic strain in Drakes Estero is unadulterated and 2) that the other regional estuaries are genetically mixed, then hatchery-produced Olympia oyster seed could be used to repopulate other regional estuaries[21]. Production of Drakes Estero oyster seed may be the best way to enhance regional populations and encourage re-establishment of the native genetic strain. Conversely, an Olympia oyster aquaculture facility that produced Olympia oysters from broodstock in Tomales Bay, San Francisco Bay, or Elkhorn Slough would be limited to producing Olympia oyster seed for restoration projects only within their specific estuary (assuming that populations are genetically-mixed).

<u>Finding</u>: *Limiting factors for Olympia oyster restoration are poorly understood and vary by site.*

Studies from estuaries and bays throughout the West Coast illustrate that Olympia oyster populations may be limited by a variety of site-specific factors and there is no "silver bullet" solution to guarantee restoration success. Due to significant variations in topography, climate, vegetation, siltation, water quality, and coastal development throughout the species' range, each estuary must be evaluated for the specific limitation(s) that hinder local Olympia oyster populations. During the 2006 West Coast Native Oyster Restoration Workshop, a panel discussion yielded the following list (see Box 1) of potential limitations to Olympia oyster populations. Specific examples and additional research from California estuaries and bays are included. Careful evaluation of the site-specific limitation(s) is the key to restoration success. A majority of early restoration efforts throughout the West Coast assumed that a recruitment limitation was

[20] Although there have been no introductions of Olympia oysters into Drakes Estero, there have been several introduction of other commercial aquacultured bivalves, most notably the Pacific oyster.
[21] Prior to any movement of oysters between estuaries, appropriate shellfish disease management protocols, including the precautionary principle, must be applied. Further testing of Disseminated neoplasia, a disease reported by Dr. James Moore to be found in Drakes Estero and some sites in San Francisco Bay (Moore, 2007), would be required before oyster seed could be transplanted to another regional estuary for restoration purposes.

the primary bottleneck in Olympia oyster recovery (White et al. 2005; McGowan et al. 2006). However, recent studies illustrate that the limitations may be more complex (Polson et al. 2006; Zacherl 2007), possibly involving post-recruitment survivorship (Trimble et al. 2007). In all cases, it is important to evaluate the estuary and local Olympia oyster population(s) before passing judgment on the likely limitations to recovery.

**Potential limiting factors to Olympia oyster recovery, including additional research findings relevant to California**

1. **Reproductive / fertilization limitation**
    a. Evidence from Tomales Bay and Mission Bay shows little support for fertilization limitation (Grosholz 2007; Zacherl 2007).
2. **Dispersal limitation**
    a. May occur in outer areas of Tomales Bay because larvae are advected out of bay (Grosholz 2007).
    b. May occur in Southern California estuaries, such as Batiquitos Lagoon and Agua Hedionda Lagoon (Polson 2007).
    c. Little evidence of dispersal limitation in San Francisco Bay (Grosholz 2007).
3. **Substrate limitation**
    a. In Wallapa Bay, WA, historic removal of dense subtidal shell combined with newly introduced Pacific oyster shell in intertidal areas may be recruitment sink (Trimble et al. 2007). This may be significant in San Francisco Bay, Tomales Bay, and Drakes Estero, where there is a history of oyster exploitation.
    b. A study in San Francisco Bay revealed that substrate may be a limiting factor that is compounded by predation by non-native drills (McGowan et al. 2006).
    c. Another study in San Francisco Bay indicated that habitat/substrate is not limiting because of the extensive amount of unoccupied hard substrate (Grosholz 2007).
    d. In Puget Sound, WA, recruitment improved on shell substrate, with Olympia oyster shell having the highest recruitment abundance (White et al. 2005). This finding is likely to be important for all future restoration projects because it illustrates the significance of Olympia shell as an ideal substrate. However, further testing is needed to identify if there is a statistical difference between Olympia, Pacific, or other shell substrates for recruitment.
4. **Water Level / Risk of Exposure** (discussed in Section 7.1)
5. **Salinity limitation**
    a. Protracted low salinity appeared to be a factor limiting Olympia oysters at one site in San Francisco Bay (Abbot 2006).
    b. Estuarine salinity was related to oyster abundance but confounded by other factors in San Francisco Bay (McGowan et al. 2006).
6. **Competition limitation**
    a. Space competitors in Tomales Bay and San Francisco Bay are seasonal and are not considered a limitation to Olympia oysters (Grosholz 2007).

**Potential limiting factors to Olympia oyster recovery, including additional research findings relevant to California (*continued*).**

7. **Predation limitation**
    a. Introduced crabs and gastropods, specifically the Atlantic oyster drill *Urosalpinx cinera*, exert top-down control on Olympia oysters in Tomales Bay because the invasive species have replaced native top predators (Grosholz 2006; Kimbro et al. 2006; Grosholz 2007).
    b. In San Francisco Bay, predators are not a significant source of mortality (Grosholz 2007).
8. **Disease limitation**
    a. Three diseases/disease agents (*Mikrocytos*-like protist (microcell), a haplosporidian and hemic neoplasia) discovered on western shores of San Francisco Bay (Friedman et al. 2005)(Friedman, proceed).
    b. Disseminated neoplasia discovered in Drakes Estero and some sites in San Francisco Bay (Moore 2004). Disease is nearly absent from Tomales Bay.
9. **Genetics limitation**
    a. There is a general lack of data regarding when populations are locally adapted versus genetically unhealthy (Camara 2007). Further research by Stick et al. (2007) may elucidate genetic trends.

**Figure 21**. Limiting factors to Olympia oyster recovery along the West Coast, including specific findings from California. List headings reproduced from the 2006 West Coast Native Oyster Restoration Workshop Proceedings.

Finding: *New research indicates that post-recruitment survival may be the critical limiting factor to population growth in West Coast estuaries with historical aquaculture operations.*

Despite the extensive list of potential limitations (and the additional possibility of interacting limitations), recent evidence by Trimble et al. (2007) illustrates that post-recruitment survival appears to be the primary limitation in Willapa Bay, WA. More importantly, post-recruitment survival may be a critical limitation to many other Olympia oyster populations throughout their range. Trimble et al.'s (2007) detailed examination of Olympia oyster limitations in Willapa Bay, WA resulted in five key findings:

1. Examination of historical data and a replicated study from 2002- 2006 revealed that Olympia oyster populations were not recruitment limited (Trimble et al. 2007). Instead, recruitment has been high and persistent for at least five decades throughout the southern portion of Willapa Bay, leading Trimble et al. (2007) to the conclusion that poor post-recruitment survival and growth represent the weak demographic link in the lifecycle. See Figure 22 for a comparison of annual recruitment of Olympia oysters and Pacific oysters from 1947 – 2006.

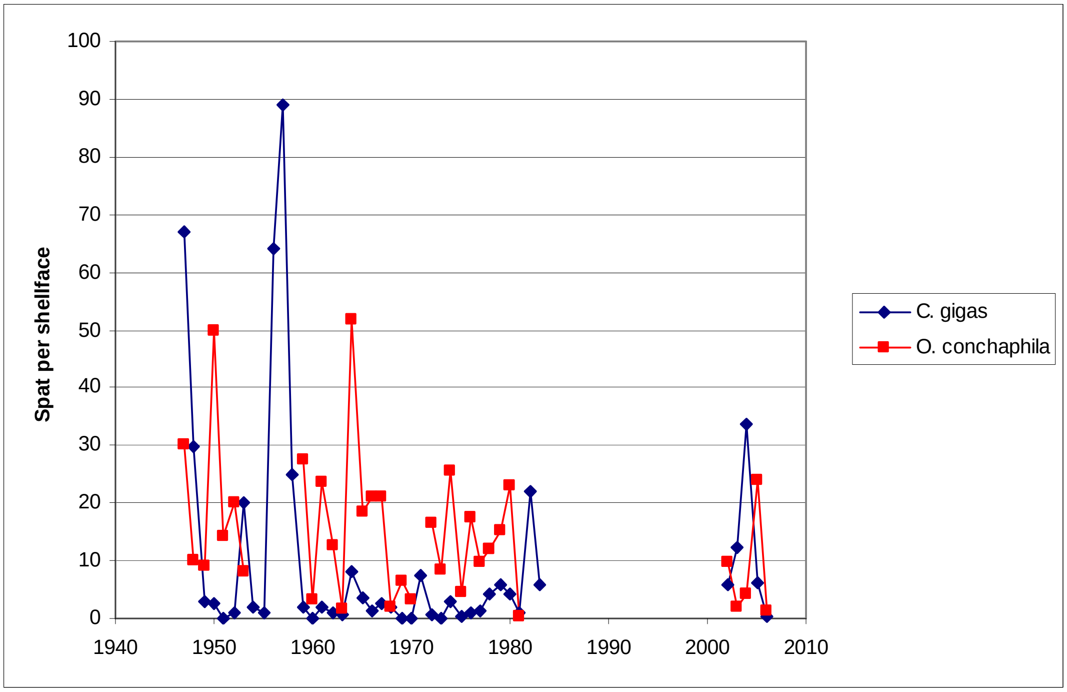



**Figure 22**. Recruitment comparison of Olympia oyster and Pacific oyster spatfall onto suspended Pacific oyster shell from 1947 – 2006. Reproduced from Trimble et al. (2007), with permission.

2. Olympia oysters suffered high mortality rates with exposure to air. Specifically, Trimble et al. (2007) discovered that Olympia oysters preferentially settle in subtidal depths, where they avoid temperature stress. Olympia oysters suffered significantly increased mortality at intertidal depths (Figure 23). Additionally, both Pacific and Olympia oysters preferentially recruit to shell habitat (largely comprised of Pacific oyster shells), creating competition for this substrate[22] (Trimble et al. 2007). See Figure 24 for a comparison of spat settlement preferences.

[22] Historically, subtidal beds of Olympia oysters lined Willapa Bay (Collins 1892, Townsend 1896 in Trimble 2007), yet they were largely removed during large-scale export in 1851 (Trimble 2007). Years later, growers introduced Pacific oysters to intertidal depths and concentrated Pacific shells in intertidal areas (Trimble 2007). Thus, Trimble et al. (2007) theorize that Olympia oysters probably recruit to the high-density, intertidal Pacific oyster shell. However, since Olympia oysters are highly sensitive to temperature stress and can be out-competed (by Pacific oysters) in intertidal areas, they have very high mortality rates (Figure 2) (Trimble 2007).

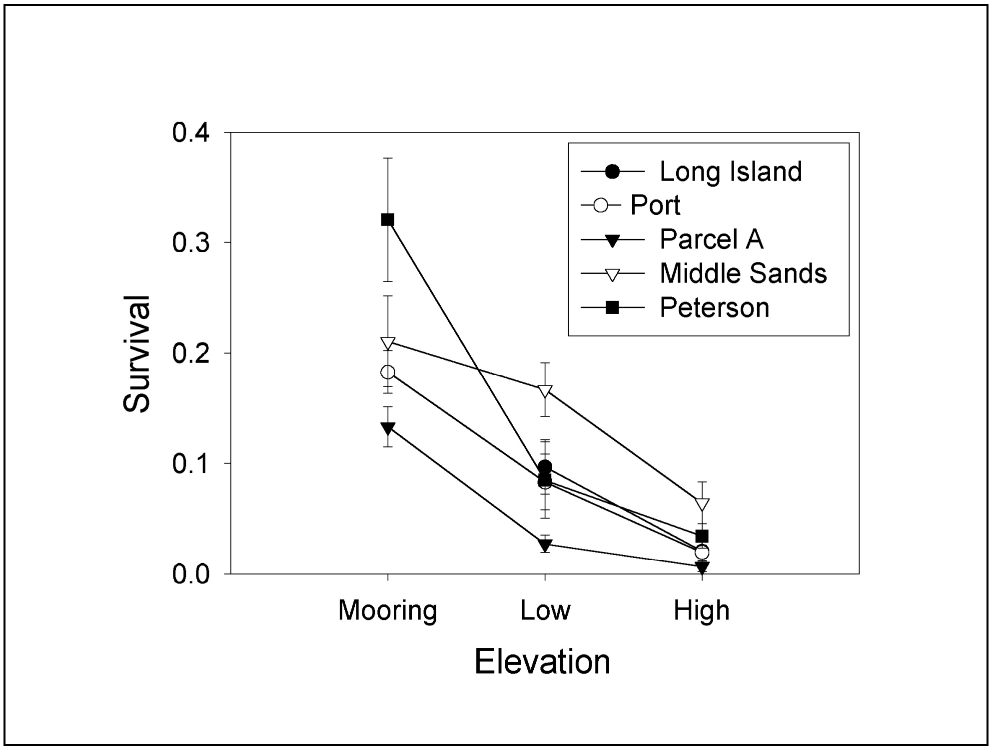
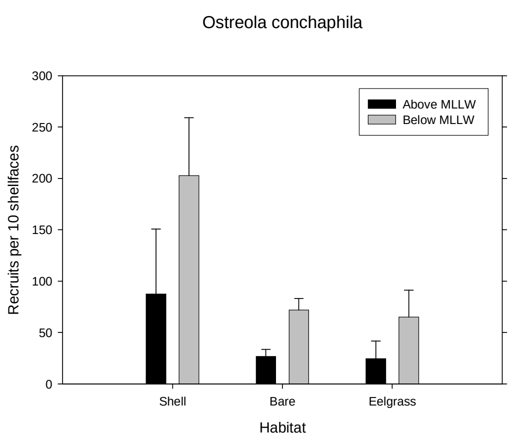



**Figure 23**. Olympia oyster survival at three tidal elevations and across five sites. Reproduced from Trimble et al. (2007), with permission.



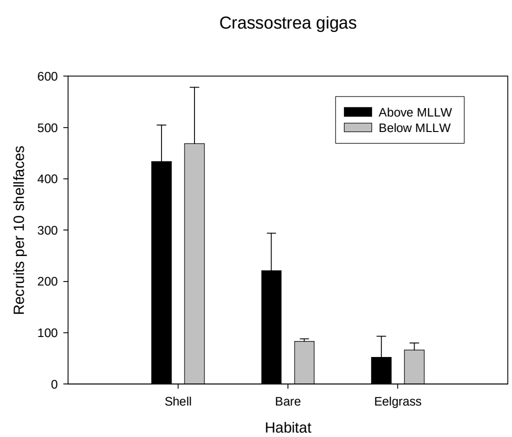




**Figure 24**. Variation in Olympia and Pacific oyster recruitment to substrate types at different tidal elevations. Reproduced from Trimble et al. (2007), with permission.

3. Fouling organisms, including space competitors such as non-native Pacific oysters, detrimentally impact the growth and survival of Olympia oysters. Trimble et al. (2007) found that removal of fouling organisms and space competitors doubled the survivorship of Olympia oysters and improved their growth significantly. Specifically, fouling organisms and space competitors reduced average survival across all elevations from 15% to 7% and they reduced the final size of Olympia oysters by 2% to 35%, depending on the site (Trimble 2007).
4. Post-recruitment performance was sensitive to stability and density of the substrate (outplant technique). Trimble et al. (2007) utilized a variety of different stability and density substrates across four sites to evaluate abundance and growth over a year. Results showed that Olympia oysters outplanted in a thin, unconsolidated layer were easily moved or buried (Trimble 2007). Though none of the treatments faired extremely well, Trimble et al. (2007) note that the stable, low-density plots produced the greatest shell lengths. Throughout the experiments, surviving Olympia oysters grew to approximately 30 mm in one year (Trimble 2007).

The findings in this study illustrate that a historical shift may have occurred in Willapa Bay as a result of commercial aquaculture shifting from Olympia oyster harvests to planting Pacific oysters (Trimble 2007). Removal of Olympia oyster shell, the addition of Pacific oyster shell to intertidal areas, the addition of Pacific oyster competition for shell substrate and structurally-insufficient (unstable) growout substrates may have shifted the local system to favor non-native Pacific oysters. As such, aquaculture of non-native commercial species may have contributed to the inability of Olympia oysters to return to their former abundances in West Coast estuaries (Trimble 2007).

## Appendix K: Olympia Oyster Aquaculture Production Cost Scenarios

This appendix outlines the rationale, assumptions, and additional results of the hatchery and growout production cost scenarios.

**Assumptions of Cost Scenarios**

To compare the alternative cost scenarios, we made two specific assumptions regarding land and aquatic property. First, all cost scenarios assume that the hatchery and growout operations will take place on property that is leased or rented through current proprietors or aquaculture operators. Specifically, these scenarios assume that land acquisition is not required to establish or operate the hatchery or growout operations. Second, these scenarios assume that the physical infrastructure, including buildings, hatchery laboratories, basic laboratory plumbing, docks, ramps, roads, etc., are already in place and accounted for in rent transactions.

Second, we assumed that all potential aquaculture operators had sufficient and appropriate acreage to accommodate the prescribed number of Olympia oyster growout trays (in the growout scenarios). All hatchery production scenarios will produce approximately 300,000 juvenile Olympia oysters per year[23], of which a certain percentage (the mortality rate) will not survive. For example, if there is a 50% mortality rate, the aquaculture operation will produce 150,000 half-shell oysters. California aquaculture operators suggest that this scale of production is appropriate and feasible in California's small estuaries, such as Drakes Estero and Tomales Bay (Finger 2007). Therefore, we constructed the cost models to this level of production and assumed that aquaculture operators in California would be able to accommodate this quantity of tray production within their operation.

More generally, all of the cost scenarios assume that the University of California, Santa Barbara, will be a collaborative partner in the production scenarios. All of the cost scenarios include the academic research community because this public partner will provide the critical research that is required to establish more efficient growout strategies and site-specific restoration techniques. As such, some of the hatchery scenarios include hatchery locations in Southern California to be closer to the UCSB research team. There is a tradeoff in the proximity to the UCSB research team (in Santa Barbara) versus the growout location (in Central or Northern California). These factors are included in cost calculations.

[23] This figure represents half-shell oyster production and does not include any shucked product. See Appendix K for a discussion of the combined production of half-shell and shucked Olympia oysters.

## Hatchery Scenarios Rationale and Additional Results

*Hatchery Scenario Rationale*

We evaluated the cost-effectiveness of three hatchery scenarios through a cost analysis. The cost analysis compared the different costs required to establish the same Olympia oyster hatchery. Costs were divided among six categories:

- Pre-hatchery broodstock collection
- Tanks and tank accessories
- Algae
- Pumps, filtration, and supplies
- Microcultch system and settlement media
- Fixed costs

After discussions with our Group Project advisors, we selected three hatchery scenarios for evaluation. Using the six cost categories (listed above), we evaluated three hatchery scenarios.

Hatchery Scenario 1: *Sub-contract a professional hatchery, Proteus SeaFarms International, Inc.*
Sub-contracting a professional hatchery to culture Olympia oysters represents the traditional way that oyster aquaculture operators acquire their juvenile oyster "seed" for growout. We selected Proteus SeaFarms International, Inc. as our first hatchery scenario because of its close proximity to UCSB (Oxnard, CA). Proteus SeaFarms International, Inc., operated by Mr. McCormick, represents a relatively accurate proxy to the costs associated with culturing Olympia oysters at a professional hatchery in California (McCormick 2007). Entrepreneurs who want to start up their own Olympia oyster aquaculture operation without a hatchery facility on-site would need to contract with a professional hatchery, like Proteus SeaFarms International Inc., to culture their specific broodstock.

Hatchery Scenario 2: *Operating an Olympia oyster aquaculture hatchery at UCSB*
As a result of Dr. Lenihan's Olympia oyster research at UCSB, there is an opportunity to utilize lab space at the University for Olympia oyster culture. Although the UCSB facilities include a state-of-the-art wet lab, an Olympia oyster hatchery operation would still require extensive capital purchases, similar to the other hatchery scenarios. The UCSB hatchery represents a unique hatchery option that is only available because of the association with Dr. Lenihan's Olympia oyster research. However, as more academic institutions develop hatchery research laboratories, future entrepreneurs may be able to partner with other academic institutions to culture their local broodstock.

Hatchery Scenario 3: *Develop a public-private partnership between UCSB and Drakes Bay Family Farms*
A public-private partnership (PPP) between UCSB and Drakes Bay Family Farms (DBFF) signifies a collaborative relationship between a public organization (UCSB) and a private corporation (DBFF) that would jointly operate the Olympia oyster hatchery at

Drakes Bay Family Farms, Inverness, CA. Under the PPP, DBFF would be the primary responsible party for funding, installing, and maintaining the hatchery. However, UCSB research funding would support a portion of the initial capital investment and provide a salaried graduate student to conduct the hatchery operations.

DBFF was selected over the other aquaculture operations as the site for the hatchery operation for several reasons. First, DBFF is located in Drakes Estero, which has abundant, consistent Olympia oyster recruitment (Lunny 2007). Abundant, regular recruitment would facilitate easy collection of genetically-diverse broodstock, thereby increasing culture success (reducing the probability of allee effects). Second, DBFF includes an existing hatchery. It would be cost-prohibitive to build and install all of the required equipment to start-up a hatchery from scratch. Furthermore, it is a stated assumption of the scenarios that the basic hatchery infrastructure must already be in place (these scenarios only add the Olympia oyster hatchery operation onto existing hatcheries). DBFF is the only aquaculture farm in the region with a hatchery on site, giving it a comparative advantage over other aquaculture operations. Third, DBFF is committed to, and has a history of, contributing to Olympia oyster restoration programs.

The rationale for a public-private partnership stems from the increasing trend toward community-based oyster restoration projects pairing with agencies, municipalities, and local aquaculture operations to enhance restoration and marine conservation (Beck et al. 2004; Udelhoven et al. 2005). Partnerships between public organizations and private industries can facilitate technical assistance and funding to restoration, while the private industry receives positive community support and a "green" image. For a complete description of these mutually-beneficial partnerships, see Appendix M. Given the trend toward increasing PPPs, it is logical for this feasibility analysis to consider a public-private partnership between UCSB and a California aquaculture operator. Until other aquaculture operators add hatchery operations to their infrastructure, DBFF represents the best partner for this collaboration.

*Hatchery Cost Results: The Significance of Labor*

The UCSB hatchery and the UCSB/DBFF PPP labor costs differ because the UCSB/DBFF PPP hatchery operation includes oversight by the DBFF hatchery expert, Luis Armienta, who is already salaried by DBFF (Lunny 2007). As such, the UCSB hatchery requires a laboratory assistant, whereas the UCSB/DBFF PPP does not.

Even if labor costs are ignored, the UCSB/DBFF PPP is clearly the most cost-effective hatchery operation. Figure 25 illustrates the cost comparison without labor costs, clearly showing that the UCSB/DBFF PPP is the most efficient and cost-effective hatchery operation.

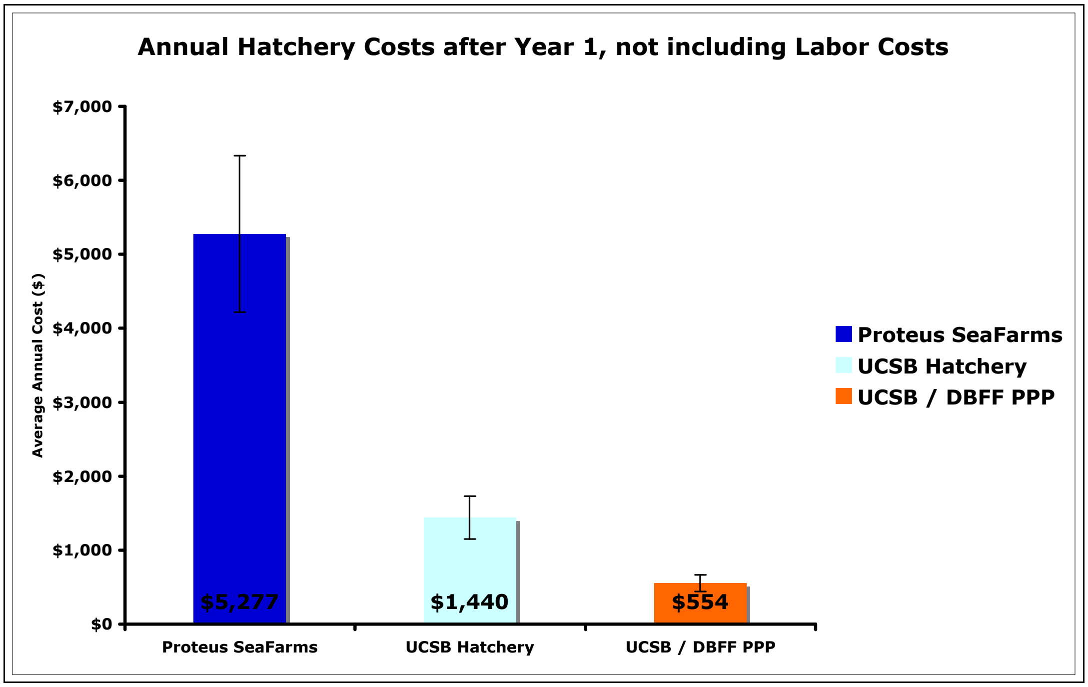



**Figure 25**. Annual Hatchery Costs after Year 1, not including Labor Costs. The UCSB/ DBFF PPP is the most cost-effective operation compared to the other scenarios.

## Growout Scenario Rationale and Additional Results

*Growout Scenario Rationale*

We identified different growout scenarios to pair with the chosen hatchery scenarios. Hatchery Scenario 1 (Proteus SeaFarms International, Inc.) was significantly more costly than the other hatcheries, so our research group eliminated it from consideration for a growout pairing. This left two alternative hatcheries (the UCSB hatchery and the UCSB/DBFF PPP hatchery) to be paired with growout sites and/or aquaculture operators.

Through discussions with aquaculture operators, seafood distributors, and our Group Project advisors, we identified six categories of costs to evaluate the alternative growout scenarios:

- tray growout costs
- experimental growout costs
- fixed costs
- marketing costs
- legal costs
- shipping costs

Next, we identified two growout scenarios to pair with the hatchery scenarios. The rationale for the selection of the two growout scenarios is described below.

Growout Scenario 1: *UCSB "start-up" aquaculture operation at Elkhorn Slough (UCSB/Elk)*
Following the entrepreneurial theme in Hatchery Scenario 1, our research group explored the possibility of starting an Olympia oyster aquaculture (growout) operation from scratch. The motivation behind the decision to include a "start-up" scenario was to answer several key questions:

- How much would it cost to operate a "start-up" Olympia oyster aquaculture operation?
- How would the "start-up" costs compare with existing aquaculture operator costs?
- Is it realistic to try to start an Olympia oyster aquaculture operation? What are the primary barriers to entry into the aquaculture market?

Since the UCSB hatchery was a competitive option for culturing Olympia oysters, it was logical to question whether the costs of running the aquaculture (growout) side of the operation would be competitive with current aquaculture operations. Thus, we researched the costs associated with starting a UCSB Olympia oyster aquaculture venture within the framework of the business model.

Preliminary research and interviews suggested that it would be extremely expensive to start an aquaculture operation from scratch. Since Olympia oysters require estuarine conditions, the potential number of growout sites is limited to the few estuaries and bays that exist along the California coast. Of the suitable estuaries, many of the most productive estuaries already have aquaculture operations; these estuaries are located in Humboldt Bay, Tomales Bay, Drakes Estero, Morro Bay, and San Diego. Starting up an aquaculture operation from scratch implies that the entrepreneur would site the operation in an estuary (or a portion of an estuary) that is not currently permitted for aquaculture. As outlined in Appendix H, the entrepreneur is required to proceed through an extensive and expensive permit application process. The complete permit approval process will take a significant amount of time (three to five years) and huge expenses ($50,000 to $360,000) (Moore 2007). Given the dearth of suitable estuaries and the extreme costs associated with permitting a new site, it is unrealistic to create a scenario that is based on an unpermitted site. Instead, we modified Growout Scenario 1 to represent a more realistic alternative for an entrepreneur.

A more realistic, economically-competitive scenario involves sub-leasing a permitted aquaculture site. Submerged lands that have already been permitted for aquaculture can be subleased out to entrepreneurs who want to growout their aquaculture products at that location (Moore 2007). This option is much more cost-effective than permitting a new site, though it does incur annual rental costs. Estimated rental costs for a generic acre of submerged lands are included in the cost model. However, there is uncertainty over the exact amount since subleased submerged lands would be rented at a proprietor-established premium. In the absence of site-specific information, the annual rental figure represents our best estimate.

Our search for a suitable growout site identified three appropriate sites for Growout Scenario 1: Drakes Bay, Tomales Bay, and Elkhorn Slough. All three estuaries feature historical populations of Olympia oysters, appropriate estuarine conditions and submerged lands that are already permitted for aquaculture. All of these locations are also within close proximity (within 100-miles) of the target market (San Francisco). Drakes Bay is the site for Growout Scenario 2, so it was eliminated as a potential site for Growout Scenario 1.

After discussions with our Group Project Advisors, we chose Elkhorn Slough over Tomales Bay as a site for Growout Scenario 1. Elkhorn Slough presents several advantages over Tomales Bay. First, Tomales Bay is one of the top producing aquaculture locations in California. As such, the leased aquaculture areas are extensively utilized by local aquaculture operators. Since such valuable aquaculture products are produced in these leased areas, the aquaculture operators are likely to demand significant annual rents to displace them from their growing areas. Following that reasoning, it is unlikely that any of the high quality growing areas will be available for sublease at a reasonable rate. In contrast, Elkhorn Slough has no active aquaculture operators, but has leases that are permitted for aquaculture (Moore 2007). The last aquaculture operator in Elkhorn Slough grew Manilla clams (*Tapes philippinarum*), but the operation closed by 1984 (Moore 2007). Further research is required to identify the aquaculture lessees, the specific water quality and hydrologic conditions in the estuary, and the potential layout design of the aquaculture operation. In addition to being the only aquaculture operation in Elkhorn Slough, this growout scenario has great potential to partner with the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve to establish an Olympia oyster restoration project in the estuary.

Though Growout Scenario 1 features the Elkhorn Slough site, it is representative of an entrepreneur who wants to start their own Olympia oyster aquaculture operation. In the scenario, UCSB would start and operate the aquaculture operation at Elkhorn Slough, similar to an entrepreneur. The cost estimates in the scenario reflect typical costs that could be expected from a start-up aquaculture operation that does not have any existing capital (no processing equipment, boat, distribution network, etc.) at the start of the business.

Growout Scenario 2: *UCSB/Drakes Bay Family Farms Public-Private Partnership (UCSB/DBFF PPP)*

An alternative to the entrepreneurial approach is to partner with an existing aquaculture operator for the growout stage. We selected DBFF as a partner in the public-private partnership for many of the same reasons they were selected in the hatchery comparisons. In addition to previously stated reasons, DBFF has other comparative advantages over other aquaculture operators in California. First, DBFF is the largest oyster producer in California due to its significantly larger growing area (Lunny 2007). As a result of their large leased areas, DBFF has more space to produce a specialty oyster, like the Olympia oyster. Second, DBFF has excellent water quality and ideal estuarine conditions because the operation is surrounded by Point Reyes National Seashore (U.S.

National Park Service) where only low-density grazing and recreation is permitted (Lunny 2007). As such, the estuarine conditions are pristine and large natural populations of Olympia oysters have been reported (Lunny 2007). Third, DBFF has the only licensed shucking plant in California, and it is located on-site. While our feasibility analysis focused on the target half-shell product, there is a market for shucked Olympia oysters (Lunny 2007). Since DBFF has an on-site shucking plant, it is likely to yield additional revenue that other aquaculture operators cannot match. Finally, DBFF is unlikely to enter into the PPP for the hatchery unless they are also involved with the growout operation. It is only logical for the entire operation (hatchery and growout) to be contained within the DBFF operation.

*Growout Scenario Results: A Comparison*

Results of the growout cost scenarios revealed that the UCSB/DBFF PPP) was more cost-effective than the UCSB/Elk aquaculture operation. Even ignoring the Year 1 costs, the UCSB/DBFF PPP is more cost-effective than the UCSB/Elk scenario (Figure 26). However, it may be possible to reduce some of the UCSB/Elk costs and make this alternative more cost-efficient. Specifically, the UCSB/Elk operation needs to reduce its annual rent. A rental reduction may be possible through subsidized rent at Moss Landing Marine Laboratories as a result of this project's academic affiliation with the University of California, Santa Barbara, and the project's restoration objectives. Additionally, there is the chance that the project could obtain a donated vessel and/or processing equipment. Reducing these costs would make the UCSB/Elk operation cost-competitive with other aquaculture operations, including the UCSB/DBFF PPP. Figure 27 and Figure 28 illustrate the similar costs of the two scenarios with a donated vessel and subsidized rent ($500 per month). After Year 1, these operations do not have significantly different costs, providing evidence that it may be possible for an entrepreneur to operate an Olympia oyster aquaculture (growout) operation at the same cost as the UCSB/DBFF PPP scenario.

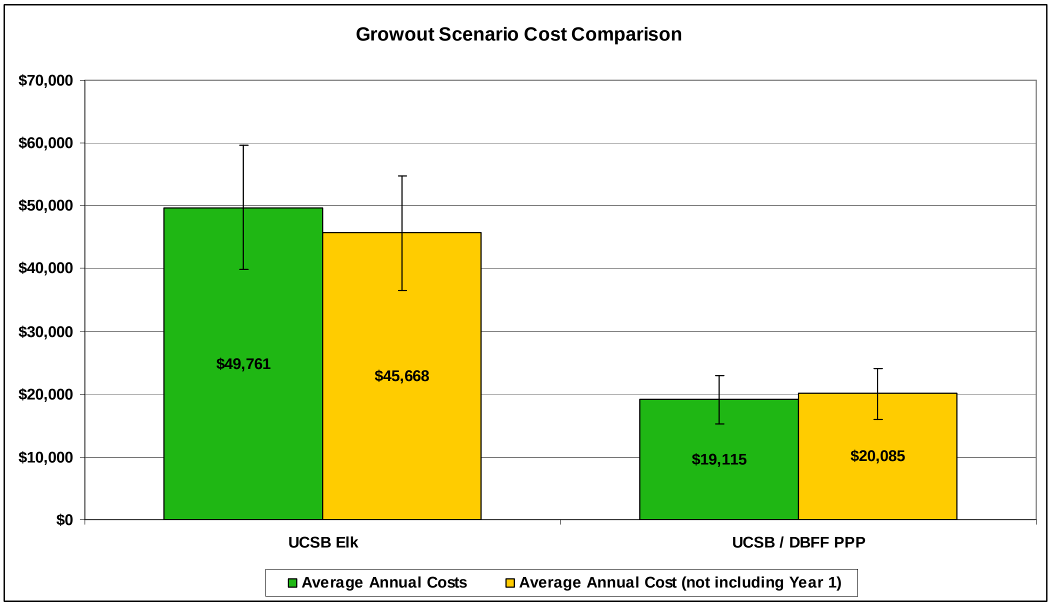



**Figure 26**. Average annual costs of different growout scenarios. Green bars represent average annual costs, while yellow bars represent annual average costs after Year 1. Error bars represent a 20% uncertainty factor applied to all cost estimates.

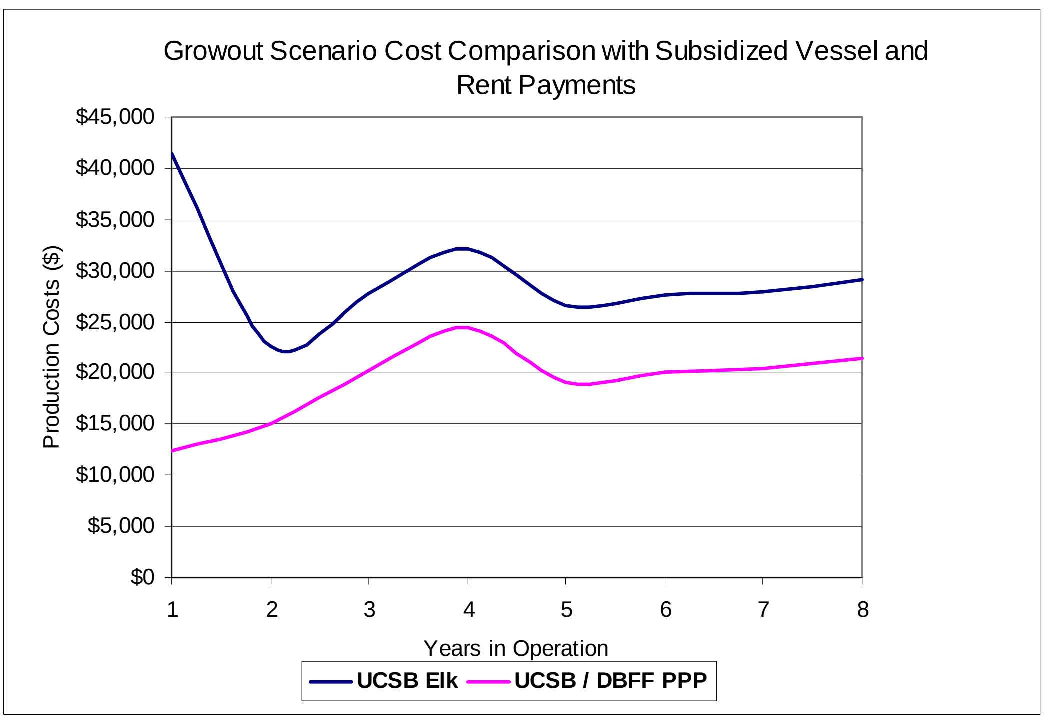



**Figure 27**. Growout scenario cost comparison over eight-year time horizon, including a subsidized rental payment ($500 per month) and a one-time (subsidized) vessel purchase ($1000).

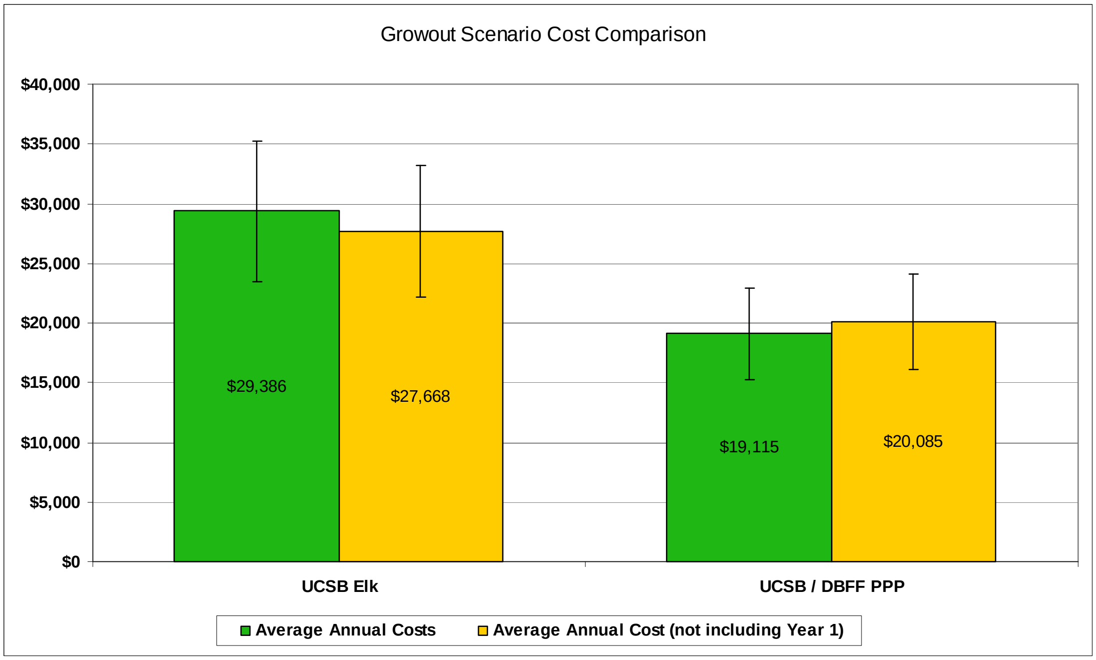



**Figure 28**. Average annual costs of different growout scenarios with subsidized rental payments ($500 per month) and a one-time, subsidized vessel purchase ($1000). Green bars represent average annual costs, while yellow bars represent annual average costs after Year 1.

This analysis suggests that if specific fixed costs are adjusted, it is possible to operate a more cost-effective, more competitive Olympia oyster aquaculture operation. While this is positive news for hopeful entrepreneurs, it is advisable to take a conservative approach to these predictions. As such, our recommended approach is to assume that the fixed costs will not be subsidized, favoring the UCSB/DBFF PPP scenario as most cost effective. [Note that in the following analysis, all cost scenarios include unsubsidized fixed growout costs, the conservative approach.]

The case for the UCSB/DBFF PPP is even stronger when considered in the context of the total cost of production. Combining the hatchery costs with growout costs illustrates the growing divide between the two scenarios. For the purposes of evaluating total production costs, we grouped the UCSB hatchery (Hatchery Scenario 2) with the UCSB/Elkhorn Slough growout scenario (Growout Scenario 1), hereafter referred to as "UCSB Elk". Similarly, we combined the hatchery and growout components of the UCSB/DBFF PPP (Hatchery Scenario 3 with Growout Scenario 2). At the same level of production, the UCSB/DBFF PPP operates with a savings of more than $40,000 per year (on average) compared to the UCSB/Elk operation.

Comparing the total production cost per oyster is a common metric to evaluate different oyster aquaculture operations that produce the same species (Finger 2007). In the comparison between the two Olympia oyster aquaculture operations, the UCSB/DBFF PPP is significantly more efficient than the UCSB/Elk operation based on the production cost per oyster. The average cost of production per oyster for UCSB/Elk is

$0.62, while the UCSB/DBFF PPP is only $0.34. The average cost per oyster clearly favors the cost-efficiency of the UCSB/DBFF PPP. In an industry that often has a "make-it-or–break-it" margin within a cent of a particular target production cost, the savings of $0.28 per oyster illustrates the magnitude of this lopsided comparison. The clear conclusion from this cost analysis is that the UCSB/DBFF PPP is the most cost-effective means to pursue an Olympia oyster aquaculture business.

### Production Cost Categories Calculated for All Cost Scenarios

**Table 16**. Hatchery production cost categories calculated for each hatchery scenario

| | | |
|---|---|---|
| **Hatchery Costs** | **Pre- Hatchery Production Costs** | |
| | **Hatchery Production Costs** | Cylindrical cones |
| | | Vexar Cages |
| | | Algae- Conditioning cones |
| | | Algae- Larval cones |
| | | Flow-Through Tanks |
| | | Pumps & Supplies |
| | | Microcultch System & Media |
| | | Fixed Costs |

**Table 17**. Overhead costs categories for each production cost scenario

| | | |
|---|---|---|
| **Overhead Costs** | **Marketing** | Advertising Costs |
| | **Legal Costs** | Fee to Sub-lease growing area |
| | | Annual Aquaculture Registration |
| | | Liability Insurance |
| | **Shipping Costs** | Shipping supplies |
| | **Taxes** | CA Tax (privilege tax) |
| | | Income Tax (CA) |
| | **Grant Funding** | |

**Table 18**. Growout production cost categories calculated for each scenario

| | | |
|---|---|---|
| **Tray Growout Production Costs** | **Tray Growout Production** | Number of trays |
| | | Line |
| | | Buoys |
| | | Styrofoam |
| | | Ground Tackle |
| | | Miscellaneous Costs |
| | | Labor |
| | | Tray System Construction |
| | | Install Tray System |
| | | Maintenance |
| | | Harvest |
| | | Total Tray System |
| | **Experimental Growout Costs** | Bag-Bottom techniques |
| | | French Pipe |
| | | Miscellaneous Costs |
| | | Set up costs |
| | | Maintenance of racks ($/ yr) |
| | | # days to harvest experimental techniques |
| | | Harvest Costs |
| | **Fixed Costs** | Sub-leasing tide lands |
| | | Land Rental Cost |
| | | Shellfish preparation/ processing equipment |
| | | Boat |
| | | Water quality monitoring |

## Appendix L: Profitability Projection Model

This appendix includes a complete description of the methods, results, and analysis of the profitability projection model, and the implications on the overall feasibility of an Olympia oyster aquaculture business in California.

**Methods**

The results of the market demand analysis and the production cost analysis provided the critical inputs required for the profitability model. The market analysis confirmed the Olympia oyster target market, optimal price, and marketability in California. The production cost scenarios identified the most cost-effective hatchery and growout combination, the UCSB/DBFF PPP. These two elements provide the critical framework for the profitability model. The basic equation in the profitability model is:

$$profitability = \sum [R - C]$$

where R= annual revenue
C= annual production costs (UCSB/ DBFF PPP)

However, for this profitability model to produce an output (a revenue projection), additional parameters must be added to both independent variables, R and C. The individual equations for each independent variable are defined as:

$$R = [(oysters_{x-2} * M) * p] + [grant]$$

where $oysters_{x-2}$ = # of oysters produced in hatchery in Year ($x$ – 2)
M = mortality rate
p = price per oyster
grant = education/ research funding

$$C = [hatchery_x] + [growout_x] + [distribution_x] + [taxes_x]$$

where $hatchery_x$ = hatchery production costs in Year $x$
$Growout_x$ = aquaculture growout costs in Year $x$
$Distribution_x$ = distribution costs in Year $x$
$Taxes_x$ = California state taxes in Year $x$

*Profitability Model Parameters*
Interviews with oyster aquaculture operators, seafood distributors, and Olympia oyster experts facilitated the formulation and definition of the feasibility model parameters. Each of the parameters is described below.

*Revenue Parameters*
<u>Parameter:</u> $oysters_{x-2}$
The number of oysters available for sale each year depends on the original hatchery production and the expected growth rate and mortality rate of the oysters. As described in Section 7.2, hatchery production is very consistent. After the hatchery produces a cohort of oysters and they are grown to a threshold size, they are outplanted in the tray

growout. The growth rate determines how long it takes for a cohort to reach marketable size (35 – 40 mm), and the mortality rate determines how many oysters actually reach market size. As described in Section 7.2, we expect Olympia oysters to reach market size in 1.5 to 2 years based on documented growth rates in California and a recent study that manipulated the growout technique to favor better survivorship (Trimble et al. 2007). Thus, the parameter $oyster_{x-2}$ represents the number of hatchery-produced oysters that were outplanted two years earlier, and are now ready for harvest.

Parameter: *M*
To determine the number of Olympia oysters that survive to marketable size, we incorporated a mortality rate, *M*, into Equation 2. We multiplied the number of marketable oysters ($oysters_{x-2}$) by the mortality rate and determined the number of Olympia oysters that survive during the growout stage of the production cycle[24]. The resulting value represents the number of surviving oysters that can be sold as half-shell product. As described in Section 7.2, we expect an Olympia oyster mortality rate between 30 – 60%. Typically, oyster aquaculture operations expect a mortality rate around 50% (Finger 2007). Olympia oysters grown with bottom culture techniques (in Washington State) have highly variable mortality rates, often reporting very low survivorship (Gordon et al. 2001). However, we expect that further research and our recommended tray growout system will yield higher survivorship because the growout technique will favor the post-recruitment survivorship characteristics outlined by Trimble et al. (2007). In most cases, we ran the profitability model with a 50% oyster mortality rate because 1) it is an industry standard and 2) it is a conservative estimate within the 30 – 60% Olympia oyster mortality range. Each model run lists the mortality rate input.

Parameter: *p*
The market survey (see Section 6.6) determined the optimal price per oyster as $0.90 per oyster. Unless otherwise noted, all revenue values[25] are based solely on half-shell oyster sales only because half-shell oysters were the desired product for the target market

[24] Hatchery mortality is accounted for in the hatchery oyster production estimates. The hatchery is configured to produce 300,000 micro-cultch Olympia oysters for the half-shell market and 184,500 Olympia oysters set on cultch (for shucked product and experimental/ research applications). These production figures are based on Olympia oyster settlement rates from professional hatcheries in Washington (Taylor Shellfish) and California (Bodega Marine Laboratory). The techniques outlined (and priced out) in all hatchery scenarios reflect techniques identical to those used in the professional hatcheries. As such, we assumed that our hatchery would match their production estimates.
[25] For the purposes of this profitability analysis, revenue values represent the revenue generated by the aquaculture operator through the sale of half-shell Olympia oysters directly to restaurants. Selling direct to restaurants is becoming more common, but can only happen if an existing distribution network is already established. In the case of the UCSB/ DBFF PPP, the distribution network is already set up, thus, all sales are direct at the $0.90 price established in the market survey. See below for further information on the distribution parameter

Parameter: *grant*

The *grant* parameter represents expected educational and research funding (revenue). As a result of the public-private partnership with the University of California, there are significant opportunities for external funding to support research and restoration associated with the Olympia oyster aquaculture operation (Lenihan 2007). External funding opportunities represent an important avenue of support for specific research/restoration objectives, such as research on optimizing post-recruitment survivorship and growout techniques before the aquaculture operation is profitable. This model assumes that the UCSB/ DBFF PPP will be awarded a grant to fund the initial research. Given the objectives and scope of the project, receiving a grant is a reasonable assumption.

We estimated the grant parameter based on a typical small-scale aquaculture grant award ($100,000). From that initial award, approximately 20% of the funding is allocated to UCSB administration, while the rest would be allocated over the four-year project. The profitability model assumes the funding will commence two years prior to the start of the commercial aquaculture. During that time, the UCSB research team will conduct initial Olympia oyster research, including a study on post-recruitment survivorship/growout techniques. Thus, the commercial Olympia oyster operation will benefit from the funding for only two years of operation, Year 1 and Year 2. However, this support will cushion the heavy capital expenses that the UCSB/DBFF PPP face in Year 1 and Year 2.

*Cost Parameters*

Parameter: $hatchery_x$

Hatchery production costs are defined in the UCSB/ DBFF PPP hatchery cost scenario (Hatchery Scenario 3). See Appendix K for a breakdown of annual hatchery costs.

Parameter: $growout_x$

Aquaculture (growout) production costs are defined in the UCSB/ DBFF PPP growout cost scenario (Growout Scenario 2). See Appendix K for a complete breakdown of annual growout costs.

Parameter: $distribution_x$

Distribution costs incorporate the costs associated with shipping Olympia oysters from the growout site (Drakes Estero) to the clients. This value does not include the supplies required for shipping the products (waxed boxes, ice chests, thermometers, labels, etc.) because these costs are already included in the growout costs. Rather, the distribution cost accounts for the specific costs associated with transporting and distributing the oysters to clients. One inherent advantage of the UCSB/DBFF PPP is that DBFF already has its own distribution network and an extensive client list. According to DBFF owner Kevin Lunny, the existing distribution network can accommodate the distribution of Olympia oyster products at no additional cost to the company. Therefore, the distribution cost is zero for all profitability model runs due to the UCSB/DBFF PPP.

The distribution cost parameter is included in Equation 3 for comparative purposes. For example, comparing the feasibility of the UCSB/Elk operation with the UCSB/DBFF PPP operation would require the inclusion of a distribution cost parameter because the UCSB/Elk operation would incur an additional cost of distribution. In the case of the UCSB/Elk operation (or an entrepreneur-driven start-up operation), the distribution cost is included because these operations do not have the capital infrastructure or the network of clients to sell their oyster products directly. As such, these operations typically utilize a commercial seafood distributor, such as Santa Monica Seafood Co., Inc.

Contracting with a seafood distributor requires that the aquaculture operation must sell their product at a significantly reduced cost. A 20-30% reduction in wholesale price is not uncommon (Santa Monica Seafood Company 2008). For Olympia oysters, a 30% price reduction means the aquaculture operator would receive $0.63 per oyster instead of $0.90 per oyster, a significant reduction in potential revenue. Therefore, the distribution parameter adds an important factor to feasibility comparisons between the UCSB/Elk operation and the UCSB/DBFF PPP operation.

Parameter: $Taxes_x$
We incorporated a tax parameter into the cost equation to account for California state taxes[26]. The exact state taxation values (revenue from the UCSB/DBFF PPP) would depend on how the public-private partnership was legally established. Facilitating the exact configuration of the public-private partnership between UCSB and Drakes Bay Family Farms is beyond the scale and scope of this research project. As such, this feasibility model assumes that the public-private partnership will be taxed as a standard for-profit company. Taxes on the commercial operation are broken down into two categories, local tax and the California Privilege Tax. Local tax is set at a standard rate of 7.25% of revenue[27] (California State Board of Equalization 2008), while the California Privilege Tax is a specific tax of $0.04 per 100 half-shell oysters sold (Moore 2008). Tax values are based on revenue and, hence, could not be incorporated into the previous hatchery or growout cost scenarios.

**Additional Profitability Model Results & Analysis**

Results from the profitability model illustrate that the UCSB/ DBFF PPP is profitable over an eight-year time horizon.

*Sensitivity Analysis*
Adjusting parameter values in the model has a significant impact on the overall profitability of an Olympia oyster aquaculture operation. By changing the parameter values, it is possible to compare the relative significance of each parameter to the model

[26] Federal taxes were omitted from the model due to a lack of data on taxation requirements for a public-private partnership.
[27] California local tax includes the standard 7.25% plus any additional county taxes (California State Board of Equalization 2008). Drakes Bay Family Farms is located in Marin County. There is no additional county tax in Marin County (California State Board of Equalization 2008).

outcome. Of the parameters, the cost parameters should be held constant unless there is a desire to change the production output (the number of oysters produced). The number of oysters was scaled to an appropriate level of production for California in the production cost scenario (see Appendix E for oyster production description). Therefore, the cost parameters were held constant[28] during feasibility iterations.

Of the revenue parameters, both *grant* and $oysters_{x-2}$ are static parameters. As stated in above, this model operates on the assumption that a $100,000 grant will support the aquaculture operation, so this revenue component will not vary. Similarly, the number of oysters ready for market will not vary because the values are based on stable hatchery production, as described in Appendix K. All environmental variability is accounted for in the oyster mortality rate ($M$).

Variations in price per oyster and oyster mortality represent realistic fluctuations in the market and in the environment. This dichotomy poses an important question: Is one parameter more influential than the other on the overall profitability of the venture? To test the relative significance of parameter variation, we ran the feasibility model and varied these two parameters one at a time to gauge their impact on overall profitability over the eight-year time horizon. Figure 29 and Table 19 illustrate the cumulative profitability under different rates of mortality, while holding the price constant at $0.90 per oyster. As Figure 29 and Table 19 illustrate, mortality rates cause the overall profitability values to vary significantly. The model predicted that the maximum variability in cumulative profits would be approximately $1.3 million dollars.

[28] Of the cost parameters, the tax parameter was the only variable that fluctuated because it was a function of the revenue. The other cost parameters were held constant throughout the feasibility projections.

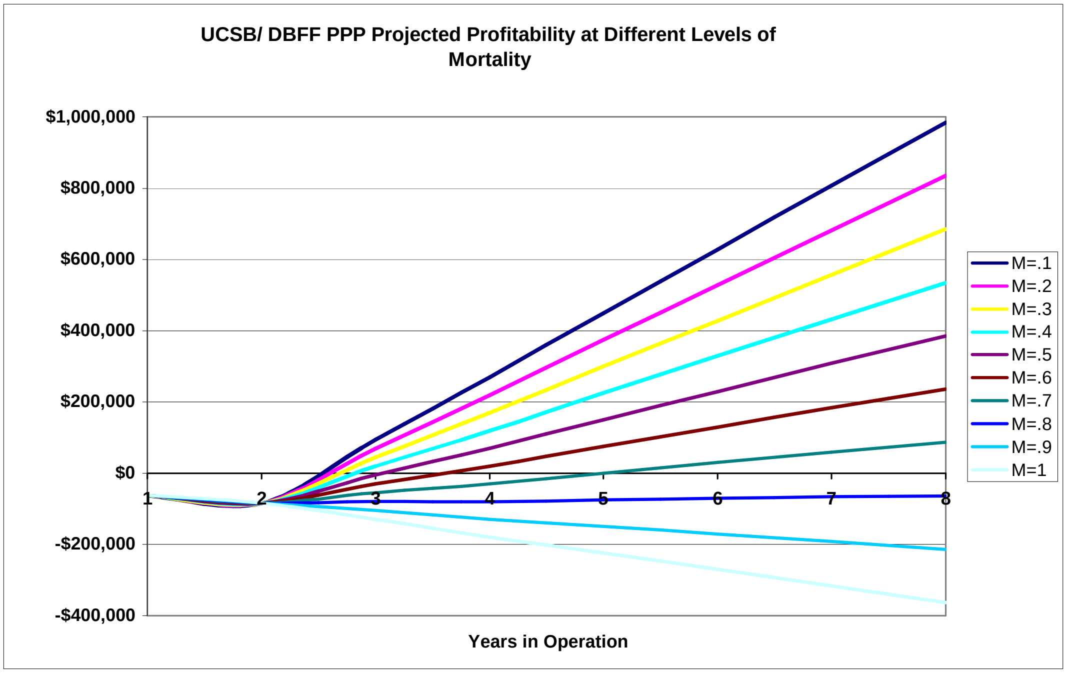



**Figure 29**. UCSB/ DBFF PPP cumulative profitability projections as a function of different mortality rates and a price of $0.90 per oyster.

**Table 19**. Projected cumulative profitability at different mortality rates

**Table 19**. Projected cumulative profitability of UCSB/ DBFF PPP with different levels of mortality and a price of $0.90 per oyster. Values in red are negative, signifying that the operation is in debt. Black values represent cumulative profits.

| Feasibility model results at different rates of mortality and price= $0.90 per oyster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Years in Operation | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Mortality Rate (%) | 10 | -$63,613 | -$85,389 | $93,698 | $268,493 | $448,769 | $628,048 | $806,940 | $984,753 |
| | 20 | -$63,508 | -$85,178 | $68,907 | $218,700 | $373,974 | $528,251 | $682,141 | $834,952 |
| | 30 | -$63,402 | -$84,967 | $44,116 | $168,907 | $299,179 | $428,454 | $557,342 | $685,151 |
| | 40 | -$63,297 | -$84,756 | $19,325 | $119,114 | $224,384 | $328,658 | $432,543 | $535,350 |
| | 50 | -$63,191 | -$84,545 | -$5,466 | $69,321 | $149,589 | $228,861 | $307,744 | $385,549 |
| | 60 | -$63,086 | -$84,334 | -$30,257 | $19,528 | $74,794 | $129,064 | $182,946 | $235,748 |
| | 70 | -$62,980 | -$84,123 | -$55,048 | -$30,265 | -$1 | $29,267 | $58,147 | $85,947 |
| | 80 | -$62,875 | -$83,912 | -$79,839 | -$80,058 | -$74,796 | -$70,530 | -$66,652 | -$63,854 |
| | 90 | -$62,769 | -$83,701 | -$104,629 | -$129,851 | -$149,591 | -$170,327 | -$191,451 | -$213,655 |
| | 100 | -$62,664 | -$83,490 | -$129,420 | -$179,644 | -$224,386 | -$270,124 | -$316,250 | -$363,456 |

**Table 20**. Projected cumulative profitability at different oyster prices (price per oyster)

**Table 20**. Projected cumulative profitability of UCSB/ DBFF PPP with different prices (price per oyster) and an annual mortality of 50%. Values in red are negative, signifying that the operation is in debt. Black values represent cumulative profits.

| Feasibility model results at various prices (price per oyster) and a mortality rate= 50% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Years in Operation | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Price per oyster ($) | 0.3 | -$62,839 | -$83,842 | -$88,142 | -$96,735 | -$99,847 | -$103,956 | -$108,452 | -$114,028 |
| | 0.4 | -$62,898 | -$83,959 | -$74,363 | -$69,059 | -$58,275 | -$48,487 | -$39,086 | -$30,765 |
| | 0.5 | -$62,957 | -$84,076 | -$60,583 | -$41,383 | -$16,702 | $6,983 | $30,280 | $52,498 |
| | 0.6 | -$63,015 | -$84,193 | -$46,804 | -$13,707 | $24,871 | $62,452 | $99,646 | $135,761 |
| | 0.7 | -$63,074 | -$84,311 | -$33,024 | $13,969 | $66,444 | $117,922 | $169,012 | $219,023 |
| | 0.8 | -$63,132 | -$84,428 | -$19,245 | $41,645 | $108,016 | $173,391 | $238,378 | $302,286 |
| | 0.9 | -$63,191 | -$84,545 | -$5,466 | $69,321 | $149,589 | $228,861 | $307,744 | $385,549 |
| | 1 | -$63,250 | -$84,662 | $8,314 | $96,997 | $191,162 | $284,330 | $377,111 | $468,812 |
| | 1.1 | -$63,308 | -$84,779 | $22,093 | $124,673 | $232,735 | $339,799 | $446,477 | $552,074 |
| | 1.2 | -$63,367 | -$84,897 | $35,873 | $152,349 | $274,307 | $395,269 | $515,843 | $635,337 |

Next, we tested the variation in cumulative profitability due to changes in the price per oyster and held oyster mortality constant at 50%. Changing the price per oyster also impacted the cumulative profitability, but to a lesser degree than the mortality rate.

Table 20 displays the projected cumulative profitability at different wholesale prices (price per oyster). The maximum projected variability due to price was approximately $750,000, considerably less than the maximum variability due to changes in the mortality rate. In relative terms, a 10% increase in mortality is equivalent to a 33% decrease in price. Therefore, the significance of the mortality parameter must be emphasized.

The extreme variability in cumulative profitability due to changes in mortality signifies that mortality is the most important parameter in the feasibility model. As such, mortality represents one of the most critical elements for a successful Olympia oyster aquaculture business. These results indicate that enhancing the survivorship of the oysters from the hatchery through their growout period will significantly influence the profitability of the business venture. Other parameters, such as price (per oyster) and taxes, also impact profitability, but the profitability model illustrates that the mortality rate is the most important component for success.

*Shucked Product Potential Revenue*

The addition of potential sales from shucked Olympia oysters increases the profitability (and feasibility) of the UCSB/ DBFF PPP. The hatchery and growout system designed in the conceptual business model generates approximately 46,000 Olympia oysters per year that are set on cultch[29]. The feasibility model assumes that 50% of the cultched oysters will be used in growout technique experiments to improve post-recruit survivorship. Of the remaining cultched oyster, 49% are assumed to be available for sale as shucked Olympia oysters. The remaining 1% is assumed to be available for half-shell sales. The 1% assumption derives from discussions with aquaculture operators who harvest the best quality cultched products and grow them out for the half-shell market[30] (Lunny 2007).

Our market survey did not quantify the target market, consumer preferences, appropriate price, or marketability of the shucked Olympia oyster product. Therefore, we do not presume a strong demand for shucked Olympia oysters. However, anecdotal evidence suggests that there is a niche market for shucked Olympia oysters (Lunny 2007). Since Drakes Bay Family Farms has an on-site shucking plant[31], we quantified the potential

[29] Olympia oysters that are set on cultch can suffer high mortality rates (Trimble et al. 2007). To be conservative, we assumed a mortality rate of 75% for the 184,000 oysters set on cultch, resulting in a harvest of 46,000 oysters for the shucked market.

[30] In Pacific oyster cultivation, selected oysters are broken off of the clutched oyster conglomerate and are grown out for the remaining growout period using the half-shell growout technique (Lunny 2007). Thus, a small percent of the shucked product can be sold as half-shell oysters. Since this technique has not been proven for Olympia oysters, the feasibility model assumes that only 1% of the shucked product will contribute to half-shell revenues, a conservative estimate.

[31] Drakes Bay Family Farms has the only licensed shucking plant in California.

revenue[32] from shucked the Olympia oyster product. The addition of the shucked product could contribute approximately $20,000 of additional revenue each year and improve the total profitability of the business (Figure 30). Over the eight-year time horizon, the addition of shucked product revenue could enhance the total profitability of the operation by more than $100,000. However, these projections assume the existence of a niche market for the shucked product, that the consumers would pay the estimated price and that the market demand would purchase all of the available shucked products.

[32] Revenue for shucked Olympia oysters was calculated as: Revenue= [# of oysters available for shucked product] * [(CPI-adjusted price)/ gallon]. The number of oysters available for the shucked product represents the 49% of surviving cultched oysters divided by 500 because there are approximately 500 "cocktail-size" oysters in one gallon (Nosho, T. Y., S. Washington Sea Grant Marine Advisory and P. Washington Sea Grant (1989). Small-scale Oyster Farming for Pleasure and Profit, Washington Sea Grant, Marine Advisory Services.). Next, the 1988 price of Olympia oysters was scaled up to present value with the consumer price index calculator. The product of these two values equals the projected revenue from shucked oysters. Finally, additional production costs were calculated to account for capital, supplies and labor required to process the Olympia oysters at the shucking plant. See Appendix J for a complete breakdown of the shucking plant's costs and revenues.

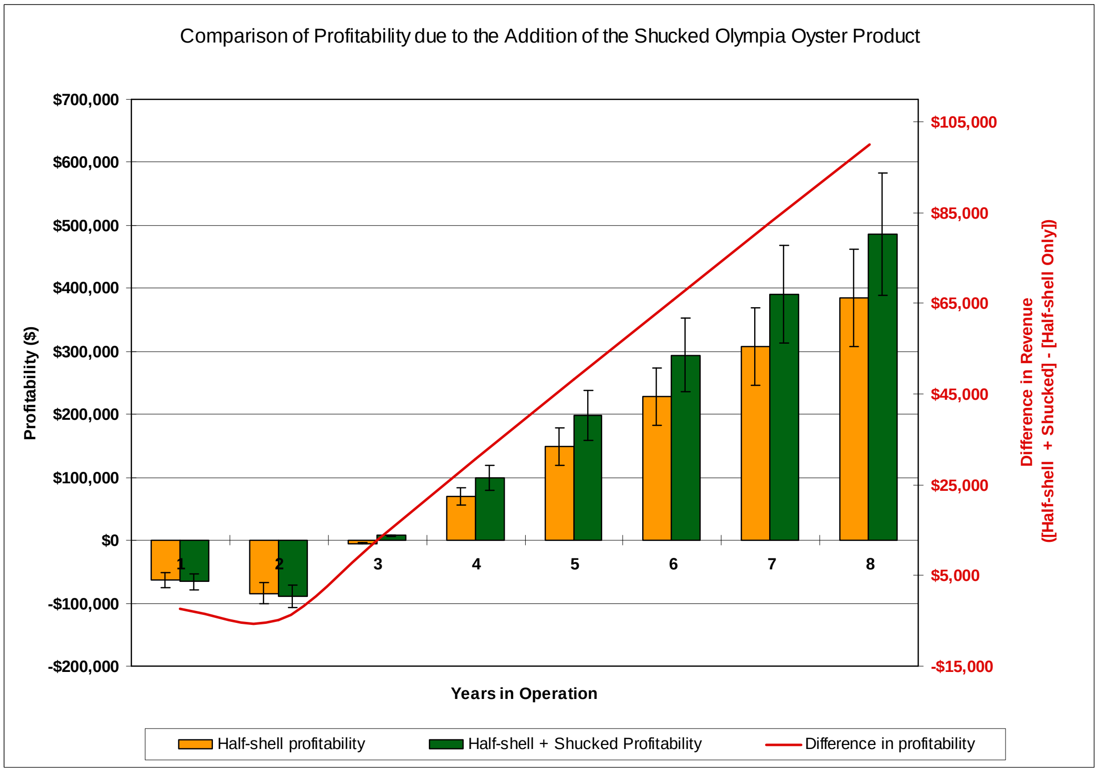
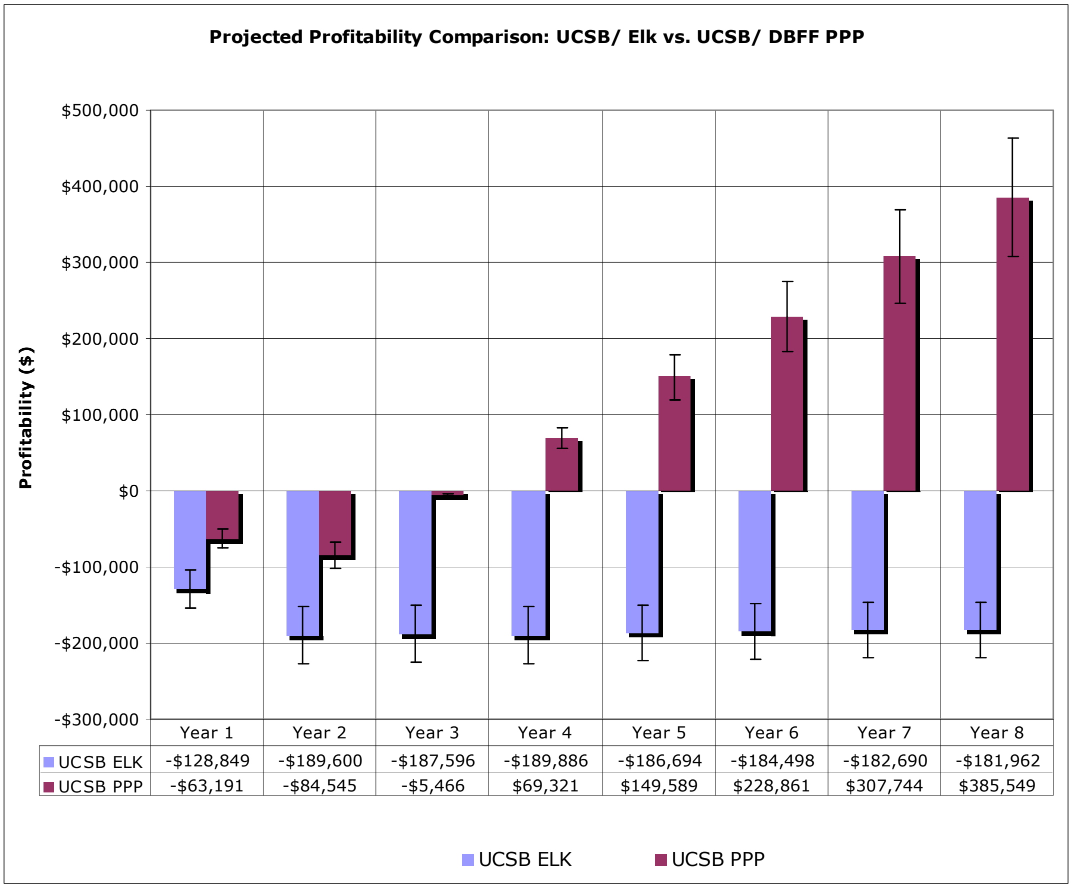



**Figure 30**. Comparison of UCSB/ DBFF PPP projected profitability under different production scenarios. Orange bars represent the expected profitability of the operation while selling only half-shell oysters to the target market (mortality= 50%, price per oyster= $0.90). Green bars represent the potential profitability of the operation while selling half-shell and shucked Olympia oysters under the same mortality and price assumptions. The red line represents the difference in profitability (the profitability of the [half-shell plus shucked production] minus [half-shell production only], and is referenced on the right y-axis in dollars.

*Comparative Profitability: UCSB/Elk vs. UCSB/DBFF PPP*

The UCSB/DBFF PPP has many comparative advantages over the UCSB Elk operation, which results in a significant disparity in the cost-effectiveness of the operations. We examined the profitability of the UCSB/Elk aquaculture operation using the same methods and assumptions as the UCSB/DBFF PPP. Figure 31 illustrates the significant difference in profitability between the two operations. The additional production costs and distribution costs add up to a significant increase in the total cost of the UCSB/Elk aquaculture operation over the eight-year time horizon. Under the expected conditions (mortality rate equals 50% and the price per oyster is $0.90), negative profitability projections suggest that the UCSB/ Elk operation is not feasible.




| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 |
|---|---|---|---|---|---|---|---|---|
| UCSB ELK | -$128,849 | -$189,600 | -$187,596 | -$189,886 | -$186,694 | -$184,498 | -$182,690 | -$181,962 |
| UCSB PPP | -$63,191 | -$84,545 | -$5,466 | $69,321 | $149,589 | $228,861 | $307,744 | $385,549 |

**Figure 31**. Profitability comparison between two Olympia oyster aquaculture operations. Blue bars represent the projected profitability of the UCSB/Elk operation. Red bars represent the profitability of the UCSB/DBFF PPP. The table shows the cumulative profits at each year during the eight-year time horizon. Error bars represent a 20% uncertainty factor applied to all projections.

Although this evidence suggests that an Olympia oyster aquaculture start-up business (similar to the UCSB/Elk scenario) is not feasible, it does not preclude the possibility of other successful public-private partnerships. The UCSB/DBFF PPP's positive profitability projections suggest that our conceptual business model is feasible. Further, these results indicate the great potential of a public-private partnership to enhance Olympia oyster restoration efforts. The UCSB/DBFF PPP represents a potential prototype for other Olympia oyster aquaculture public-private partnerships. Aquaculture operators throughout California (Carlsbad Aquafarms and Hog Island Oyster Company, to name two) have the critical capital infrastructure, technical expertise and distribution networks to build similar Olympia oyster aquaculture public-private partnerships. However, it is unlikely this network of Olympia oyster public-private partnerships will transpire without documented, reliable Olympia oyster growout techniques and a proven business model. Securing funding to start the UCSB/DBFF PPP would be the first step to turn the conceptual business model into an actual business.

## Appendix M: Public-Private Partnerships

This appendix provides background information on public-private partnerships.

**Public-Private Partnerships**

Olympia oyster aquaculture in Southern California has the potential to enhance local restoration projects through a public-private partnership. Restoration projects provide an opportunity to combine public improvement projects with local business ventures. Partnerships can be structured in a variety of ways to achieve specific goals and objectives. Different public-private partnership structures, components for success, and case examples are discussed below. There may be opportunities in Southern California to partner a private Olympia aquaculture business with nearby restoration efforts in such a way that both parties benefit from the enterprise.

*Definition*
A public-private partnership is defined as a contractual agreement between public and private sectors to achieve some public service or business venture. These partnerships can entail a transfer of funds from one partner to another or can share in the operation of a service. Public- private partnerships in public works projects have been particularly successful, resulting in the construction of roads, hospitals, and water treatment facilities (Seader 2002). The privatization of government services can lower the cost of the project, reduce the time to completion, and efficiently accomplish project goals (Oakley 1998).

Recently, community restoration projects incorporated public-private partnerships. Restoration projects are extremely costly, time consuming, labor intensive, and require continual fundraising. Partnering federal agencies with local communities or organizations can solve both of these problems. Federal organizations can supply funding and technical expertise to a project while local communities can supply manpower and volunteer time (Brumbaugh et al. 2006; NOAA 2006). Academic institutions also supply valuable technical assistance (Brumbaugh et al. 2006).

Public-private partnerships are flexible and can take many forms to accommodate a wide range of goals. For example, private entities may provide funding in exchange for an environmental or green image.

*Critical components for success*
While there are distinct advantages to using a public-private partnership to accomplish restoration goals, there are some difficulties as well. It can be challenging to develop a partnership that provides comparable benefits to both parties involved. Once an appropriate incentive for partnership is identified, the key to a successful project is the development of a clear contract and business plan (Surprenant 2006). Clear expectations, methods of communication, and conflict resolution are essential for public-private partnership success. The business plan should address each partner's responsibilities and

specific measures of progress along the way. Some partnerships may require active involvement of both parties, while others will entail one partner taking a more passive role in the project.

*Examples of successful public-private partnerships*

NOAA has developed their Community-based Restoration Program to create public-private partnerships in habitat restoration. NOAA provides a forum for partners to connect and funding for selected projects. The motivation for this program stems from the idea that involving the local community in restoration at the grassroots level leads to a higher success of projects. Since its induction in 1996, the program has funded 1,000 projects, involved 100,000 local volunteers, and restored over 24,000 habitat acres across the United States (NOAA 2006).

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