CONFLUENCE
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Pierce County Shoreline Master Program

SHELLFISH AQUACULTURE IN PIERCE COUNTY: TECHNICAL AND SCIENTIFIC INFORMATION

Prepared for:

Plauché & Carr

April 2016





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1.0 INTRODUCTION

This technical report provides information related to the updated Pierce County Shoreline Master Program (SMP) submitted to the Washington State Department of Ecology (Ecology) for review and approval. The updated SMP contains language and definitions that are not supported by the existing scientific literature or the Ecology (2016a) Handbook. The goal of this technical report is to provide scientific and technical information pertaining to shellfish aquaculture to facilitate revisions to the SMP by Ecology during its review process.

1.1 Existing Shellfish Aquaculture in Pierce County

Aquaculture, as defined in the Washington Administrative Code (WAC), is "the culture or farming of fish, shellfish, or other aquatic plants and animals. Aquaculture does not include the harvest of wild geoduck associated with the state managed wildstock geoduck fishery" [WAC 173-26-020(6)]. This document addresses aquaculture of shellfish (bivalves) only and does not include finfish (e.g., salmon), focusing on information specific to Pierce County where possible.

The species of bivalves currently cultured in Pierce County include Pacific oysters (*Crassostrea gigas*), Kumamoto oysters, (*Crassostrea sikamea*), Manila clams (*Venerupis philippinarum*), and geoducks (*Panopea generosa*). There are 25 existing farms within Pierce County (Figure 1), many of which have been operating for 50+ years. These historical farms pre-date the original SMP that was established in 1974 and designation of shorelines in 1975 (Pierce County 2013). These farms are still operating in a manner consistent with aquaculture policies and regulations (as discussed below). Existing shellfish aquaculture represents about 11.2 miles (4.9%) out of a total of 229.4 miles of the Pierce County shoreline.

All of the historical farms in Pierce County are also in areas that were identified in the Bush Act, 1895, as valuable for shellfish aquaculture (DNR 2016). This includes the historical farms of Rocky Bay, Minter Bay, Burley Lagoon, and Filucy Bay (Figure 1). Estuaries are desirable locations for shellfish aquaculture because of wide stretches of tideflats, protection from wave and wind fluctuations, relative ease of access, and availability of food and nutrients. Section 3.4 discusses the compatibility of shellfish aquaculture with sensitive species use of these areas.

1.2 Report Organization

This report directly addresses code changes to the Pierce County Code (PCC) identified within the updated SMP. Each PCC is called out in bold type (e.g., **PCC 18E.40.040(D)**) and followed by a discussion of relevant scientific information applicable to the updated SMP. The information provided in this technical report is divided into five main sections:

- Submerged Aquatic Vegetation (SAV) Buffers (Section 2.0)
- Prohibitions of Shellfish Aquaculture (Section 3.0)
- Forage Fish Spawning Areas (Section 4.0)
- Predator Protection Gear (Section 5.0)
- Additional Literature Provided to Pierce County (Section 6.0)

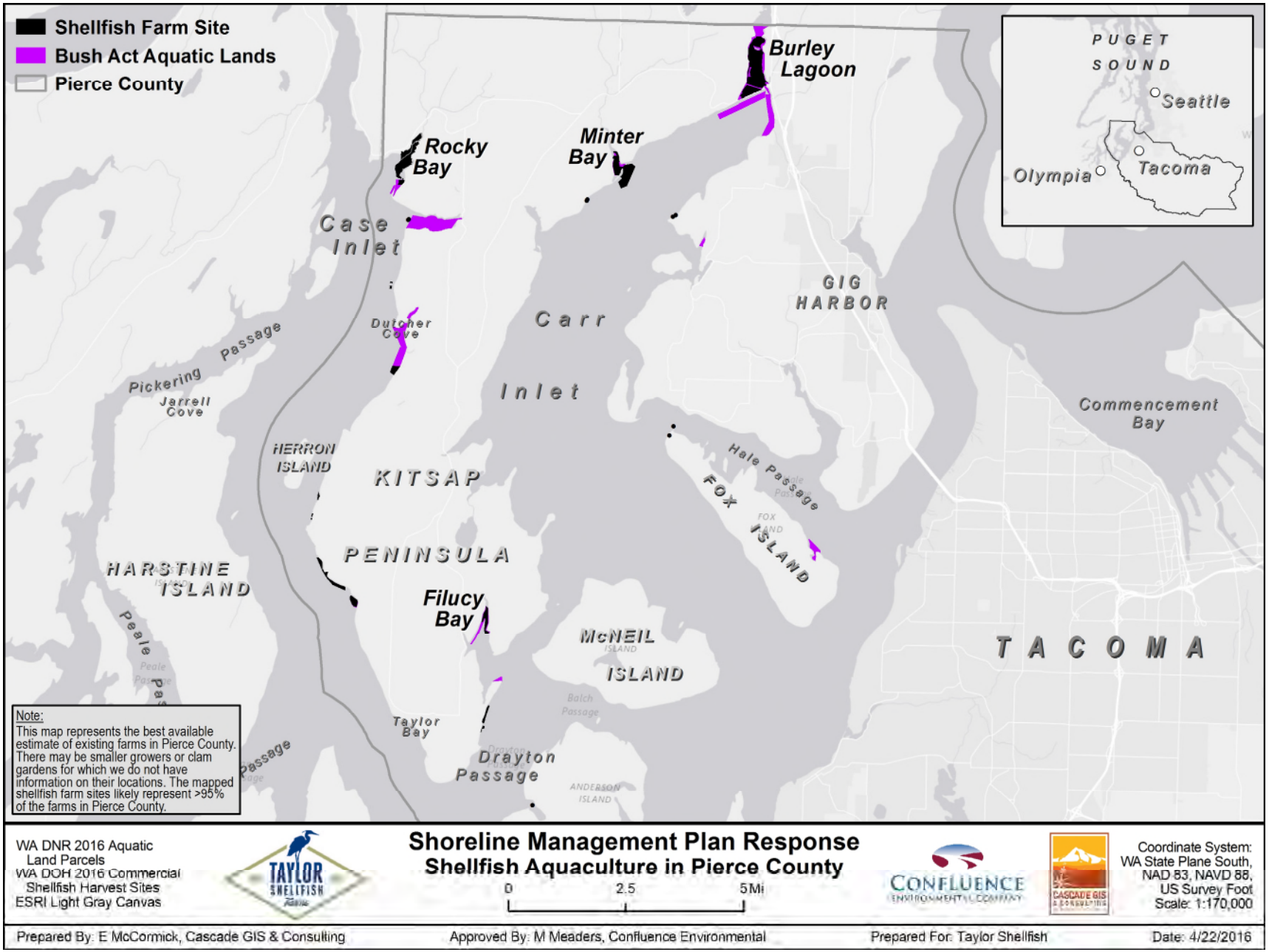


Figure 1 **Existing Shellfish Farms within Pierce County**

2.0 SUBMERGED AQUATIC VEGETATION (SAV) BUFFERS

This section is responding to **PCC 18E.40.040(D)**:

> Eelgrass, kelp, and intertidal vascular plants shall be protected by maintaining an undisturbed area between regulated activities described in Table 18E.40.040-1 [Table 1 below] and the boundary of the bed. Limited activity may occur within the undisturbed area (i.e., foot traffic and temporary storage of materials associated with permitted activities). Table 18E.40.040-1 indicates the baseline undisturbed area width for each type of regulated activity. These widths may be adjusted by the Department during the review process to reflect site specific conditions, current research, and advances in technology.

Table 1 Suggested Submerged Aquatic Vegetation Buffers (SAV) Associated with Regulated Activities, per PCC Table 18E.40.040-1.

Regulated Activity	Required Undisturbed Area Widths*
Shellfish Harvest	Intertidal Manual Harvest: 25 feet (ft) Intertidal Mechanical Harvest: 50 ft Subtidal: 180 ft
Mussel Rafts	50 ft within low-energy shoreline areas including, but not limited to, bays, coves, and estuaries.
Fish Pens	300 ft
Docks and Floats	4 ft vertical separation or 25 ft horizontal separation, whichever is greater.
Other	A minimum separation of 25 ft shall be required for all other activities.
*Required undisturbed area widths do not apply to eelgrass that establishes naturally following commencement of approved aquaculture activities.	

Additionally, this section is responding to the following sections:

- **PCC 18S.40.040(B)(5):** "Individual aquaculture uses and developments shall be separated by a sufficient distance to ensure that significant adverse cumulative effects do not occur."
- **PCC 18S.40.040(C)(4):** "Aquaculture activities shall be set back a minimum of 10 feet from adjacent parcels not associated with the aquaculture activity. The 10-foot setback requirement shall be increased when the shoreline contains multiple individual aquaculture activity areas and when it is demonstrated that a greater distance setback is needed between areas or adjacent parcels to ensure maintenance of other shoreline uses, such as recreation or public access, or to ensure protection of shoreline functions and processes. The expanded setback required shall be based upon water body and shoreline characteristics and an analysis of legally established shoreline development."

This section includes a discussion of buffer widths and the science that supports what buffer widths are appropriate to avoid or reduce impacts to SAV associated with specific types of aquaculture activities. In addition, this section provides an overview of the role of buffers in protecting saltwater habitats of special concern.

2.1 Buffer Rationale and Definition of an Eelgrass Bed

Eelgrass is the primary SAV identified in the literature related to potential interactions with shellfish aquaculture due to the potential spatial overlap in intertidal and shallow subtidal areas. Eelgrass is widely recognized as an important nearshore resource that provides direct and indirect food sources for marine ecosystems, and provides habitat structure for marine species (Phillips 1984). Kelps are also important components of nearshore aquatic communities; however, they require rocky habitat (or some kind of hard substrate) for attachment. Aquaculture does not occur in rocky habitat, but smaller hard substrate materials (e.g., cobbles, boulders, bivalve shells, etc.) may be present in aquaculture locations. It is also important to note that aquaculture gear and cultured bivalves provide hard substrate, which can serve as attachment points for kelps and typically enhance intertidal areas by increasing other macroalgae species (discussed in Section 3.2 below). Floating kelp (*Macrocystis integrifolia* and *Nereocystis leutkana*) represent 7% of aquatic vegetation within Pierce County compared to 26% for eelgrass and 44% for non-floating kelp (e.g., *Laminaria* spp., *Egregia menziesii*) (DNR n.d.).

Several researchers have evaluated the relationship between shellfish aquaculture, eelgrass, and macroalgae. However, we are not aware of studies documenting potential interactions between shellfish aquaculture and kelp. As stated above, kelps and macroalgae are generally more abundant in areas with aquaculture due to increased opportunities for attachment. Because kelps are found in similar environments as eelgrass (e.g., intertidal and shallow subtidal habitats with enough light to sustain growth), but are more restricted by sediment type, it is assumed that measures intended to protect eelgrass will be similarly protective of kelp and other SAV communities of interest.

Buffers between regulated activities and SAV are created primarily to avoid and minimize damage to documented SAV from activities associated with the regulated activity. Before understanding how these criteria relate to shellfish aquaculture, it is important to note that there are critical differences between the function of terrestrial and marine buffers. Terrestrial buffers often serve additional functions, such as providing wildlife habitat, detrital input (i.e., food resources), and/or additional habitat structure to the buffered habitat. Although regulation of marine habitats follows a similar approach to regulation of terrestrial habitats, the functions of marine buffers are different because of differences in how the marine environment is structured.

Unlike in the terrestrial setting, buffer habitat adjacent to SAV may not provide tangible benefits to the species present in SAV. For example, SAV provides refugia (i.e., places to hide from predators) as well as food resources for juvenile fish of many species. Adjacent buffer habitat does not provide such benefits. In the marine setting, the function of buffers is primarily to limit potential negative impacts to SAV from direct disturbance (trampling or boats), shading, or changes to sediment composition. Therefore, an important metric to consider when establishing buffer widths is the range of natural disturbance that SAV communities encounter and the resilience of the habitat to those disturbances. The question for buffers in the marine setting is whether the regulated activity generates disturbance beyond the natural disturbance

regime, and, if it does, at what distance the disturbance falls back to natural levels. This is explored more thoroughly below in the existing scientific literature (Section 2.2).

The Nationwide Permit 48 (NWP 48) provides authorization for commercial aquaculture activities, first for existing (regardless of eelgrass) and then for new or expanded, which includes eelgrass buffers. Therefore, many current aquaculture beds were established in areas occupied by SAV, which has provided a number of opportunities to study how shellfish aquaculture and SAV interact.

Furthermore, while shellfish aquaculture and other approved uses may be in place for an indefinite period, eelgrass beds are dynamic and may migrate up to 2 m to 5 m (6.6 ft to 16.4 ft) per year (DNR 2014). Note that eelgrass migration is typically in a lateral direction because beds are typically constrained landward due to desiccation and seaward due to light limitations (DNR 2014). Kelp beds may be even more dynamic, with annual populations expanding or contracting in response to environmental conditions.

2.2 Existing Scientific Literature

Dumbauld and McCoy (2015) suggested that shellfish aquaculture influences eelgrass, both positively and negatively, through the following mechanisms:

- Physical structure of shells/reefs;
- Nutrient additions to sediments and water column through feces or pseudofeces[1] (also known as biodeposits); and
- Increased water clarity through biological filtration.

In addition, the authors suggested that physical effects to, and competition with, SAV may include:

- Shading of the plants, which reduces light levels below what is required for eelgrass to survive or grow;
- Desiccation from hanging up on aquaculture gear;
- Changes to substrate to support the activity (e.g., introduction of shell hash);
- Changes to turbidity and/or sediment deposition.

These effects can be short-term and transitory (e.g., increased turbidity during harvest of geoduck clams) or semi-permanent (e.g., modifications to the substrate size and type). Logically, many of these effect mechanisms are limited to the culture plot, including: physical structure, shading, desiccation, and changes to substrate. Potential impacts of shellfish

1 Pseudofeces are biodeposits resulting from a specialized method of expelling materials by filter-feeding bivalves that enables them to excrete suspended particles that cannot be used as food (e.g., particles of silt). The rejected particles are wrapped in mucus and expelled without having passed through the digestive tract.

aquaculture to SAV are described below, broken down into the three main culture types, similar to those described in Table 1: (1) intertidal culture, (2) subtidal culture, and (3) floating culture.

Studies of interactions of shellfish aquaculture with SAV have tended to focus on effects within the footprint of the culture plot, often using areas immediately adjacent (e.g., within 1,000 ft) to the plot as control or reference sites for measuring impacts. The observations of studies considered below attempt to characterize either direct effects of shellfish aquaculture on SAV or identify effects outside of the culture plot footprint. From these studies, the level of scientific support for buffers between shellfish aquaculture and SAV is identified. The locations of various studies discussed below, in relation to Pierce County, is provided in Figure 2.

2.2.1 Intertidal Culture

The proposed 25-ft buffer for manual shellfish harvest and 50-ft buffer for mechanical harvest (Table 1) appear to be unrelated to field observations. Establishing a 50-ft buffer for mechanical harvest creates an implicit assumption that this activity is more intensive and disturbing beyond the culture plot than manual harvest, and that the effects will be transmitted twice as far. However, this assumption ignores the range of potential harvest methods and frequency of activity. Because the literature related to intertidal culture is extensive, the following discussion is broken down by two primary cultured species: Pacific oysters and geoduck clams.

Pacific Oysters

Tallis et al. (2009) evaluated the effects of oyster bottom culture (hand and drag dredge harvest) and cultch-on-longline culture in Willapa Bay, Washington, over a period of 3 years (2002 to 2004). The authors documented the complex relationship between oyster culture and eelgrass where oyster culture led to decreases in eelgrass density but also resulted in comparative increases in individual plant productivity through reductions in competition between plants (also discussed in Wisehart et al. 2007). In general, bottom culture, whether hand or dredge harvested, had greater effects on eelgrass than longline culture. The effects of oyster culture on eelgrass were attributed to three primary mechanisms: (1) harvesting techniques that damaged plants and rhizomes, (2) direct competition for space in bottom culture (plants can't grow through oysters), and (3) mechanical damage from the oysters on eelgrass, specifically desiccation leading to breakage and hence decreased plant viability leading to shoot death and lower density.

Direct effects to eelgrass described by Tallis et al. (2009) were somewhat offset by increases in plant productivity in eelgrass beds with lower density, likely related to decreased intraspecific competition and shading impacts. Lower density beds were thought to provide increased light levels, which led to higher relative growth rates in these areas in comparison to beds with greater density. This increase in productivity, however, did not necessarily offset decreased density from culture activities, especially in dredge harvested plots where their data indicate 70% fewer eelgrass plants within the culture plots in comparison to uncultivated plots.

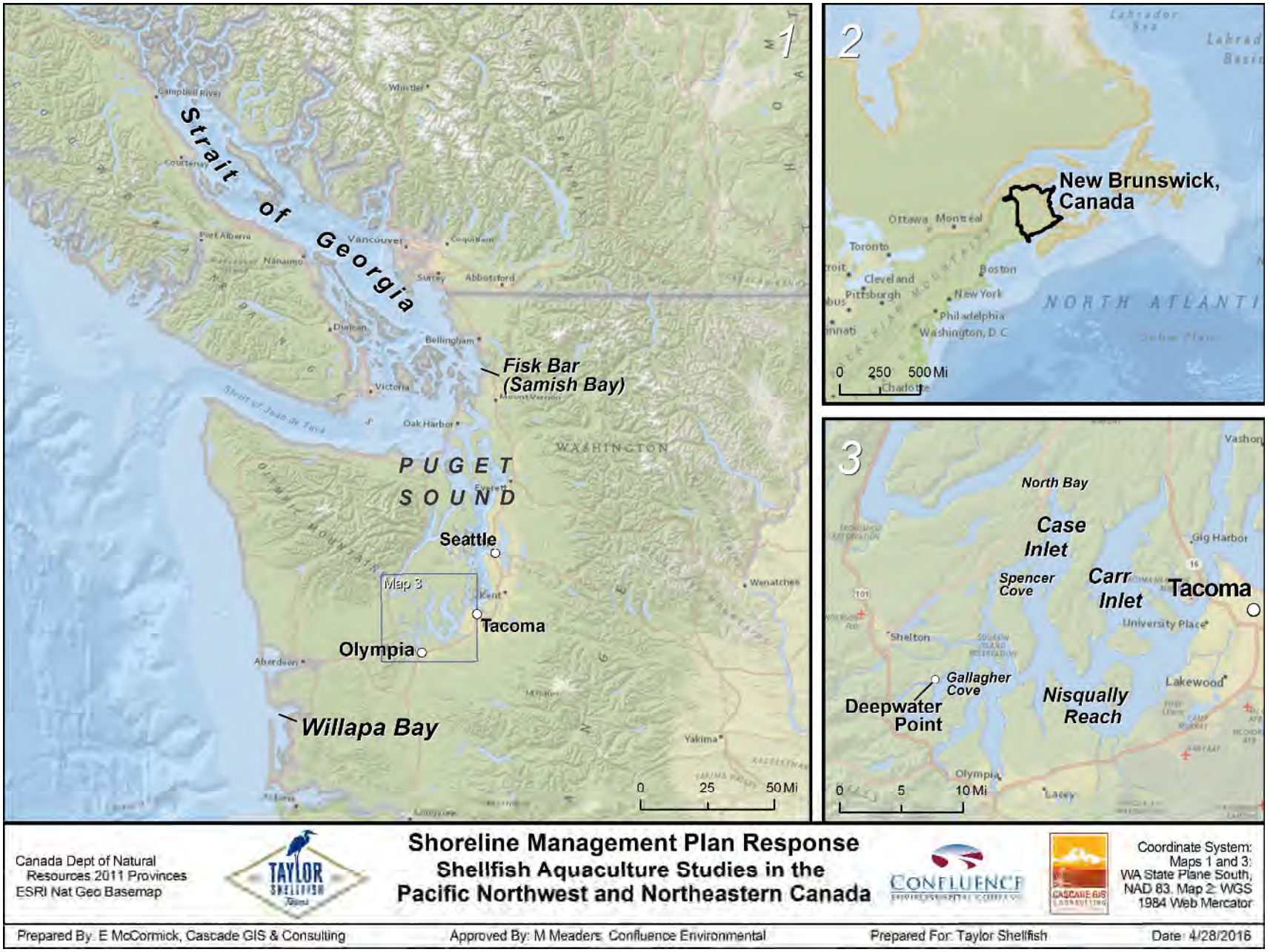


Figure 2 Location of Studies Related to Shellfish Aquaculture Effects

A study of suspended bag oyster aquaculture in shallow subtidal habitat (<5 m or 16.4 ft) of New Brunswick, Canada, Skinner et al (2013) "demonstrated that impacts were limited to the lease footprint by sampling eelgrass along a gradient at multiple leases." In addition, there was a lack of significant differences across a range of measures of eelgrass growth at all reference stations outside of the culture plot. Subsequent studies by Skinner et al (2014) supported the hypothesis that shading from suspended bag aquaculture stock and equipment is the main factor responsible for the reduction in eelgrass structure, morphometrics, and photosynthesis in commercial culture areas. Similarly, Forrest et al. (2009) reviewed the effects of off-bottom oyster and Manila clam culture in estuaries and found that direct benthic effects associated with cultivation were highly localized to farmed areas. Therefore, imposition of buffers beyond the areas where either shading or direct displacement due to aquaculture might occur do not appear to be supported by scientific studies or field observations.

Finally, Dumbauld and McCoy (2015) examined how eelgrass and oyster culture interact at a broad landscape scale in Willapa Bay. In addition, the authors provided a greater than 100-year perspective on the interaction of oysters and eelgrass in the bay. In general, oysters (historically native and now cultured) cover less of the bay now than in historic times (estimated 6,220 hectares [ha] in late 1800s compared to about 1,764 ha under cultivation today). Comparatively, eelgrass shows an opposite trend with dramatic increases over time (estimated 3,139 ha in the 1850s to 4,845 ha in the 1950s to about 6,951 ha today). Oyster culture in Willapa Bay occupies about 5,000 ha (22%) of the total intertidal zone in the bay.

Dumbauld and McCoy (2015) used a logistical model to evaluate the effects of oyster culture on eelgrass at the landscape scale in Willapa Bay. The model used aerial imagery over a period of 3 years (2005, 2006, and 2009), where a pixel size represented a 5-m (16.4-ft) radius on the ground. Total cover was then ground-truthed into general bins of 25%, 50%, 75%, and 100% eelgrass cover. Through this model, the authors were able to attribute from a minimum of 0.4 ha to a maximum of 83.5 ha of "missing" eelgrass in any given year, representing less than 1.5% of the total eelgrass in the bay. This minor effect of aquaculture at the landscape scale was also mirrored in other similar situations cited by the authors from off-bottom culture in Mexico, New Zealand, and France (Ward et al. 2003, Barille et al. 2010, Martin et al. 2010, Bulmer et al. 2012).

The other important conclusion of the Dumbauld and McCoy (2015) study relates to the resilience of eelgrass over a period of more than 100 years to not only coexist with ongoing aquaculture activities but to thrive and expand dramatically over time. The authors conclude that "current oyster aquaculture practices do not substantially reduce and may enhance the presence of *Z. marina* at the estuarine landscape scale." In other words, oyster culture in the bay has not changed materially over a period of decades, yet eelgrass has expanded greatly over the same time period (see values presented above). There are certainly factors that lead to annual variability in eelgrass density and biomass (Thom et al. 2003), but the evidence presented in Dumbauld and McCoy (2015) demonstrates an expanding distribution in the bay. Thus, eelgrass habitat was seen as resilient over both short and long timeframes at the landscape scale and resilient to potential disturbance from oyster aquaculture in Willapa Bay. The authors

concluded that their research in Willapa Bay "suggests that oyster aquaculture as disturbance is generally within the scope of existing 'natural' disturbances to the system (e.g., winter storms) and eelgrass is inherently adapted to this scale of disturbance." This information suggests that a buffer beyond the footprint of the shellfish farm is not necessary to protect eelgrass.

Geoduck Clams

Ruesink and Rowell (2012) studied effects from geoduck aquaculture to eelgrass habitat in North Bay, at the north end of Case Inlet. The study included 36 1-m^2 plots with 2-m (6.6-ft) spacing established on June 30, 2004, at -1.9 ft mean lower low water (MLLW). Geoducks were transplanted into study plots at typical culture densities (12.4-year-old geoducks per m^2). Geoduck-addition plots were indistinguishable from control plots by November 2004. Ruesink and Rowell (2012) reported eelgrass growth and recovery in geoduck-addition plots and control plots over a 2-year period. The study planted directly in eelgrass, and did not explore the concept of a buffer between eelgrass and geoduck aquaculture.

Ruesink and Rowell (2012) reported seasonal changes in eelgrass within the culture plots. During summer, eelgrass density was reduced in the cultured area by 30%, although this result had marginal statistical significance based on an analysis of variance of eelgrass density. The geoduck-addition plots also resulted in increased shoot length by 13% ($F_{1,18} = 4.36$, $P = 0.05$) and clonal branching by 9% ($F_{1,18} = 14.9$, $P = 0.001$), which was statistically significant. The authors indicated that the increased shoot length and clonal branching were likely related to reduced interspecific competition between eelgrass shoots at the lower density. During winter, geoducks did not reduce the density of eelgrass, and appeared to stabilize eelgrass density compared to control plots.

The main conclusion of the Ruesink and Rowell (2012) study for planting effects was that, "eelgrass of the small morphotype found in south Puget Sound coexists with geoduck clams, given reduced summer density but enhanced size and branching." Comparatively, a geoduck harvest resulted in a 70% reduction of eelgrass, but was similar to unharvested plots within 15 months post-harvest. However, a winter storm came through after the harvest event and reduced both the treatment and control plot, making recovery calculations inadequate. Based on the Ruesink and Rowell (2012) data, it appears that geoduck planting operations do not cause a significant change in eelgrass metrics, and can even coexist with eelgrass habitat. In terms of the effects from a harvest event, in which recovery was shown to occur well within the 5- to 7-year harvest cycle, the authors concluded that, "Harvest practices that generate small gaps or leave higher densities of remnant shoots should improve resilience in exclusively clonal populations," such as those in south Puget Sound.

Horwith (2013) did study "spillover effects" from geoduck harvest related to an adjacent eelgrass bed. This study was based on a 5,000-m^2 (1.2-acre) geoduck farm in Fisk Bar, Samish Bay, Washington. Prior to harvest, eelgrass density did not vary as a function of distance to the farm, but eelgrass near the farm (up to a distance of 9 m or 29.5 ft) had lower above-ground biomass. During the summer following a harvest event, eelgrass showed higher shoot densities

closer to the farm. Eelgrass bordering the farm again had lower above-ground biomass in the summer, although the trend was not consistently significant. Differences in these parameters were not evident in the spring or fall, only during the peak portion of the eelgrass growing season. In a conversation with Dr. Ruesink (pers. comm. 2015) related to the need to buffer from geoduck aquaculture activities, and associated with the results from Horwith (2013), she indicated that, "the effects of geoduck farming are likely restricted to the farm footprint, and buffers would be important to consider primarily [for] access issues" and indicated that a 10-ft buffer would likely account for access issues.

2.2.2 Subtidal Culture

The proposed 180-ft buffer for subtidal harvest (Table 1) appears to be derived from a buffer distance that was used for wild-stock geoduck harvests co-managed by Washington State Department of Natural Resources (DNR) and Washington Department of Fish and Wildlife (WDFW). These harvests used a "2-foot vertical or 180-foot horizontal (on very gradual slopes) buffer between geoduck tracts and the deepest occurrence of eelgrass" (DNR 2008). This buffer was implemented through State–Tribal management agreements and harvest plans. It is important to note that the 2-ft vertical or 180-ft horizontal buffer was not determined to be necessary to protect eelgrass and was not incorporated as a conservation measure as part of the Supplemental Environmental Impact Statement that addressed wild stock geoduck harvest in Puget Sound (DNR 2001). DNR does not support this buffer distance for shellfish aquaculture operations, and believes that a 25-ft buffer or 10-ft buffer with monitoring is more appropriate (Palazzi, pers. comm., 2013, ENVIRON 2013). While DNR does not lease subtidal land for geoduck aquaculture, there is an attempt to distinguish between wild-stock geoduck harvest and shellfish aquaculture operations.

The Short and Walton (1992) study of commercial geoduck wild-stock harvest conducted in the Nisqually Reach tract is often cited as a rationale for a 180-ft buffer for subtidal harvest. However, according to Bob Sizemore, the WDFW wild-stock geoduck lead (pers. comm., 2013), the 180-ft distance was the extent to which a minimal amount of sediment deposition occurred from a harvest event. The turbidity plume was shown to drop back to background conditions within 20 m (65.6 ft) down-current from the harvest site. Even under cumulative conditions, the amount of sediment that was deposited at 180 ft was calculated as having an average thickness of about 0.4 cm (0.2 inches); a deposition that was considered "inconsequentially small."

Short and Walton (1992) estimated that if all sediment put in suspension by a commercial geoduck harvest were to settle on the harvested tract, then the deposition would range from 7.9 to 8.83 kg/m^2/year. This is within the natural background range of 2.6 to 12.0 kg/m^2/year for Puget Sound as a whole (Lavelle et al. 1986). This suggests that subtidal geoduck harvest may not increase sediment deposition above the natural range and, therefore, effects to eelgrass are expected to be minimal from this mechanism.

A more recent study published by Liu et al. (2015) on the direct effects of geoduck harvest on adjacent eelgrass beds is the most applicable and significant study to date, and it is specifically

related to shellfish aquaculture effects in the Strait of Georgia, B.C. Liu et al. (2015) studied the sedimentation effects of commercial subtidal geoduck harvest and simulated the effects (by digging harvest holes) of commercial intertidal geoduck harvest on adjacent areas, including eelgrass beds. Sediment traps were put in place to monitor sedimentation during the harvest events and up to 1 year before and after. Sedimentation during the harvest day were lower than the average daily sedimentation leading up to the harvest event for all sampling locations outside of the subtidal harvest bed. Effects of sedimentation for the intertidal harvest simulation were noted up to 5 m (16.4 ft) for the intertidal bed, though this increase was not significant compared to the daily range of background sedimentation. Suspended sediments collected during harvesting were similar to those during a calm sea, but much lower than those during a rough sea just before harvest. All other parameters (e.g., sediment grain size, infaunal community, and various metrics for the eelgrass beds) resulted in no significant changes detected at either study site in response to harvesting. The study concluded that the low levels of sediments caused by harvesting near the eelgrass beds would be inconsequential at both the intertidal and subtidal study sites when compared with natural variation. This information suggests that, similar to intertidal shellfish aquaculture, a buffer beyond the footprint of the shellfish farm is not necessary to protect eelgrass in subtidal areas.

2.2.3 Floating Culture

The proposed 50-ft buffer for floating culture, which is larger than the 25-ft buffer for docks and floats (Table 1), does not appear to be supported by the existing literature. Chapter 12 of Ecology's SMP Handbook provides guidelines for recreational and commercial piers, docks, and overwater structures (Ecology 2011b). The Ecology SMP Handbook, as well as other studies of the effects of floating structures on eelgrass (e.g., Burdick and Short 1999, Nightingale and Simenstad 2001, Shafer 2002), list light as the primary factor affecting eelgrass growth and survival. Shading from overwater structures should, therefore, be the principal consideration when attempting to quantify buffers for SAV in relation to floating culture. The guidelines suggest that surfaces of floating structures be designed to allow maximum light penetration. Unlike many floating docks used for recreational or commercial purposes, shellfish culture rafts are typically designed with open decking, allowing light penetration to the water column and sea floor. Floating raft and longline clusters are typically oriented in the direction of longshore transport, which tends to be predominantly north to south in Puget Sound. In general, researchers have pointed towards the north to south orientation as preferential because the shaded area moves, which results in large areas shaded but no single area being shaded for a significant portion of the day (Burdick and Short 1999). Additionally, floating culture is built with large spaces between the culture structures. Both of these mitigation measures ensure minimization of the effects of shading on SAV.

The unique aspect of floating culture (compared to piers, docks, and floats) is that shellfish filter feeding creates biodeposits that contribute to biogenic sources of sediment (Peterson and Heck 2001, Dumbauld et al. 2009). Suspended culture results in only the transfer of organic matter to sediment, which can reduce oxygen in areas with low flushing rates, although this has been primarily observed for culture methods that are much closer to the sediment surface such as

rack-and-bag culture (Nizzoli et al. 2005). Kaspar et al. (1985) found that sediments under suspended mussel cultures in New Zealand contained 8.0 to 8.7% total volatile solids (TVS) in comparison with 7.0 to 7.1% TVS found at reference sites. The authors concluded that the differences in sediment nitrate and nitrite were not significantly different. Similar results were reported for sampling under the floating mussel farm at Deepwater Point and Gallagher Cove (Totten Inlet), where the signal associated with the mussel rafts was considered minor and disappeared within 20 inches of the sediment surface (Brooks 2005). Since 2013, quarterly monitoring of a floating geoduck nursery in Spencer Cove (Mason County) has identified no changes to sediment quality due to the installation and operation of that similar facility (Selleck and Barrett 2013, 2014; Stutes and Barrett 2015).

The National Marine Fisheries Service (NMFS 2009) evaluated the production of biodeposits by shellfish in rafts and the accumulation of this material under the rafts in its Biological Opinion on NWP 48 for existing aquaculture activities in Washington State. The Biological Opinion reviewed several studies that evaluated the potential effects on sediment from aquaculture when examining dense three-dimensional suspended raft systems of scallops and kelp (Grant and Bacher 2001) and mussels (Saxby 2002). The studies suggested that sediment effects depend on the density of the culture system, ambient currents, tidal flows, wave energy, bottom topography and elevations, and sediment type and deposition characteristics. In West Coast estuaries, some limited sediment accumulation has been observed, but no adverse effects have been documented. Mallet et al. (2006) determined sedimentation rates of off-bottom oyster culture in New Brunswick, Canada, to be approximately 50 g/m^2/day. Using an estimated sediment density of 1.84 g/m^2 (Short and Walton 1992), the accumulation of suspended sediments would be approximately 0.004 cm/day. Relating these sedimentation levels to background sedimentation rates studied in Liu et al. (2015), sedimentation from floating culture would fall on the low end of the natural sedimentation spectrum (0.002 cm - 0.2 cm/day). Mallet et al. (2006) also noted that the organic content of sediment collected in traps beneath off-bottom oyster culture was not significantly higher than at reference sites.

Given that typical floating shellfish structures are designed with open decking that allows for light penetration, and that sedimentation and nutrient accumulation is likely to be minimal and confined to areas directly beneath the floating culture, floating aquaculture would likely have a smaller area of effect on SAV compared to traditional recreational and commercial overwater structures. Therefore, buffers between SAV and floating shellfish culture should be at least the same as those around other overwater structures and not larger.

2.3 Information to Consider Associated with Shellfish Aquaculture

The effects of intertidal shellfish culture are short-term and primarily confined to the culture plot; the highest level of potential effect occurs during harvest. Manila clams and oysters are typically grown on 6-month to 3-year cycles, which would limit localized effects to a maximum of two events per year. Geoduck harvest events are even more infrequent, and occur on a 5- to 7-year cycle. Harvest activities have not been shown to have a significant effect on SAV outside

of the footprint of the area being cultured. The frequency of activity would further limit the opportunities for intertidal culture to affect adjacent eelgrass beds.

Geoduck is currently the only commercially cultured shellfish species that is grown in subtidal habitat (aside from floating aquaculture). As noted above, geoducks are typically harvested in 5- to 7-year cycles. Sedimentation during harvest is the most likely mechanism for effect to adjacent SAV, and these harvests have not been shown to have a significant effect outside of the culture plot. Given that geoduck harvest sedimentation studies show highly localized effects, which are themselves insignificant compared to natural background (control) processes, and that geoduck harvest is a twice-per-decade (maximum) event, it is highly unlikely that geoduck culture would have a significant effect on SAV.

2.4 Summary

The proposed 25-ft buffer for manual shellfish harvest and 50-ft buffer for mechanical harvest appear to be unsupported by scientific literature and unnecessary to achieve no-net-loss of ecological functions. Observations that have been made comparing hand cultivation to other cultivation methods characterized the relative impacts within beds, and observed that impacts between culture methods were similar on eelgrass plant size and production. Therefore, there does not appear to be a basis for requiring larger buffers for mechanically harvested beds. Current scientific and technical information suggest no buffer is needed outside of the farm footprint to protect SAV, with the possible exception of access.

Where aquaculture and SAV co-occur, the relationship between culture and vegetation appears to be primarily a competition for space and relative growth rate, but plant size and production are unaffected by oyster density. In scientific literature, authors have consistently commented that observed oyster and geoduck clam aquaculture impacts were limited to the culture plot. The existing literature indicates a lack of significant differences across a range of metrics of eelgrass growth outside of the culture plot. Therefore, imposition of buffers beyond the areas where either shading or direct displacement due to aquaculture might occur does not appear to be supported by scientific studies or field observations.

The 180-ft buffer for subtidal aquaculture appears to be derived from historical DNR, WDFW, and Tribal protocols for wild-stock harvest, and as such, are inappropriate to apply to commercial subtidal shellfish aquaculture. The scientific literature indicates that most effects would be confined to the culture plot. Increased sedimentation during geoduck harvest would likely have the largest area of adverse effect. However, the magnitude of effect has been shown to be insignificant outside of culture plots compared to natural coastal processes. Increases in sedimentation are also limited to harvests that occur on a 5- to 7-year cycle, and are within the range of natural events that increase sediment on a short-term basis.

No effects of floating culture to SAV have been measured outside of the farm footprint in Puget Sound, which is primarily due to the location of these structures in the shallow and deep subtidal habitat. Additionally, structures associated with floating culture are designed with

open decks to maximize light penetration, and are therefore less likely to cause adverse effects to SAV compared to more traditional recreational and commercial structures. Other effects of floating culture (e.g., sedimentation and nutrient loading) have been shown to be minimal and confined to directly underneath the culture structures.

Suggested buffers should be founded on current scientific literature, as outlined above, and should reflect the negligible effects of shellfish farm operations outside of the culture plots. No buffers appear necessary to protect SAV based on current scientific and technical information, and a buffer of 5 m (16.4 ft) between shellfish farms and SAV would be very conservative for all types of culture methods and habitats. This buffer could be used as a precautionary measure to minimize effects of shellfish farms on SAV (e.g., shading, desiccation, displacement, and sedimentation), and to facilitate site access.

For many of these same reasons, sections PCC 18S.40.040(B)(5) and 18S.40.040(C)(4), which would respectively call for buffers between individual aquaculture activities and between aquaculture activities and adjacent parcels even when there is no SAV present, are unsupported by current scientific and technical information, unnecessary to achieve no net loss of ecological functions, and unwarranted.

3.0 PROHIBITIONS OF SHELLFISH AQUACULTURE

A number of prohibitions on shellfish aquaculture are proposed in the updated Pierce County SMP. Some are associated with upland designations of the shoreline (e.g., aquatic areas abutting Natural Shoreline Environmental Designation [SED]). In general, shellfish aquaculture does not affect upland designations, but rather upland designations can significantly impact the sustainability of shellfish aquaculture. Therefore, there appears to be no basis for prohibiting aquaculture in aquatic areas due to potential concern to the upland environment. The effects associated with shellfish aquaculture, when conducted appropriately, are sustainable within the environments identified for prohibition. Therefore, the prohibitions are unwarranted and inappropriate. The specific chapters of the SMP that will be addressed are identified within each individual sub-section below.

3.1 Avoidance, Conservation, and Minimization Measures

Shellfish aquaculture is regulated by numerous agencies, and through these regulatory processes, numerous avoidance, conservation, and minimization measures have been identified. Considering the impacts associated with shellfish aquaculture in light of these measures is necessary in order to understand the actual or likely impacts associated with shellfish farming, rather than hypothetical impacts that would not, in practice, be realized. The following avoidance, conservation, and minimization measures are from the typical permitting process with federal, state, and local jurisdictions.

3.1.1 Federal Permitting Process

Most shellfish aquaculture in Washington State falls under the NWP 48, which is a federal program administered by the U.S. Army Corps of Engineers (Corps). Activities authorized by a Nationwide permit must be similar in nature, and cause only minimal adverse environmental effects on the aquatic environment when performed separately or cumulatively (33 CFR § 322.2[f]). The Corps, from its consultation with the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) – also known collectively as the "Services" – on NWP 48 for the State of Washington, created 16 terms and conditions for projects to be approved under NWP 48. Shellfish aquaculture farms that do not have NWP 48 authorization have an individual permit, and the same conditions typically apply. Typical conditions under a NWP 48 authorization or individual permit through the Corps include, taken nearly verbatim from the Corps' consultation with the Services:

1. Washed gravel shall be used for shellfish bed preparation.
2. Unsuitable material (e.g., trash, debris, car bodies, asphalt, tires) shall not be discharged or used as fill (e.g., used to secure nets, create berms, provide nurseries).
3. A Pacific herring (*Clupea pallasii*) spawn survey shall be conducted prior to undertaking the activities listed below if any of these activities will occur outside the approved work window for the project area's Tidal Reference Area. The activities requiring a spawn survey are: (1) mechanical dredge harvesting, (2) raking, (3) harrowing, (4) tilling or other bed preparation activities, (5) frosting or applying oyster shell on beds, and (6) geoduck harvesting, net removal, or tube removal. Vegetation, substrate, and aquaculture materials (e.g., nets, tubes) shall be inspected for Pacific herring spawn. If Pacific herring spawn is present, these activities are prohibited in the areas where spawning has occurred until such time as the eggs have hatched and Pacific herring spawn is no longer present. The Corps encourages the permittee to complete a training class on identifying Pacific herring spawn with WDFW[2]. A map showing the Tidal Reference Areas and a table with the approved work windows for Pacific herring can be found at the Corps, Seattle District, Regulatory Branch website. You shall maintain a record of Pacific herring spawn surveys, including the date and time of surveys; the area, materials, and equipment surveyed; results from the survey; etc. The record of Pacific herring spawn surveys shall be made available upon request to the Corps, NMFS, and USFWS.
4. Newly positioned shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) shall not be placed within 10 horizontal feet of eelgrass (*Zostera marina*) or kelp.

2 There is currently no WDFW training for Pacific herring egg identification although there is a Pacific Shellfish Growers Association-sponsored class, as discussed in Section 4.0 below.

5. Newly positioned[3] shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) shall not be placed above the tidal elevation of +7 ft MLLW[4] if the area is documented as surf smelt (*Hypomesus pretiosus*) spawning habitat by the WDFW. A map showing the location of documented surf smelt spawning habitat is available at the SalmonScape interactive program on the WDFW website.
6. Newly positioned shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) shall not be placed above the tidal elevation of +5 ft MLLW[4] if the area is documented as Pacific sand lance (*Ammodytes personatus*) spawning habitat by the WDFW. A map showing the location of documented Pacific sand lance spawning habitat is available at the SalmonScape interactive program on the WDFW website.
7. You shall not use tidelands waterward from the line of mean higher high water (MHHW) for the storage of aquaculture gear (e.g., bags, racks, marker stakes, rebar, nets, tubes) for a consecutive period of time exceeding 7 days.
8. All pump intakes (e.g., for geoduck harvest, washing down gear) that use seawater shall be screened in accordance with NMFS and WDFW criteria. **Note:** This does not apply to work boat motor intakes (jet pumps) or through-hull intakes.
9. Land vehicles (e.g., all-terrain, trucks) and equipment shall not be washed within 150 ft of any stream, waterbody, or wetland. All wash water shall be treated before being discharged to any stream, waterbody, or wetland.
10. Land vehicles shall be stored, fueled, and maintained in a vehicle staging area placed 150 ft or more from any stream, waterbody, or wetland. Where this is not possible, documentation must be provided to the Corps as to why compliance is not possible, written approval from the Corps must be obtained, and the operators shall have a spill prevention plan and maintain a readily available spill prevention and clean-up kit.
11. Inspect all vehicles operated within 150 ft of any stream, waterbody, or wetland daily for fluid leaks before leaving the vehicle staging area. Repair any leaks detected in the vehicle staging area before the vehicle resumes operation.
12. All tubes, mesh bags, and area nets used on the tidelands below the line of MHHW shall be clearly, indelibly, and permanently marked to identify the permittee name and contact information (e.g., telephone number, email address, mailing address). On the nets, identification markers will be placed with a minimum of one identification marker for each 50 ft of net. **Note:** You will have 180 days from verification to implement this

3 "Newly positioned" is defined as being placed within a portion of the project area where aquaculture is not currently located and has not previously occurred.

4 Note that the predominant surf smelt spawning habitat of +7 ft MLLW and sand lance spawning habitat of +5 ft MLLW is relative to the Seattle datum (Dionne, pers. comm., 2016). Correcting this for Pierce County results in a higher elevation in south Puget Sound. Therefore, restricting culture to +7 ft MLLW and +5 ft MLLW in Pierce County is a conservative approach for protecting spawning habitat for these forage fish species.

condition. If this special condition cannot be met, you shall submit a plan to the Corps for written approval describing specific measures and/or best management practices that will be undertaken to prevent the inadvertent release of aquaculture equipment into waters of the U. S.

13. At least once every 3 months, beaches in the project vicinity shall be patrolled by crews who will retrieve aquaculture debris (e.g., anti-predator nets, tubes, tube caps, stakes) that escapes from the project area. Within the project vicinity, locations shall be identified where debris tends to accumulate due to wave, current, or wind action, and after weather events these locations shall be patrolled by crews who will remove and dispose of aquaculture debris appropriately. You shall maintain a record with the following information and the record shall be made available upon request to the Corps, NMFS, and USFWS: date of patrol, location of areas patrolled, description of the type and amount of retrieved debris, other pertinent information.
14. You shall ensure area nets (e.g., anti-predator nets) are tightly secured to prevent them from escaping from the project area.
15. You must submit a request for permit modification to the Corps if there is an increase in the reported amount of gravel that is being applied to "frost" (i.e., to harden) the substrate at a mudflat or vegetated shallow, which are special aquatic sites. Mudflat is defined at 40 CFR 230.42(a) and vegetated shallow is defined at 40 CFR 203.43(a).
16. Vessels used for shellfish culturing at the project area shall not ground in eelgrass (*Zostera marina*) beds. If this special condition cannot be met, within 90 days of verification, you shall submit a plan to the Corps describing specific measures and/or best management practices that will be undertaken to minimize negative effects to eelgrass from vessel operation and receive Corps written approval.

3.1.2 Pierce County Regulations

Pierce County has a robust review process through the shoreline substantial development(SSD) permit and an environmental review pursuant to Chapter 197-11 (SEPA Rules) of the WAC and Title 18D (Development Regulations – Environmental) of the PCC. A number of measures typically are adopted by Pierce County land planners for shellfish aquaculture operations that emphasize avoidance of potential effects as the first priority. Typical conditions (or mitigation measures) associated with an SSD permit through Pierce County include[5]:

1. The farm shall be subject to the most current version of the Pacific Coast Shellfish Growers Association Environmental Codes of Practice as well as the Washington State Geoduck Growers Environmental Codes of Practice.

5 These terms and conditions are based on geoduck aquaculture applications, as those are the most recent shellfish farms that have been required to obtain permits, and for which permits were issued in Pierce County.

2. Tubes and large nets shall be marked so as to identify ownership. Markings shall withstand the elements.
3. Small nets shall be securely fastened to the tubes. Fasteners shall withstand the elements.
4. The Proponent shall post with the County a financial guarantee in the amount of $1.00 per planted tube. The amount shall be based upon the maximum number of tubes that are planted at any one time. In the event that it becomes necessary for the County to remove the tubes, the financial guarantee shall be forfeited.
5. Tubes and nets shall be removed as soon as geoducks are not vulnerable to predators.
6. Non-secured gear and equipment shall be removed from the farm when crews are not present. This provision shall not apply to planted gear.
7. If vessels are approved to be moored on or near the site when crews are not working, any gear and equipment approved to be stored on the vessels shall be secured such that it does not fall off.
8. Tidelands within 1/2 mile of the farm shall be patrolled (subject to beach owner's permission to enter) by the Proponents on a weekly basis and within a day following a severe storm event. When work onsite requires use of divers, underwater areas immediately abutting the farm shall also be patrolled. Any observed geoduck farm debris shall be retrieved regardless of its source. Patrolling does not need to occur if no gear is installed on-site.
9. The Proponents shall provide their phone number and/or e-mail address to anybody who requests such for the purpose of filing complaints.
10. The Proponents shall promptly respond to any complaints.
11. The Proponent shall inform all crew of these mitigation measures.

3.1.3 Summary of Avoidance, Conservation, and Minimization Measures

The regulatory process for shellfish aquaculture is robust, and every project in Washington State is required to have all federal, state, and local permits in place prior to conducting activities. Avoidance of impacts is the primary goal of these regulations, as well as maintaining ecological functions within the surrounding environment. As stated under the requirements of the NWP 48, these projects must cause only minimal adverse environmental effects on the aquatic environment when performed separately or cumulatively. The numerous avoidance, conservation, and minimization measures stated above, as well as the robust regulatory process, ensure that individual projects adhere to this main criterion. In light of these measures, which have been feasible for growers to implement and ensured that commercial shellfish farms meet federal, state, and local regulatory requirements, the question arises whether there is sufficient scientific, technical, or other justification for outright prohibitions on aquaculture in the Pierce County SMP update. As discussed in more depth below, there does not appear to be such justification, and hence these prohibitions are unwarranted and inappropriate.

3.2 Natural Shoreline Environmental Designation (SED) Prohibition

This sub-section is responding to **PCC 18S.60.030-1**: "Aquaculture is prohibited in Aquatic SEDs abutting Natural SEDs." See also **PCC 18S.20.030(B)** (aquaculture is not listed as an allowed use in the Natural SED).

3.2.1 Definition of a Natural SED

According to PCC 18S.20.30, "the intent of the Natural SED is to ensure long-term preservation of shorelines that are ecologically intact or minimally degraded, sensitive to human influence, or retain value because of their natural, unaltered condition." The designation criteria include shorelines that are "performing irreplaceable function or ecosystem-wide process that would be damaged by human activity." Many historical shellfish aquaculture farms (e.g., Burley Lagoon, Rocky Bay, Minter Bay, Filucy Bay) that have been operating in Pierce County for 50 to 70 years were designated as Natural SEDs in 1975, and areas adjacent to new shellfish farms that began operating after 1975 continue to be designated as Natural (e.g., Foss farm) (Figure 3). This confirms that commercial shellfish farming is mutually sustainable with the Natural shoreline environment and that this use does not adversely affect or compromise the criteria used to designate an area as Natural.

Aside from farms that fit within the criteria of a Natural SED, two major management policies are relevant to shellfish aquaculture. The first is that, "low intensity agricultural and forestry uses may be consistent when they are limited to ensure that the intensity remains low." Shellfish aquaculture (even for larger farms in Washington) is typically a low intensity use of the shoreline environment. As is typical with many farms, advances in technology and culture methods improve interactions between farm operations and the surrounding environment. For example, along the southwestern corner of Burley Lagoon is a floating upwelling system (FLUPSY), which is a type of nursery for growing shellfish seed. The FLUPSY was historically made up of 120 to 150 creosote-treated wood and Styrofoam which were typical float materials at the time. Between 2011 and 2014, many floats were removed from the lagoon and the remaining floats were replaced with aluminum floats. This updated technology resulted in a 70% reduction of overwater structure in that location (Figure 4).

The second major management policy relevant to shellfish aquaculture within or adjacent to a Natural SED is that, "any use that would degrade ecological functions, natural features, and overall character of the shoreline area shall not be allowed." The following section on no-net-loss of ecological function discusses the potential negative and positive interactions of shellfish aquaculture, and how the net impact of aquaculture, if managed appropriately, conforms to this policy. A later section (Section 3.2.4) provides examples of how upland activities unrelated to shellfish aquaculture can both affect the Natural SED and existing shellfish aquaculture operations.

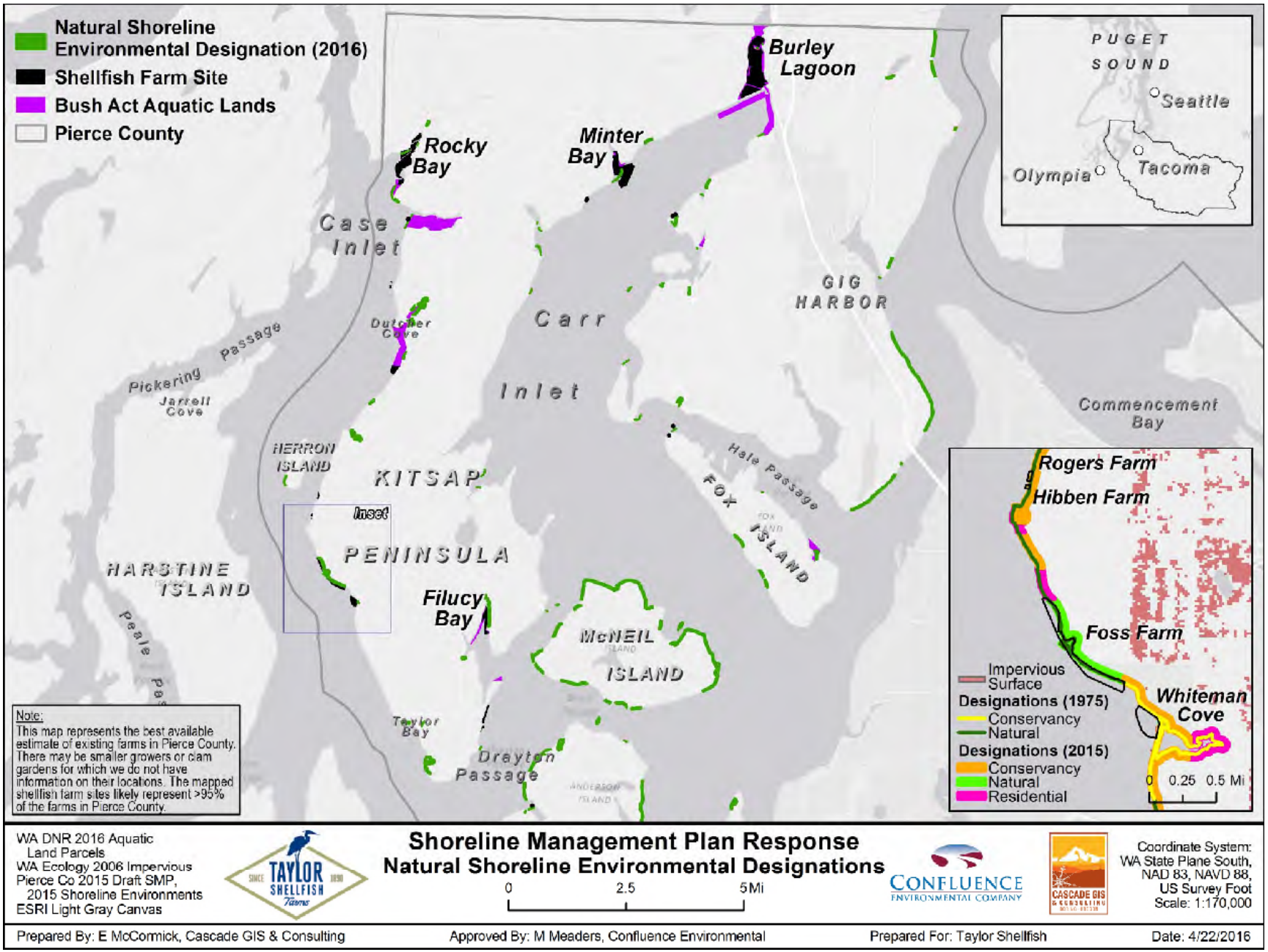


Figure 3 **Historical Shellfish Farms in Pierce County and Natural Shoreline Environmental Designations**



Figure 4 Comparison of Aerial Imagery and Site Photographs Before and After Aquaculture Debris Removal Efforts

Source: Google Earth (2015)

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3.2.2 No-Net-Loss of Ecological Functions

A net impact assessment assumes that development will result in a change, which may be ecologically positive (e.g., improvement in water quality) or negative (e.g., reduction in aquatic habitat for fish), but adequate measures are used to mitigate negative effects such that the post-development conditions are at least no worse overall than the pre-development conditions. The avoidance, conservation, and minimization measures discussed above (Section 3.1) are in place for this purpose. These measures have been practical for shellfish farmers to implement on new farms, and they have proven successful in achieving the no-net-loss standard. The following sections provide an understanding of the best available science related to negative and positive interactions of shellfish aquaculture with the surrounding environment, and how this relates to a no-net-loss of ecological functions.

Negative Interactions of Shellfish Aquaculture

While the placement of gear or activities associated with shellfish aquaculture can result in a disturbance, this change does not necessarily equate to a negative impact. The interactions that can potentially result in a disturbance to the surrounding environment include: (1) shellfish aquaculture gear, (2) working practices, and (3) cumulative effects with other stressors. This information primarily focuses on kelp and native eelgrass (or SAV), which is identified as a "potential fish and wildlife conservation area" (PCC 18E.40.020(E)(1)), similar to commercial and recreational shellfish aquaculture areas, in the Pierce County Code. Dumbauld et al. (2009) indicated that it is important to not only consider disturbance in terms of a degradation from baseline functions, but also how disturbance can influence the resilience of the system to withstand or recover from additional disturbances. This concept of resiliency is also explored in this section in relation to eelgrass habitat and shellfish aquaculture.

Shellfish Aquaculture Gear

Equipment associated with the culture of shellfish (e.g., nets, racks, bags) can lead to shading, which may affect the spatial extent and density of SAV in the immediate vicinity of shellfish gear. The type and concentration of equipment influence the level of this effect. For example, Everett et al. (1995) found that oyster racks could lead to a total loss of eelgrass directly under the racks. Comparatively, Rumrill and Poulton (2004) determined that the spatial extent of an eelgrass bed and shoot density were negatively influenced when oyster longline culture was closely spaced (1.5 ft to 2.5 ft) but showed no significant effects compared to control sites when spacing occurred at 5-ft and 10-ft spaces between longlines.

Predator exclusion netting used in Manila clam and geoduck clam aquaculture can be detrimental to SAV. Predator exclusion netting is generally not placed over shellfish in areas with eelgrass. However, in at least one example in Washington State (Fisk Bar, Samish Bay), eelgrass recruited into a geoduck clam culture area after the placement of aquaculture gear stabilized the sediment and protected the new eelgrass shoots from erosive wave energy (see the discussion below in positive interactions of shellfish aquaculture). During the grow-out portion of the culture cycle, predator exclusion nets were placed on the bed and Horwith (2013)

reported a total loss of eelgrass under predator exclusion netting due to shading effects from *Ulva* sp. growth on the net surface. It should be noted that the eelgrass was shown to recover within 2 years of net removal (Horwith, pers. comm., 2014). Under such a scenario, the functions of eelgrass may have been temporarily offset by the development of a macroalgal community, as described by Powers et al. (2007). Predator exclusion nets or culture gear often gets colonized with macroalgae (Figure 5), which was quantified by Powers et al. (2007) as providing comparable ecosystem functions (e.g., nursery habitat, epibiota biomass) as seagrass beds. However, for the time that they are in place, the netting can negatively impact SAV directly underneath the predator exclusion nets.



Figure 5 Macroalgae Colonizing Oyster Lines in Blue Heron Bay

Source: Dewey, pers. comm., 2015

Other effects of shellfish aquaculture gear to SAV include the potential to abrade, scour, or desiccate the plants, although the overall effects can be both positive and negative. For example, Wisehart et al. (2007) explored the concept that, while shellfish can break eelgrass blades through abrasion or harvesting techniques, the reduction in density can release individuals from intraspecific light competition and result in increased growth rates near the aquaculture plots. Similarly, Wisehart et al. (2007) reported that scouring or dredging can result in higher eelgrass seedling density and seed production in the disturbed areas from a mechanical dredge harvest. Alternatively, eelgrass blades can desiccate on shellfish or aquaculture gear, which can

eventually lead to a reduction in shoot size (Wisehart et al. 2007, Tallis et al. 2009). These tradeoffs are explored in more detail below.

Working Practices

Shellfish harvest can cause localized and temporary increases in suspended sediments, physical damage and/or removal of SAV, as well as changes to other metrics (e.g., biomass, seed germination, growth). The two practices that likely generate the most suspended sediment are mechanical harvest of oysters and geoduck clam harvest. Shellfish aquaculture typically occurs in areas with sand or gravel substrate, which are substrate sizes that have high settling velocities. For example, Mercaldo-Allen and Goldberg (2011) reported that suspended sediments may take 30 minutes to 24 hours to resettle in areas typical of oyster and clam aquaculture operations. Suspended sediment effects of shellfish harvest are generally short-lived and recovery is rapid (Short and Walton 1992, Liu and Pearce 2011). Additionally, shellfish culture often occurs in shallow estuarine embayments where freshwater runoff, currents, and wind waves can lead to naturally high background levels of suspended sediments. Therefore, pulse disturbances of suspended sediment by shellfish harvesting often fall within baseline measurements and the natural variability of the system.

Tallis et al (2009) compared eelgrass densities in areas that were harvested: (1) by hand in ground culture, (2) using a mechanical dredge harvester, or (3) by hand on longlines. Although there was a 70% reduction in eelgrass productivity at all aquaculture sites when averaged together, Tallis et al. (2009) pointed out that effects to eelgrass from aquaculture occurred in both directions (positive and negative), and the magnitude of effects observed were dependent on the site and type of harvest method. For example, mechanical dredge harvesting had the greatest level of impact and longline and ground culture had the lowest. While the authors suggested that it is impossible to incur no effect when oyster aquaculture takes place in an eelgrass bed, they also indicated that there are ample opportunities for decreased impact with tailored culture methods and timing.

Wisehart et al. (2007) also examined the effects of different aquaculture techniques on eelgrass biomass, density, and growth rates in Willapa Bay. As discussed above, the authors reported that shellfish aquaculture may facilitate increased growth rates due to a reduction in intraspecific competition by surrounding plants (e.g., increased light availability), increased seed supply and germination, and a more open seed dispersal setting. In addition, while oysters grown on longlines caused some minor reduction in eelgrass density and cover, the highest eelgrass growth rates occurred at the longline culture and reference sites. These areas also had the greatest eelgrass biomass, density, and percent cover. The study reported statistically significant site and culture type interactions for most variables, suggesting that site-specific conditions may be just as influential as aquaculture techniques in determining eelgrass parameters.

Boat access can also result in potential negative impacts to eelgrass shoots. Ruesink et al. (2012) conducted experimental treatments in Willapa Bay where they imposed two disturbance types:

shoot damage and shoot removal. For the most part, the extent of damage from boat propellers would result in taking off the ends of the shoots (i.e., shoot damage), but not removing the entire shoot. Regrowth for eelgrass that is only damaged on the surface requires branching of the plant to replace the lost biomass. Growth rates of eelgrass affected by shoot damage for less than 4 weeks recovered within 2 months following a single cutting event when the rhizome was still rooted. There would be no long-term damage in terms of eelgrass density for this type of action.

Potential longer term impacts were calculated based on an accumulation of shoot removal over a year or more (e.g., consistent access routes). If the shoot is removed, the removal area can be repopulated by rhizome extension from shoots at the edge (asexual reproduction) or germination of seeds (sexual reproduction). Ruesink et al. (2012) reported that recovery of eelgrass after complete shoot removal (6.6 x 6.6 ft gaps) could occur after 2 years. Based on this rate of recovery, a conservative estimate of a propeller scar width of 3 ft could replace the lost biomass in approximately 0.9 year. If regrowth occurs at a rate faster than removal, it can be assumed that there would be no significant loss in biomass from this type of activity unless an area is not allowed to regrow through continuous disturbance.

Cumulative Effects with Other Stressors

Boström et al. (2006) conducted a meta-analysis of the scientific literature associated with plant-animal interactions in seagrass landscapes. According to this analysis, the authors indicated that, "The growth and recruitment dynamics of seagrasses as well as man-made and/or natural disturbances create complex spatial configurations of seagrass over broad (metres to kilometres) spatial scales. Hence, it is important to identify mechanisms maintaining and/or threatening the diversity-promoting function of seagrass meadows and to understand their effects on benthic populations and communities." It is well recognized that there are a variety of natural and anthropogenic stressors on aquatic environments (Dennison 1987, Fonseca and Bell 1998, Shaughnessy et al. 2004, Boese et al. 2005, Mumford 2007, Thom et al. 2011, Stevens and Lacy 2012).

A few studies address landscape-scale changes to eelgrass relative to shellfish aquaculture. The most comprehensive analysis of factors that drive the changes at a landscape-scale was conducted by Dumbauld and McCoy (2015). This study modeled eelgrass (*Z. marina*) density in Willapa Bay and compared a number of predictors, including: (1) distance to estuary mouth, (2) distance to channel, (3) salinity, (4) elevation, (5) cumulative wave stress, and (6) shellfish aquaculture. The model results indicated that eelgrass cover was lower in oyster aquaculture beds, but the impact directly associated with aquaculture represented less than 1.5% of the total predicted eelgrass density in any year.

Aside from the overall low amount of impact to eelgrass at the landscape-scale, the Dumbauld and McCoy (2015) work also indicated that the harvest method was a significant predictor in explaining eelgrass reduction. For example, mechanically harvested beds had a significantly lower amount of eelgrass compared to beds harvested by hand or with a mixed harvest

technique (similar to the results reported by Tallis et al. 2009). Comparatively, the type of aquaculture (e.g., longline, seed bed, fattening ground) was not a significant contributor to the variation of eelgrass predicted versus actually observed. The authors suggested that, overall, aquaculture resulted in a minor change to eelgrass at the landscape-scale because the effect of culture was variable enough at smaller spatial scales as to eliminate a significant effect at the landscape-scale.

As stated throughout this report, the landscape-scale is very important to consider when trying to protect for mobile species, such as fish and crabs. This sentiment was stated within Semmens (2008), where the author indicated that, "From a management perspective, it may therefore be tempting to downplay the importance of fine-scale benthic habitats in favor of larger-scale estuarine features such as deep tidal channels and salinity gradients for smolt-sized fish." Although it is important to understand small-scale effects in order to effectively manage potential effects to eelgrass, it is the landscape-scale that drives how species will use the habitat.

Eelgrass Resilience

Holling (1973) defined resilience as "a measure of the ability of these systems to absorb change of state variables, driving variables, and parameters, and still persist." Native eelgrass exhibits a stable and possibly increasing trend in distribution and abundance in areas like Willapa and Humboldt bays where oysters have been actively farmed for over 100 years and are currently operated by commercial growers (Barrett 1963, Tallis et al. 2009, Dumbauld et al. 2011). Therefore, it appears that there is resilience of eelgrass to the level of shellfish aquaculture activities in these estuaries. It is notable that shellfish aquaculture in both Willapa Bay and Humboldt Bay represent approximately 20% or more of the surface area within the bay.

Positive Interactions of Shellfish Aquaculture

Many effects of shellfish aquaculture can be considered a positive interaction with SAV and the surrounding habitat. According to Forrest et al. (2009), "the acceptability of aquaculture operations or new developments should recognize the full range of effects, since adverse impacts may be compensated to some extent by the nominally 'positive' effects of cultivation." There are a number of effects described below that can potentially result in beneficial changes to the surrounding environment.

Sediment Stabilization and Eelgrass Colonization

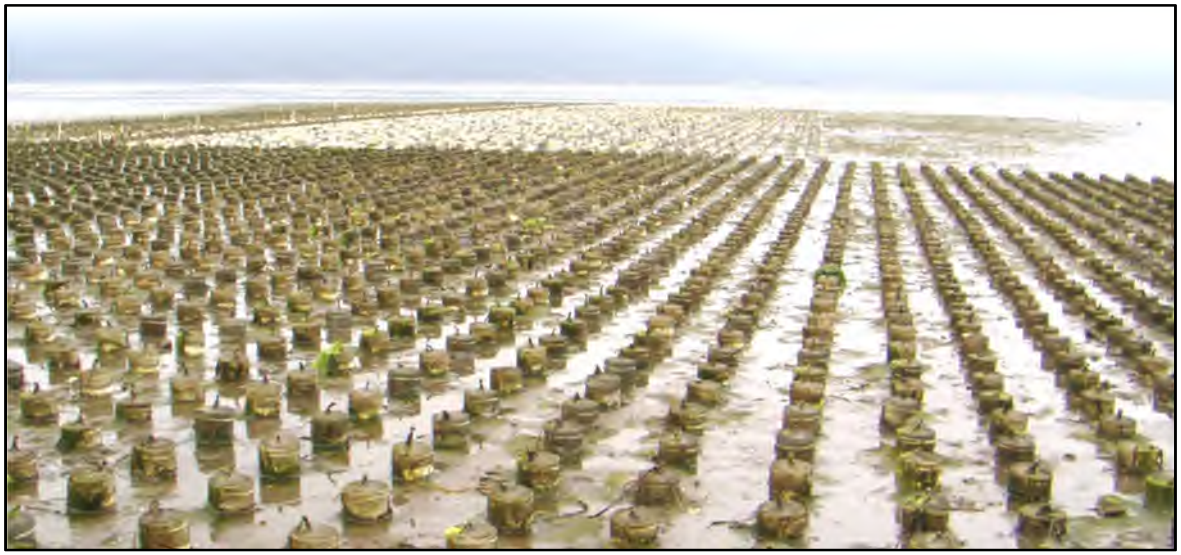
Shellfish have been labeled "ecosystem engineers" because of the ecological roles that they play in coastal habitat processes (Jones et al. 1994, Lenihan 1999). For example, the presence of shellfish can protect shorelines from erosion by stabilizing sediments and dampening waves (Meyer et al. 1997, Scyphers et al. 2011, Spalding et al. 2014). This same function provided by shellfish can benefit eelgrass. Eelgrass has been known to expand into areas after sediments are stabilized. There are numerous examples along the West Coast where eelgrass expanded into shellfish aquaculture plots. The information for most of these examples is primarily anecdotal, with notable exceptions (e.g., Ward et al. 2003), and the cause has not been directly linked to the

aquaculture operation. Overall, current shellfish aquaculture practices have not been associated with significant loss in the spatial extent of eelgrass and in some cases can be linked to expansion of eelgrass at a landscape-scale.

Potential recruitment of eelgrass into shellfish aquaculture plots is driven by three main mechanisms. First, by providing a larger boundary layer and slowing water current speed, shellfish may increase recruitment of floating seeds as they travel singly or within detached reproductive shoots. Retention of seedlings could also be facilitated by the structure shellfish gear provide, although the density and type of gear can impede seed dispersal (see Tallis et al. 2009). Seed dispersal is typically limited outside of an eelgrass bed; approximately 80% of seeds travel within 33 ft (10 m) of parent plants (Orth et al. 1994, Ruckelshaus 1996). Therefore, this effect is only important when eelgrass beds are nearby. Second, by filtering seawater and increasing sediment organic content, bivalves provide superior conditions for seed germination. Eelgrass seed germination is dependent on burial depth, with the highest germination occurring at the anaerobic/aerobic interface (Bigley 1981). Seeds buried below this depth have very low germination and are essentially lost from the population. Shellfish may act to bury and fertilize seeds at a depth that is appropriate for germination. Third, shellfish may increase the survival of seedlings, which have very high mortality rates, by increasing light levels, nutrients, and protecting against erosion and herbivory (Orth et al. 1994, Ruckelshaus 1996). Note that filter-feeding effects to light levels are discussed in more detail below.

A case study that highlights the potential for eelgrass to colonize into an area previously devoid of eelgrass is a sand bar (Fisk Bar) in the center of Samish Bay, Washington. Prior to geoduck aquaculture on Fisk Bar, seeds from the surrounding eelgrass beds would occasionally result in ephemeral shoots on the sand bar that would get eroded during winter storms. In 2002, geoduck nursery tubes (6-inch-diameter polyvinyl chloride [PVC] tubes) for planting geoduck seed were placed to establish the first geoduck crop on Fisk Bar (Figure 6). Shortly after nursery tubes were placed, eelgrass began to fill in and establish a dense bed around the tubes (Dewey, pers. comm., 2015). For this first crop of geoduck, individual net caps were placed on each tube. When the tubes were removed 2 years after seeding, eelgrass was established well enough that it remained and thrived on the sand bar.

In 2008, when the geoducks were harvested, eelgrass was significantly reduced but not eliminated. After this first harvest event, nursery tubes were reinstalled, seeded with geoducks, and the entire tube field was covered by predator exclusion nets. As described above, Horwith (2013) reported a total loss of eelgrass in areas where the predator exclusion netting was placed. The eelgrass loss was attributed to shading effects from *Ulva* sp. growth on the net surface. Recovery of eelgrass began 1 year after removal of tubes and nets. In July 2014, Dr. Horwith (pers. comm., 2014) indicated that, "there is no longer any significant difference in eelgrass coverage or density between the farmed and unfarmed areas" (see Figure 6). Overall, the Fisk Bar eelgrass appears to be resilient and thriving in an area where it could not previously establish.



Fisk Bar, Samish Bay, 2002: Planting Geoduck Seed with Culture Tubes and Individual Net Caps. No eelgrass bed present prior to planting activities.



Fisk Bar, Samish Bay, 2014: Eelgrass Bed prior to Harvest Activities

Figure 6 Eelgrass at Fisk Bar, Samish Bay, between 2002 and 2014

Source: Dewey (pers. comm., 2015)

Increased Water Clarity and Light Penetration

Shellfish aquaculture can result in a reduction in turbidity due to removal of phytoplankton and particulate organic matter through filtration (Peterson and Heck 2001, Newell and Koch 2004, Cranford et al. 2011). By consuming phytoplankton and particulate organic matter, shellfish increase the amount of light reaching the sediment surface that is available for photosynthesis (Dame et al. 1984, Koch and Beer 1996, Newell 2004, Newell and Koch 2004). Improvements to water clarity and light penetration can improve habitat conditions that promote the growth of SAV and other aquatic vegetation. There is an optimum range for feeding efficiency, identified as suspended solid concentrations between 5 mg/L and 25 mg/L based on oysters in Chesapeake Bay, Maryland (Cerco and Noel 2007). Therefore, this benefit can be limited when suspended sediment concentrations are outside of this range.

The removal of nutrients (especially nitrogen) through filtration can also benefit SAV growth by reducing epiphytes and macroalgae (Figure 7). Epiphytes (primarily diatoms) can form thick layers on eelgrass blades. This is a natural process, and important in the food chain because this layer of epiphytes is grazed by aquatic invertebrates (van Montfrans et al. 1984, Nelson and Waaland 1997). However, overproduction of epiphytes is a result of nutrient water column pollution (Williams and Ruckelshaus 1993, Hauxwell et al. 2001, Nielsen et al. 2004). Shellfish aquaculture can provide mitigation of these conditions through water filtration and control of nutrients that promote the growth of epiphytes.

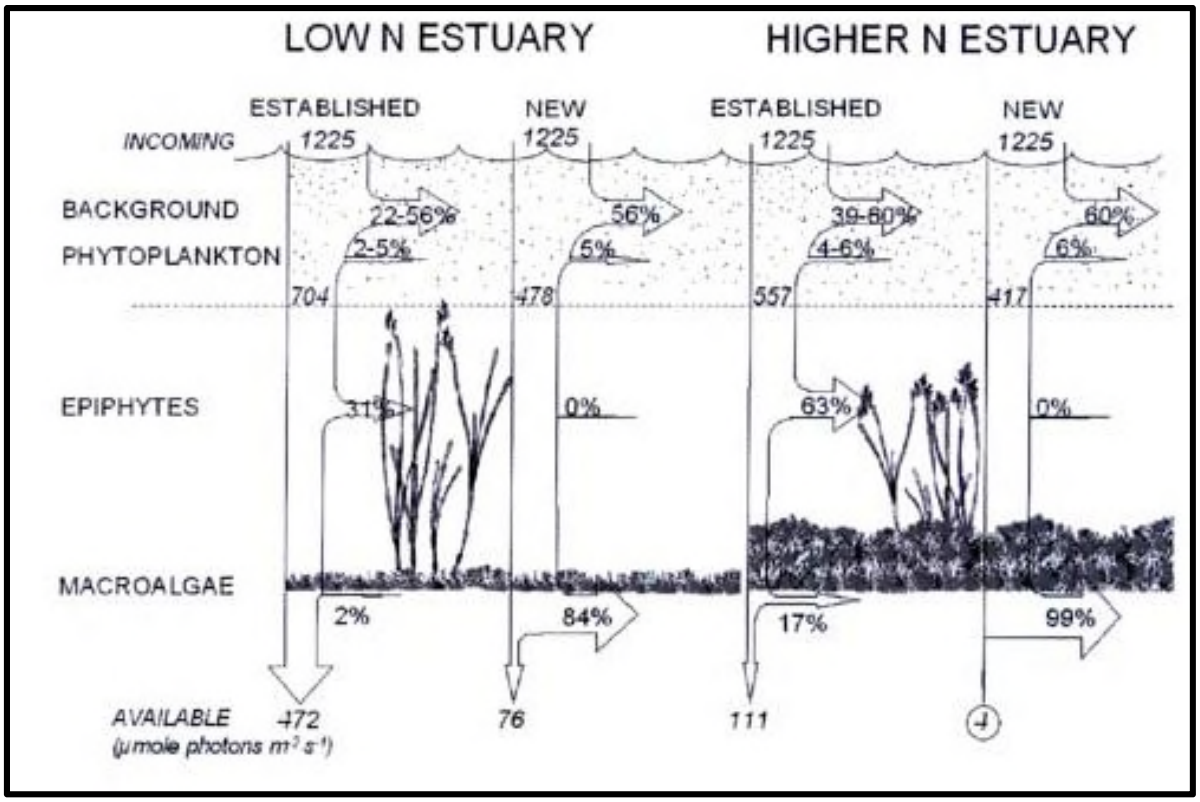


Figure 7 Illustration of Nitrogen Concentration Effects to Eelgrass
Source: Hauxwell et al. (2001)

Another service potentially provided by shellfish related to epiphytes was explored by Peterson and Heck (2001). The authors observed a significantly reduced epiphytic load on seagrass leaves when mussels were present. Spaces between shells of adjacent mussels were thought to provide a predation refuge for epiphytic grazers (e.g., small gastropods and amphipods). Increased densities of epiphytic grazers could then lead to an increased amount of grazing, which consequently might lead to an increase in leaf light absorption. This study also noted that the mussels themselves may potentially reduce epiphytic loads by consuming the epiphyte propagules before recruitment to the leaves. Although likely a benefit to eelgrass, the shellfish would need to be in the eelgrass bed to provide this service for epiphytic grazers.

Macroalgae does not colonize eelgrass shoots in the way that epiphytes do, but changes in the amounts of nutrients in the aquatic environment can shift the competitive balance between aquatic vegetation species, allowing plants that can respond quickly to nutrients to dominate (Taylor et al. 1995, Schramm and Nienhuis 1996, Taylor et al. 2001, Cardoso et al. 2004, Nielsen et al. 2004, Mumford 2007, Smetacek and Zingone 2013). The mechanism for loss of eelgrass and other SAV is likely related to a combination of light competition (Nienhuis 1996), smothering by macroalgal blooms (den Hartog and Phillips 2000), and competition for nutrients (Nienhuis 1996).

Improvements to Dissolved Oxygen and Nutrient Sequestration

Phytoplankton, as primary producers, create oxygen through photosynthesis. The mechanism by which dissolved oxygen (DO) is reduced is a result of a phytoplankton bloom produced by an increase in nitrogen in the system. As Albertson et al. (2002) indicated, south Puget Sound is sensitive to nitrogen addition generating phytoplankton blooms. When excess plankton die from not being consumed, bacteria consume the plankton and have a secondary bloom as a result, which consumes oxygen and results in low DO concentrations. This process is also known as the biochemical oxygen demand (BOD) of the system.

Ecology created a model of south and central Puget Sound (Ahmed et al. 2014) to identify how much nutrient sources are contributing to low DO concentrations. The model predicted minimum DO concentrations under natural conditions (left map of Figure 8), which was then used to evaluate whether water quality standards (right map of Figure 8) were being violated. Figure 8 shows that DO falls below the applicable criterion throughout most of south and central Puget Sound. Ahmed et al. (2014) also predicted that reducing the internal human nutrient load would decrease the magnitude and extent of DO depletion in south and central Puget Sound. According to recent modeling by Banas and Cheng (2015), the authors hypothesized that "these inlets [Henderson, Eld, Totten, Hammersley, and upper Case inlets] are at noticeably lower risk of eutrophication than they would be in the absence of shellfish aquaculture."

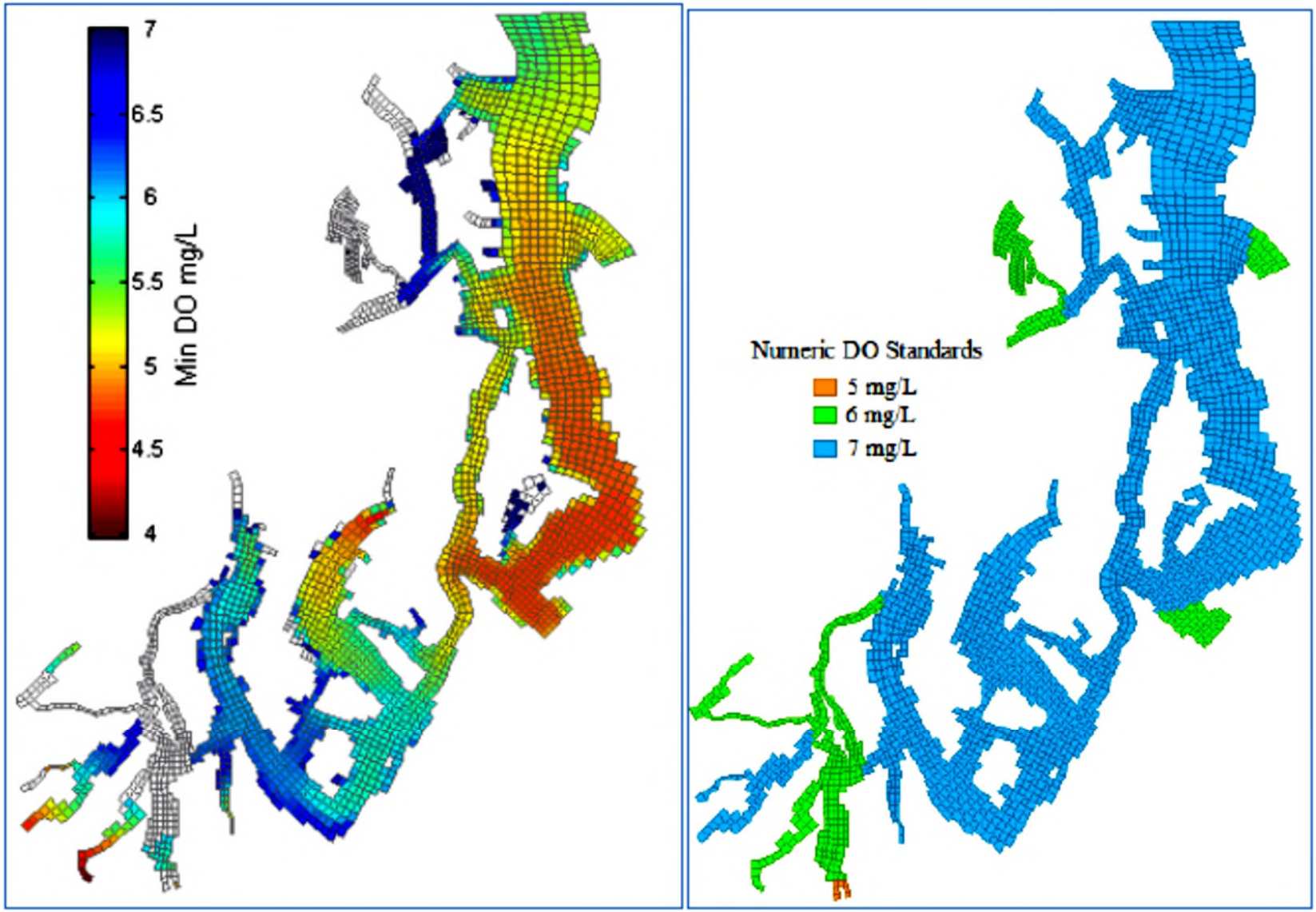


Figure 8 Minimum Dissolved Oxygen below the Numeric Standard under Natural Conditions

Source: Ahmed et al. 2014

An emerging body of literature is indicating that shellfish aquaculture, or the presence of a dense bivalve community, may provide some control of human nutrient loading to water bodies (Newell 2004, Shumway et al. 2003, Newell et al. 2005, Burkholder and Shumway 2011, Kellogg et al. 2013, Banas and Cheng 2015, Bricker et al. 2015). Bivalves remove more nutrients from the water column than they input as biodeposits, which can have a net benefit to water quality. As bivalves filter organic matter from the water column, they assimilate nitrogen and phosphorus into their shells and tissue (Figure 9).

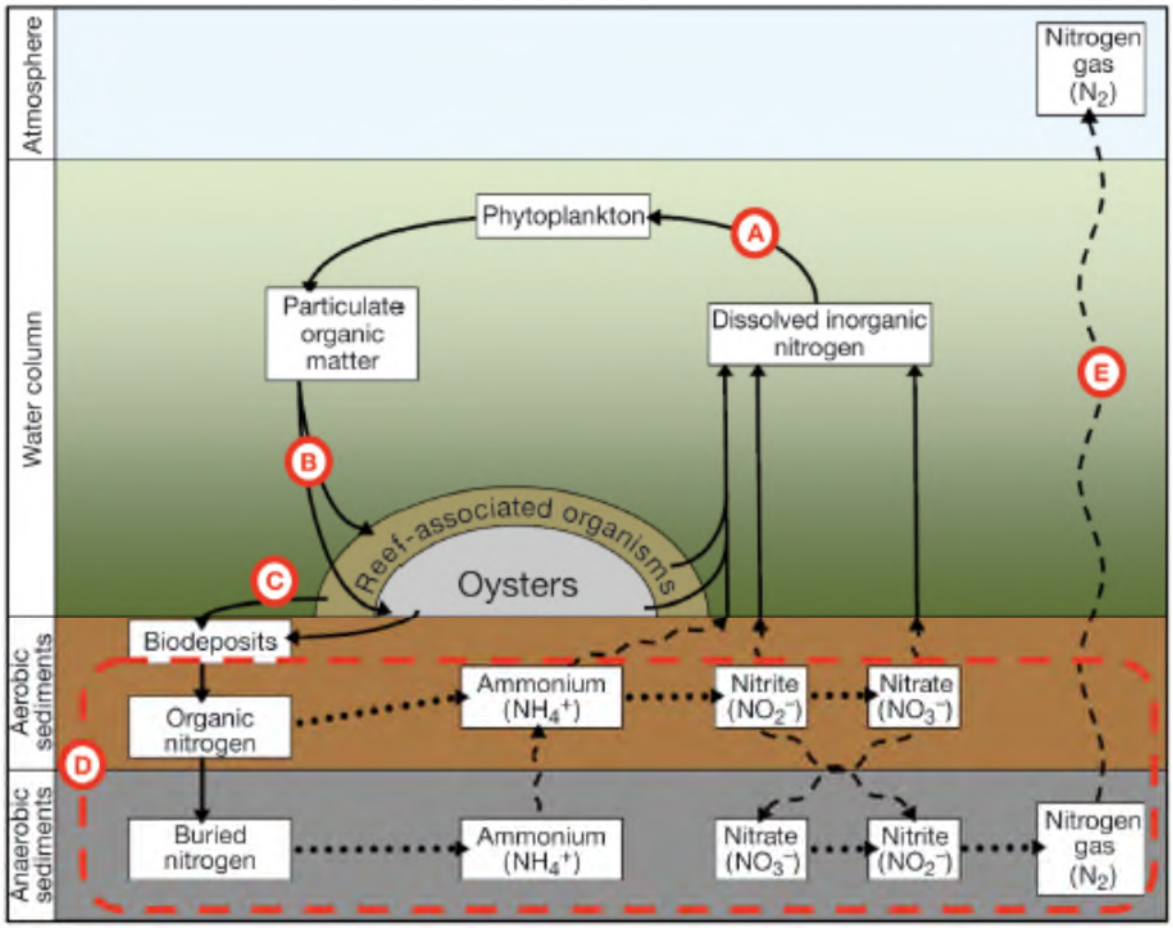


Figure 9 Nitrogen Pathways Associated with Oysters and Reef-Associated Organisms

Notes: Phytoplankton use dissolved inorganic nitrogen for their growth (A), oysters and reef-associated organisms filter phytoplankton and other particulate organic matter from the water column (B), some of the associated nitrogen is incorporated into organisms and some is deposited on the surface of the sediments (C), and, given the right conditions, a portion of the nitrogen in these biodeposits is transformed into nitrogen gas (D) which diffuses out of the sediments back to the atmosphere where it is no longer available to phytoplankton for growth (diagram adapted from Newell et al. 2005).

Source: Kellogg et al. (2013)

When shellfish are harvested, the sequestered nutrients are permanently removed from the system, also known as bioextraction. According to Newell (2004), bioextraction is one of the only methods available that removes nutrients after they have entered a system, which can then

make that system more resilient to nutrient loading and ultimately decreases in DO. Similarly, bivalve filter-feeding also serves an important role in improving water quality conditions through benthic-pelagic coupling, which is when biodeposits become incorporated into aerobic surficial sediments, and microbially mediated processes facilitate nitrification-denitrification coupling to permanently remove sediment-associated nitrogen as nitrogen gas (also shown on Figure 9).

The amount of benefit to water quality is dependent on species-specific filtration rates. A recent effort to calculate filtering capacity within south Puget Sound (Ferriss 2015) compiled clearance rates for Pacific oyster, Manila clam, and geoduck (Table 2). According to Banas and Cheng (2015), the potential for local control by shellfish was shown to be possible in Henderson, Eld, Totten, Hammersley, and upper Case inlets, and Oakland Bay. Therefore, shellfish filtration in estuaries could have an influence on local water quality parameters, even if small compared to the inputs into the system.

Table 2 Clearance Rate Calculations for Pacific Oyster, Manila Clam, and Geoduck.

Species	Indiv. W_{wet} (g)	L hr^{-1} $indiv^{-1}$	L hr^{-1} W_{wet}^{-1}	Source
Pacific oyster	11.52	3	0.260	Kobayashi et al. 1997, Ruesink et al. 2006
Manila clam	18.19	1	0.060	Ruesink et al. 2006, Solidoro et al. 2003
Geoduck	980	3	0.003	Davis 2010
Source: Banas and Cheng 2015				

An example of the potential benefits offered by shellfish filtration and nutrient sequestration is provided by Kellogg et al. (2013), who partially quantified the removal of nutrients from the water column at a subtidal oyster reef restoration site compared to an adjacent control site in the Choptank River within Chesapeake Bay, Maryland. The authors indicated that denitrification rates at the oyster reef in August were "among the highest ever recorded for an aquatic system." In addition, a significant portion (47% and 48% of total standing stock) of the available nitrogen and phosphorus were sequestered in the shells of live oysters and mussels. An ancillary benefit of the shellfish reef structure, which is also true for shellfish aquaculture gear and shellfish, was that the structure and faunal composition provided ample microhabitats for communities of nitrifying microbes. One of the conclusions by Kellogg et al. (2013) was that oyster reef restoration could be considered a "safety net" to reduce additional downstream impacts to water quality. Because shellfish aquaculture provides many of the same benefits, with the added benefit of the total removal of nutrients at harvest, commercial shellfish aquaculture can be considered a net benefit to water quality ecosystem functions.

Sediment Enrichment

The biodeposits created through bivalve filter feeding contribute to organic materials in the sediment surface, as described above. When organic materials accumulate, the amount of DO needed to break down the material can be exceeded and lead to anoxic conditions in the sediment (Nizzoli et al. 2005). Effects are variable, depending on the type of culture. For

example, suspended culture results in only the transfer of organic material to sediment compared to more mixing for ground culture. Effects are expected to be localized, and the extent is influenced by the density of shellfish relative to water circulation (Callier et al. 2006, Dumbauld et al. 2009, Konrad 2013).

Eelgrass can derive nutrients from both the sediments and the water column. The interstitial water (or sediment porewater) contains relatively higher concentrations of dissolved inorganic and organic nutrients than the water column, and eelgrass obtains most macronutrients from sediments. Sediment reservoirs of nutrients can become depleted when biogeochemical regeneration rates cannot meet plant demands (Short 1987). However, in the course of removing water column particulates, shellfish also alter sediment characteristics positively by moving carbon and nutrients from the water column to the benthos. Although studies related to sediment "fertilization" from bivalve deposition have shown enhanced eelgrass growth along the East Coast (e.g., Peterson and Heck 1999), similar studies in the Pacific Northwest appear to show no effect on eelgrass growth (Wagner et al. 2012, Ruesink and Rowell 2012, Wheat and Ruesink 2013). Studies in the Pacific Northwest indicate that eelgrass is not generally nutrient limited or that sediment porewater nutrients are naturally high.

Reduced Desiccation

As the tide recedes, shellfish retain seawater as they shut down filter feeding to wait for the returning tide. The water that is retained in the mantle cavity is expelled prior to the tide returning, creating a spray of water that is released into the surrounding environment. One of the species that can expel a significant amount of water is the geoduck (Figure 10). Water retention and release from other shellfish species may act in a similar fashion. Although this is likely a minor ecosystem function, it potentially reduces desiccation pressure when eelgrass is exposed during a low tide.

Shellfish gear can also result in the creation of micro-habitat around the structures, which can also retain water and provide opportunities for eelgrass growth. For example, at an existing longline aquaculture operation in Humboldt Bay, California, there is scouring around the PVC posts and eelgrass is growing within the depressions. Based on the surrounding habitat, the presence of culture is providing a slight change in elevation that allows eelgrass to persist. While sediment changes shift seasonally, especially at higher elevations, existing data suggests that sediment changes are minor, especially in relation to the natural sediment dynamics that drive the system (Forrest and Creese 2006, Forrest et al. 2009, Osborne 2015).

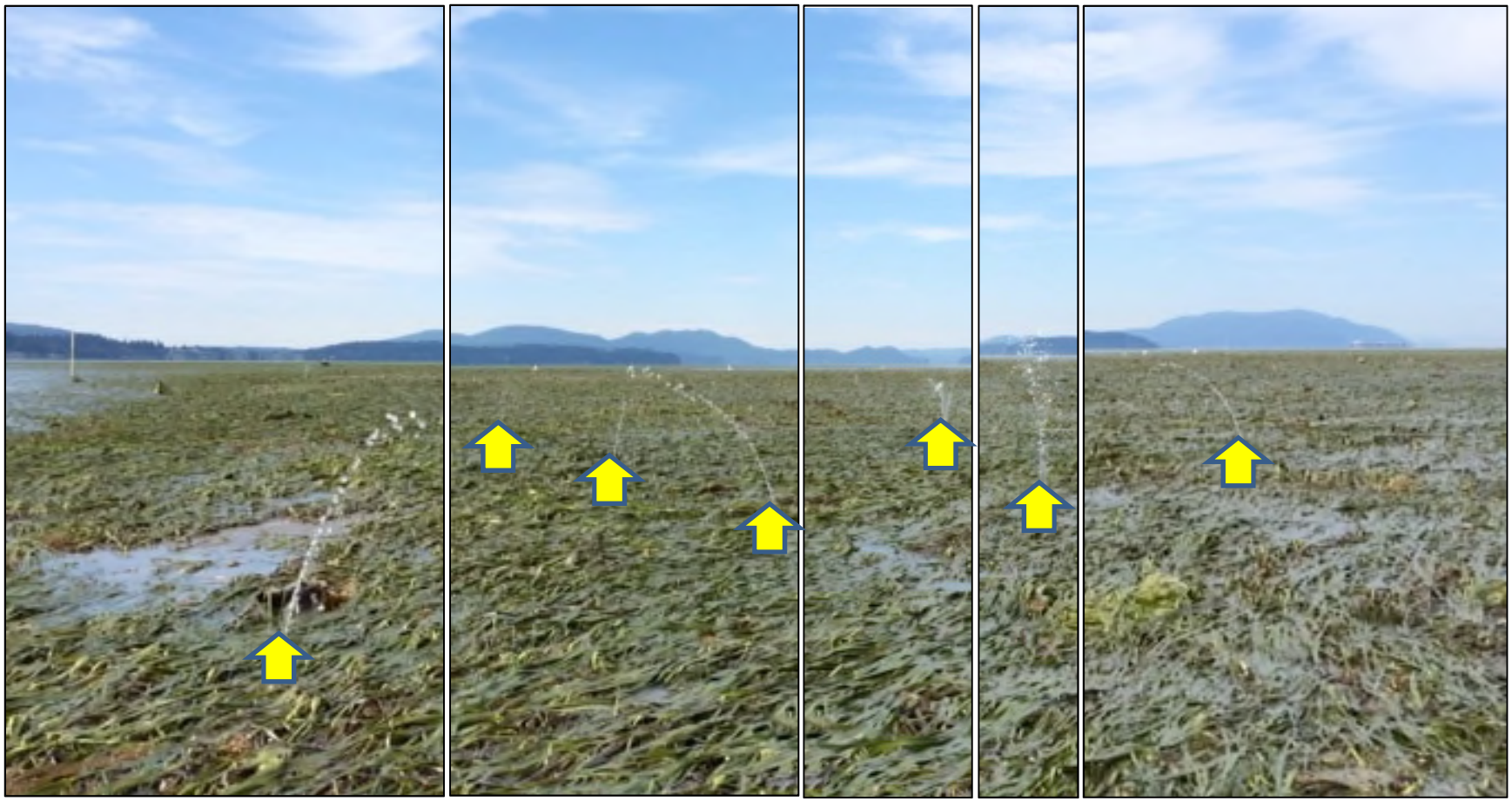


Figure 10 Potential Ecosystem Service (Reduced Desiccation) Provided by Geoduck Aquaculture to Native Eelgrass

Notes: Arrows indicate geoduck expelling water onto the adjacent eelgrass bed.

Source: Dewey (pers. comm., 2015)

Support of the Food Web

Eelgrass and kelp (i.e., SAV) are common perennial aquatic plants that create three-dimensional habitat structure and form extensive intertidal and subtidal beds in estuaries and coastal areas. These beds are an important component of coastal ecosystems because they stabilize coastal sediments, provide direct and indirect food sources for marine species, and provide nursery habitat for many marine species (Phillips 1984, Short et al. 2000, DNR n.d.). Because eelgrass and kelp are autotrophs, which means that they produce complex organic compounds (e.g., carbon-based solid) from simple substances present in the surrounding environment (e.g., light and nutrients), many ecosystem functions of plants cannot be replaced by higher trophic organisms, such as shellfish. That said, many of the cultured shellfish crops, with the exception of triploid oysters, spawn several times before reaching harvest size. These events produce billions of planktonic larvae, the vast majority of which are consumed by predators.

In addition, structured habitat (both eelgrass and shellfish aquaculture plots) can result in a higher abundance of prey organisms. Hosack (2003a) reported that important fish prey, such as harpacticoid copepods, exhibited an inverse trend with higher densities in both dense eelgrass and oyster habitats. These observations parallel those of Ferraro and Cole (2007, 2011, 2012), from oyster bottom culture in Yaquina Bay, Oregon, Willapa Bay, Washington, and Grays Harbor, Washington. The authors reported similar species abundance and richness in benthic macrofaunal communities between native eelgrass and oyster habitat in the three areas studied. Both eelgrass and oyster habitats had significantly more prey resources than mudflat or sandy habitats. This serves to illustrate the relative importance of eelgrass and shellfish-rich habitat in coastal estuaries as refugia and a source of prey for foraging nekton and other marine life.

A recent study by Dumbauld et al. (2015) studied whether intertidal oyster aquaculture in Willapa Bay effects the distribution and feeding ecology of juvenile salmonids. The study identified no significant differences in the density of juvenile salmonids caught in the four habitat types analyzed (undisturbed open mudflat, seagrass, channel habitats, and oyster aquaculture), and few significant associations with the prey items that the fish consumed. The majority of salmon found over low intertidal habitats were not dependent on structured habitat (e.g., eelgrass or oyster aquaculture) for prey items. Chum salmon was the possible exception, which is typically a smaller fish during estuarine residency. The final conclusion by Dumbauld et al. (2015) was that: "Permanent or 'press' disturbances like diking marshes, dredging and filling shallower estuarine habitats and even hardening shorelines would be expected to have significant impacts for other stocks and life history variants with smaller juveniles that utilize upper intertidal areas (Fresh 2006; Bottom et al. 2009), but our research suggests that short term 'pulse' disturbances like aquaculture which alter the benthic substrate in lower intertidal areas used primarily by larger juvenile salmon outmigrants may pose a less significant threat to maintaining resilience of these fish populations."

Finally, McDonald et al. (2015), included observations of fish species and groups associated with PVC tubes and nets, including flatfish, demersal fish, and surfperch (discussed in more detail below). The results of the McDonald et al. (2015) study were incorporated into a recent

model for central Puget Sound that looked at the effects of geoduck aquaculture on food web ecology (or predator-prey interactions). This effort reported that a 120% increase in the current level of geoduck culture would result in substantial increases in biomass densities of surfperch, nearshore demersal fish, and small crabs, and decreases in great blue herons, bald eagles, seabirds, flatfish, and certain invertebrates (e.g., predatory gastropods and small crustaceans) (Ferriss et al. 2015). The results were based on the mediating function in the Ecopath with Ecosim (EwE) model, which to a certain extent forced the entire food web to use the resources associated with the geoduck farms rather than more broadly. When this was not the case (e.g., without the mediating function), there was no change in the food web ecology associated with central Puget Sound. Based on a recent conversation with the authors, it was understood that the Ferris et al. (2015) paper was intended as a way to identify new research priorities and potential pathways of effect, and was not intended to be used as a way to represent realistic impacts from an increase in gear associated with geoduck aquaculture operations.

Preikshot et al. (2015) developed a similar EwE model, but for south Puget Sound with parameters extracted from observations during the period 1970 to 2012, and not using the mediation functions in the same manner as Ferriss et al. (2015). This parameterized model by Preikshot et al. (2015) was used to evaluate the potential effects of growth in shellfish aquaculture on other aspects of the food web. The model forecasted various scenarios through 2054, and the scenarios that included a 10-fold expansion of shellfish aquaculture (oysters, mussels and geoduck clams) was unlikely to significantly influence the biomass of other species. While such ecosystem models can identify biomasses of ecosystem components, they are not an effective mechanism for identifying the mechanism for biomass change and the cause of that change may be due to processes outside of the modelled area (e.g., salmon life stages that occur beyond the modelled area). That said, the model identified few negative feedbacks associated with bivalve aquaculture. Overall, the study suggested that shellfish aquaculture, as presently configured and even with a significant expansion of culture activities, is benign or beneficial to most species.

Habitat Structure (Density-Dependent)

A significant benefit offered by shellfish aquaculture is the ability to provide nursery habitats that create transitional zones between mudflats and SAV habitat. One of the most comprehensive analyses of the attributes relevant to identifying the role of nursery habitat was performed by Heck et al. (2003). The authors conducted a meta-analysis of more than 200 papers that compared seagrass beds to other habitats, and examined the data using the attributes suggested by Beck et al. (2001) for defining the ecological processes operating in nursery habitats, including: density, growth, survival, and migration to adult habitat. The results indicated that few significant differences existed between the relevant attributes when seagrass meadows were compared to other structured habitats, such as oyster reefs, cobble reefs, or macroalgal beds. The most important determinant of nursery value was the presence of structure rather than the type of structure.

What does appear to be an important determinant in terms of the quality of habitat provided is density and diversity. Optimal foraging/movement and fitness strategies depend on a mosaic of different habitats, and edges or transitional zones between two habitat types often represent areas with increased biological diversity (Holt et al. 1983, Orth et al. 1984, Boström et al. 2006). For example, several species of fish are found in higher densities in patchy eelgrass beds versus continuous dense beds (Orth et al. 1984). Holt et al. (1983) suggested that some species of fish require open feeding areas and refuge areas in the same location, and that patchy vegetation with a high percentage of edges may support higher densities of mobile foraging species.

The observations of edge effect are partially supported by a recent study in Humboldt Bay, California, by Pinnix et al. (2013). The study used acoustic transmitters that were surgically implanted into out-migrating coho salmon (*Oncorhynchus kisutch*) smolts. During their residency in Humboldt Bay, coho smolts primarily used deep channels and channel margins. They were detected near floating eelgrass mats adjacent to the channels, but not over eelgrass beds. The results from this study potentially emphasize the importance of edge habitat and the need for structural heterogeneity during salmonid residency and migration through the estuary.

In terms of prey resources, similar to that reported above, Tanner (2005) found epifauna, such as tanaids and gammaridean amphipods (i.e., typical salmonid prey items), exhibited significantly higher abundances at sand/seagrass edges versus seagrass bed interiors. Similarly, Hirst and Attrill (2008) determined that eelgrass patches, regardless of size or number of plants, were found to support a higher level of biodiversity than surrounding sand habitats. Thus, it could be argued that modest displacement of eelgrass resulting in some patchiness may be neutral or beneficial for certain species, such as salmonids, provided that an abundance of eelgrass was present in the surrounding environment to ensure that none of the other ecological functions provided by eelgrass were significantly reduced.

Ancillary Benefits

In addition to direct beneficial interactions between shellfish aquaculture and eelgrass, the presence of aquaculture within an embayment or watershed may provide indirect benefits to SAV through a variety of mechanisms. The aquaculture industry is inherently reliant on the maintenance of good water quality conditions to ensure the safety and survival of their product. Because of this incentive, there are numerous examples of actions taken by aquaculture companies and their supporters that result in improvements to water quality and/or the prevention of anthropogenic activities threatening water quality and habitat function in areas were aquaculture occurs (Dewey et al. 2011).

Examples of some ancillary benefits of the shellfish aquaculture industry include:

- Working with local jurisdictions and regulators to identify and eliminate point and non-point source pollution, including agricultural, industrial, and municipal discharges.
- Participating and providing input on regulatory updates to ensure that high water quality standards are included in local, state, and federal policies.

- Lobbying state and federal legislatures for improvements to water quality and developing water quality standards (e.g., shellfish industry contribution to the enactment of the Clean Water Act in 1972).
- Maintaining ownership or leases of large aquatic areas and upland, thereby eliminating the risk of environmentally deleterious uses.
- Participating in and collecting water quality samples as part of monitoring programs with federal and state agencies (e.g., National Shellfish Sanitation Program) to track water quality trends and identify areas targeted for improvement. These efforts have directly resulted in numerous areas now being determined suitable for shellfish harvesting and have provided data for other target areas with opportunities for improvement.
- Donating to local and state organizations to improve water quality conditions within the estuaries that shellfish aquaculture occurs.
- Organizing and participating in beach cleanup events that collect marine debris from both shoreline development and shellfish aquaculture operations.
- Actively engaging in efforts to quickly remediate and clean up oil spills and other hazardous waste sites to protect water quality and the health of shellfish.
- Encouraging shellfish gardening through sponsored seed and gear sales (e.g., Taylor Shellfish annual events in Washington State). Shellfish gardening encourages land owners to learn about the importance of maintaining properly functioning septic systems, controlling pet and domestic animal wastes, and the fate of herbicides and pesticides from lawns and gardens.

Summary of Natural SED and Concurrence with Programmatic Consultations

Shellfish aquaculture can have both positive and negative interactions with the surrounding environment. However, in combination with avoidance, conservation, and minimization measures, a well-managed farm can result in a net positive (or at least neutral) effect to ecological functions. Some of the positive effects to ecological functions include improvements to water quality. Current research hypothesizes that the presence of shellfish aquaculture may be a factor in lowering the risk of eutrophication (i.e., excess nutrients) within south Puget Sound inlets, including locations such as Case Inlet in Pierce County. While there are changes associated with culture activities, those changes do not occur at an intensity and frequency that would adversely impact a Natural SED. In fact, most of the locations where historical shellfish aquaculture operations occur were designated as a Natural SED 10 to 30 years after activities began in that estuary. Even more relevant, lands designated under the Bush Act were chosen in 1895 because of the value related to commercially growing bivalves. Most of these areas have now also been designated as Natural or Conservancy SEDs. Prohibiting shellfish aquaculture in these areas would directly conflict with this previous legislation.

The finding of benign to beneficial ecological effects are consistent with, and supported by, state-wide analyses of shellfish aquaculture by the Corps and the Services (USFWS and NMFS)

conducted under the NWP 48 consultation for Endangered Species Act (ESA) listed species, critical habitat, and essential fish habitat (EFH) for the State of Washington (NMFS 2009, USFWS 2009, NMFS 2011, Corps 2012). According to the Corps (2012), the basis for reissuing NWP 48 for both existing and new shellfish farms was because, "properly sited, operated, and maintained commercial shellfish aquaculture activities support populations of shellfish that provide important ecological functions and services for coastal waters, and should be authorized by a single NWP." In order for the Corps to authorize activities under a Nationwide permit, the activities need to individually and cumulatively have minimal adverse impacts to the aquatic environment (33 CFR § 322.2[f]). As part of the NWP issuance and renewal process, the Corps is required to analyze activities likely to be approved under NWPs and support the regulatory standard for NWPs to result in individually and cumulatively minimal adverse impacts. The Corps issued the original NWP 48 in 2007, and then subsequently reauthorized NWP 48 in 2012 based on meeting this standard.

Similarly, the ESA consultation evaluating potential effects of aquaculture to ESA-listed species and designated critical habitat determined that shellfish aquaculture activities in Washington State (including those in Pierce County) represent effects that are limited in space (typically the aquaculture plot with some minor spillover) and duration (activities occur over a 1- to 2-year culture cycle or longer), and they are "not likely to adversely affect" fish or critical habitat (NMFS 2009, USFWS 2009, NMFS 2011). A determination of "not likely to adversely affect" is synonymous with effects that are discountable and insignificant. There were minor exceptions to this determination, such as use of carbaryl in Grays Harbor and Willapa Bay, but those exceptions are not relevant to south Puget Sound where carbaryl is not used. Both the analyses and conclusions of the Corps and the Federal Services are consistent with the recognition that shellfish aquaculture has a minimal adverse effect on the aquatic environment.

These recommendations are consistent with the recognition that effects to aquatic habitat upon which managed species rely is minimal. In typical situations, the grower can provide ways in which to further minimize potential effects, such as limiting the amount of gear present in any one year, diversifying gear type, and minimizing the use of predator exclusion netting.

Finally, ancillary benefits to having aquaculture within an estuary is the presence of an industry that is dependent on good water quality conditions. In numerous examples, this has resulted in improvements to ecosystems to attain the goal of supporting commercial shellfish aquaculture operations. In summary, the criteria used to designate a Natural SED is mutually sustainable with existing shellfish aquaculture operations, which is in agreement with conclusions made by regulatory agencies for Washington state shellfish aquaculture operations.

3.2.3 Research within Historical Farms of Pierce County

Multiple farms in Pierce County have been the subject of intense research as well as other surveys for permitting documents. This information further emphasizes the point that current shellfish aquaculture operations are consistent with the management policies of a Natural SED.

Case Inlet Research

Multiple Case Inlet farms were part of the Washington Sea Grant-funded work that looked at the effects of two phases of geoduck aquaculture (planting and harvest) on benthic invertebrates, Pacific staghorn sculpin (*Leptocottus armatus*), and water quality. The following includes a description of the major results from each of the four studies of the Sea Grant-funded research, broken down into planting effects and harvest effects.

Planting Effects:

- McDonald et al. 2015 (published in Journal of Shellfish Research in April 2015)
  - Typical patterns for transient macrofauna (transient macrofauna = crabs, sea stars, fish) significantly favor structure-associated species when gear is present; patterns of abundance were similar to reference plots after gear was removed.
  - The provision of foraging and refuge habitat is the primary reason for the attraction to the aquaculture gear, especially for smaller fish and crabs.
  - The increased foraging pressure by transient macrofauna may explain the slightly depressed densities of resident macrofauna (resident macrofauna = amphipods, polychaetes, shrimp).
  - There were no consistent differences in the benthic infaunal or epifaunal communities between reference plots and culture plots.
  - Difference in the community composition between the culture and reference plots when gear was present did not persist after gear was removed.
  - Effects from gear were considered short-term with a short recovery period.
- McPeek et al. 2014 (published in Estuaries and Coasts on-line in November 2014)
  - Study tagged and measured >1000 sculpin/plot, although the recapture rate was only about 5% due to ability of fish to hide within the tube field during beach seining. Because Pacific staghorn sculpins are so ubiquitous in south Puget Sound, diet may reflect composition of the local benthic invertebrate community.
  - While geoduck aquaculture gear results in some changes in staghorn sculpin prey, it does not appear to alter the types of food webs that sculpin exploit.
  - The lack of differences between cultured and reference plots in the stable isotope data was corroborated by the results of sculpin fitness metrics, which showed no differences between the plots for sculpin gut fullness or body condition.

Harvesting Effects:

- VanBlaricom et al. 2015 (published in Journal of Shellfish Research in April 2015)
  - The most significant effect on the benthic infaunal community was natural seasonal and spatial abundance patterns.
  - This natural variation was consistent with previous studies that found substantial variation in benthic assemblages within intertidal sandflats in Puget Sound, which is especially true of Case Inlet (e.g., Dethier et al. 2003, Dethier and Schoch 2005) where the Haley Beach site is located.

- There was little evidence of effects on community structure associated with geoduck harvest activities within cultured plots, and no indication that harvest effects extended beyond the cultured plot.
- While there were modest effects for individual species, these effects persisted for a maximum of four months, and the community overall remained unchanged between harvest and reference plots.
- The authors suggested that the relatively active natural disturbance regime of Puget Sound that occur at comparable intensity but more frequently than harvest events contributes to the benthic infauna experiencing insignificant impacts and quick recovery.
- For example, the frequency of small-scale disturbances (e.g., winter storm) is 1,000x more significant than the disturbance from a geoduck harvest event and occurs more frequently in one area (3-4 per decade).

- Cornwell et al. *in review* (may be published in Aquaculture)
  - Examined nutrient pore water chemistry of geoduck and reference sediments, sediment-water exchange rates of nutrients, and the release of nutrients during harvest.
  - The study found that the cultivation of geoducks at even high densities (~15 m^{-2}) leads to generally low to moderate levels of accumulation of inorganic nitrogen, phosphorus, and silica in the pore waters of the sediment.
  - The authors indicated that the feeding mode of geoducks means that there is not a major way to get particulate or dissolved water incorporated directly within the sediments. However, bioturbating infauna (e.g., amphipods and polychaetes) likely rapidly incorporate this material into the sediment.
  - The harvest release of nitrogen (primarily as ammonium) represents about 0.001% of the daily annual load of nitrogen from wastewater or riverine inputs when considering all cultivated geoduck harvest in south Puget Sound on a daily basis, which was considered to be an "inconsequential fraction of the Puget Sound nutrient balance."
  - This release of ammonium would not stimulate an algal bloom, and the magnitude of nutrients overall is small compared to new anthropogenic nutrient inputs into Puget Sound.

Burley Lagoon Research

Multiple studies and surveys have been conducted in Burley Lagoon or adjacent to Burley Lagoon. These studies are particularly informative, as the tidelands in Burley Lagoon were deeded under the Bush Act for the purpose of shellfish cultivation, and Burley Lagoon tidelands have been actively farmed for over 80 years. These studies and surveys include water quality studies, eelgrass surveys, sediment surveys, flow studies, benthic invertebrate surveys, and Pacific herring spawner surveys. The studies have been conducted by both private consulting and government agencies. Overall, research in Burley Lagoon has documented the diversity of habitat conditions and many improvements in the health of the system, especially

related to water quality (e.g., Newton et al. 1998, Morley 2000, KCHD 2001, Alberti and Bidwell 2005, DOH 2012, Pierce County 2013, KPHD 2015, Snyder 2015). There are also many existing challenges to water quality in Burley Lagoon, including an increase in shoreline development that results in nutrient input from on-site septic systems (OSS) and stormwater input from impervious surface area (SPSCG 2008).

One of the indicators of ecosystem health are the presence of a healthy forage fish population. Henderson Bay and Burley Lagoon support a herring stock (Purdy Herring Stock) that was first identified in 2008 (Stick et al. 2014). There are no confirmed trends in the stock associated with this area, but spawning has been relatively consistent since 2008. More importantly, the shellfish aquaculture operation in Burley Lagoon does not appear to be affecting the presence of herring or spawn deposition.

In a recent modeling study (Preikshot et al. 2015), the potential for a 10-fold increase in shellfish aquaculture production in south Puget Sound from 2012 to 2054 was evaluated in terms of effects within the food web (as discussed in Section 3.2.2 above). Herring was one of the focal species modeled, and results of the model appear to be consistent with showing a neutral effect on the herring population from shellfish aquaculture. Herring biomass increased by at least 50% in most of the ecosystem scenarios simulated except for a doubling of jellyfish biomass. In general, herring maintained a robust population in modeled simulations.

3.2.4 Factors that Affect Natural SEDs

An example of how shoreline development in Pierce County may have affected a Natural SED, but existing shellfish aquaculture has not, is in the Foss farm area of Key Peninsula. Figure 11 is a reproduction of the inset from Figure 3 focusing on the SED changes between 1975 and 2015. In comparing the 1975 SEDs to 2015 SEDs, it is apparent that locations outside of the farmed areas have changed from Natural or Conservancy SEDs to Residential SED. Conversely, areas associated with shellfish farms (i.e., Rogers Farm, Hibben Farm, Foss farm, Whiteman Cove) have all either maintained their designation or gone from a Natural to Conservancy SED.

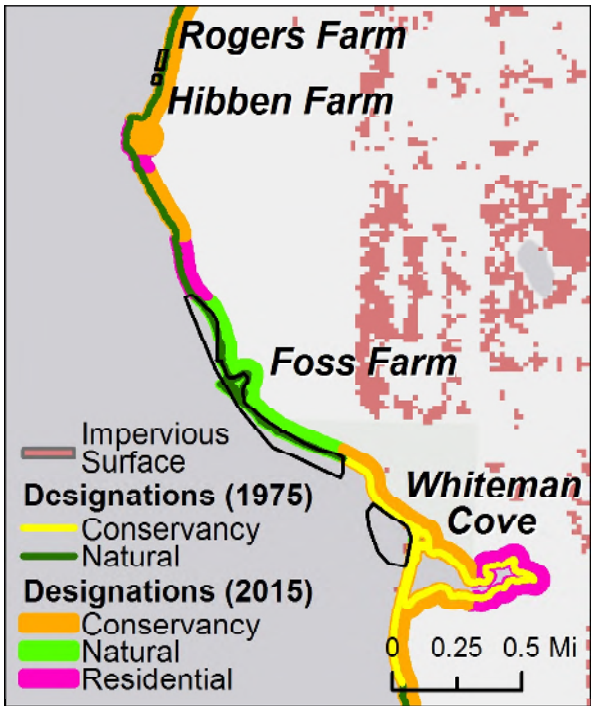


Figure 11 Shoreline Designations Associated with the West Side of Key Peninsula between 1975 and 2015

There is a direct correlation between shoreline development and down-grading shoreline designations, as discussed in PCC 18S.20.30. Increased shoreline development typically includes removal of riparian vegetation and replacement with buildings, landscaping, and increased impervious surfaces. Impervious surface is a main influence in increased drainage and sediment load because of the loss of floodplain and slope vegetation (Haring 2000, PSAT 2007). Impervious surfaces increase the flashiness[6] of the system, which causes more erosion and sediment inputs because there is less vegetation to hold sediment in place. Impacts to streams occur even at low levels of development (<2% impervious area), and degraded channel conditions are typically evident when impervious surfaces exceed 10% (Haring 2000, PSAT 2007, Squaxin Island Tribe 2012).

Other factors that affect Natural SEDs include bulkheads and hardened shorelines. The erosion of feeder bluffs is a principal source of sediment to the shoreline and adjacent beaches. Sediment input from feeder bluffs is disrupted by shoreline modifications, which will tend to impound sediment behind the structure and limit the amount of sediment supply within the transport cell associated with that feeder bluff (Shipman and Canning 1993, Johannessen and MacLennan 2007). Additionally, fine sediments around bulkheads are preferentially transported away, further limiting the sediment supply and changing the sediment size distribution within that localized area. According to the Pierce County Shoreline Inventory and Characterization Report (ESA Adolfson 2009), the example above that includes the Whiteman Cove shoreline (2.5 miles) is 28% modified with 64% of the reach mapped as vegetated. The portions of the shoreline that remain unmodified (by hardened shorelines) are associated with the shellfish farms. Therefore, while shoreline development associated with residential structures can degrade the shoreline and affect the Natural SED designation, shellfish farms appear to maintain conditions associated with this designation.

In contrast, the Foss farm is the largest geoduck farm in Pierce County and has been in place for over 15 years. It was installed under the current Natural designation, and given how long it has been in place, if shellfish farming actually degraded or compromised the Natural SED characteristics, then it would have done so by now. The fact that Pierce County designates the upland areas as Natural confirms that aquaculture, under criteria established for the SMP, is an appropriate use in the abutting aquatic area that does not harm the Natural SED.

3.2.5 Summary of Interactions between Shellfish Aquaculture and Natural SED

Based on the information presented above, there is both a lack of justification for a prohibition of aquaculture within and abutting the Natural SED and extensive information that demonstrates that shellfish aquaculture is consistent with, and does not compromise, the Natural SED setting.

6 The "flashiness" of a stream reflects how quickly flow increases and decreases during a storm.

3.3 Nisqually Reserve Prohibition

This sub-section is responding to **PCC 18S.40.040(C)(17)**: "With the exception of Olympia Oyster propagation which is a conditional use, new commercial shellfish aquaculture operations are prohibited within the Nisqually Reach Aquatic Reserve."

The Nisqually Reach Aquatic Reserve (Nisqually Reserve) encompasses nearly 15,000 acres of DNR-managed tidelands and bedlands. It was designated as a reserve in 2011, and has a 90-year reserve term (DNR 2011). It extends from the Nisqually National Wildlife Refuge to the south up to McNeil Island to the north (Figure 12). It is primarily in Pierce County, although a portion is in Thurston County.

3.3.1 Management Goals of the Nisqually Reserve

DNR Aquatic Reserves can be environmental, scientific, educational, or a combination of these. The Nisqually Reserve was designated as all three types, and is guided by a management plan to support the preservation of the habitats and species identified for protection (DNR 2011). The management plan also promotes public stewardship of the area. There are five goals of the management plan:

- **Goal One:** Preserve, restore and enhance the aquatic nearshore and subtidal ecosystems with a special emphasis on native habitats for forage fish, salmonids, and waterbirds.
- **Goal Two:** Protect and restore the functions and natural processes of nearshore, deepwater, and open water ecosystems within and adjacent to the reserve.
- **Goal Three:** Promote stewardship of riparian and aquatic habitats and species by supporting and providing opportunities for outdoor education, scientific research including Citizen Science and interpretive studies.
- **Goal Four:** Promote sustainable management of traditional recreational (e.g., boating, water skiing, fishing), commercial and cultural water-dependent uses in and adjacent to the site in a manner consistent with the goals for the reserve.
- **Goal Five:** Support the recovery and protection efforts for federal and state threatened and endangered species, species of special concern and their habitats.

The Nisqually Reserve management plan both allows for continued use of existing activities, as well as new uses that are consistent with the reserve's goals, objectives, and management actions. According to the management plan (DNR 2011), this includes low intensity shellfish aquaculture and Olympia oyster restoration activities.

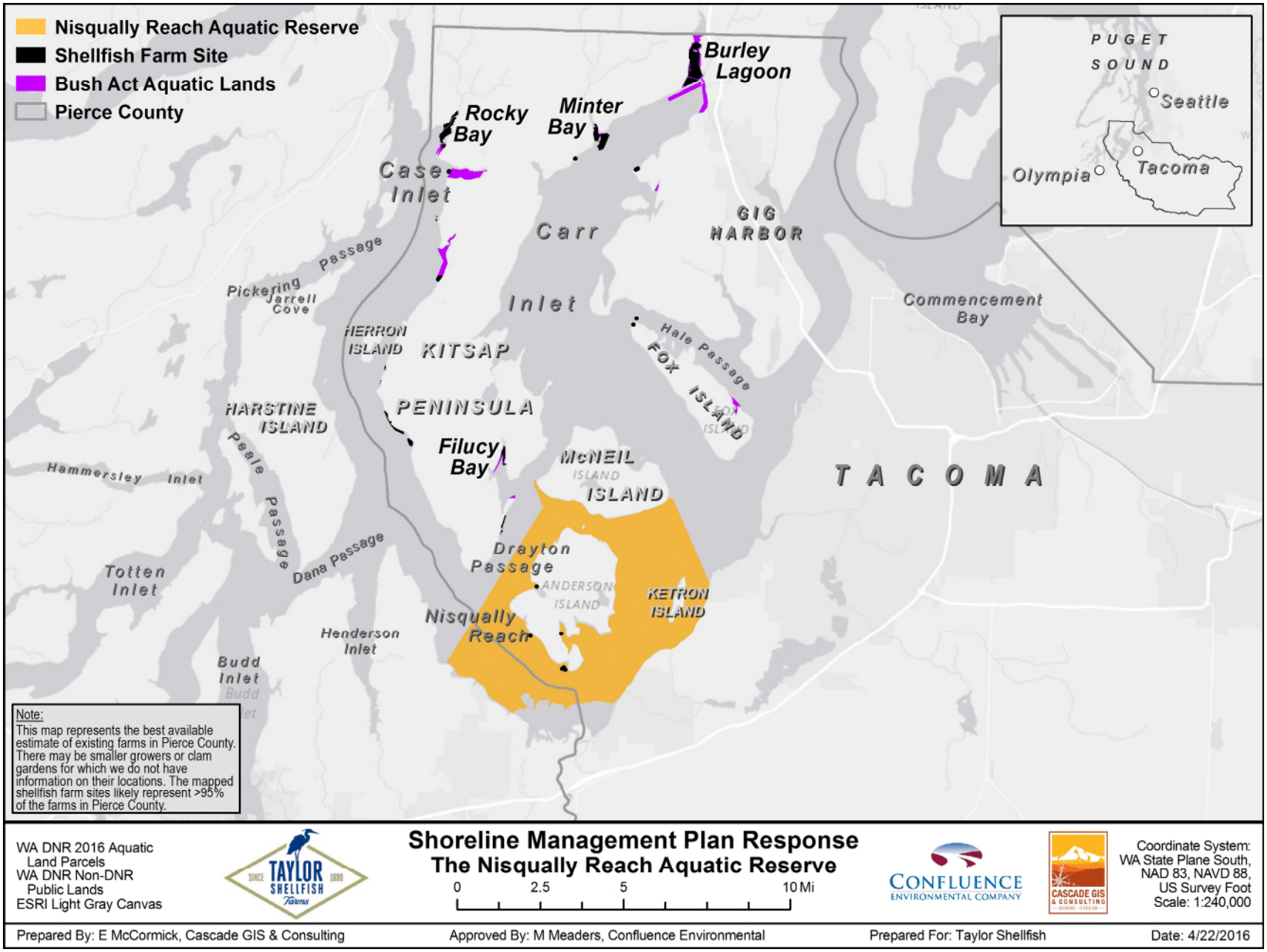


Figure 12 **Nisqually Reach Aquatic Reserve Relative to Shellfish Aquaculture in Pierce County**

3.3.2 Sustainability of Shellfish Aquaculture in the Nisqually Reserve

The Nisqually Reserve management plan both allows for continued use of existing activities, as well as new uses that are consistent with the reserve's goals, objectives, and management actions. There is existing aquaculture occurring within the Nisqually Reserve. It is located on the west and south sides of Anderson Island and includes geoduck, oyster, and FLUPSY operations (DNR 2011, Figure 13). The criteria for new shellfish aquaculture or Olympia oyster restoration activities is similar to a Natural SED:

> Protection of aquatic resources within the Nisqually Reach Aquatic Reserve is primarily achieved by restricting DNR authorizations that may harm, alter the naturally occurring condition, or further degrade sensitive and unique aquatic resources within the reserve and ensuring re-authorization and new use authorizations are consistent with the goals, objectives and management actions of the Nisqually Reach Aquatic Reserve Management Plan.

The review associated with shellfish aquaculture within a Natural SED (Section 3.2) are relevant to the Nisqually Reserve. DNR (2011) has already determined that shellfish aquaculture is a sustainable use of the Nisqually Reserve, and has indicated in a Marcy 11, 2016 letter that this prohibition on aquaculture goes against the management goals and best available science, and should therefore be removed.

3.4 Estuary and Tidal Channel Prohibition

This sub-section is responding to the following PCC sections:

- **18S.40.040(C)(18):** "Aquaculture is prohibited in Estuaries within 300 feet of the mouth of freshwater streams (as measured at extreme low tide)."
- **18S.40.040(G)(1):** "Aquaculture activities shall not be located within tidal channel portions of streams and rivers with direct utilization by anadromous species."

Based on the definition of an estuary shoreline from PCC 18S.40.040(C)(18), Figure 13 presents the freshwater streams in Pierce County and the associated estuary shorelines (within 300 ft of extreme low tide). However, the definitions in the PCC and associated prohibitions of shellfish aquaculture is both flawed and unsupported by the literature.

3.4.1 Definition of an Estuary and Tidal Channel

Most streams in Pierce County are small, perennial streams with direct discharges to Puget Sound (ESA Adolfson 2009). Most of these streams do not have an estuary, are non-fish bearing, and have limited reaches that are essentially considered marine waters as soon as they outfall into south Puget Sound. Larger streams have small estuaries with a limited mixing zone between the freshwater input and tidal influence from Puget Sound (Figure 14). Sediment transport in small estuaries is driven primarily through a mixture of fluvial processes and tidal flows (Shipman 2008, Schlenger et al. 2011), which is different than the wave-driven processes typical of barrier estuaries and bluff-backed beaches.

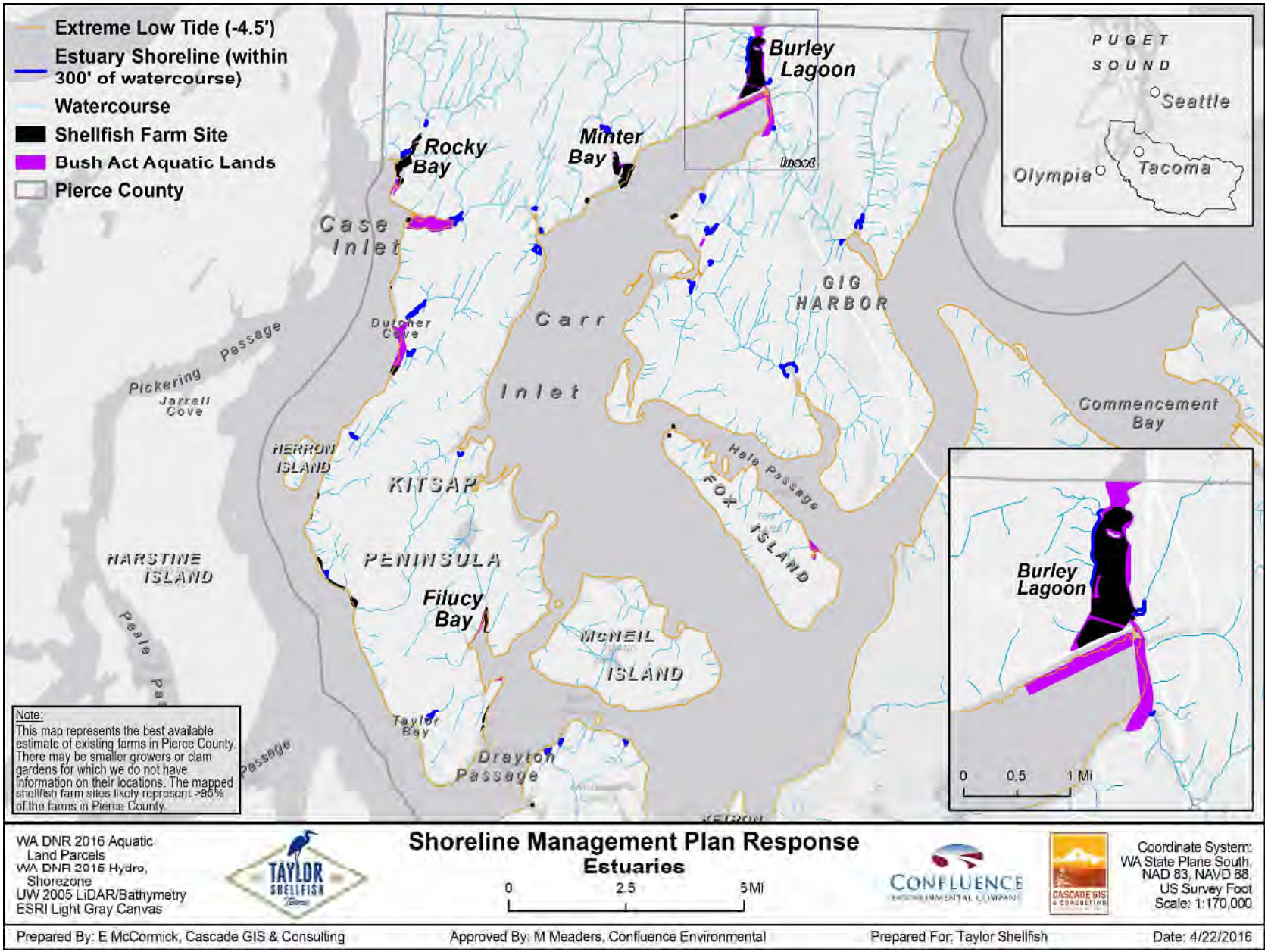


Figure 13 Estuarine Shorelines within 300 feet of a Freshwater Stream in Relation to Shellfish Farm Sites and Bush Act Aquatic Lands in Pierce County, Washington

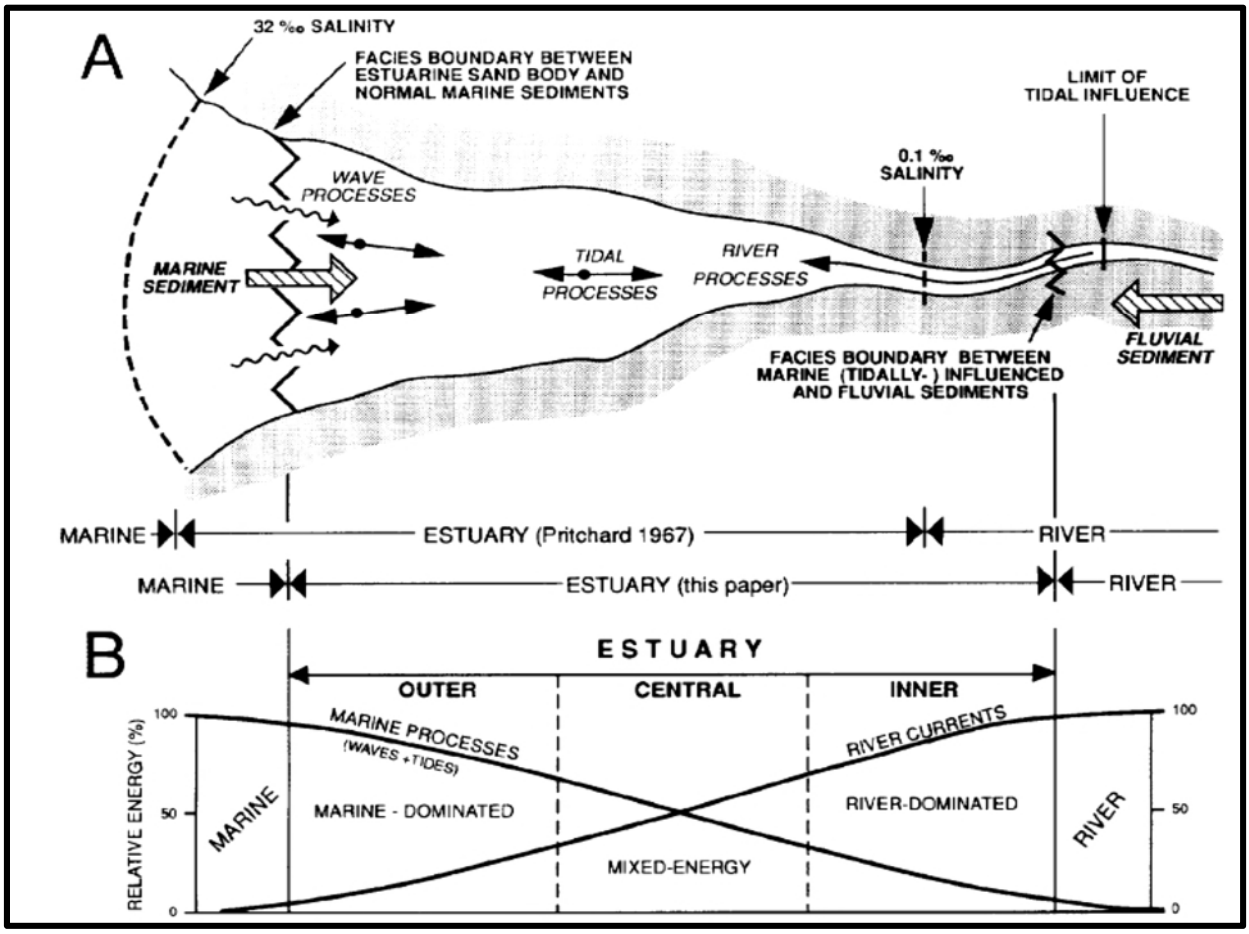


Figure 14 Definitions of an Estuary According to Pritchard 1967 (A) and Distribution of the Physical Processes Operating within an Estuary (B)

Source: Dalrymple et al. 1992

In the transition region between marine-dominated processes and river-dominated processes (Figure 14B), there is a preference for fine-grained material to settle out along the margins of the channel while coarser sediments (e.g., gravel and sand) are present within a single dominant (main) channel or tidal channel (Dalrymple et al. 1992). The perimeter/margins of the tidal channel are submerged during high tides. These submerged channel margins exhibit a reduction in current velocity relative to the current in the channel, which allows finer materials (e.g., silt and fine sand) to settle out of the water column, promoting deposition of fine-grained sediment. Higher velocities (both tidal and fluvial) promote scour and serve to develop and maintain a dominant channel in the areas landward (upstream) from the location of typical shellfish farms.

3.4.2 Species Use of Estuary/Tidal Channel

Anadromous salmonids are the primarily species that use both estuaries and tidal channels. There are seven species (and a few runs) of anadromous salmonids in Pierce County: Chinook

salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), steelhead (*O. mykiss*), sockeye salmon (*O. nerka*), pink salmon (*O. gorbuscha*), and bull trout (*Salvelinus confluentus*). However, current returns of Chinook salmon are attributed to releases from hatcheries (PSIT and WDFW 2010), and three species (sockeye salmon, pink salmon, and bull trout) use the Puyallup and Nisqually rivers but not the smaller drainage that are more prevalent in Pierce County (Table 3). The timing and use by salmonids is highly variable, and depends on the species and run of salmon. Chum and coho salmon are the anadromous species most commonly found in the type of stream typical of Pierce County.

If large enough, the tidal channels in Pierce County freshwater systems serve as migration and/or nursery zones for anadromous fish. The portion of a stream that is used for migration and/or nursery habitat by salmonids is morphologically and functionally different than the intertidal areas where shellfish aquaculture occurs. A fluvial- or river-dominated system has a well-defined main channel with water flowing upstream or downstream within the channel throughout a typical tidal cycle (Dalrymple et al. 1992). These areas can provide migration corridors for juvenile salmonids when they are present in the system. The length of time juvenile salmon migrants remain in a specific location along the shoreline is generally short. Outmigration studies in Hood Canal indicated travel distances for juvenile chum salmon ranged from about 4 to 14 km/day (2.5 to 8.75 mi/day) (Bax et al. 1980, Whitmus and Bax 1981).

3.4.3 Potential Impacts to Estuaries and Tidal Channels and Species Use

Migration along the shoreline is a major component of salmonid management concerns (NMFS 2009, USFWS 2009, NMFS 2011, Schlenger et al. 2011). Access to mid-sized and smaller streams have often been compromised by various human activities such as roads, railroad crossings, dikes, and shoreline armoring. Culverts under roads and railroads, among other human caused changes, are often a passage barrier to anadromous fish (Schlenger et al 2011).

Shellfish aquaculture activities do not constitute a barrier to anadromous fish during their migration to spawning or rearing habitat. Adult salmon typically remain in deeper water and the deepest portion of tidal channels where they are unlikely to encounter activities or structures related to shellfish aquaculture. Comparatively, juvenile salmon may encounter areas of aquaculture during their use of marine shorelines. These areas usually provide additional structure in the environment, and this structure can be beneficial to juvenile salmonids. For example, several studies have demonstrated that oyster culture areas provide similar productivity and aquatic food resources when compared to adjacent eelgrass meadows (Ferraro and Cole 2007, Ferraro and Cole 2011, Ferraro and Cole 2012). Further, marine invertebrates associated with shellfish gear from various studies in the Salish Sea (Puget Sound and the Strait of Juan de Fuca but not extending up to the Strait of Georgia) were both similar to the invertebrates found associated with eelgrass and included the same groups of invertebrates used by juvenile salmonids as food resources (Cross et al. 1978, Fresh et al. 1978, Fresh et al. 1979, Simenstad et al. 1980).

Table 3 Anadromous Salmonids Use of Streams and Rivers in Pierce County.

Water Body	Fall Chinook	Coho Salmon	Summer Chum	Fall Chum	Winter Chum	Winter Steelhead	Sockeye Salmon	Pink Salmon (odd year)	Bull Trout
Puyallup River	M, S, R	M, S, R		M, S, R		M	M	M	M
Nisqually River	M, S	M, S			M, S	M, S	M	M, S, R	M
Artondale Creek		M, S		M					
Burley Creek*	M, S, R	M, S	M, S	M, S		M			
Chambers Creek	P(B)	M, S	M	M	M	M			
Crescent Valley Creek	M	M, S		M, S		M			
Lockey Creek		M		M					
McCormick Creek									
Minter Creek	M	M, S		M, S		M			
North Creek		M, S		M, S		M			
Purdy Creek		M, S				M			
Red Salmon Creek	P(M)	M			M, S	M	P(M)	P(M)	
Rocky Creek	M	M, S	M, S	M, S		M			
Vaughn Creek				M					
Unnamed Stream 1		M, S		M					
Unnamed Stream 10		M							
Unnamed Stream 11		M							
Unnamed Stream 12		M		M					
Unnamed Stream 13		M		M					
Unnamed Stream 14		M		M					
Unnamed Stream 15		P(B)							
Unnamed Stream 16		M		M					
Unnamed Stream 17		P(P)							
Unnamed Stream 18		M							
Unnamed Stream 2		M		M					
Unnamed Stream 3		M, S		M					
Unnamed Stream 4		M		P(B)					
Unnamed Stream 5		M		M					
Unnamed Stream 6		M		M					
Unnamed Stream 7		M		M					
Unnamed Stream 8		M							
Unnamed Stream 9		M		M					

Source: WDFW 2016a; M = Migration, S = Spawning, R = Rearing, P(B) = Potential: Blocked, P(M) = Presence Modeled, P(P) = Presence Presumed
*Burley is in Kitsap County, but discharges into Burley Lagoon, which is in Pierce County

Based on radiotelemetry studies conducted by the USFWS (Brenkman et al. 2007), juvenile salmonids will orient to their perception of the bottom depth—whether that be relatively featureless sand, the top of culture tubes colonized with invertebrates, or the top of a predator exclusion net that is colonized with macroalgae. In other words, minor changes created by a shellfish gear will not be recognized in the same manner compared to an overwater structure or a structure that extends through the water column (Ward et al. 1994). Depending on the tidal cycle, fish can easily swim over, around, or through these structures, if necessary.

While nets can pose a risk to entanglement, the majority of cases for which this has occurred involves derelict commercial fishing gear (e.g., gill nets) that occur vertically in the water rather than horizontally on the sediment surface (e.g., Rueggeberg and Booth 1989, Laist 1997, Moore et al. 2007, Gregory 2009). Nets need to be properly maintained and secured on a regular basis in order to avoid negative interactions with fish or other macroinvertebrates, and this is a management practice that shellfish growers in Washington State capably perform.

In summary, as long as gear is properly maintained, aquaculture gear in the intertidal area is not expected to affect migration, access, or refugia pathways for juvenile fish that utilize shallow water. The presence of aquaculture gear may even serve as additional foraging habitat or cover from predators for smaller fish and invertebrates. In addition, the speed with which these fish are moving in their migration (miles/day) indicates that they would only encounter scattered aquaculture operations for a brief period since the extent of these areas are measured in feet or yards in length and not miles.

3.4.4 Sustainability of Shellfish Aquaculture in Estuaries/Tidal Channels

Section 3.2 provided an understanding of how shellfish aquaculture is a sustainable use of the environment in relation to Natural SEDs, and when managed appropriately, can result in a no-net-loss of ecological functions. The same discussion pertaining to the Natural SED is relevant to estuaries and tidal channels, many of which are also Natural SEDs. Some of the more salient points directly related to estuaries and tidal channels include:

- Shellfish aquaculture is a highly regulated activity (Section 3.1). Conservation measures related to estuaries/tidal channels include:
    - Unsuitable material (e.g., trash, debris, car bodies, asphalt, tires) shall not be discharged or used as fill (e.g., used to secure nets, create berms, provide nurseries).
    - Water quality and maintenance requirements within 150 ft of any stream, waterbody, or wetland.
    - No modification of the course of streams is allowed for new shellfish aquaculture developments.
- Shellfish aquaculture is dependent on excellent water and sediment quality conditions to be suitable for human consumption. Therefore, the presence of shellfish aquaculture has been a driving force in the clean-up of sources of contamination to both the freshwater and nearshore marine environment (e.g., failing septic systems).

- Shellfish aquaculture promotes clean water through the filtration of plankton and organic particles from the water column. This can help reduce phytoplankton blooms caused by excess nutrients in the runoff from the developed land in the watershed. These nutrients originate from a number of human sources, including the use of fertilizers in urban landscapes, septic systems, and rural agriculture.
- Shellfish aquaculture structure provides similar functions to other structure in the nearshore marine environment (e.g., eelgrass) through the support of invertebrate communities that are important prey resources for juvenile salmonids and other fishes that use these habitats as nursery and rearing habitat.
- Shellfish aquaculture operations do not inhibit the normal migration patterns of juvenile or adult anadromous salmonids.

In summary, we encountered no information that could justify the prohibitions on aquaculture in proposed PCC sections 18S.40.040(C)(18) and 18S.40.040(G)(1), and in fact current scientific and technical information demonstrates these prohibitions are inappropriate.

3.5 Residential Prohibition

This sub-section is responding to **PCC 18S.40.040(C)(19)**: "Aquaculture is prohibited adjacent to residential neighborhoods in Horsehead Bay, Wollochet Bay, Lay Inlet and adjacent to Raft Island due to water quality and visual impacts."

Shellfish aquaculture has a long history of being present in areas with residential development. Figure 15 shows the overlap of shellfish operations within residential SEDs. Although there is no current aquaculture in the residential areas of Horsehead Bay, Wollochet Bay, Lay Inlet or adjacent to Raft Island, there is Bush Act Aquatic Land in Lay Inlet, which was specifically designated for oyster culture (Figure 16, also see Section 1.1). More importantly, water quality and visual impact concerns do not provide a basis for prohibiting aquaculture.

The Ecology (2011a) SMP Handbook states that "The presence of water pollution, navigation channels, and residential neighborhoods are not automatic reasons to prohibit aquaculture." The best available science supports a conclusion that aquaculture can improve water quality (Section 3.2 above), and that aesthetic impacts are minimal from both intertidal and subtidal aquaculture gear (Section 3.5.2 below). Finally, growers conduct a number of conservation measures to maintain the aesthetic quality of the work areas (Section 3.5.3).

3.5.1 Water Quality

The sections below detail (1) how water quality is classified in Washington State, (2) Burley Lagoon as a case study for water quality, and (3) the benefits shellfish can have on water quality.

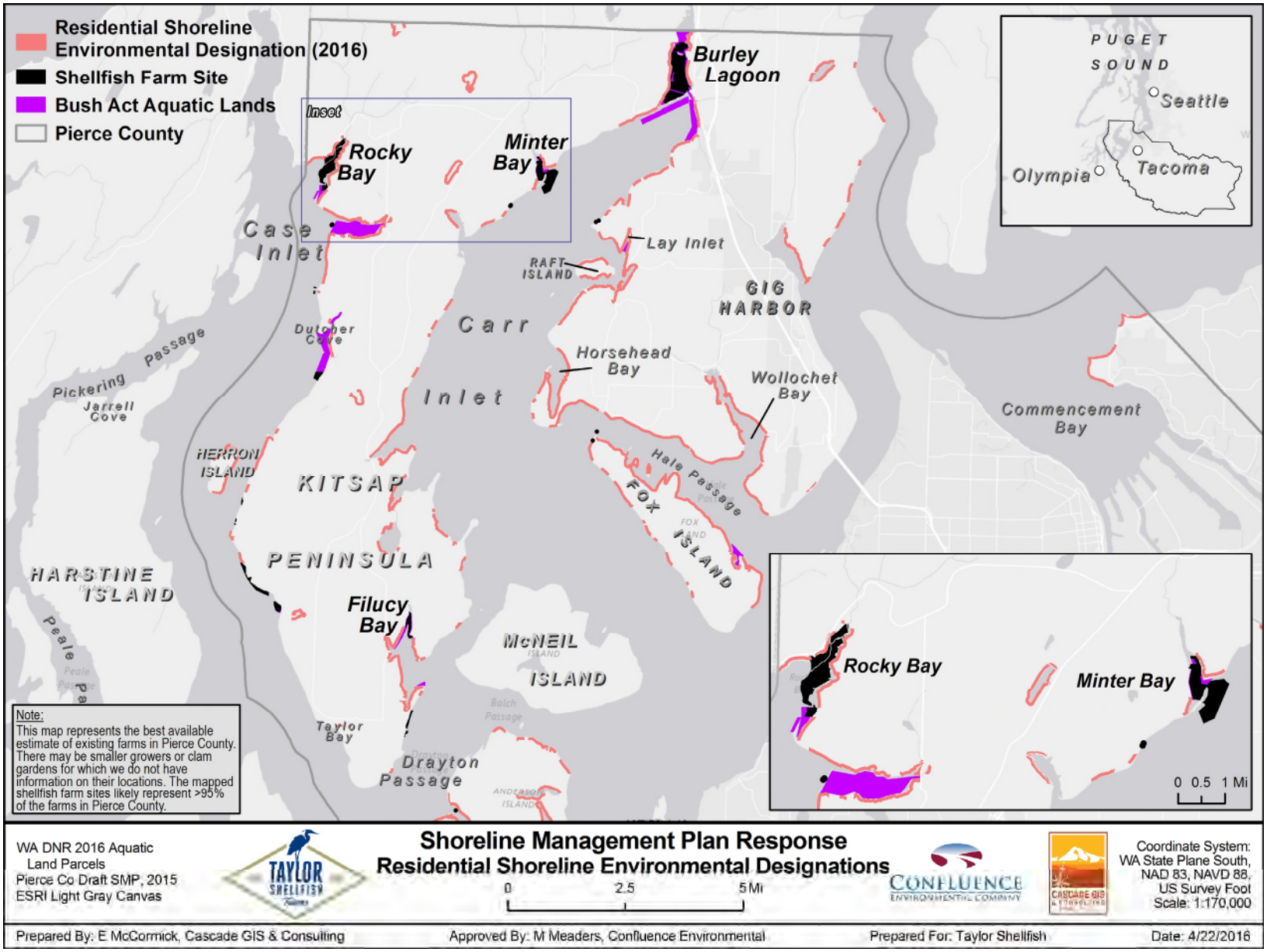


Figure 15 **Residential SED Relative to Shellfish Aquaculture and Bush Act Lands in Pierce County**

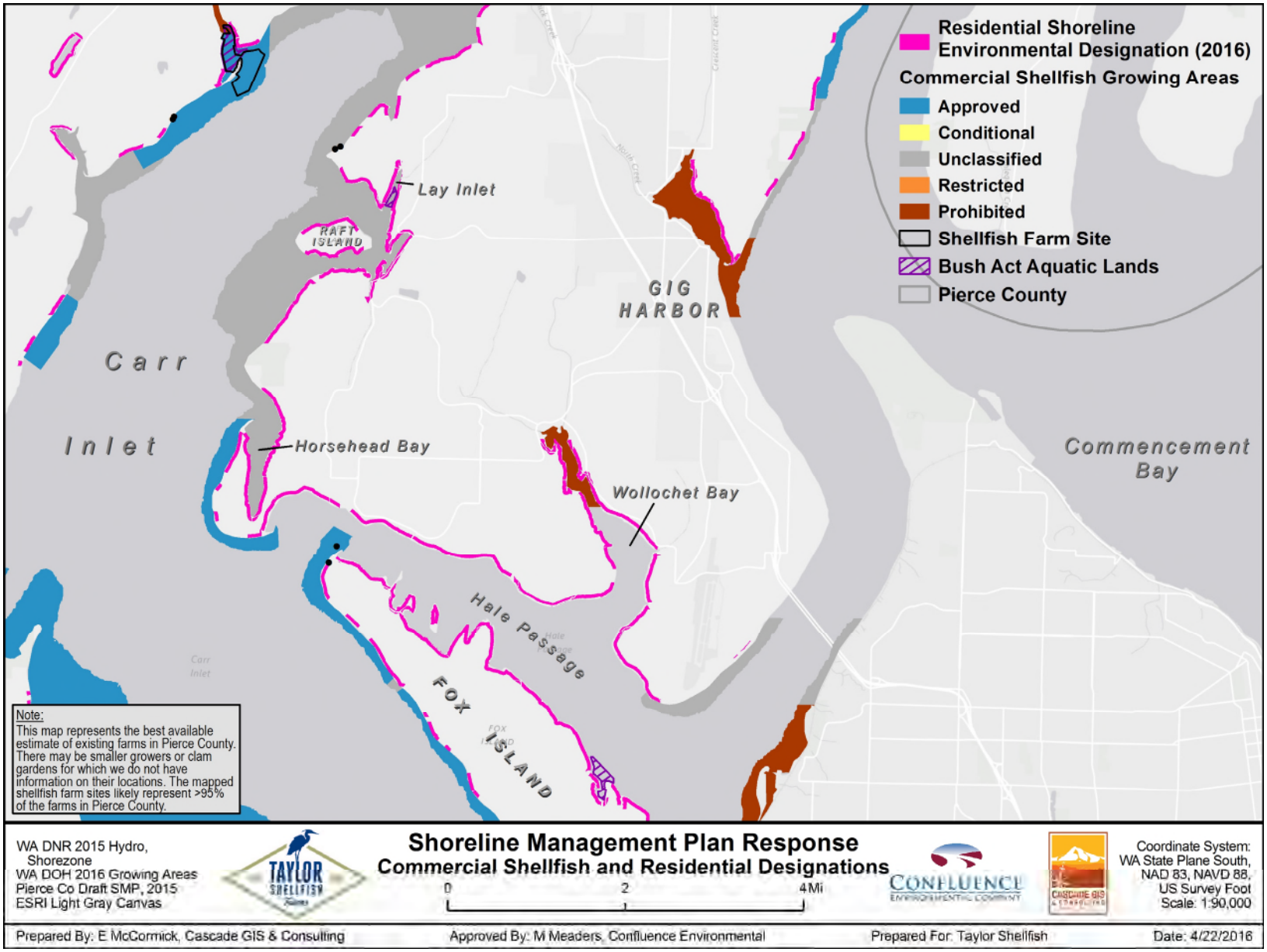


Figure 16 **Washington Department of Health, Shellfish Growing Area Classifications for Horsehead Bay, Lay Inlet, Wollochet Bay, and Areas near Raft Island**

Classifying Water Quality

There are two authorities that classify water quality in Washington state –Ecology under the federal Clean Water Act and through its 303 (d) list, and the Washington Department of Health (DOH) Shellfish Growing Area Program.

Ecology 303(d) Assessment

The Ecology 303(d) assessment measures a number of factors such as temperature, dissolved oxygen, bacteria, and heavy metals. The residential areas of Horsehead Bay, Wollochet Bay, Lay Inlet, and adjacent to Raft Island are not on Ecology's 303(d) list for water quality concerns (Ecology 2016).

DOH Shellfish Growing Area Program

The DOH water quality assessment focuses on fecal coliform. A portion of Wollochet Bay is classified as "Prohibited" by the DOH Shellfish Growing Area Program), while the other areas (Horsehead Bay, Lay Inlet, and areas near Raft Island) are "Unclassified" (DOH 2016a) (Figure 16). DOH has five classifications for Commercial Growing Areas: Approved, Conditionally Approved, Restricted, Prohibited, and Unclassified. Prohibited is defined as "when the sanitary survey indicates that fecal material, pathogenic microorganisms, or poisonous or harmful substances may be present in concentrations that pose a health risk to shellfish consumers. Growing areas adjacent to sewage treatment plant outfalls, marinas, and other persistent or unpredictable pollution sources are classified as Prohibited. Commercial shellfish harvests are not allowed from Prohibited areas" (DOH 2016b). Commercial shellfish harvest is also not allowed in Unclassified areas, but it is a simple request from DOH to add an area for classification (Berbells, pers. comm., 2016). According to DOH, Wollochet Bay was listed as Prohibited in 2003 because of the high number of marinas and boats (Berbells, pers. comm., 2016).

Classifications by DOH are not static; they can shift when data changes from year to year, or with collection of new data. DOH has monitoring stations in each classified area that measure fecal coliform. Annually, DOH releases reports with this data as well as classification changes that may have occurred (i.e., upgrades or downgrades) based on the data. Also, shellfish growers can request that DOH classify previously unclassified areas. DOH can deploy monitoring equipment to assess a new area and classify it (Berbells, pers. comm., 2016). Thus, the Unclassified areas of Horsehead Bay, Lay Inlet, areas near Raft Island, and Wollochet Bay could be monitored and classified by DOH, if requested.

The DOH classification of Prohibited does not exclude all types of shellfish aquaculture. Since the DOH prohibition is only in relation to harvest, shellfish "seed" can be raised in nursery systems (e.g., FLUPSYs) in areas that are classified as Prohibited by DOH because juvenile shellfish can be transferred and later harvested in Approved areas. Therefore, even in northern Wollochet Bay, which is Prohibited for harvest, shellfish seed could be grown in a FLUPSY.

The DOH classification system is based on potential effects to human health through consumption of contaminated shellfish, not on the potential for shellfish aquaculture to adversely affect water quality. In addition, the classification of areas by DOH as Restricted or Prohibited can be the signal to a community, or shellfish aquaculture operations, that levels of fecal coliform are affecting all water-dependent activities, which can then lead to actions for the pollution problems. There are many examples throughout the Salish Sea where poor water quality for shellfish harvest has created opportunities and funding mechanisms to improve water quality issues (e.g., Dungeness Bay). The following is a case study related to water quality issues created by the surrounding community and the changes that led to improvements in the DOH classification for Burley Lagoon.

Case Study: Burley Lagoon

Shellfish aquaculture has occurred in Burley Lagoon since the 1930s. Due to poor permeability of surrounding soils along the shoreline, elevated average rainfall, and high seasonal water table, Burley Lagoon has frequently experienced high fecal coliform levels. Since the 1970s, areas of Burley Lagoon have been closed or restricted for shellfish harvest due to fecal coliform from upland sources (KCHD 2001). Efforts to reduce fecal coliform contamination have focused on both the correction of failing septic systems and improving livestock waste management (KCHD 2001). Based on trend data associated with fecal coliform specific to Burley Lagoon (Figure 17), improvements made to on-site septic systems in the watershed resulted in lower levels of fecal coliform between 1996 and 2013. Between 2012 and 2015, 36 acres of the area classified as Restricted was upgraded to Conditionally Approved (Figure 18), primarily because of a reduction in fecal coliform (DOH 2012, Snyder 2015, KPHD 2015). This result is beneficial for commercial shellfish aquaculture, as well as all other uses of the water area. Kitsap Public Health continues to work in the Burley watershed to raise awareness about faulty septic systems, and to investigate high priority farm properties (KPHD 2015).

Shellfish Aquaculture Benefits to Water Quality

As discussed in Section 3.2.4, there are factors associated with shoreline development that can lead to the degradation of SED designations and also affect the surrounding shellfish aquaculture operation. Similarly, shoreline development has more potential impacts on water quality than shellfish aquaculture, which can have benefits to water quality. The positive interactions of shellfish aquaculture to water quality include (1) an increase in water clarity and light penetration through consumption of phytoplankton and particulate organic matter, (2) increased dissolved oxygen by reduction of excess phytoplankton, and (3) nutrient sequestration by incorporation of nitrogen and phosphorus into their shells and tissues, (i.e., bioextraction). Section 3.2.2. provides detail on each of these positive interactions.

3.5.2 Visual Quality and Aesthetics

There are three main concerns related to visual quality and aesthetics relevant to different shellfish aquaculture: (1) lighting and glare, (2) intertidal aquaculture gear visibility, and (3) floating aquaculture visibility. These concerns are discussed below.

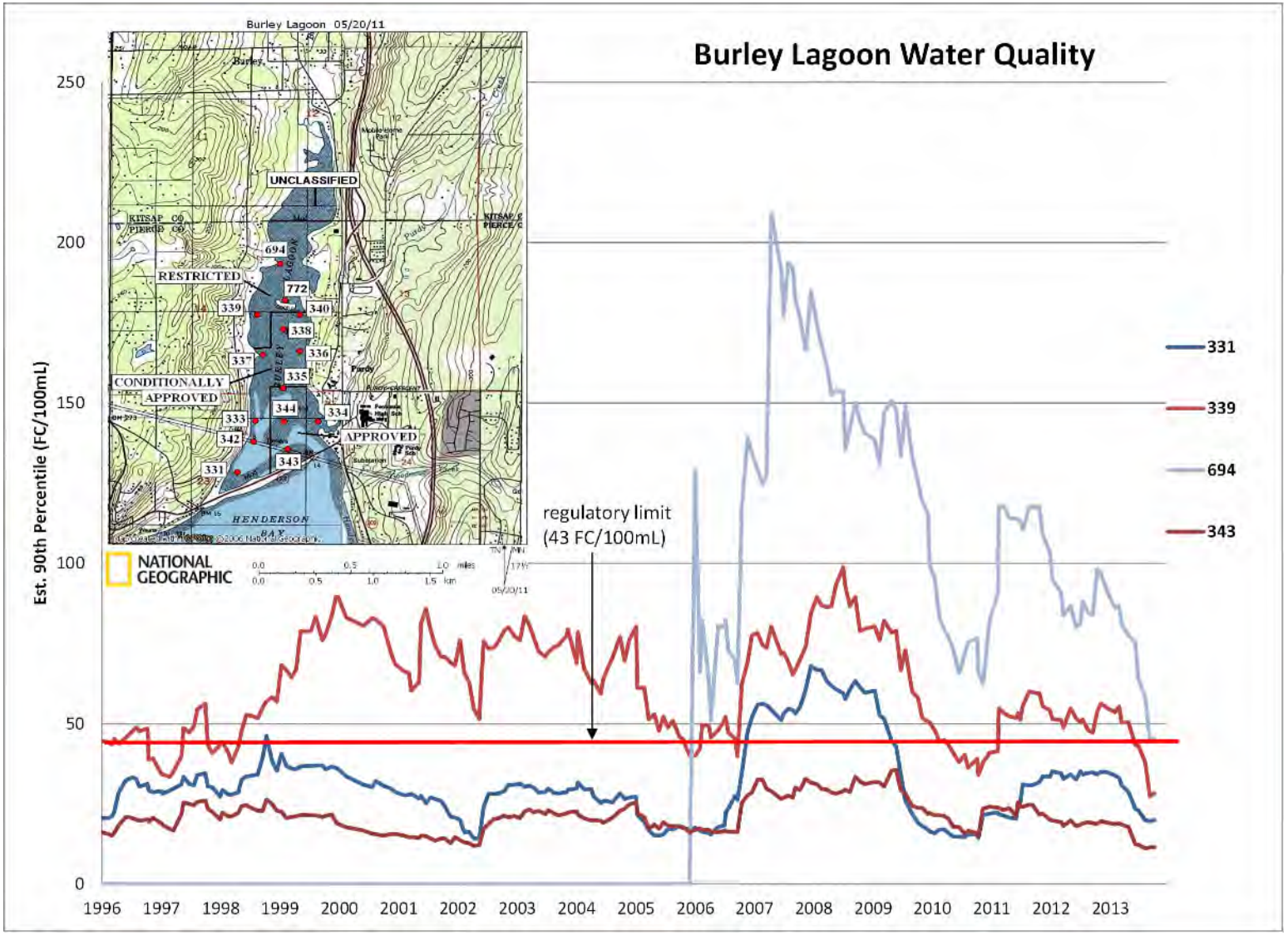


Figure 17 Fecal Coliform Sampling in Burley Lagoon

Source: Schultz, pers. comm., 2014

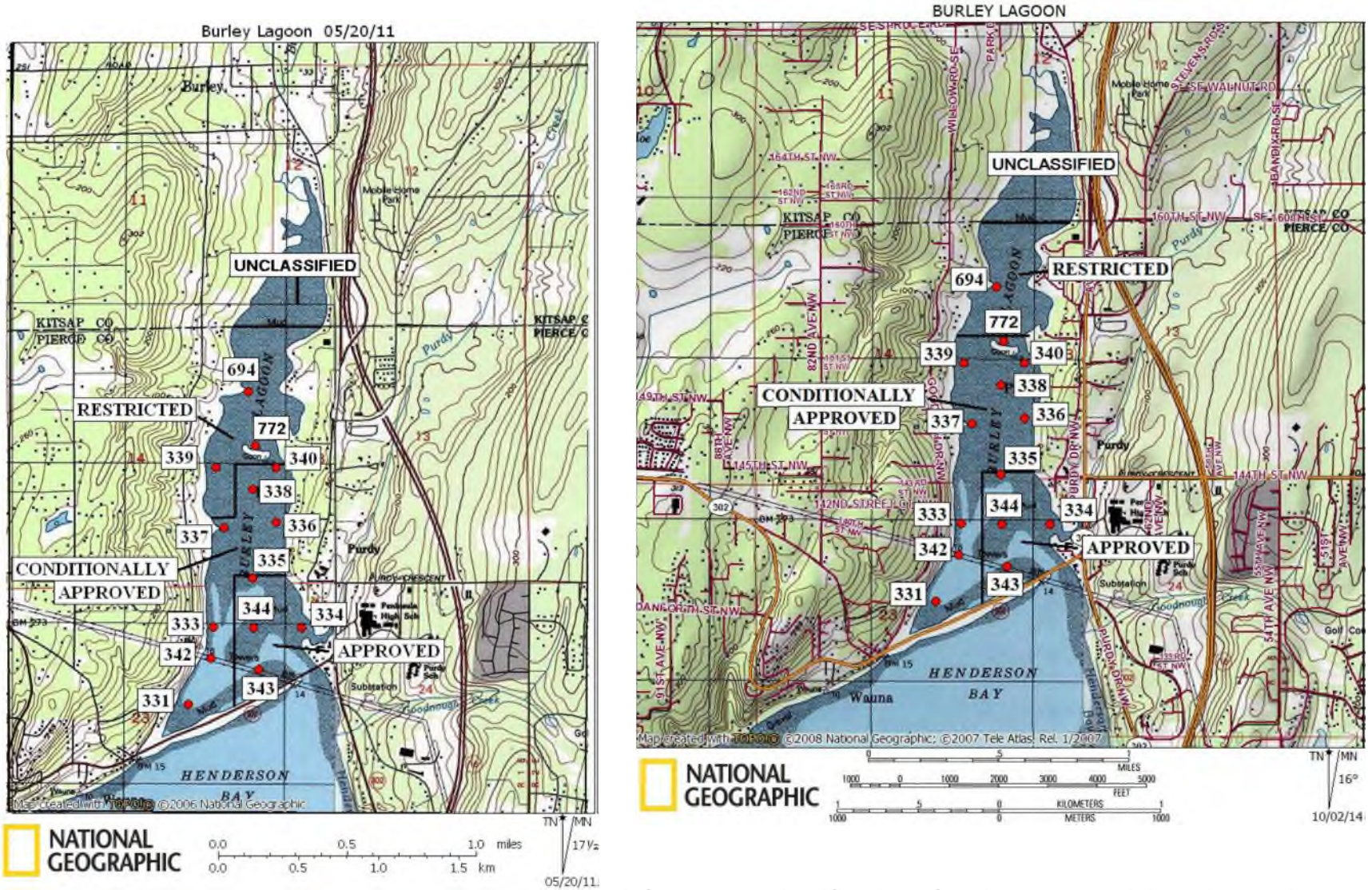


Figure 18 **DOH 2012 Classification of Burley Lagoon (left) vs. 2015 Classification of Burley Lagoon (right). The southern portion of the Restricted area was upgraded to Conditionally**

Lighting and Glare

Permanent lighting is not permitted for shellfish aquaculture, except as required for navigation (Pierce County 2012). U.S. Coast Guard (USCG) regulations (33 CFR 66.01-5) require all structures in navigable waters to be lit for safety. Structures like aquaculture rafts must have lights that are visible for at least one mile and are yellow in color. USCG also reviews project applications and may require more specific lighting and markings for the particular project and waterway. To the extent practicable, operations minimize adverse impacts from light and glare on nearby properties. This includes the use of headlamps when working during a night tide. The light associated with headlamps extends a maximum of 630 ft for a C4® LED light (Streamlight 2016). Headlamps are pointed toward the ground and used in a manner that is respectful of surrounding neighbors.

Intertidal Aquaculture Gear Visibility

Much of the recent attention regarding intertidal gear visibility has concerned geoduck aquaculture. Culture tubes are used to protect the geoduck "seed" during the first 1 to 3 years after planting. These tubes may be made of PVC pipe or a flexible mesh similar to an oyster bag (see the description in Section 5.0). PVC tubes are typically white, although minimization measure have proposed a more neutral color (e.g., gray). Culture tubes are typically covered by a predator exclusion net. Netting and tubes quickly become covered with marine organisms, so that they are the same color as their surroundings. The tubes are also placed at lower tidal elevations so are only seen during daytime low tides. Finally, the tubes are temporary, and are removed once geoduck are bigger, thus they do not remain a permanent part of the landscape.

An alternative to PVC tubes that may be used at the site is black, flexible extruded plastic mesh (Marine-grade Polyethylene) tubes for geoduck 'seeding' (planting). Because the mesh tubes are flexible and dark in coloration, they may not be as visible to surrounding residential occupants as PVC tubes.

Tubes are visible for a short period of daylight hours during the year. Figure 19 depicts an analysis of tube visibility based on low and high tide predictions from Wauna, Washington (Station ID: 9446291) in 2011. The entire tidal cycle was calculated from observations at Tacoma, Washington (Station ID: 9446484), and the daylight hours that the tubes would be visible were calculated using the tidal data. This evaluation is based on daylight tides that range from +2.5 ft mean lower low water (MLLW), which is the upper extent of proposed typical farm, down to extreme low (-4.5 ft MLLW).

Over the course of a geoduck culture cycle (estimated as an average of 6 years), at typical planting elevations, geoduck tubes are visible for less than 5% of daylight hours. The remainder of daylight hours, shown in orange on Figure 19, occurs when tides are above a 2.5-ft tidal elevation (i.e., the tops of the culture tubes). During the months when tubes are not visible or rarely visible (e.g., October to February), the low tide occurs at night. It should also be noted that the exposure hours depicted in Figure 19 include tides that expose any portion of the intertidal habitat below 2.5 ft, no matter how small. For example, in March, tides rarely go

below 0 ft MLLW, so even though the graph indicates that tubes would be visible, this would only be the very top of the farm. A depiction of this concept is provided in Figure 20 below.

Oyster aquaculture typically does not occur much higher than the upper elevations of geoduck aquaculture. Manila clam aquaculture occurs at higher elevations than geoduck and oyster aquaculture but does not involve any gear other than a net that lies directly on the bed.

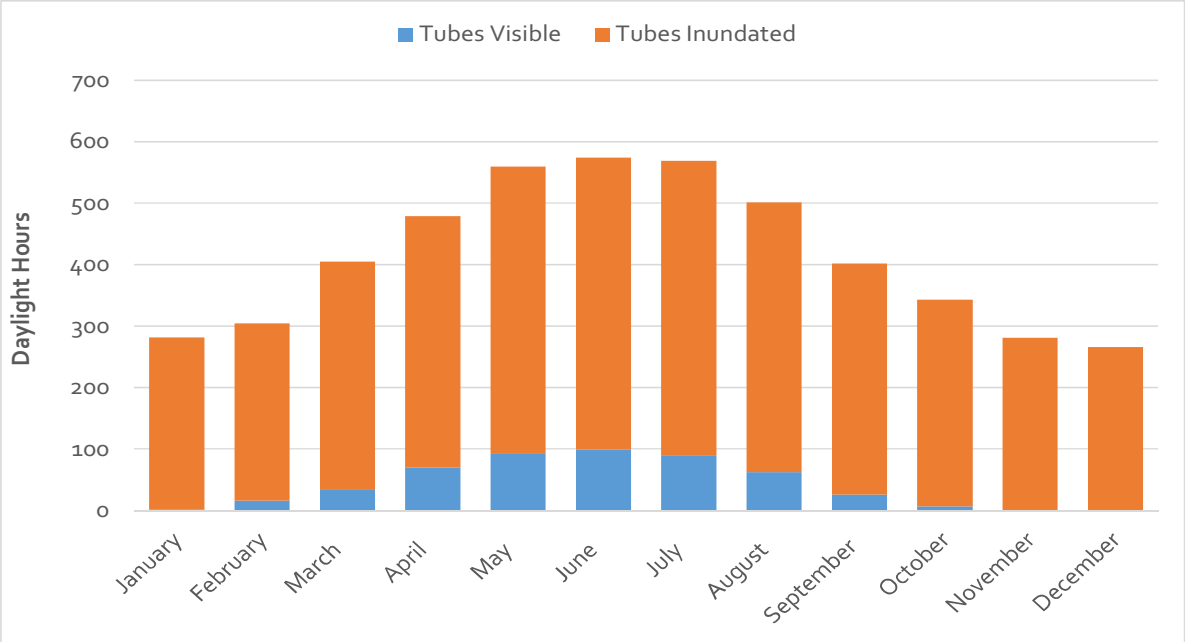


Figure 19 Tube Exposure Analysis Based on Daylight Hours in Olympia and Potential Exposure up to a +2.5 ft MLLW Tidal Elevation

Note: Tubes would be visible during tides that occurred below +2.5 ft MLLW based on culturing up to +2 and 0.5 ft of the tube extending from the sediment surface.

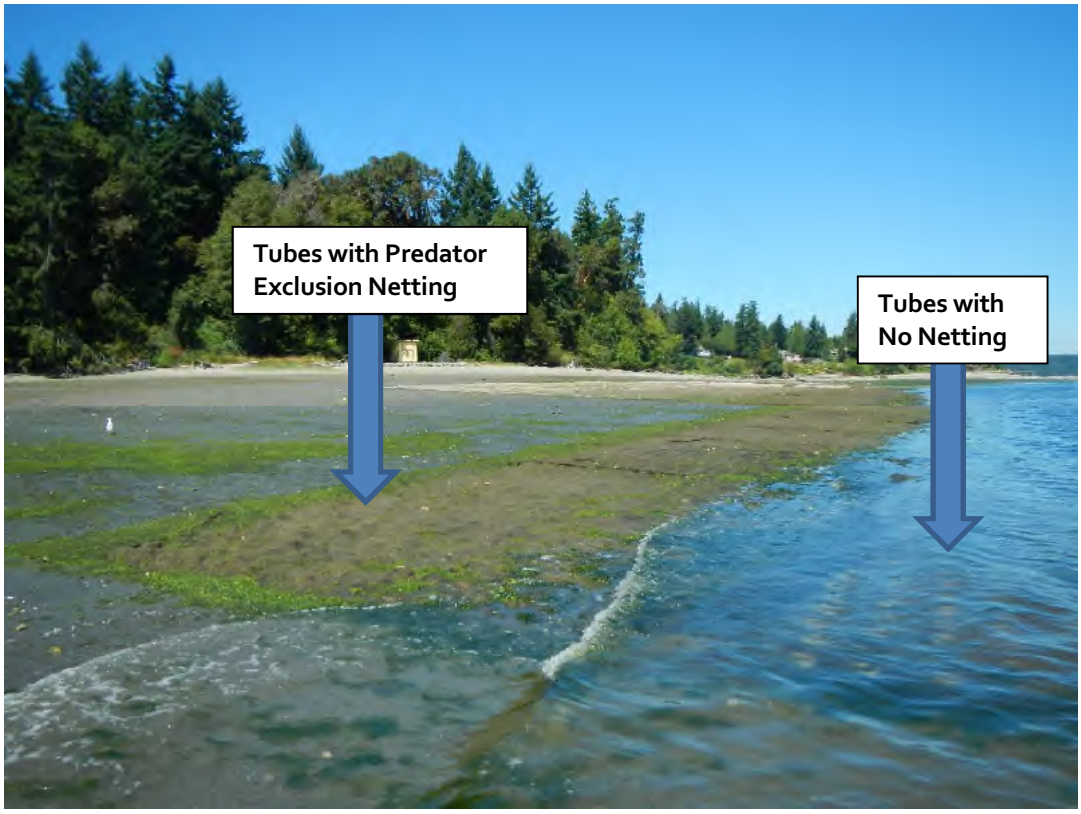


Figure 20 Geoduck Farm Planted up to 0 ft MLLW in Henderson Inlet during a 0.3-ft Tide
Note: only the very top of the farm is visible; typically, the farm would be visible for approximately 5% of the culture cycle with tides that expose the planted area.

Floating Aquaculture Visibility

Due to the subjective nature of aesthetics, frameworks have been developed to allow for more objective evaluation of project aesthetics for developments that have more structure associated with them (e.g., floating aquaculture). One such methodology is the Aquaculture Siting Study (Ecology 1986). In Washington, aquaculture, which encompasses shellfish, finfish, and algae culture, has long been met with opposition by shoreline residents, with visual impacts as a top concern. The Siting Study states its purpose as to "…assist industry members, citizens' groups, planners, upland owners and elected officials in their effort to assess and mitigate such impacts."

Methodology

The Siting Study uses typical visual impact analysis methodology, which "provides visual and analytic tools evaluating and mitigating the visual impact of proposed aquaculture facilities" (Ecology 1986). The Siting Study includes an analysis protocol that considers three factors: (1) the scenic quality of the setting, (2) the sensitivity of the potential viewers of the proposed project, and (3) the visibility of the proposed project. Each of these factors is scored as low,

medium, or high and then a final impact score (I to IV) is assigned based on a matrix that compiles the scores of individual factors (Figure 21).

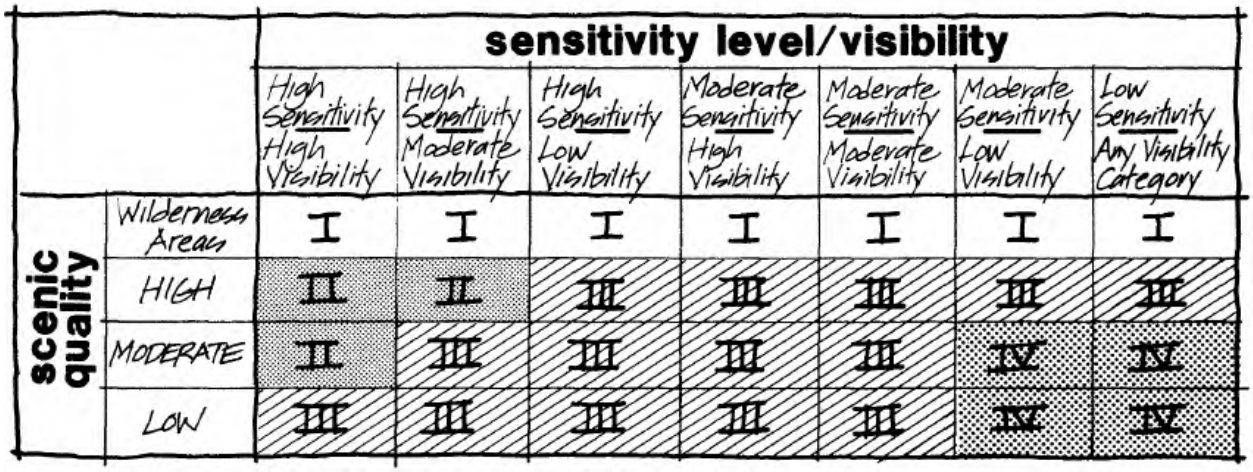


Figure 21 Rating Matrix for Visual Impact Analysis

Scenic Quality considers the environmental condition, spatial definition, and adjacent scenery of the proposed aquaculture site. It considers the overall setting in which the potential aquaculture project is proposed to be sited.

Sensitivity considers the number of potential viewers from adjacent travel routes[7], public use areas, or existing residential development, that is, from "key observation points." The concept of key observation points is important in understanding the sensitivity factor. The Siting Study asks assessors to identify "key observation points" around the area where aquaculture may be sited. This differs for each project, and may include residential areas, designated recreation areas, and travel routes. The view from these key observation points then informs the aesthetic analysis. The potential for visual impact increases as the height of the adjacent shoreline increases (Ecology 1986). That is, an aquaculture facility in the water takes up smaller portion of the view of an observer located close to sea level, while it takes up a larger portion of the view of the observer located at a higher elevation.

While scenic quality and sensitivity consider an area as a whole, visibility is largely based on project design. Visibility considers view obstruction, distance of the proposed project offshore in relation to the observer position, and viewshed coverage. In this context, viewshed is defined as the percentage of normal "cone of vision" occupied by proposed aquaculture facility. Cone of vision refers to the 60-degree area which is visible from the normal human eye. For an observer viewing an aquaculture facility, the facility would take up horizontal space across the view of the landscape.

7 The Siting Study methodology only considers potential viewers from land, thus travel routes in Case Inlet were not considered. Additionally, Case Inlet does not contain vessel lanes (See Section 4.1), and does not host tour boats.

According to the Siting Study methodology, using the scores from the three factors, scenic quality, sensitivity, and visibility, visual impacts may be classified in one of four categories. The categories are: Class I: Severe Visual Impact, Class II: High Visual Impact, Class III: Moderate Visual Impact, or Class IV: Low Visual Impact.

Summary

Determining aesthetic impacts of floating culture requires a detailed look at the landscape setting, the number and location of the viewers, and the design of the project. The potential impact would need to be a consideration for any floating aquaculture project, and cannot be determined outright simply by proximity to a residential shoreline designation.

3.5.3 Conservation Measures regarding Aesthetics

The following conservation measures regarding aesthetics of shellfish aquaculture sites are typically included in permitting documents:

- Unnatural materials (e.g., tubes, nets) shall be removed as soon as practical when shellfish are no longer vulnerable to predators. Marker stakes and buoys also will be removed when they are no longer necessary.
- Intertidal areas must not be used to store materials such as tools, bags, marker stakes, stakes, or nets. Materials that are not in use or immediately needed must be removed to an off-site storage area and the site kept clean of litter.
- Predator exclusion nets are designed so they do not break free and cause beach littering on site or off site. The grower shall ensure that predator exclusion nets are tightly secured to prevent them from escaping from the project area.
- All excess or unsecured materials and trash shall be removed from the beach prior to the next incoming tide so that all unnatural debris are maintained and prevented from littering the waters or beaches.
- Unsuitable material (e.g., trash, debris, asphalt, or tires) shall not be discharged or used as fill (e.g., used to secure nets, create berms, or provide nurseries).
- At least once a month and directly following storm events, beaches in the project vicinity shall be patrolled by crews who will retrieve aquaculture debris (e.g., predator exclusion nets, tubes) or unnatural debris (e.g., bottles, cans) that escapes from the project area. Within the project vicinity, locations shall be identified where debris tends to accumulate due to wave, current, or wind action, and after weather events these locations shall be patrolled by crews who will remove and dispose of debris appropriately. The grower shall maintain a record with the following information and the record shall be made available upon request to the Corps, NMFS, and USFWS: date of patrol, location of areas patrolled, description of the type and amount of retrieved debris, and other pertinent information.

- The grower shall not use tidelands waterward from the line of mean higher high water for the storage of aquaculture gear. All aquaculture gear shall be stored and sorted at an upland facility and transported to the project area by boat at the time of deployment.

3.5.4 Summary

It is important to consider the water quality and aesthetic impacts of any marine project. However, simply the existence of nearby residences or degraded water conditions (which are typically caused by upland development) does not warrant a prohibition on aquaculture projects. Baseline water quality of an area is typically classified by Ecology or DOH, and may adversely affect aquaculture, while aquaculture has many positive effects on water quality. Aesthetic considerations for aquaculture include lighting, geoduck aquaculture gear visibility, and floating aquaculture visibility. Shellfish growers employ a number of conservation and minimization measures to maintain the aesthetic quality of the shoreline in areas that they work.

3.6 Summary of Shellfish Prohibitions

The updated SMP has a number of suggested prohibitions for shellfish aquaculture. There is no basis for the proposed prohibitions, and they are contrary to current scientific and technical information pertaining to shellfish aquaculture.

4.0 FORAGE FISH SPAWNING AREAS

This section is responding to **PCC 18E.40.040(E)**:

1. Regulated activities waterward of the ordinary high water mark (OHWM), in areas of confirmed spawning habitat, shall be suspended during spawning periods unless a survey by a qualified professional confirms that spawning is not occurring or approval is obtained from WDFW.
2. Regulated activities in areas where a survey demonstrates that no spawning is occurring are still subject to avoidance and minimization requirements of PCC 18E.40.050.

There are three species of forage fish that spawn in intertidal areas in Washington: surf smelt, Pacific sand lance, and Pacific herring. WDFW is the state agency charged with protecting forage fish species, which includes documenting their spawning areas. Each species has specific spawning behavior and preferences. Surf smelt and Pacific sand lance are considered beach spawners because they spawn within intertidal habitat primarily within the upper portion of the beach. Pacific herring spawn over vegetation or other structure lower in the intertidal and shallow subtidal, in areas that overlap with shellfish aquaculture. Non-professionals can be taught to recognize Pacific herring spawn—an approach that is accepted by regulating agencies.

4.1 Grower Training Program

In order to manage forage fish species, WDFW offers courses to train professionals how to recognize spawn from surf smelt and sand lance. The most recent set of training, which significantly updates the original methodology described in Moulton and Penttila (2001), was offer in April 2016 by the current lead scientist at WDFW Phillip Dionne. This set of classes was recently attended by biologists from Confluence and regulatory compliance managers from Taylor Shellfish Farms, among other professionals. The list of trained professionals maintained by WDFW (http://wdfw.wa.gov/licensing/hpa/ApprovedBiologistList.pdf) will be updated in the coming months. There is no current training course for herring through WDFW, nor (to our knowledge) has there ever been a WDFW training for herring egg identification. The forage fish class offered by WDFW covers general identification on herring eggs, but nothing in detail.

Because training is not offered through WDFW for herring spawn recognition, shellfish growers have received training from professional fish biologists. This training on forage fish egg identification for shellfish growers has been conducted in Puget Sound and Willapa Bay, Washington. The training, titled "Pacific Herring Egg Identification Training Session" was sponsored by the Pacific Coast Shellfish Growers Association (PCSGA). More than 100 shellfish growers were trained in these sessions. The training included an overview of the biology of the fish, and a photo-intensive presentation to show what the eggs look like and the natural and manmade materials to which the eggs are known to adhere.

This training fulfills the Corps NWP 48 recommendation to complete a training class to identify Pacific herring spawn. The survey and reporting methods explained during the training also fulfill the Pierce County requirements.

4.2 Regulatory Authority

Conditions regarding forage fish are issued at a federal level by the Corps, and locally as part of SSD Permits issued by Pierce County. The state authority on forage fish, WDFW, do not have jurisdiction on shellfish aquaculture, but projects depend on information this agency provides. WDFW has conducted extensive surveys for forage fish species and has documented "areas of confirmed spawning habitat." They maintain a public database with this information, including the years in which spawn deposition has been documented at specific beaches throughout the Salish Sea and along the Coast in Grays Harbor and Willapa Bay (WDFW 2016b).

4.3 Conservation Measures

Aquaculture activities do not typically overlap with the dominant surf smelt or Pacific sand lance spawning locations. Clam culture occurs the highest in the intertidal, but new culture is not positioned higher than +5 ft MLLW in areas with documented spawning. Thus, the dominant spawning areas are avoided. These avoidance measures are detailed in the permitting documents associated with aquaculture farms (see Section 3.1 above).

Shellfish aquaculture activities may overlap with Pacific herring spawning areas. Unlike with beach spawners, there is not a vertical elevation separation. Because of this potential for spawn in areas of active shellfish aquaculture, a number of conservation methods are followed by growers, including only working within prescribed work windows, and documenting any observed spawn deposition. See Sections 3.1.1 and 3.1.2 above. Shellfish companies are also creating ways to track spawn occurrences on their farms more easily, as well as do quality checks at farm sites. For example, Taylor Shellfish has developed an application for cell phones that go through a series of questions to document whether spawn is observed at farm sites that employees fill out. Documentation of spawn surveys are part of the requirements for NWP 48 and SSD permits.

4.4 Summary

Three forage fish species spawn in intertidal areas of Puget Sound. Only one of these species, Pacific herring, spawn at a tidal elevation where the predominant spawning locations overlap with shellfish aquaculture. Existing federal and local regulations protect forage fish spawning habitat and spawn deposition. State regulations through WDFW provide maps with "areas of confirmed spawning habitat." Shellfish growers have, and will continue to, receive training from professional biologists to recognize and report Pacific herring spawn. This training satisfies permitting requirements and fully equips the shellfish growers, thus a "qualified professional" is unnecessary to perform these surveys (assuming "qualified professional" means a professional fish biologist).

5.0 PREDATOR PROTECTION GEAR

This section is responding to the following PCC chapters:

- **18S.40.040(B)(2):** "Give preference to aquaculture projects that do not involve the placement of tubes, structures, or alterations to the shoreline."
- **18S.40.040(C)(11):** "Predator control shall not involve deliberate killing or harassment of birds, invertebrates, or mammals. Approved controls include, but are not limited to plastic tubes or netting. Predator control equipment shall be removed as defined within the approved schedule, but no longer than two years after installation."
- **18S.40.040(D)(5):** "All equipment and structures and/or tubes, nets, and bands, shall be marked to identify ownership, and shall be removed as defined by a County approved schedule.
- **18S.40.040(F)(1):** "The installation of structures and/or equipment shall demonstrate the following: a. The structures and/or equipment proposed are the minimum necessary for feasible aquaculture operations . . .

Culturing shellfish in the marine environment exposes the species to predation. Typical predators include shorebirds (such as scoters), sea stars, crustaceans, drills, and moon snails. Various types of predator protection are used by shellfish growers, and may include PVC tubes, flexible mesh tubes, predator exclusion netting, mesh bags, and suspended racks (Figure 22).

While geoduck culture often entails netting in place for two years (though it could be longer), other types of culture may have netting in place for more than two years to be effective. Studies have shown that predator protection is necessary to ensure success of shellfish aquaculture (see Section 5.2). Additionally, there is a wide body of literature that has examined the effects of predator protection gear to the surrounding environment (See Section 5.2), but the effects are typically insignificant and can be alleviated by implementing avoidance, conservation, and minimization measures.

5.1 Types of Predator Protection Gear

The species of shellfish currently cultured in south Puget Sound include Pacific oysters, Kumamoto oysters, Olympia oysters, Eastern oysters, Manila clams, geoducks, and mussels (*Mytilus galloprovincialis*). Note that mussels are not currently grown in Pierce County. All oysters, and Manila and littleneck clams are grown in the intertidal (Table 4). Geoduck may be grown via ground culture in the intertidal or subtidal habitat. Mussels are grown in the subtidal in either rafts or longlines. The early life stage, or "seed," of oysters, clams, and geoduck may be grown in FLUPSYs or nursery rafts before being planted in the ground.

Table 4 Culture Methods for Typical Shellfish Aquaculture in South Puget Sound.

Species Cultured	Culture Method					
	Intertidal		Subtidal			
	Ground	Staked – Flipbag	Ground	FLUPSY*	Raft**	Longlines
Oyster *Crassostrea gigas*	X	X		X	X	
Clam *Venerupis philippinarum* and *Mercenaria*	X			X	X	
Geoduck *Panopea generosa*	X		X	X	X	
Mussels *Mytilus galloprovincialis*					X	X

*FLUPSYs are Floating Upweller Systems used to grow shellfish "seed," or the early life stage of each species. The seed are then outplanted onto the substrate for growth until appropriate size for harvest.
**Species may be cultured in trays or from "droppers," i.e., various types of grow-out support structure (e.g., ropes, strips of mesh, socks or socking, tapes of flat material, or plastic tubes)

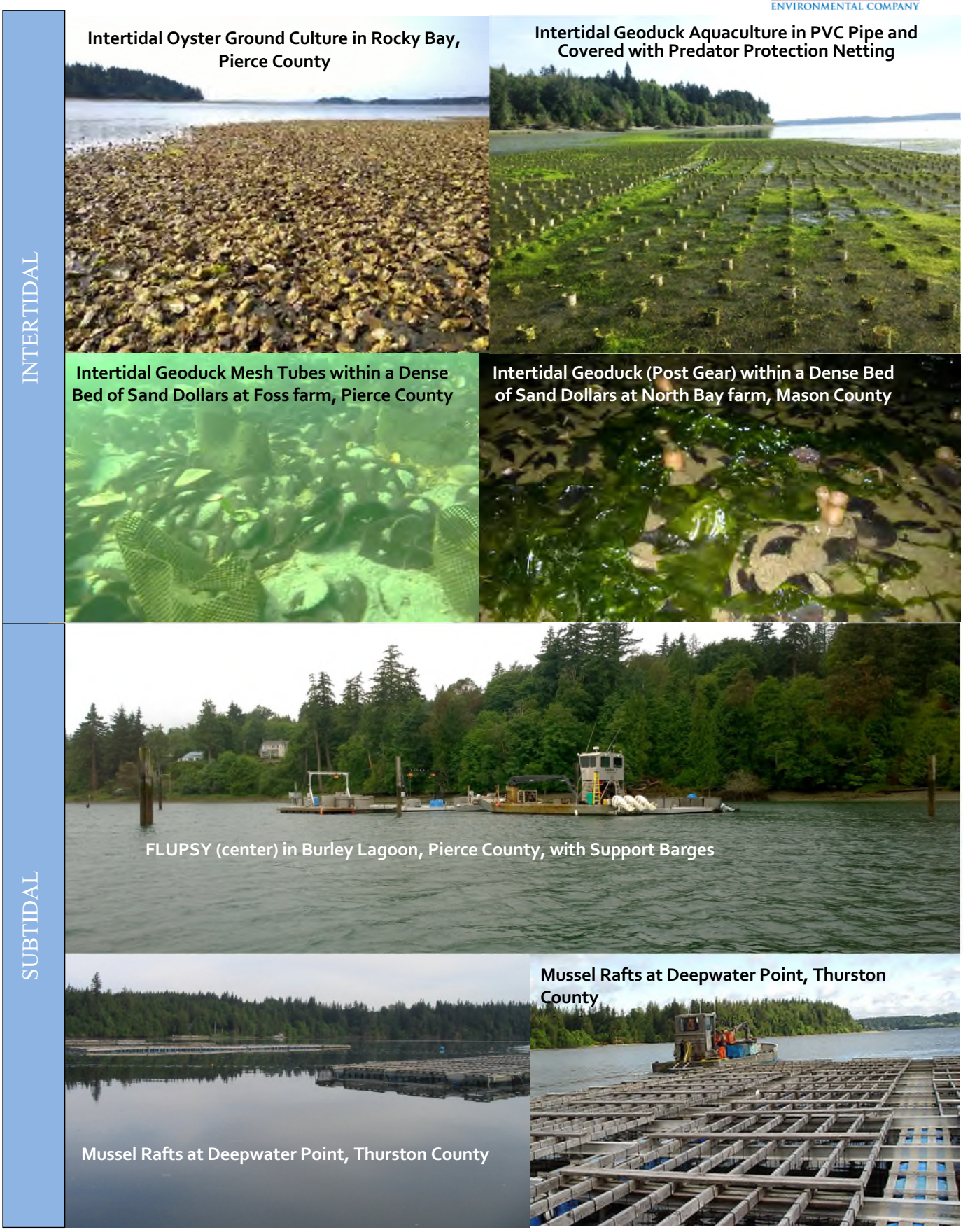


Figure 22 Photos of Typical Shellfish Culture Methods in South Puget Sound

Intertidal Shellfish Culture Methods

Intertidal shellfish aquaculture typically includes oyster, clam, and geoduck (Figure 23). Oysters are cultured either on the ground, or in bags and do not include predator netting. Clams are cultured on the ground and do use predator netting. Geoduck are cultured on the ground and use various "tubes" (see definition, below) for protection, as well as predator netting.

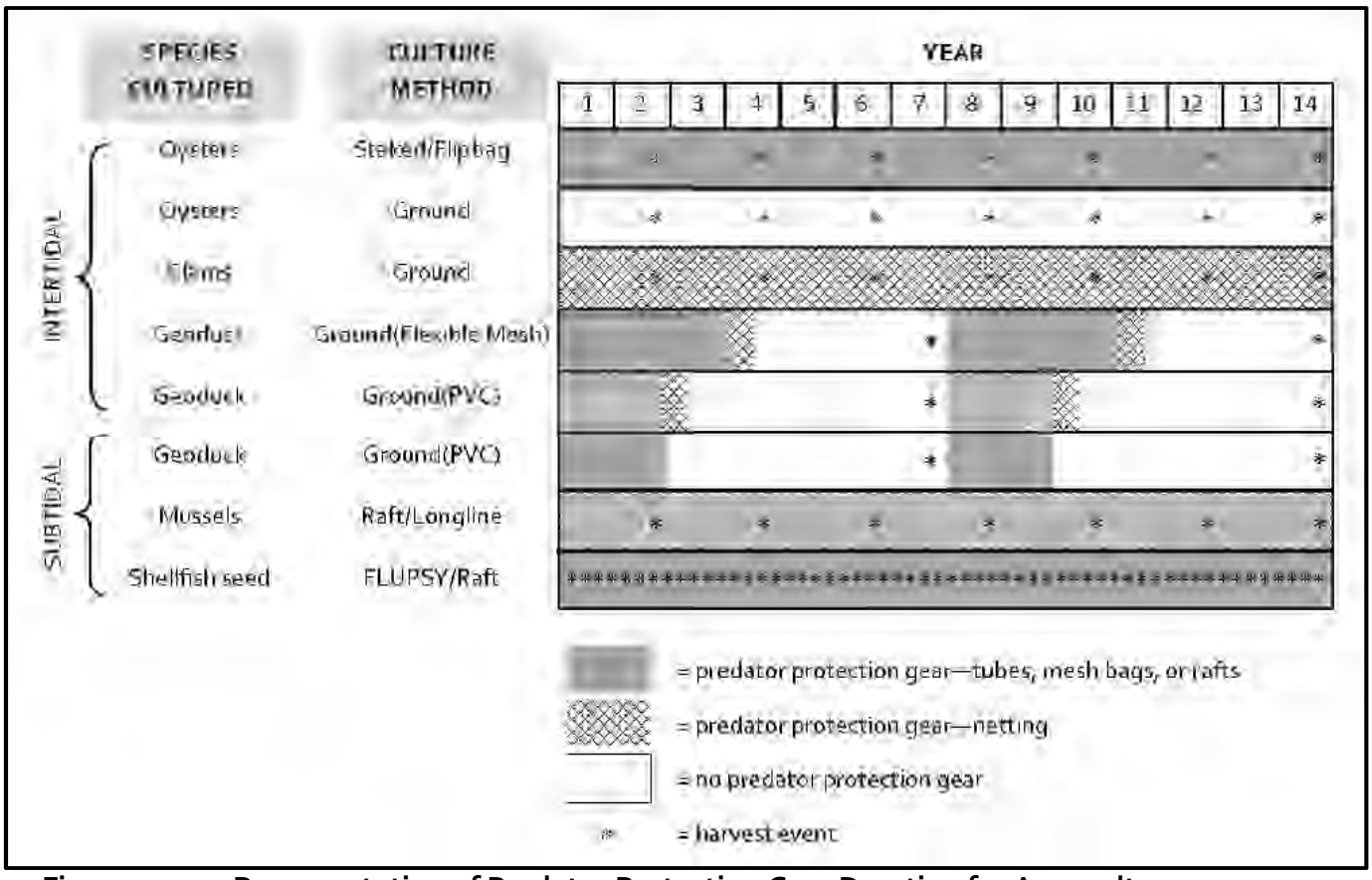


Figure 23 Representation of Predator Protection Gear Duration for Aquaculture Methods

Oyster

Oysters are typically planted at tidal elevations ranging from approximately extreme low tide (ELT) to +5.0 ft MLLW. Pacific oysters can be planted in any substrate type using a variety of different methods. Larger gravels will typically have on-ground culture while smaller substrate types (e.g., sand or small gravel) will have bags. Oyster seed would be placed in two- to eight-millimeter (mm) mesh bags or on-bottom without bags and without predator protection netting. When bags are used, they are strung together and staked to the ground.

Routine maintenance would involve checking bags for rips and making sure the bags are securely staked. Ripped bags would be repaired or replaced and unsecure sections of bag would be re-staked.

The oysters would remain in the bags during the nursery phase (usually 1 year) until they reach about three inches in size. depending on growth rate, oysters may be removed from the bags and spread directly onto the tidelands and allowed to mature and harden. Oysters may also remain in grow-out bags until ready to harvest. Removing the oysters from the bags and placing them on the ground would occur weekly until all of the oysters are placed on the ground or in grow-out bags.

Once the oysters are mature (typically a 2-year grow out cycle), they would be handpicked during low tide either by forking oysters into tubs or pulling bags and removing from the site by boat. Harvesting provides a regular supply of shellfish throughout the year. Therefore, harvesting would occur over a small area, approximately 3 events every 2 years.

Clam

Manila clams are typically planted at tidal elevations ranging from approximately extreme low tide (ELT) to +5.0 ft MLLW. Clams are generally planted in areas with small or pea-sized gravel. Clam seed would be spread directly onto the tidelands. Clam beds would be covered by securely staked predator exclusion nets. Predator exclusion nets used are placed directly on the sediment surface (i.e., no vertical relief) and secured every 8 to 10 ft along the perimeter with U-shaped stakes. Routine maintenance would involve checking nets for rips, ensuring nets are secure, and/or cleaning nets as needed. Rips would be repaired using cable ties and unsecure sections of nets would be re-staked.

Geoduck

Geoduck seed are highly vulnerable to predation because they are not of a size or at a depth in the sediment that would provide adequate protection. No active predator removal is performed. Predator control would be achieved through exclusion by planting geoduck seed into culture tubes. The ability to have a variety of predator exclusion options (e.g., different culture tube designs) available allows the grower to adapt to site-specific conditions.

There are two types of culture tubes available depending on site conditions: PVC tubes and flexible mesh tubes (made of high density polyethylene or HDPE). Culture tubes range from 4 to 6 inches in diameter, and from 8 to 10 inches in length. Culture tubes are pushed into the substrate by hand or foot. PVC tubes are gray tubes that extend approximately 3 to 4 inches above the substrate, and are maintained for approximately 2 years. If PVC tubes are used, either an individual predator net is affixed to the top of the tube with a rubber band designed for marine application or a predator exclusion net is affixed over the entire plot (Figure 24). Flexible mesh tubes are shaped like a diamond (Figure 25), which allows the grower to install the tubes into the prevailing direction of sediment transport. Predator exclusion nets are not used when flexible mesh tubes are present. Flexible mesh tubes extend approximately 4 to 5 inches above the substrate surface. Flexible mesh tubes are maintained for 3 years. Both types of tubes would be positioned approximately 12.2 inches apart on center.



Figure 24 PVC Tubes Used for Geoduck Seed Grow-Out

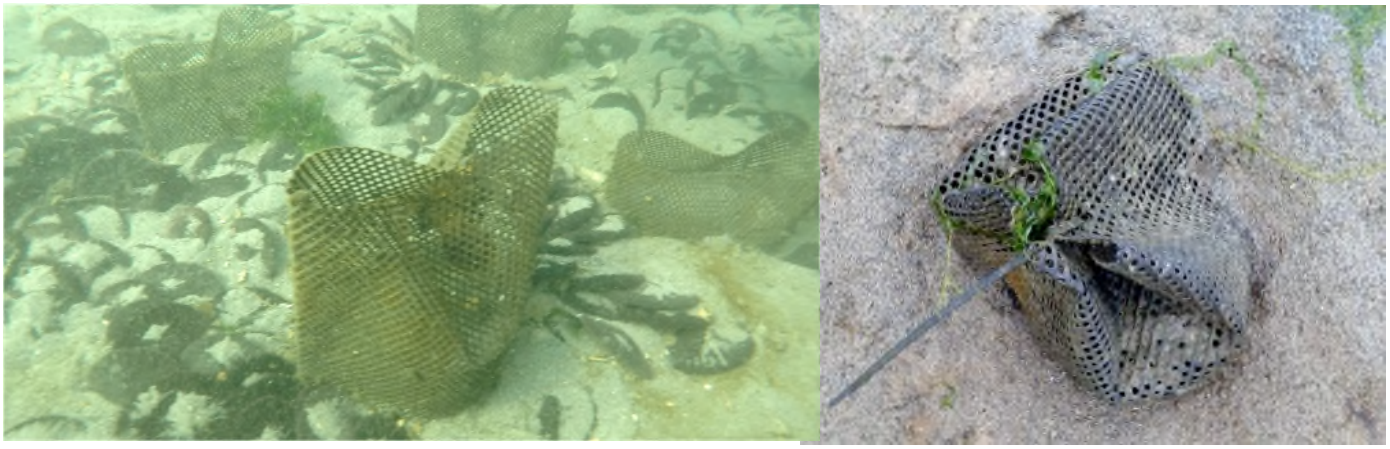


Figure 25 Flexible Mesh Tubes Used for Geoduck Seed Grow-Out

Notes: Top: at installation; Bottom: after installation.

After the culture tubes are removed, predator exclusion netting may be placed over the bed for up to 6 months so that the geoduck clams can adjust to the lack of predator protection provided by the culture tubes without experiencing excessive predation. Predator exclusion nets used are placed directly on the sediment surface (i.e., no vertical relief) and secured every 8 to 10 ft along the perimeter with J-shaped stakes.

Planting of geoduck seed typically occurs within the intertidal zone between ELT to +3.0 ft MLLW, in any season with suitable growing conditions and within suitable substrate. The project area would have protective gear present for 2 to 3 years of a 5- to 7-year cycle for geoduck aquaculture, depending on the type of culture tubes used. Tube placement and seeding would occur during a low tide by beach crews or during a high tide by divers.

5.1.1 Subtidal Shellfish Culture Methods

Shellfish cultured in subtidal habitat include geoduck grown in the ground, mussels grown on rafts or longlines, and shellfish seed grown in trays suspended from rafts or FLUPSYs (as shown in Figure 22).

Geoduck

Subtidal geoduck aquaculture uses similar methods to intertidal geoduck aquaculture (see above), but typically uses individual predator net affixed to the top of the tube with a rubber band designed for marine application, rather than a predator protection net that covers a large area of tubes. Harvest and planting are performed by divers.

Mussels

Mussels are typically grown on two different overwater structures: rafts and longlines. Raft platforms are typically constructed of lumber, galvanized steel, and plywood. Flotation is generally made from reclaimed polyurethane food-grade barrels, or coated or vinyl-wrapped polystyrene foam. Raft structures and longlines are anchored in place, frequently with concrete anchors attached with nylon or polypropylene line. Rafts are not a solid surface, but rather mostly open on top with cross beams that create "wells" from which lines suspend. Rafts may be periodically wrapped with nets to exclude predators.

Surface longlines are typically made of heavy polypropylene or nylon rope suspended by floats or buoys attached at intervals along the lines and anchored in place at each end. Anchors are frequently made of concrete, and floats are either foam filled or recycled food-grade containers.

Shellfish Seed

Clam, oyster, and geoduck seed may be grown in trays suspended in FLUPSYs, prior to outplanting in the ground. The FLUPSY is an integral part of many companies' seed production systems, is a highly efficient method for growing seed out to a larger size. They take advantage of the natural algae in marine water to feed and grown the seed.

A FLUPSY is an in-water raft-like structure designed to upwell nutrient-rich water through shellfish seed bins to provide a consistent source of nutrients to growing shellfish. Seed is typically placed in a FLUPSY when it is approximately 0.4 mm to 2.0 mm in size, and removed when it reaches 4.0 mm to 18.0 mm. This process takes approximately 2 to 6 months, depending on the season, local growing conditions, and species of shellfish cultured.

A FLUPSY is a rectangular structure generally constructed of aluminum with poly-encapsulated floats for buoyancy. It has a submerged trough at both ends containing a paddle wheel or small electric pump. Along the length of the FLUPSY, there are open wells containing upwelling bins where the shellfish seed is placed. The paddle wheel or pump turns and moves water out of the trough. In order for the trough to refill, water must pass through the upwelling bins. The bottom of the upwelling bins has 1.2 mm to 1.8 mm mesh screens, which allows water to come up through the upwelling bin and exit the bin through the troughs. FLUPSYs typically hold 8 to 28 upwelling bins.

5.1.2 Best Management Practices

Shellfish growers adhere to a number of best management practices (BMPs) to minimize impacts on the natural environment. The typical BMPs are discussed in the Environmental Code of Practices for PCSGA (2011). Individual farms also create farm management plans for the needs and issues particular to the individual farms. A few of the typical BMPs related to gear maintenance are listed below.

- Unnatural materials (e.g., tubes, nets) shall be removed as soon as practical when shellfish are no longer vulnerable to predators. Marker stakes and buoys also will be removed when they are no longer necessary.
- Damage to aquatic vegetation and substrates from boats or barges must be minimized/ avoided through the following practices: Predator exclusion nets are designed so they do not break free and cause beach littering on site or off site. The grower shall ensure that predator exclusion nets are tightly secured to prevent them from escaping from the project area.
- At least once a month and directly following storm events, beaches in the project vicinity shall be patrolled by crews who will retrieve aquaculture debris (e.g., predator exclusion nets, tubes) or unnatural debris (e.g., bottles, cans) that escapes from the project area.

5.2 Existing Scientific Literature

The following is a review of the main scientific literature related to shellfish aquaculture gear and effects to the surrounding environment.

5.2.1 Predator Gear Efficacy

Munroe et al (2015) reviewed over 35 peer-reviewed articles on the efficacy of protective netting for clam aquaculture. The literature review included research from the Pacific Northwest, the US Atlantic, Europe, Japan, Australia, and the Pacific, and found that "Properly installed and

maintained predator protection is essential for successful clam culture." The Munroe et al. (2015) work found consensus in 40 studies that protective netting is more effective than controls that do not use screen protection. They also acknowledge that predator netting may be a small contributor to plastic pollution in the ocean, but that industry-driven best management practices is a solution to this risk.

5.2.2 Sediment Changes from Predator Exclusion Netting

Predator exclusion netting used in Manila clam culture can reduce the local circulation where nets occur and result in an accumulation of sediment under the nets, as reported in a 5-year study of Manila clam culture in the River Exe estuary, Devon, UK (Spencer et al. 1996, 1997, 1998). This research indicated an accumulation rate up to four times higher in netted plots compared to control plots (Spencer et al. 1996). Throughout the 2-year grow-out period, there was an elevated profile of approximately 3.9 inches in a 32.8 ft x 4.9 ft plot (or 1.8 cubic yards [cy]). However, the effect was localized, and did not change sediment accumulation volumes in adjacent areas.

Another study, Simenstad and Fresh (1995), reported that predator exclusion netting used in Manila clam culture in Willapa Bay had consistently finer mean grain size in netted plots compared to the natural beach, but only significantly so during one of three months. The authors indicated that netted plots decreased near-bed resuspension and trapped more materials transported alongshore. Simenstad and Fresh (1995) reported an increase of less than 0.04 to 0.08 inch in treatment plots, which persisted as long as nets were in place. Finally, a study in British Columbia compared paired netted and non-netted Manila clam plots and found no significant differences in sedimentation (Munroe and McKinley 2007). Overall, when predator exclusion netting is present there is a potential to result in minor increases in sediment deposition and nutrients. Changes associated with the use of netting in Manila clam culture, as used in Pierce County, do not result in significant environmental impacts and are restricted to the netted plots.

There is also the potential to accumulate sediment within the culture tubes for geoduck aquaculture. Golder (2011) estimated the potential accumulation of sediment within tubes with predator exclusion nets present from an existing geoduck aquaculture operation in south Puget Sound (the Foss farm). Based on a visual inspection, an average height of 2.5±0.5 inches of sediment accumulation was reported within the 4 inches of tube that was exposed above the sediment bed. This equates to a volume of approximately 31.4±6.3 cubic inches per tube. Golder (2011) then calculated net accumulation over a 1.0-acre area to be approximately 29.3 cy of sediment. This amount of net accumulation would be expected to rapidly re-distribute through wave and current action after one or two tidal cycles (or a few days with typical wave conditions) following the removal of nets and tubes.

To put this into perspective, there was about 9,407 cy of sediment transported during the December 15, 2006 storm event along the shoreline of the existing Stratford-Meyer farm in Pierce County (ENVIRON 2013), which is more than 300 times greater than the amount that

could potentially accumulate in one acre during the planting phase and then be redistributed along the beach. Therefore, sediment accumulation during geoduck operations is insignificant and not expected to affect ecological functions or processes. Further, if a variety of culture tubes (e.g., flexible mesh tubes and PVC tubes) or culture methods (e.g., Pacific oyster bags) are used, then this amount of accumulation would be unlikely.

5.2.3 Benthic Infauna and Epifauna

Placement of gear (both geoduck culture tubes and oyster bags) is not expected to significantly affect benthic epifauna. Once the gear is placed, it is rapidly encrusted with epibiota that creates a reef-type structure and a biogenic source for associated food organisms of juvenile salmonids. For example, work by Hosack (2003b) reported that important fish prey organisms, such as harpacticoid copepods, exhibited higher densities in oyster habitats. These observations parallel those of Ferraro and Cole (2011, 2012) who studied oyster culture in Yaquina Bay (Oregon), Willapa Bay (Washington), and Grays Harbor (Washington). The authors reported similar higher abundance and richness in benthic macrofaunal communities in oyster habitat compared to mudflat habitat in the three areas studied.

Potential effects to the benthic community from the introduction of PVC tubes with predator exclusion nets was studied by McDonald et al. (2015). The sampling design followed the before-after-control-impact (or BACI) design with a "treatment" and "reference" plot within 75 meters (m) or 246 ft of each other. Each plot was about 2,500 m^2 (or about 0.6 acres). The spatial scale was intended to approximate commercial operations, to the extent practicable. The goal of the McDonald et al. (2015) study was to understand planting effects before and after the introduction of geoduck aquaculture gear.

Effects on the benthic community from the presence of geoduck aquaculture gear were considered by McDonald et al. (2015) to be short-term with a short recovery period. Similarly, as discussed above, the presence of shellfish aquaculture gear and/or oyster habitat may increase benthic invertebrate prey resources compared to what may be present without shellfish culture. Therefore, presence of gear was considered to be an insignificant and potentially beneficial effect to benthic infauna and epifauna.

5.2.4 Summary

The literature shows that predator protection is essential for production of shellfish product, and that effects to the sediment, bathymetry, and benthic infauna are localized, short-term, and can be minimized with best management practices. A preference against tubes, structures, and alterations is not supported by current scientific and technical information and is not necessary to achieve no net loss of ecological functions. Additionally, some forms of aquaculture require gear to be present for more than 2 years, and hence a 2-year limit is infeasible and would threaten the viability of certain shellfish crops.

5.3 Invasive Species Control

Predator control methods used by shellfish growers are typically passive, through the use of protective gear. However, there are some species that cause economic harm and must be more actively controlled. These species are known as invasive species. As per Executive Order 13112 an "invasive species" is defined as a species that is: (1) non-native (or alien) to the ecosystem under consideration, and (2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

Washington State takes invasive species very seriously, and has established several groups to control invasive species. In 2005, The Aquatic Invasive Species Prevention and Enforcement Program (AIS Program) was established to prevent and control aquatic invasive species, primarily via watercraft inspections. In 2006, the Washington Invasive Species Council ("the council") was established by the legislature and "tasked with providing policy level direction, planning, and coordination for combating harmful invasive species throughout the state and preventing the introduction of others that may be potentially harmful." (RCO 2009). The AIS program and the council both maintain lists of priority species that are of high threat in Washington. Many marine invertebrate species are on the lists including: *Carcinus maenas* (European green crab), a number of tunicates, and *Dreissena rostriformis bugensis* (quagga mussel).

An example of a plant species that has been actively controlled by shellfish growers, and others, is the cordgrass *Spartina alterniflora*. *S. alterniflora* is a Class A noxious weed in Washington (control is required) which invades tidelands and converts them into monoculture meadows, which then limits the habitat for native species, aquaculture, and recreation. Active eradication of *S. alterniflora* has vastly reduced the infestation, and allowed tideland habitat to once again be available to native species such as birds and fish, and for shellfish aquaculture (PCSGA 2011).

There is an invertebrate, the oyster drill, recognized by WDFW as an aquatic invasive species (WDFW 2016c,d). There are two species of oyster drills (*Urosalpinx cinerea* and *Ceratostoma inornatum*) that are of great concern to shellfish farmers, and for which predator protection gear does not suffice. Oyster drills prey on oysters and other shellfish by drilling holes into their shells and consuming the animal, and seem to prefer smaller oysters (Buhle and Reusink 2009, Duckwall 2009). Buhle and Ruesink (2009) looked at the impacts of oyster drills on the native Olympia oyster (*Ostrea lurida*) in Willapa Bay, and found that predation by drills may be a component in limiting the recovery of the native oyster population. In 2008, the council developed an Aquatic Nuisance Species Watch List (RCO 2008a) and a Strategic Plan (RCO 2008b) that included the oyster drills. Protective aquaculture gear is not enough to ward off these species because of their small size; growers must proactively remove these species from their culture areas, so they do not lose product.

Oyster drills life cycle does not include a planktonic larval stage, thus eggs or adults must be removed to control the spread of the population. WDFW encourages shellfish growers to take preventative measures, including: (1) not introducing the drills to new areas through the shells

of adult oyster, and (2) not transplanting drills into previously drill-free areas (WDFW 2016c). Recreationally, WDFW also requires oysters to be shucked on the beach so that any drills attached to the shells are not spread to other beaches (WDFW 2016d). WDFW also restricts the transfer of shellfish from areas known to contain oyster drills; the restriction has been codified in WAC 220-72-011 and 220-72-015.

Bolstered by Washington state's values around control of invasive species, and their own economic interest, control of oyster drills by shellfish growers is key.

5.4 Summary

Commercial shellfish aquaculture is not viable without predator protection gear. There is a variety of culture gear, depending on the type of species cultured and the culture method. Using gear is a passive form of predator protection and results in minimal effects to the farmed footprint and limited-to-no effects that extend beyond the farmed footprint. There is no science to justify the restriction stated in the Pierce County SMP to give preference to projects without aquaculture gear or restrict use of that gear for a two-year period.

Additionally, the restriction that predator control shall not involve deliberate killing or harassment of birds, invertebrates, or mammals is fine as long as the restriction allows for continued control of AIS, per Executive Order 13112. Both active removal and conservation measures during operations, are effective measures for the control of invasive species. Overall, the changes in the Pierce County SMP related to predator protection gear appear to be a result of not understanding either industry needs or legislative mandates.

6.0 ADDITIONAL COMMENTS AND LITERATURE PROVIDED TO PIERCE COUNTY

Based on a review of the record before Ecology pertaining to the County's SMP update, several documents were submitted to Pierce County on the potential effects of shellfish aquaculture. These documents do not provide persuasive and current scientific or technical information supporting the prohibition and other restrictions on aquaculture discussed in this report. These documents included comments and literature that were considered in this review (Table 5). If a comment was not addressed through the information provided above, then additional information directly related to these responses is provided below Table 5. Finally, the Shorelines Hearings Board (SHB) has issued numerous recent decisions confirming shellfish aquaculture is a preferred use, and the farms under appeal would not likely result in significant environmental impacts. Where these hearings are related to subjects discussed in the additional comments provided by Pierce County, they are referenced in Table 5.

Table 5 Summary of Additional Comments and Literature Provided by Pierce County.

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
Existing Shellfish Aquaculture (see Section 6.1)					
Cumulative Impacts and Intensity of Use of the Nearshore	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Ned Quistorff	▪ Shellfish Aquaculture Initiative (NOAA 2007) ▪ Pictures of aquaculture farming ▪ SHB decisions (SHB No. 11-019, SHB No. 13-016, SHB No. 14-024) ▪ Map showing locations of leases in Pierce County (red dots) (no reference provided) ▪ Sierra Club industrial shellfish aquaculture PowerPoint and website (no longer active) ▪ Dumbauld et al. 2009	▪ There is a loss of ecological functions from shellfish aquaculture. ▪ SHB decisions that identify when a cumulative impacts analysis should be performed. ▪ Shellfish aquaculture activities are altering over 6,400 acres of natural shorelines in south Puget Sound. ▪ High densities of shellfish planted in the nearshore. ▪ The concept of a "production" estuary (Dumbauld et al. 2009) is more than 10% of an estuary includes shellfish aquaculture, which includes Willapa Bay, Washington, and Humboldt Bay, California. It is notable, as discussed in Dumbauld et al. (2009), that culture has occurred in these estuaries for 100+ years within eelgrass habitat. ▪ No literature exists that demonstrates no effect of high intensity of growing animal mass in close quarters.	▪ No-net-loss of ecological related to shellfish aquaculture and the surrounding habitat is discussed in Section 3.2 above. ▪ Concerns regarding cumulative impacts under SEPA have been raised and rejected during recent SHB cases [SHB No. 11-019 (Findings of Fact "FF" 21, and Conclusions of Law "COL" 9); SHB No. 14-024 (FF 52-59 and COL 27-30)] ▪ Concerns regarding cumulative impacts under SMA have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 15); SHB No. 13-006c (FF 46-48 and COL 21-27); SHB No. 14-024 (FF 52-59 and COL at 23)] ▪ High density of organisms does not necessarily result in impacts. As discussed by multiple authors, shellfish aquaculture does not result in long-term exclusion of other organisms and can increase biodiversity of benthic organisms. ▪ Approximately 4.9% of Pierce County's shorelines are currently used for shellfish aquaculture. The 6,400-acre value presented by the Coalition is a misrepresentation of actual farm activity in south Puget Sound. The maps were an effort used for the NWP 48 consultation, and represent leased habitat that was a total of 4,748 acres (NMFS 2009). However, not all of this was, or is currently, active culture. ▪ It is notable that one of the distinct advantages of shellfish aquaculture is the ability to spread out activities over a larger area, and thus reduce the overall impacts at a landscape scale. This concept was explored in Dumbauld and McCoy (2015) in relation to eelgrass in Willapa Bay (see Section 3.2 above). ▪ Finally, the Dumbauld et al. (2009) was a literature review that emphasized the point that scale is an important management consideration. The main conclusion from the study, which is in direct contrast to just focusing on the term "production," is that "local and short term effects from aquaculture are clearly evident in U.S. West Coast estuaries, bivalve aquaculture does not remove area from the estuary or degrade water quality like other anthropogenic influences, and thus has not been implicated in shifts to alternate states or reduced adaptive capacity of the larger ecological system."	Section 3.2
Suspended Sediment (Geoduck Harvest)	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Email from Dave Risvold to Debby Hyde (December 2011) ▪ Quote from Charles Simenstad (1999 letter from SEIS 2001)	▪ Prohibition of geoduck hydraulic harvest techniques within a Natural Shoreline Environmental Designation (SED). ▪ Damage to adjacent properties through siltation from geoduck harvest events. ▪ Wild geoduck harvest potentially affects salmonid migration due to exposure to sediment plumes, alteration of migration behavior, sedimentation of intertidal habitat, shading impacts to plants, and attraction or aggregation of potential predators.	▪ Effects of suspended sediment are discussed in detail in Section 2.2, above. ▪ Concerns regarding waves, currents, and sediment transport have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 6, 14, 16, and COL 6, 14); SHB No. 13-006c (FF 24-26, 30-32 and COL 13, 15); SHB No. 14-024 (FF 32-38 and COL 13, 19)] ▪ Concerns regarding harvest activities have been raised and rejected during recent SHB cases [SHB No. 14-024 [FF 16-18 and COL 13, 15; SHB No. 13-006c (FF at 24-26, 30-32); SHB No. 11-019 (FF 13-18, 22, and COL 14)] ▪ Harvest disruptions are expected to be highly localized and consistent with the existing range of normal storm/wave activity. ▪ Sediment size structure may temporarily change post-harvest, but these changes return to baseline conditions within four months of harvest. ▪ While sediment may be loose directly following a harvest event, reconsolidation of sediments occurs very quickly. In laboratory experiments with fine-grained marine sediment, resistance to resuspension was shown to double approximately every 12 hours (Southard et al. 1971 *as cited in* Short and Walton 1992). Therefore, the sediment redeposited during a harvest event will tend to regain its original shear strength within 1-2 days. ▪ Sedimentation due to gear and geoduck harvest events are a small percentage of the sediment budget, and large-scale off-site deposition or erosion is unlikely.	Section 2.2, Section 6.1.1

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
Nutrients	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Bouwman et al. 2013 ▪ Shumway et al. 2003	▪ Intensive production of molluscs can become point sources of regenerated nutrients.	▪ Changes to water quality associated with nutrients are discussed in Section 3.2 above. ▪ The Bouwman et al. (2013) study is more of a summary from a larger modeling effort reported in Bouwman et al. (2011). ▪ The goal of both studies was to identify nutrient inputs to the system from shellfish aquaculture, and areas that may be affected by intensive production. Estuaries in China are the locations that fit this definition, compared to the 1.5% of North America that contributes to the global production of bivalves. ▪ Bouwman et al. (2013) provided recommendations for siting shellfish aquaculture operations in order to avoid deleterious impacts to water quality, including the use of fallow periods, moving production into deeper waters, or siting in areas with favorable flushing characteristics.	Section 3.2, Section 6.1.2
Shellfish Beds as Fisheries	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Beck et al. 2009 ▪ Chiesa et al. 2011	▪ Shellfish have been managed for harvesting rather than restoration around the world. ▪ Non-native shellfish cannot replace wild native species and result in the same ecosystem services as shellfish reefs.	▪ Beck et al. (2009) is about a loss of oyster reefs (>85%), primarily from destructive fishing practices such as dredging, overharvesting of shellfish, introduction of non-native shellfish, habitat loss, and declines in water quality. ▪ Beck et al. (2009) is about wild harvest impacts, not impacts from shellfish aquaculture. ▪ One of the main measures suggested by Beck et al. (2009) to relieve pressure on reefs and wild stocks is to provides well-managed shellfish aquaculture. ▪ The authors also see the value in establishing shellfish partnerships across sectors, including the aquaculture industry, environmental non-governmental organizations, and resource managers to help conserve and restore the coastal water quality that is vital to cultured and wild shellfish. ▪ The final key recommendation in the report is to support sustainable shellfish aquaculture, which "can be done more sustainably than most other fisheries or aquaculture, and these businesses rely on clean coastal waters and are key stakeholders for preserving and improving water quality." ▪ Chiesa et al. (2011) studied DNA sequence of Manila clams in Italy, and discovered that there were at least two sources of the invasive clams. Little significance to local impacts.	N/A
Pesticide and Herbicide Use	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Ned Quistorff ▪ Heather McFarlane	▪ Davis (no date or reference provided) ▪ 2003 Aquatic Botany, The influence of burrowing Thalassinid shrimps on the distribution of intertidal seagrasses in Willapa Bay, Washington, USA ▪ This Isn't Your Grandfather's Farm	▪ Carbaryl and imidacloprid use in Willapa Bay. ▪ Glyphosate and imazapyr use in Washington estuaries. ▪ Spraying of imazamox in Willapa Bay. ▪ Impact of additives used in aquaculture on surrounding ecosystem.	▪ Pesticides and herbicides are not used by growers in Pierce County for intertidal aquaculture.	N/A
NWP 48	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Sierra Club (Laura Hendricks)	▪ NMFS 2009 ▪ USFWS 2009 ▪ Bill Dewey letter to NMFS (April 2011) ▪ NMFS letters to Corps (April 2011, October 2011, February 2012) ▪ Corps 2012	▪ Various quotes related to potential impacts to ESA listed species and critical habitat from Washington State shellfish aquaculture activities. ▪ Responses from NMFS resulting in fewer regulations for shellfish aquaculture operations. ▪ Conditions are inadequate to protect ESA listed and non-listed species (references back to Simenstad 1999 letter in SEIS 2001).	▪ Shellfish aquaculture is a highly regulated activity (see Section 3.1 above), and the letters from NMFS indicated standard conservations measures that apply to all Corps-permitted projects. ▪ The conclusions of the consultation with NMFS (2009, 2011) and USFWS (2009) were provided in Section 3.2 above. ▪ The Services concluded that changes related to shellfish aquaculture "may affect, but not likely to adversely affect" ESA listed species and critical habitat.	Section 3.1
Submerged Aquatic Vegetation					
Buffers	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ None	▪ Intertidal Mechanical Harvest: a 50-ft buffer is not adequate and not based on best available science. ▪ Mussel Rafts: a 50-ft buffer is not adequate and not based on best available science.	▪ The best available science related to interactions of shellfish aquaculture and the surrounding environment, especially as it relates to SAV, is discussed in Section 2.0. ▪ While the commenter claims that the buffers are not based on best available science, they provide no literature to support what buffers should be used.	Section 2.2

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
				▪ The literature associated with shellfish aquaculture indicates that effects do not extend, or extend minimally, beyond the footprint of the farm, and results support a buffer distance of 10 ft or 16.4 ft to be conservative.	
Eelgrass	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Sierra Club (Laura Hendricks) ▪ Ned Quistorff	▪ WSG 2015, Appendix V ▪ WSG 2010, 2011 (Interim Reports) ▪ Ruesink and Rowell Sea Grant video ▪ This Isn't Your Grandfather's Farm	▪ Effects to eelgrass reported in Micah Horwith's study on Fisk Bar. Analysis indicates some "spillover" effects of geoduck aquaculture on the adjacent eelgrass meadow. ▪ Eelgrass density with geoducks and harvest resulted in a 70% reduction in eelgrass density.	▪ The results of the Fisk Bar study are discussed in Section 2.2 and Section 3.2. Overall, effects to eelgrass were shown to be short-term, restrained to the farm footprint (except in the summer when effects extended up to 9 m), and recovery occurred within 1 year following conclusion of the study. ▪ The Ruesink and Rowell (2012) study indicated that: o "eelgrass of the small morphotype found in south Puget Sound coexists with geoduck clams, given reduced summer density but enhanced size and branching." o Geoduck harvest resulted in a 70% reduction of eelgrass, but was similar to unharvested plots within 15 months post-harvest. o Geoduck planting operations do not cause a significant change in eelgrass metrics, and can even coexist with eelgrass habitat. o In terms of the effects from a harvest event, in which recovery was shown to occur well within the 5- to 7-year harvest cycle, the authors concluded that, "Harvest practices that generate small gaps or leave higher densities of remnant shoots should improve resilience in exclusively clonal populations," such as those in south Puget Sound.	Section 2.2, Section 3.2
Aquatic Vegetation	▪ Sierra Club (Laura Hendricks) and Futurewise	▪ EnviroVision, Herrera Environmental and Aquatic Habitat Guidelines Program, October 2007, Revised June 2010	▪ Preserving intact vegetation is one of the most important ways to protect nearshore health. Also, developing intact areas with intensive uses removes large areas of vegetation.	▪ The majority of literature related to aquatic habitat indicates that edge habitat is extremely productive (Holt et al. 1983, Orth et al. 1984, Boström et al. 2006), and as long as a habitat mosaic is provided, species use of an estuary would not be significantly altered (Hosack et al. 2006). In a comparison of intertidal mudflat, seagrass (*Zostera marina*), and oyster (*Crassostrea gigas*) habitat use, Hosack et al. (2006) indicated that, "Fish and decapod species richness and the size of ecologically and commercially important species, such as Dungeness crab (*Cancer magister*), English sole (*Parophrys vetulus*), or lingcod (*Ophiodon elongatus*), were not significantly related to habitat type.". ▪ A recent study by Dumbauld et al. (2015) identified no significant differences in the density of juvenile salmonids caught in the four habitat types analyzed (including seagrass and oyster aquaculture). The authors went on to say that compared to permanent or 'press' disturbances "our research suggests that short term 'pulse' disturbances like aquaculture which alter the benthic substrate in lower intertidal areas used primarily by larger juvenile salmon outmigrants may pose a less significant threat to maintaining resilience of these fish populations." ▪ If BMPs are applied, there is no identified impact associated with shellfish aquaculture that is likely to result in habitat fragmentation of aquatic vegetation. Therefore, fragmentation effects to aquatic vegetation from shellfish aquaculture are considered less than significant.	Section 3.2
Forage Fish, Benthic Invertebrates, and Sand Dollars (see Section 6.2)					
Work Windows	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Dan Penttila presentation (SHB No. 11-019)	▪ Shellfish aquaculture needs to comply with salmon and forage fish work windows.	▪ Work windows only apply to construction activities. Growers adhere to the salmonid and forage fish work windows for construction activities. The work windows do not apply to ongoing farm activities.	N/A
Ingestion of Forage Fish Larvae	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Sierra Club (Laura Hendricks)	▪ McKindsey et al. 2006 ▪ Lehane and Davenport 2006 ▪ Troost et al. 2008 ▪ Wong and Levinton 2006 ▪ Dan Penttila presentation and testimony (SHB No. 13-006c) ▪ Penttila comments on Corps Permit Conditions (March 2012)	▪ Studies document that all types of shellfish consume fisheries resources (eggs and larvae). ▪ Activity of geoducks in the winter in New Zealand (Gribben et al. 2004) conflicts with information reported from Washington State (Goodwin 1977).	▪ Concerns regarding shellfish ingestion of forage fish larvae have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 7, 8, and COL 6); SHB No. 13-006c (FF 29 and COL 13); SHB No. 13-016c (FF 67)] ▪ Forage fish in southern Puget Sound spawn in the winter, and geoduck are relatively dormant during this time. ▪ Geoducks target small particles in the range of 0.00004 to 0.0006 inches, also known as phytoplankton, while at hatch, sand lance and surf smelt larvae are about 0.2 inches and herring larvae are about 0.3 inches.	Section 6.3.1

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
		▪ This Isn't Your Grandfather's Farm			
Forage Fish Spawning Habitat	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Sierra Club (Laura Hendricks) ▪ Tahoma Audubon and Sierra Club (Kirk Kirkland)	▪ Blake Island, Washington Study Results-Spawning and Wild Geoduck Harvest (no reference provided) ▪ Port Gamble, Washington Study Results (no reference provided) ▪ Penttila 2007 ▪ Shaffer (no reference provided) ▪ Jim Johannessen presentation and testimony (SHB No. 11-019, SHB No. 13-006c) ▪ SHB decision (Longbranch SHB No. 11-019) ▪ NMFS letter to Pierce County, November 15, 2013	▪ Evidence of sand lance eggs in water column and DNR separation of dive harvesting from sand lance habitat. ▪ Sand lance burrows in the lower intertidal sediments results in a loss of habitat when geoduck tubes are installed. ▪ Dredging operations routinely take place on or near tide flat areas containing herring spawn (WDFW, unpublished data). ▪ Use of the nearshore by juvenile salmonids and forage fish. ▪ Siltation of forage fish spawning habitat.	▪ Information associated with forage fish conditions and training are provided in Section 4.0 above: o Only Pacific herring overlap with aquaculture operations. The two other beach spawners: Pacific sand lance and surf smelt spawn higher in the intertidal. Conservation measures from Pierce County exclude aquaculture from elevations where sand lance and surf smelt spawn. o Growers have received training in recognizing Pacific herring spawn, and avoid disturbance to those areas during spawn events. This training meets regulatory conservation measures. ▪ Concerns regarding harm to forage fish spawning beds have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 7, 12, 14, 18, and COL 6); SHB No. 13-006c (FF 17-29, and COL 10-13; SHB No. 14-024 (FF 19-25 and COL 13, 16)] ▪ Although this activity results in changes in elevation and sediment grain size, both appear to quickly return to baseline conditions post-harvest. At Samish Bay, Micah Horwith (2009) reported that post-harvest loss of elevation was not evident within one month of a harvest event. Reconsolidation of sediments occurs as water content decreases, and shear strength and resistance to erosion increases. In laboratory experiments with fine-grained marine sediment, resistance to resuspension was shown to double approximately every 12 hours (Southard et al. 1971 *as cited in* Short and Walton 1992). ▪ Commenter did not provide reference materials regarding claims about eggs in water column, thus it is not possible to verify claims and provide a response.	Section 4.0
Clearing Beaches of Native Species (sand dollars and moon snails)	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Sierra Club – "beach clearing" photographs ▪ Cook & Bendell-Young (2010)	▪ Sand dollars are removed from the farm site. ▪ Moon snail effects on the bivalve community are small. Therefore, moon snail removal should not be implemented at shellfish farms	▪ Sand dollars have been historically removed from shellfish aquaculture sites on limited occasions. However, current BMPs do not provide for the removal of sand dollars from a planting bed. Instead, planting of shellfish occurs adjacent to sand dollar populations whenever possible, and, in the case of a very dense sand dollar bed, sand dollars are moved aside by hand. ▪ After the tubes are in place, sand dollars would be able to move back to an orientation that allows for feeding. Based on research on sand dollar aggregation and movement, sand dollars would be able to aggregate and right themselves even if they are overturned during planting activities (Chia 1969; Birkeland and Chia 1971; Highsmith 1982). ▪ Removal of geoducks during harvest may result in a temporary void that sand dollars may fall into. However, it is unlikely that deep burial would result because the void fills in from the sides as the geoduck is pulled out (i.e., sediment acts as a liquid collapsing from the bottom filling the hole immediately). Any sand dollars that are buried would likely be relatively shallow, and within the range of depths that these animals routinely burrow (e.g., see Chia 1969). ▪ Geoduck operations and sand dollar beds are not mutually exclusive and do not appear to affect the long-term persistence of a sand dollar bed in a geoduck farm, as discussed in Confluence (2015). ▪ Local shellfish BMPs do not provide for the removal or "clearing" of moon snail populations from shellfish farms.	N/A
Benthic Invertebrates	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Friends of Burley Lagoon (Heather McFarlane)	▪ VanBlaricom et al. 2015 ▪ McDonald et al. 2015 ▪ DeFrancesco and Murray 2010 ▪ Key Peninsula News article (2012) ▪ Toupoint et al. 2008	▪ Caveats in published literature indicate that results may not be appropriate to extend findings to other sites. ▪ Slides that document continual disturbance of planting and harvesting that document fish and macroinvertebrate communities differ between	▪ Concerns regarding impacts to the benthic community have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 17); SHB No. 13-016c (FF 64, 74-77 and COL 15); SHB No. 14-024 (FF 15 and COL 13-14)] ▪ Potential effects to benthic invertebrates and the most recent SeaGrant-funded publications on geoduck aquaculture effects are addressed in Section 3.2 above. ▪ The photographs of "beach clearing" shown by commenters are shellfish harvests. While there are some native organisms that are incidentally removed because they are attached	Section 3.2

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
			culture (+ structure) and reference plots in that patters favor structure-oriented species. ▪ Organisms are removed during "beach cleaning" activities. ▪ Manila clam cultivation in the English Channel: increase in fine particles and benthic community immediately post-harvest, increase in biomass of *Lanice conchilega* ("engineer species") due to "good will of the farmers"	to the harvested shellfish (e.g., barnacles, sea stars), these represent a small proportion of species affected. ▪ In addition, as indicated in the research above, these tend to be areas with higher species abundance and richness because of the presence of shellfish aquaculture. Therefore, the species that are incidentally removed may not be supported in that habitat without the presence of shellfish aquaculture. ▪ Toupoint et al. (2008) found increase in *L. conchilega* biomass increased near Manila clam farms. ▪ Toupoint et al. (2008) concluded that the survival and increase of *L. conchilega* was largely due to "goodwill of the farmers," showing that proper BMPs and awareness can have a positive effect on the native community.	
Salmon Habitat	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Sierra Club (Laura Hendricks) and Futurewise	▪ Chinook and Bull Trout Recovery Approach for Puget Sound 2007 ▪ Simenstad and Fresh 1995 ▪ Brennan et al. 2004 ▪ Semmens 2008 ▪ Clancy et al. 2009	▪ Aquaculture Stressor Chart ▪ Preference of eelgrass over other structured benthic habitats (e.g., oyster beds) in an enclosure study. ▪ Development actions across Puget Sound have caused various species populations to decline, which are related to destruction, degradation, and fragmentation of habitats.	▪ Use of nearshore habitats, and specifically shellfish aquaculture habitats, by salmonids is discussed in Sections 3.2 and 3.4 above. ▪ Presence and overlap with shellfish aquaculture during migration periods does not necessarily result in an effect to juvenile salmonids. ▪ The Services weighed in on effects to Chinook salmon and bull trout from existing shellfish aquaculture during the NWP 48 consultation. The NMFS (2009) BiOp concludes: "NMFS determined that although the effects of these activities could include changes in the environment, none do so to an extent that would impair normal behavioral patterns of listed species."	Section 3.2, Section 3.4, Section 6.3.2
Food Web	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Bricklin & Newman (on behalf of CPPSH and Case Inlet Shoreline Association)	▪ Puget Sound Partnership 2008 ▪ CISA/CPPSH v. Pierce County and Longbranch Shellfish, SHB 11-019, Final Decision (July 13, 2012)	▪ "Intensive shellfish aquaculture may divert materials to benthic food webs, alter coastal nutrient dynamics, and have cascading effects on estuarine and coastal food webs, water quality, and aesthetics are a current concern but very few studies have been conducted to examine them." ▪ In dissent, Dave Somers noted that geoduck aquaculture creates a level of competition outside any range of naturally occurring competition.	▪ Effects to the food web from shellfish aquaculture is discussed in Section 3.2 above. ▪ The information presented by commenters are based on conjecture without data to support the claims or hypotheses. ▪	Section 3.2
Predator Protection Gear (see Section 6.3)					
Predator Exclusion Netting	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Heather McFarlane	▪ Maps of net use within Pierce County ▪ Bendell-Young 2015 ▪ Bendell and Wan 2010 ▪ Bendell et al. 2010 ▪ Jim Johannessen Presentation (SHB 14-024) ▪ Chris Waldbillig (WDFW) Email March 13, 2012 ▪ Washington Shellfish vs. Pierce County Witness Testimony ▪ Terrence McCarthy Pierce County Hearing Examiner (AA16-07) ▪ Young 2006	▪ Intertidal regions with farming had lower species richness, different bivalve composition (greater bivalve richness on farmed sites), abundance, and distributions, and a foreshore community dominated by bivalves, as compared to the intertidal region where no farming occurred. ▪ Beaches that were actively farmed had greater accumulations of organic matter and silt. ▪ Nets may cover a more significant portion of the usable intertidal in B.C. than previously thought.	▪ The use, and effects, of predator exclusion netting are discussed in Section 5.0 above. ▪ Concerns regarding predator exclusion netting have been raised and rejected during recent SHB cases [SHB No. 14-024 (FF 14-15 and COL 13); SHB No. 13-006c (FF 16-18)] ▪ There are short-term changes to sedimentation and benthic infaunal communities as a result of netting practices in shellfish aquaculture. However, research indicates that effects from the use of canopy nets are short term and do persist after removal of the nets or recover quickly post-harvest (Simenstad and Fresh 1995, Spencer et al. 1998, Price 2011, VanBlaricom et al. 2012). ▪ Bendell et al. (2010) indicates that there are significant changes in the geochemical composition of farmed vs. unfarmed sites in Baynes Sound, Canada. Although there is a significant difference between the two areas, there is no indication that these changes would impact water or sediment quality of farmed sites. In contrast, Cornwell and Newell (2010) indicated that nutrients released during a geoduck harvest is not a significant addition to the water quality of Puget Sound, and would be far outweighed by the amount of nutrients shellfish filter out of the water column. ▪ Many researchers have commented that shellfish aquaculture does not negatively affect the foraging behavior of most marine shorebirds or wading birds (Kelley et al. 1995, Hilgerloh et al. 2001, Connolly and Colwell 2005, Žydelis et al. 2006). Based on the pattern of use by marine birds within Baynes Sound, as presented by Bendell and Wan (2010), it does not appear that shellfish aquaculture is restricting the distribution or use of	Section 5.0

Subject	Commenter(s)	Literature/Citations	Comment	Response	Additional Information
				shorebirds and wading birds. In fact, the authors indicated that population trends of the species that may be affected by aquaculture were either positive (dunlin) or experience no change (scoters). No change and positive changes in the populations of these marine birds indicates that habitat or foraging is not limiting to these species within Baynes Sound in the presence of shellfish aquaculture. The negative changes in the Pacific loon and Western grebe populations do not appear to be related to aquaculture	
Bird Interactions	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Curt Puddicombe	▪ Photographs of eagle on top of net (2006) ▪ DeFrancesco and Murray 2010 ▪ Buchanan 2006 ▪ Heffernan et al. 1999 ▪ Kelly et al. 1996 ▪ This Isn't Your Grandfather's Farm ▪ Bendell and Wan 2009	▪ Harassment of seagulls, crows, ravens, and waterfowl. ▪ Killing birds by hunters from shellfish industry docks in Eld Inlet (2009) and Henderson Inlet (2010). ▪ Decrease of marine birds between 1978 and 2004. ▪ Aquaculture may prevent birds from feeding in areas covered with nets. ▪ Decrease in some bird species observed near intertidal shellfish farms	▪ Concerns regarding impacts to birds have been raised and rejected during recent SHB cases [SHB No. 13-016c (FF 78-79 and COL 15); SHB No. 14-024 (FF 26-28 and COL 13, 17)] ▪ Although entanglement with predator exclusion nets is noted in the literature as a possibility (e.g., Forrest et al. 2009, Straus et al. 2013), there are only rare examples of this occurring. Overall, this is risk is considered to be minor as long as netting is well maintained. ▪ Programmatic assessments found that commercial shellfish aquaculture activities throughout Washington State do not significantly impact listed birds and marine mammals (NMFS 2009, NMFS 2011, USFWS 2009). ▪ Benthic disturbance is expected to be highly localized and consistent with the existing range of normal storm/wave activity. Therefore, the prey resources of higher trophic organisms (e.g., birds and mammals) would not be significantly affected by the geoduck farm activities.	Section 6.4.1
Plastics and Toxicity	▪ Coalition to Protect Puget Sound (Laura Hendricks) ▪ Curt Puddicombe ▪ Bricklin & Newman (on behalf of CPPSH and Case Inlet Shoreline Association)	▪ Charles Moore presentation and testimony (SHB No. 14-024) ▪ Center for Biological Diversity petition to EPA ▪ Andrady 2011 ▪ Curtis Ebbesmeyer quote (no date or reference provided) ▪ Sierra Club – Plastic Pollution ▪ Sample bag of aquaculture plastic pollution presented at April 3, 2014 meeting ▪ The Use of PVC Plastics for Aquaculture in Puget Sound ▪ RCW 90.58.020 ▪ This Isn't Your Grandfather's Farm	▪ Add marine plastic pollution as a "pollutant" under the Clean Water Act. ▪ The particulate plastic from PVC tubes enters the food web and harms creatures in Puget Sound, including us. ▪ Pollution of beaches due to loss of gear. ▪ Need for tagging aquaculture equipment. ▪ RCW 90.58.020 states that, "a preferred use is one that controls pollution and prevents damage to the natural environment."	▪ Concerns regarding microplastics generated by shellfish farming have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 9); SHB No. 13-006c (FF 41-42 and COL 16); SHB No. 14-024 (FF 44-47 and COL 13, 20)] ▪ Concerns regarding marine debris generated by shellfish farming have been raised and rejected during recent SHB cases [SHB No. 11-019 (FF 10, 11, and COL 6, 14); SHB No. 13-006c (FF 36-42 and COL 16); SHB No. 14-024 (FF 39-43, 47 and COL 13, 20)] ▪ PVC is a very stable material. PVC manufactured in the United States does not use lead, arsenic, cadmium or mercury (PVCplus 2012). PVC tubes are unlikely to degrade based on the low ultraviolet exposure (related to the small portion of time that the tubes are exposed to daylight), low wave energy in Puget Sound, and debris management efforts (Baker 2012). ▪ Growers abide by many avoidance, conservation, and minimization measures in relation to gear including securing all gear, not storing loose gear below the OHWM, and maintenance of the project area, which would include cleaning up unnatural debris	Section 6.4.2
Parasites, Disease, Invasive Species, and Genetics (see Section 6.4)					
Parasites, Disease, and Genetics	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ WSG 2010 (Interim Report) ▪ Hand and Marcus 2004 ▪ Molnar et al. 2008 ▪ Bivalve major and sporadic pest list (PMSP)	▪ A Steinhausia-like microsporidian parasite within geoduck eggs. ▪ There are genetic and disease risks from importing seed from outside areas, such as Washington State, entering BC waters.	▪ Concerns regarding density, genetics, diseases, and parasites have been raised and rejected during recent SHB cases [SHB No. 14-024 (FF 29-31 and COL 13, 18); SHB No. 11-019 (FF 8)] ▪ The shellfish industry is highly regulated by WDFW and DOH to prevent transfer of disease.	N/A
Invasive Species	▪ Coalition to Protect Puget Sound (Laura Hendricks)	▪ Ruesink et al. 2005 ▪ Ruesink et al. 2006 ▪ Forrest et al. 2009	▪ There are ecological risks associated with oyster introductions.	▪ Control of invasive species associated with shellfish aquaculture operations is provided in Section 5.3 above. ▪ Given the current regulatory and management practices that are in place, there is no significant of commercial shellfish farms in Washington causing adverse impacts with respect to parasites, disease, invasive species, and genetics.	Section 5.3, Section 6.5

6.1 Existing Shellfish Aquaculture – Additional Information

Additional information related to suspended sediments (geoduck harvest) and nutrients generated from a shellfish aquaculture operation is provided below.

6.1.1 Suspended Sediment (Geoduck Harvest)

Suspended sediment is generated from a geoduck harvest. A geoduck harvest event is limited in space (about 0.1 acres for one day), duration (4 to 6 hours), and occurs infrequently compared to the entire culture cycle (i.e., 5 to 7 year grow-out period prior to harvest). Further, a harvest event covers a small portion of the intertidal habitat (0.1 acres). The intensity and duration of turbid conditions are related to the concentration of suspended sediment, suspended sediment grain size, water temperature, currents, and tidal flow conditions at the site (NMFS 2009). The sediment particles associated with typical geoduck aquaculture farms (e.g., predominantly sand) settle back to the seafloor rapidly and only a minor fraction will typically be transported from the harvest location (Golder 2011). The majority of sediment is typically deposited within 3 ft from the harvest hole (Short and Walton 1992).

New research from Fisheries and Oceans Canada, Pacific Biological Station in British Columbia, Canada has shown insignificant or minor effects from wet harvest events. A two-year research program in both intertidal and subtidal habitats reported that the sediment plume generated during a geoduck harvest event was generally limited to within approximately 16 ft of the harvest plot, and the levels were not greater than those reported during storm conditions (Liu et al. 2015). In addition, a harvest event did not result in significant overall material changes down-current above natural background sedimentation levels.

Effects to Fish from Suspended Sediment

Exposure to high levels of suspended sediment can cause behavioral stress in fish (e.g., gill flaring), sublethal effects (e.g., gill damage, increased susceptibility to disease), or reduced survival and growth. Newcombe and MacDonald (1991) suggested that a good indicator of suspended sediment effects is the product of sediment concentration (mg/L) and duration of exposure (h). Fisher et al. (2008) evaluated whether the TSS generated during a harvest event could result in significant effects to fish using the suspended sediment risk assessment model developed by Newcombe and Jensen (1996). The results indicated that fish were likely to exhibit avoidance responses to the TSS levels generated during a harvest event. If there is no confinement of fish in the area (i.e., the site is located along an open shoreline) there is no mechanism for fish to be exposed to suspended sediments from a harvest for a significant amount of time.

Published literature that addresses suspended sediment effects to juvenile and larval estuarine fishes also report limited effects at the concentrations generated during a geoduck harvest event. Juvenile Chinook salmon have been observed to increase their rates of foraging in relation to increased turbidity (18-150 Nephelometric Turbidity Units [NTU]), which was

attributed to the increase in cover provided by turbid waters (Gregory and Northcote 1993, Gregory 1994). The maximum concentration of turbidity that juvenile Chinook salmon experienced before reduced foraging was observed was 150 NTU for individuals that were 2 to 3 inches in fork length (Gregory 1994). Studies have also reported increased feeding incidence and intensity for larval Pacific herring at TSS concentrations ranging from 500 mg/L to 1,000 mg/L (Boehlert and Morgan 1985). Boehlert and Morgan (1985) attributed the enhanced feeding to improved "visual contrast of prey items on the small perceptive scale used by the larvae." Finally, Griffin et al. (2012) noted that TSS levels of 400 mg/L did not result in adverse effects for Pacific herring larvae for exposure times of 16 hours.

All of the TSS and turbidity levels noted from the literature above are either within or significantly higher than that measured from a geoduck harvest event. For example, Short and Walton (1992) measured TSS between 4 mg/L to 21 mg/L at the starting point of the harvest activity from a 0.2-acre harvest area. Further, the duration of exposure noted during the Griffin et al. (2012) study was four times longer than a typical harvest event (16 hours vs. 4 hours). Therefore, suspended sediment effects is considered insignificant for estuarine fish, even more sensitive larval stages.

Summary

A geoduck harvest event increases suspended sediment for short periods of time (one to two tidal cycles); is typically confined to a small area (about 0.1 acres per day); and occurs infrequently (every 5 to 7 years). Fish would be expected to either avoid the sediment plume generated during a dry or wet geoduck harvest or use the plume or disturbed sediment as a foraging opportunity. Suspended sediment and turbidity levels measured during geoduck harvest events were within or lower than the range in which juvenile Chinook salmon and Pacific herring larvae were observed to successfully forage. Overall, effects from suspended sediments are considered insignificant.

6.1.2 Nutrients

The main literature associated with shellfish aquaculture and nutrients is provided in Section 3.2 above. Based on additional literature raised in the comment letters, this section will expand upon that discussion, focusing on three studies: (1) Bouwman et al. (2011), (2) Bouwman et al. (2013), and (3) Bricker et al. (2015).

According to Bouwman et al. (2011), North America produced approximately 1.5% of the global production of bivalves in 2006, compared to 83% in areas with more intensive aquaculture like China[8]. Bivalves clear seston particles consisting of phytoplankton, suspended silt and clay particles, and detritus from the water column. This process transforms a portion of the nutrients contained in algae into bio-available forms that may support further phytoplankton production,

8 It is notable that China is the only country for which aquaculture output exceeds wild capture output and more than 90% of the domestic consumption of seafoods is from aquaculture. This is based on a population estimate of 1.3 billion with a yearly growth rate of 0.6% (http://tinyurl.com/zutc8gc).

while excreted nitrogen (N) and phosphorus (P) from biodeposits may regenerate nutrients, thus also adding to the amount of dissolved nutrients in the water column.

Bouwman et al (2011) created a budget model to describe the flows of nutrients in aquaculture systems using global production data. Bivalve production removes large amounts of nutrients from the water. The estimated amount of nutrients released through marine shellfish aquaculture is small (<1% in 2000) compared to global river export. Scenarios suggest that nutrient release from marine shellfish aquaculture will increase further over the coming decades, however the only region where shellfish are currently a significant contributor to nitrogen and phosphorus levels is China where more than 90% of current shellfish production is located. In that region, shellfish are an important contributor to nitrogen release (approximately 7% of predicted inputs) and phosphorus (12%). These levels are projected to grow to 19% for N and 30% for P by 2050 for China. This amount of production is not applicable to current operations in Washington State and Pierce County because the scale of operation is orders of magnitude greater, even the more productive estuaries such as Burley Lagoon and Totten Inlet.

As a follow-up to the work by Bouwman et al. (2011), another modeling study indicated that aquaculture[9] leads to release of dissolved nutrients that are N-rich (Bouwman et al. 2013). The changes in dissolved nutrients from finfish, crustacean, and shellfish aquaculture were modeled for China, Mexico, and Chile for the period 2010 to 2050. Aquaculture waste products were predicted alter the nutrient composition, not just the total quantity of dissolved nutrients, and the composition of nutrients created feedback loops that supported harmful algal blooms (HABs). The extent to which HABs may be affected by aquaculture are based on whether the system is retentive or well-flushed. The results suggest that under intensive production, which include locations where aquaculture growth is already rapid (e.g., China), bivalves can regenerate nutrients. The primary area where this has been observed is in a poorly flushed, shallow lagoon in Italy (Sacca di Goro) where high density (2,500 individuals/m^2) Manila clam culture occupies one-third of a 26 km^2 lagoon that has an average depth of 1.5 meters (Burkholder and Shumway 2011). However, again, this example is unrelated to operations in Washington State and Pierce County because both magnitude of culture operations and location provide enough circulation to control for adverse impacts from an accumulation of nutrients. Even Burley Lagoon, which is technically a barrier estuary and not a lagoon, that had water quality issues in the past from upland OSS and was able to drastically improve conditions through control of septic systems and other nutrient inputs.

The best research recently in the U.S. related to shellfish aquaculture and nitrogen is a modeling study by Bricker et al. (2015) in Long Island Sound, New York. The authors note that aquaculture removes nitrogen from the system and can, therefore, represent a potential best management practice for achieving total nitrogen targets. Using this approach, aquaculture

9 Note that this study includes all aquaculture, including finfish and crustaceans (e.g., shrimp and lobsters), and not just bivalve aquaculture. Bivalve aquaculture contributes significantly less nutrients than finfish and crustacean aquaculture. Additionally, shellfish aquaculture in this context include mussel longlines from rafts and not ground culture.

could be considered a solution to nitrogen reduction and could be one of the tools deployed by managers to achieve nitrogen loading targets that may be more cost effective than other methods (e.g., water treatment). They note that shellfish stocking densities that are well below production and ecological carrying capacities can create nitrogen drawdown of almost 10% in the estuary the Great Bay/Piscataqua Region Estuaries. Therefore, shellfish aquaculture may be a valuable tool to achieve nutrient abatement targets.

There is literature available to indicate the extreme examples of bivalve culture in estuaries of China and other countries. These studies, while valuable warnings, are not relevant to U.S. conditions. The scale of operations is typically orders of magnitude greater. Studies in the U.S. have shown that bivalves can improve water quality and mitigate anthropogenic sources of nitrogen in coastal systems through filter feeding. At current densities, and even in modeled scenarios that are 10x greater than current production levels in south Puget Sound (see Preikshot et al. 2015), existing shellfish aquaculture is likely a benefit to water quality rather than creating further issues with nutrients.

6.2 Forage Fish, Benthic Invertebrates, and Sand Dollars – Additional Information

Additional information related to forage fish larvae ingestion and salmon habitat and prey in relation to shellfish aquaculture operations is provided below.

6.2.1 Forage Fish Larvae Ingestion

Commenters raised concerns over shellfish ingestion of forage fish larvae. The scientific record does not support a conclusion that shellfish ingest forage fish larvae to the extent that would even be measureable. There are two pieces of information that make this potential impact unlikely (Davis 2013). First, forage fish in southern Puget Sound spawn primarily in the winter, and shellfish are dormant or reduce feeding during this time. This is from studies that document lower filtration rates of bivalves when phytoplankton populations are reduced (Lehane and Davenport 2002), such as in the winter, which would make the consumption of forage fish larvae insignificant.

The second condition is that shellfish target small particles in the range of 0.00004 to 0.0006 inches, also known as phytoplankton. Although bivalves have been shown to ingest up to a 0.2-inch amphipod (Lehane and Davenport 2006), the upper size limits of bivalve ingestion represented a minor fraction of the diet composition (Lehane and Davenport 2006, Wong and Levinton 2006, Troost et al. 2008). To put this into perspective, at hatch, sand lance and surf smelt larvae are about 0.2 inches and herring larvae are about 0.3 inches (Griffin et al. 2012, Penttila 2013). Wong and Levinton (2006) also indicated that there is a certain amount of discrimination between microalgae and larger particles, and larger prey items would likely be more mobile, which would also make them less likely to be consumed.

In summary, while ingestion of zooplankton by shellfish has been observed in the literature, even the authors of these studies indicate that these occurrences represent a minor fraction of the diet composition.

6.2.2 Salmon Habitat

One of the main papers cited in the comment letters to indicate that salmon do not prefer shellfish aquaculture is Semmens (2008). Although the study did find that juvenile Chinook salmon (of hatchery origin) preferentially used eelgrass over open mudflat or small patches of oysters (Crass*ostrea gigas*), Semmens (2008) argued against a myopic view of eelgrass conservation without an understanding of how conservation rules, such as no-net-loss of native eelgrass, are relevant at the landscape management scale. The following two points illustrate how this study was likely misinterpreted: (1) Semmens (2008) indicated that depth may have been a major factor in the results, and (2) fish were primarily located along the enclosure walls, which may have caused a behavioral change not accounted for in the results. It is also important to reiterate that this experiment was a manipulated enclosure study, which limits its applicability to natural settings. Furthermore, both the eelgrass and constructed experimental oyster plots were relatively small areas that do not represent either a continuous, dense bed of eelgrass or commercial-scale production of oysters (Dumbauld, pers. comm., 2015).

The first issue regarding the influence of depth on the study results can be understood through an exploration of the maps provided by Semmens (2008), reproduced below. The different habitat types (e.g., native eelgrass, oyster plots, non-native eelgrass [*Z. japonica*], and cordgrass [*Spartina alterniflora*]) are stratified by depth with native eelgrass at the lowest elevations and cordgrass at the highest elevations (Figure 26). Semmens (2008) stated that, "reducing habitat features such as depth to a single-parameter component of an equation describing movement may not capture the entirety of the complex and context-dependent influences of such habitat attributes." In other words, survival may have been controlled by depth, which is not accounted for in the study results, and it is difficult to attribute behavior to specific habitat types for mobile species. The complexity of habitat use, and the potential to gravitate to greater depths, is evident based on the distribution of fish primarily in the lower portion of the enclosure area (Figure 27).

The second issue regarding the net enclosure can also be understood through an exploration of the maps and behavioral responses of hatchery Chinook smolts. The net walls obstructed free movement of the test animals, which are highly mobile species and accustomed to traveling much longer distances than the enclosure dimensions allowed. Semmens (2008) stated that the enclosure had a "clear influence" on fish movement and noted that they would spend a large proportion of time at the wall, adding that hatchery Chinook are less adapted to avoid predators than their wild counterparts. Another point raised by Dr. Dumbauld (pers. comm., 2015), who has worked closely with Dr. Semmens in Willapa Bay, was that although avian predation has been shown to be a significant source of mortality to juvenile salmonids in Pacific Coast estuaries, work is still necessary to determine how habitat, tidal stage (depth), and water clarity influence the source of mortality at the landscape scale.

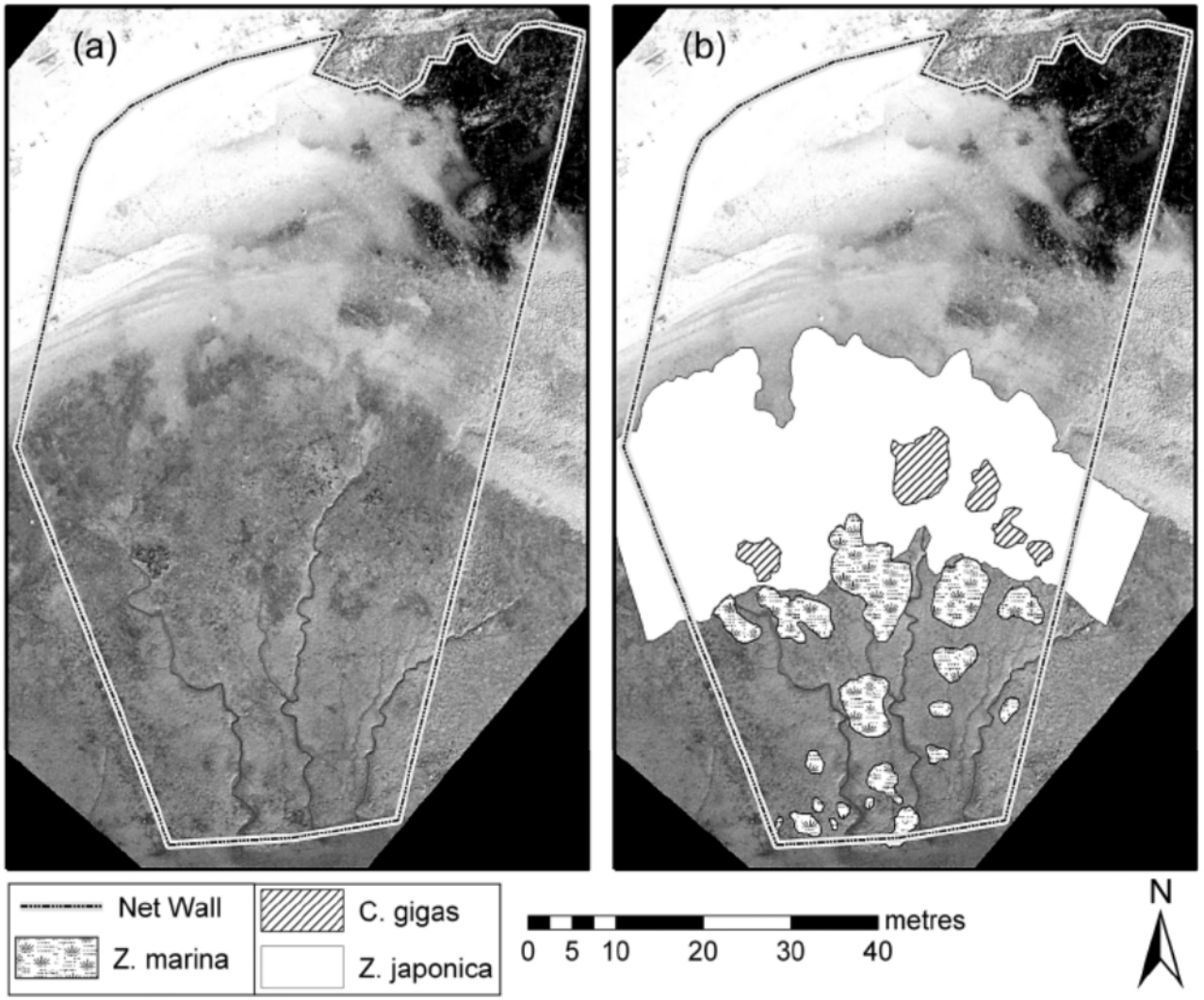


Figure 26 Orthorectified Aerial Photograph of the Enclosure and Digitized Habitat Features

Notes: (a) orthorectified aerial photograph of the enclosure taken during a low tide. (b) digitized benthic habitat features in the enclosure. Non-native cordgrass habitat (dark area at the top right) was not digitized because no tagged fish swam into the area during the study.

Source: Semmens (2008)

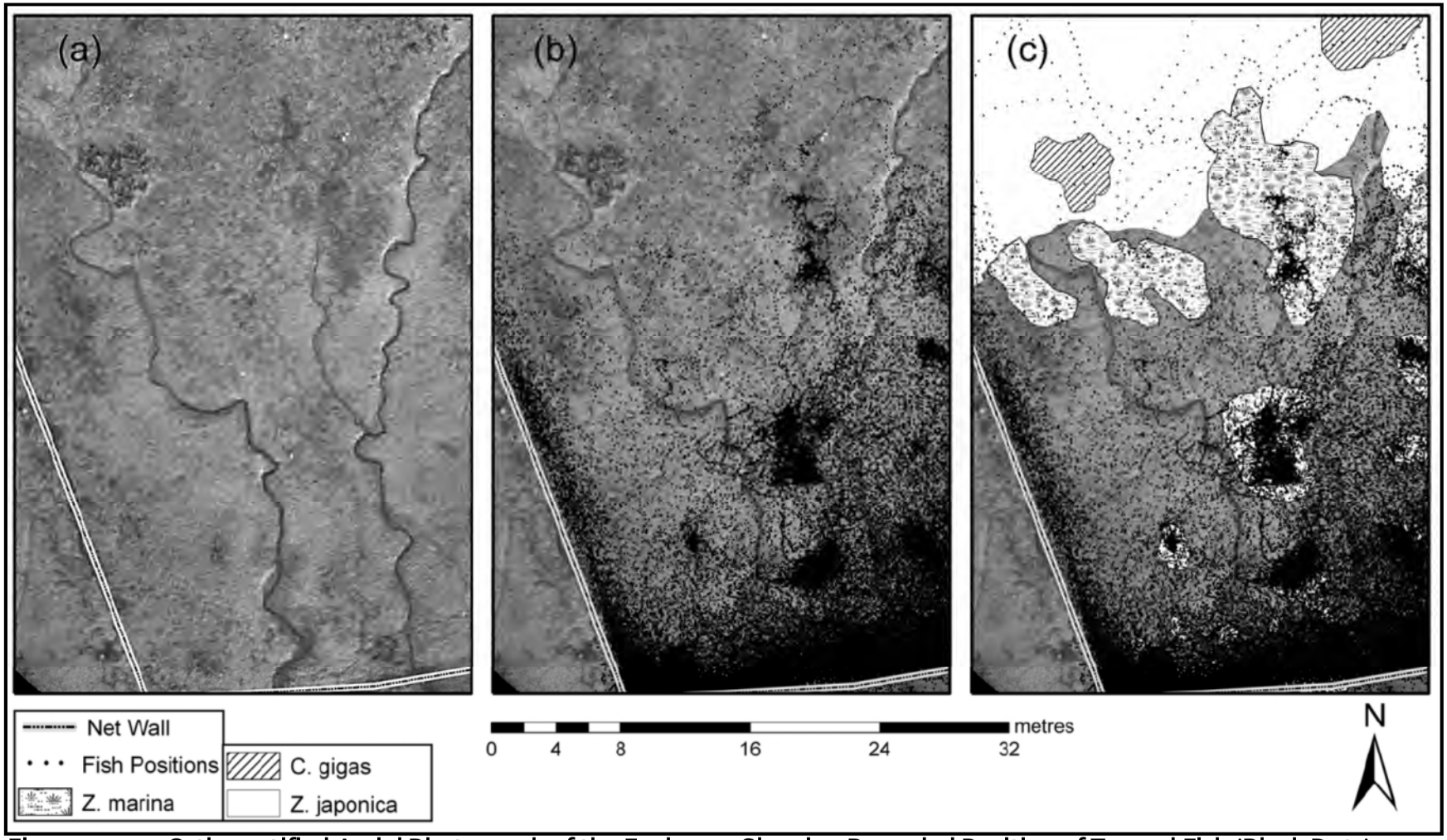


Figure 27 Orthorectified Aerial Photograph of the Enclosure Showing Recorded Position of Tagged Fish (Black Dots)

Notes: (a) map of the lower-left (southwestern) corner of the enclosure. (b) map including all of the recorded positions of the tagged individual that survived the longest during the study. (c) map including an underlay of polygons representing the benthic habitats in the enclosure.

Source: Semmens (2008)

6.3 Predator Protection Gear – Additional Information

Additional information related to bird interactions and plastics and toxicity from a shellfish aquaculture operation is provided below.

6.3.1 Bird Interactions

Commenters have raised concerns that shellfish aquaculture, especially the use of predator exclusion netting, results in impacts to marine birds. However, the scientific record does not support a conclusion that shellfish farming negatively impacts bird use. In fact, there is strong evidence that shellfish, whether cultured or wild, forms an important source of food for a wide variety of marine shorebirds, seabirds, and raptors (Dankers and Zuidema 1995, Norris et al. 1998, Hilgerloh et al. 2001, Lewis et al. 2007, Žydelis et al. 2006, Forrest et al. 2009).

Foraging Birds

Studies have shown either positive impacts—increasing avian species richness and abundance due to increased foraging opportunities, or benign impacts—eliciting no significant difference in use from natural beds. Through their foraging habits, migrating marine shorebirds can significantly alter the community structure of wild bivalve populations in soft-bottom intertidal areas (Lewis et al. 2007). At shellfish aquaculture sites, some species of marine birds feed directly on the shellfish products themselves (e.g., Dankers and Zuidema 1995), while others feed on the macrofauna and flora that colonize shellfish aquaculture gear (e.g., Hilgerloh et al. 2001). Shellfish growers have documented numerous bird species foraging on their shellfish beds, including scoters, dunlins, killdeer, godwits, sand pipers, eagles, great blue herons, and gulls. Figure 28 presents a few of the species mentioned using shellfish beds for foraging habitat.



Figure 28 Marine Birds Foraging in Shellfish Beds

Note: least sand pipers on oyster bags (top left), dunlins in oyster bed (top right), and godwits (bottom) around and on oyster bags.

Due to the relatively recent history of geoduck aquaculture, and the fact that intertidal geoduck beds are exposed for a short portion (approximately 6%) of the culture cycle, there are limited examples that illustrate how birds interact with geoduck aquaculture gear. However, there is both anecdotal evidence and some photography to show potential interactions. One of the best examples is the mutually beneficial relationship between shellfish aquaculture practices and scoters. In some areas, geoduck nursery tubes, oyster crops, and culture gear will get coated with sets of mussels. When not protected by nets, the young mussels attract scoters that provide a service to growers by grazing the fouling mussels off the crops and gear. When the mussels set on geoduck nursery tubes under predator nets, crews need to remove the nets and clean out the mussels. At the Foss farm in Case Inlet, crews removed nets and when they returned the following night to clean out the mussels, they were gone. They removed more nets and deployed a GoPro® camera to discover scoters were cleaning off what ended up being thousands of pounds of mussels (Figure 29).



Figure 29 Scoters Foraging on Mussels Encrusting Geoduck Culture Tubes

Note: photograph taken using a Go-Pro camera on the Foss farm in Case Inlet.
Source: Dewey, pers. comm., 2015

Shellfish aquaculture sites can influence the abundance of marine shorebirds. For example, Connolly and Colwell (2005) observed 17 different bird species using the intertidal habitat in Humboldt Bay, California. Abundance of most species (7 shorebirds and 4 wading birds) were shown to be more abundant on oyster longline plots compared to adjacent mudflat habitat not containing culture. The only shorebird that showed lower abundance in longline plots was the black bellied plover. The authors concluded that the greater bird abundances on longline plots were likely in response to increased foraging opportunities or greater prey diversity present because shorebird densities are commonly correlated with the densities of their principal prey (see references cited within).

Although marine shorebirds feed at shellfish aquaculture sites, the aquaculture sites themselves do not necessarily attract larger numbers of birds compared to non-cultured areas (Hilgerloh et al. 2001). For instance, Žydelis et al. (2006) found that natural environmental attributes were the primary determinants of densities of wintering surf scoters and white-winged scoters in Baynes Sound, British Columbia. Moreover, the authors found that shellfish aquaculture variables did not necessarily predict bird densities for the scoter species studied. According to Žydelis et al. (2006), these findings suggest that winter scoter populations and the shellfish aquaculture industry may be mutually sustainable because there was no evidence of a negative impact on scoter populations at the current level of shellfish farming practiced in Baynes Sound. It is notable that in 2001, Baynes Sound had over 20% of habitat used for shellfish culture (Carswell et al. 2006).

Potential Negative Impacts of Marine Birds

While shellfish aquaculture may increase foraging opportunities for most marine birds, there is the potential to negatively affect behavior and foraging opportunities for certain species through alteration of food sources, displacement of foraging habitat, and disturbance (e.g., noise) related to farm activities (Kaiser et al. 1998, Kelly 2001, Connolly and Colwell 2005, Forrest et al. 2009). For example, Kelly (2001) reported evidence of avoidance of oyster structures compared to open tidal flats by dunlin and western sandpiper in Tomales Bay, California, although the author also indicated that roosting by both species in floating oyster culture bags suggested possible benefits to shorebirds. Further, both of these species are frequently observed in large numbers on shellfish plots with gear present (see Figure 28 above). For species that avoid structure, the placement of gear for 2-3 years (either temporary as for geoduck culture or semi-permanent as for Manila clam culture) would likely result in displacement. However, that does not indicate a significant impact or reduction in foraging opportunities.

Noise associated with human presence and boat motors during geoduck planting, maintenance, and harvesting activities could result in temporary displacement of birds from the immediate area and masking[10] essential communication among foraging birds. However, Strachan et al.

10 Masking = interference with the detection of one sound by another (Dooling and Therrien 2012 *as cited in* Teachout 2013).

(1995) commented that marbled murrelets that are found around heavy boat traffic do not appear to be adversely affected by the ambient noise of an urban area. Other waterbirds have shown behavioral changes in response to noise, but not to the extent that would cause population-level effects as long as distances of approximately 164 to 328 feet are maintained from nesting habitats (Carney and Sydeman 1999, Borgmann 2010). There are both natural avoidance measures and best management practices that would reduce or avoid disturbance to birds. For example, planting activities typically occur during a time of year that avoids the majority of wintering foraging and migrating activities. While harvesting activities can potentially occur year around, there are measures in place (e.g., muffling motors, training crews, dive harvesting) that would reduce effects to foraging birds to the point that would not result in significantly altering behavior. Overall, shellfish aquaculture can be a sustainable use of suitable habitat and, through the use of best management practices, avoid adverse effects to marine birds.

Potential for Net Entanglement

Although entanglement with predator exclusion nets is noted in the literature as a possibility (e.g., Forrest et al. 2009, Straus et al. 2013), there are only rare examples of this actually occurring. In terms of determining the potential for entanglement, the lack of evidence can be just as powerful as positive evidence. Baynes Sound had 152 acres of predator exclusion nets actively used for Manila clam aquaculture operations in 2001. The estuary is a good example of illustrating lack of evidence, because it is: (1) characterized by extensive, low gradient, intertidal mud and sandflat habitat, (2) a critical staging, breeding, and wintering area for migratory birds, (3) a Pacific herring spawning ground (both herring eggs and the herring are an energy-rich food that attract marine birds), and (4) extensive bird surveys and radio tagging studies were conducted in Baynes Sound from 2001 to 2005 during the peak wintering use by scoters (Lacroix et al. 2005, Žydelis et al. 2009). After at least five years of specifically collecting observations over shellfish beds that contained predator exclusion nets, there were no reports of entanglement by diving ducks.

Two images are consistently used by opposition groups of geoduck aquaculture related to potential net entanglement: (1) a live juvenile eagle on top of a predator exclusion net from 2006, and (2) a dead gull carcass in an assortment of what appears to be aquaculture-related netting dated October 24, 2014. (Note that the gull was misidentified as an osprey in the original release of this image.) The juvenile eagle had grabbed the predator exclusion net and did not let go. Juvenile eagles have a difficult time releasing their talons until they mature. In this case, recreational kayakers and an adjacent shellfish worker helped the eagle get off the net and moved it to the upper beach under a tree where it later flew away. WDFW reviewed the incident and concluded that the use of predator exclusion nets does not pose a significant threat to eagles (Huber 2006).

Positive identification of the gull carcass was provided by an expert in bird taxonomy, and was primarily based on the shape of the beak. The origin of the photograph could not be confirmed, as well as the conditions that resulted in the gull being entangled in the net. The photograph

includes two different types of net that would not typically be found in the same location within the intertidal: (1) bagging material used for oyster seed and/or clams, and (2) predator exclusion netting commonly used to cover Manila clam beds or geoduck nursery tubes. It is conceivable that an unmaintained aquaculture operation would potentially result in this situation, but farm management practices, such as ensuring netting is properly secured and conducting frequent monitoring of gear, can effectively mitigate this concern.

The fact that shellfish aquaculture has occurred in Puget Sound for over 100 years, and growers have been using predator exclusion nets for more than 40 years in intertidal habitats with few documented incidents of entanglement, is a good indication of this being an insignificant risk to migrating and foraging birds.

Summary

Based on anecdotal observations and existing literature, marine shorebirds, seabirds, and raptors are known to occur on (or near) shellfish aquaculture gear without incident. The scoters feeding on mussels encrusting geoduck nursery tubes noted above is one example. Other examples include the increased potential to provide prey opportunities to birds within aquaculture plots. Based on over 100 years of aquaculture in Puget Sound, more than 40 years of using predator exclusion nets, and observations in and around aquaculture gear, the potential for entanglement appears to be an insignificant risk with proper farm management. Based on the potential to increase foraging opportunities, there may be a net benefit to bird populations.

6.3.2 Plastics and Toxicity

Plastics are commonly used in the marine environment. A few examples of marine plastics are buoys, floats, nets, fishing line, and boat components. The concerns with plastics are the increased generation of both macroplastics and microplastics. Macroplastics are defined as any solid material greater than 5 millimeters (mm) or 0.2 inches in diameter, while microplastics are materials less than 5 mm that are primarily composed of synthetic polymers (Baker et al. 2011, Davis and Murphy 2015).

Microplastics occur in the marine environment from primary sources (e.g., pellets in facial scrubs), or from the disintegration of larger plastic materials. Microplastics were sampled from the upper 1.6 ft of the Puget Sound water column by the Center for Urban Waters and the University of Washington (Baker et al. 2011). The study reported that microplastics are ubiquitous in all coastal waters. Within Puget Sound, microplastic concentrations were found to be highly variable in space and time, did not appear to be correlated to specific source locations, and were similar to levels in the open North Atlantic and Eastern Pacific. Comparatively, the PTMSC study collected material directly from the beaches rather than from the water column (Davis and Murphy 2015). This study reported that the majority of microplastics observed were located in north and central Puget Sound, typically in close proximity to marinas and urban centers. Styrofoam was by far the majority (75% of the count) of anthropogenic microdebris found in these areas, followed by plastic fragments (9%) and glass (12%). There appears to be a

strong positive correlation between the areas of high microplastic abundance and population density.

Risk Assessment Process

In her testimony for the Haley hearing (SHB No. 14-024), Dr. Schoof (2015a) described the process of risk assessment to assess potential for adverse effects from chemical exposures. She describes assessing for two elements: toxicity and exposure. An exposure assessment includes establishing a complete exposure pathway. This pathway has four components: (1) source and mechanism of release, (2) transport mechanism, (3) receptor and exposure point (i.e., point of potential contact with a contaminated medium), and (4) an exposure route (e.g., ingestion) at the exposure point for a specific receptor (Figure 30).

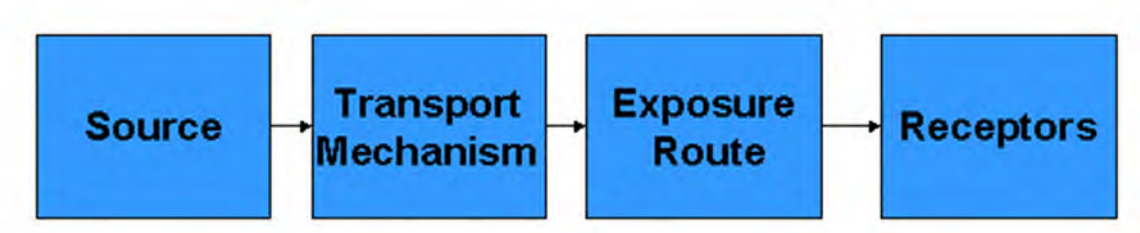


Figure 30 Exposure Pathway Flowchart

In regards to aquaculture gear, Dr. Schoof testified that, given the conditions of farm approval to: (1) minimize gear escapement, (2) remove gear as soon as it is no longer needed, and (3) regularly patrol tidelands and retrieve gear, there is not an exposure pathway. Without an exposure pathway, there is no risk. Assuming that there is even a slight risk, a discussion regarding the potential toxicity of shellfish aquaculture gear is presented below.

Potential Effects

Plastics are a component of any shellfish aquaculture operation in the form of culture tubes (both PVC and/or HDPE material), PVC marker poles, predator exclusion netting (HDPE material), and oyster bags (HDPE material). Concerns were raised during the Longbranch Hearing (SHB 11-019) regarding the potential to release plastics and metals into the environment through the use of PVC tubes during the first two years of grow-out. According to Baker (2012), releases of macroplastics (or PVC tubes) into the environment was considered unlikely due to tide and wave action that would transport tubes up the beach, which would then be collected during regular site visits. Additionally, the canopy nets and beach patrols further reduced the risk of tube escapement. During a more recent hearing (SHB 13-006c), Dr. VanBlaricom (2013) observed that tubes that did escape from the canopy nets also filled in quickly with sediment and were maintained in close proximity to the farm until they were collected during beach patrols. Good initial results on gear retention for flexible mesh tubes also indicate that use would not significantly contribute to the generation of macroplastics due to the breakdown of derelict gear, as described by Dr. Baker for PVC tubes during the Longbranch Hearing (Baker 2012). Similarly, net and bag maintenance would avoid the potential introduction of other macroplastics into the environment.

The potential to create microplastics was thoroughly reviewed by Dr. Joel Baker during the Longbranch Hearing. According to his testimony (Baker 2012), PVC tubes are unlikely to degrade based on the low ultraviolet exposure (related to the small portion of time that the tubes are exposed to daylight), low wave energy in Puget Sound, and debris management efforts. To confirm that microplastics were not created within a tube field, bulk sediment samples (a total of three pounds of sediment) were taken from existing tube fields, and tested in an EPA-approved lab. Dr. Schenk (2011) reported that there was no evidence of microplastics in the sediment samples. Further confirmation that microplastics are not created was based on a review of stomach samples from fish collected in geoduck tube fields. Dr. VanBlaricom (2013) testified that out of 235 fish collected there was no evidence of microplastics in their stomachs.

While there are no known data specific to the potential to generate microplastics from the use of HDPE materials, there is no evidence that microplastics are a significant issue in south Puget Sound (Davis and Murphy 2015). This is a meaningful result given the large amount of shellfish aquaculture that occurs in south Puget Sound. According to Schoof (pers. comm., 2015b), the life cycle of HDPE spans longer than the intended use (e.g., decades vs. 2 years). Therefore, it is unlikely that use of HDPE materials would significantly contribute to the generation of microplastics.

In a review of potential impacts of microplastics in the marine environment, Andrady (2011) commented that microplastics were most likely generated on beaches, which would have extended exposure to light and weathering if not collected. The author mentioned that beach cleanups are an effective mitigation strategy to avoid or limit the creation of microplastics. He concluded his comments on beach cleanup by stating, "Beach cleanup therefore can have an ecological benefit far beyond the aesthetic improvements of the beaches, and by reducing microplastics, contributes towards the health of the marine food web." The conditions of farm approval include maintenance of the project area, which would include cleaning up unnatural debris. The PCSGA organizes a beach cleanup of south Puget Sound twice a year in which many shellfish growers participate.

Although PVC manufactured in the United States does not use lead, arsenic, cadmium or mercury (PVCplus 2012), concern has been raised that these or other metals can be found in PVC and are susceptible to leaching into the environment from its use in geoduck aquaculture which may then be available to bioaccumulate in the surrounding biota. PVC is a very stable material. It is unlikely to release metals or chemicals naturally and leach into the surrounding environment, which is why it is used in drinking water infrastructure. PVC is sensitive to high temperature, high ultraviolet exposure, and acid conditions (Younan et al. 1985). These conditions would not be likely to occur in the marine environment associated with geoduck culture. The potential for PVC tubes to leach into the surrounding sediment was reviewed during the sediment sampling completed for the Longbranch Hearing. Dr. Rosalind Schoof (2011), an expert in human toxicology, looked at the data collected and compared it with sediment testing throughout Puget Sound. She reported that exposure to metals originating from PVC tubes is extremely unlikely, and there is no reason to think that these metals would accumulate in biota and ultimately reach the human food chain.

Summary

In summary, with proper farm management, it is unlikely that shellfish aquaculture farms would result in the creation of macro- or microplastics. There is no evidence that existing farms in south Puget Sound are creating plastics debris or resulting in metals leaching into the sediment from the use of PVC tubes or HDPE materials. Therefore, these potential effects are considered to be insignificant with proper farm management.

6.4 Parasites, Disease, Invasive Species, and Genetics

Humans have transported many species unintentionally, and some of these species find an open niche and are able to establish and even displace native species. These species are known as invasive (see definition in Section 5.3, above). Shellfish aquaculture has also, historically, inadvertently transported non-native species, some of which are detrimental to aquaculture itself. Three studies have been used to show that aquaculture is furthering the problem of invasive species. These studies are outlined below.

- Forrest et al (2009) published a synthesis of oyster cultivation effects. Regarding invasive species, they state that structures used to grow oysters can provide a substrate for fouling organisms, including pest species. These pest species can then be introduced to new areas when oysters are cultivated and transferred. Finally, they also raise concerns regarding the naturalization of non-native oysters into reefs in areas outside their native range. The concern is that the naturalization could lead to adverse ecological changes, though the potential results are highly species- and situation-specific.
- Ruesink et al. (2005) looked at the introduction of oyster species worldwide, and the various ecological roles the introduced species have played. Their literature review resulted in crediting non-native oyster culture with bringing in 78 invasive species in nine regions around the world.
- Ruesink et al. (2006) discussed the impact of four introduced species in Willapa Bay, WA: two bivalves (*Crassostrea gigas* and *Ruditapes philippinarum*) and two plants (*Spartina alterniflora* and *Zostera japonica*). The study argues that these introduced species have dramatically increased secondary and primary production in the bay, while reshaping its ecological character. The conclusion was that *S. alterniflora* and *Z. japonica* should continue to be controlled, and that *C. gigas* and *R. phillippinarum* should be carefully planted to protect estuarine resources.

As discussed in Section 5.3, the State of Washington has several programs in place to reduce invasive species, and shellfish growers are held to very strict standards by WDFW not to transfer invasive species. Shellfish growers are affected by invasive species like *S. alterniflora*, *Z. japonica*, and oyster drills, and have been, and continue to be, part of the solution to reducing their spread. Given the current regulatory and management practices that are in place, there is no significant of commercial shellfish farms in Washington causing adverse impacts with respect to parasites, disease, invasive species, and genetics.

7.0 CONCLUSIONS

Based on our review of the updated SMP, it did not appear that changes made by Pierce County related to shellfish aquaculture are supported by the scientific literature. This technical report provided a review of the relevant literature, as it pertains to interactions between shellfish aquaculture and the surrounding environment, in order to facilitate revisions to the Pierce County SMP by Ecology during its review process. Overall, the shellfish aquaculture industry is a highly regulated activity within federal, state, and local jurisdictions. As indicated by numerous independent researchers and agencies, a well-managed farm can result in a no-net-loss to ecological functions, and for some parameters (e.g., water quality) can result in net positive benefits to the surrounding environment. Evidence of this in Pierce County can be observed by numerous historical farms that are mutually sustainable with the Natural shoreline designation criteria provided under PCC 18S.20.30. Shellfish aquaculture, as conducted in Pierce County, works within the resiliency of the system because of the avoidance, conservation, and minimization measures developed, and advancing technologies that allow for a reduction of human presence within a farm.

There were numerous comments provided by citizen groups, tribes, and agencies on the updated SMP. While this information was substantial, no additional information was brought forward that provided an indication that shellfish aquaculture in Pierce County is intensive or resulting in significant effects to Pierce County shorelines. Many of the articles provided actually further support the position that the shellfish aquaculture industry has a unique incentive to develop sustainable practices in an ever changing setting within Puget Sound. Water quality will continue to threaten the ability of shellfish growers to provide high quality products. Taking steps to reduce or eliminate expanded culture within Pierce County, without suitable justification, does not conform to consistent management and legislative decisions. Therefore, we do not feel that Ecology should approve the language provided by Pierce County, or should at the very least significantly alter the conditions so as to represent the best available science related to shellfish aquaculture interactions with the surrounding environment.

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