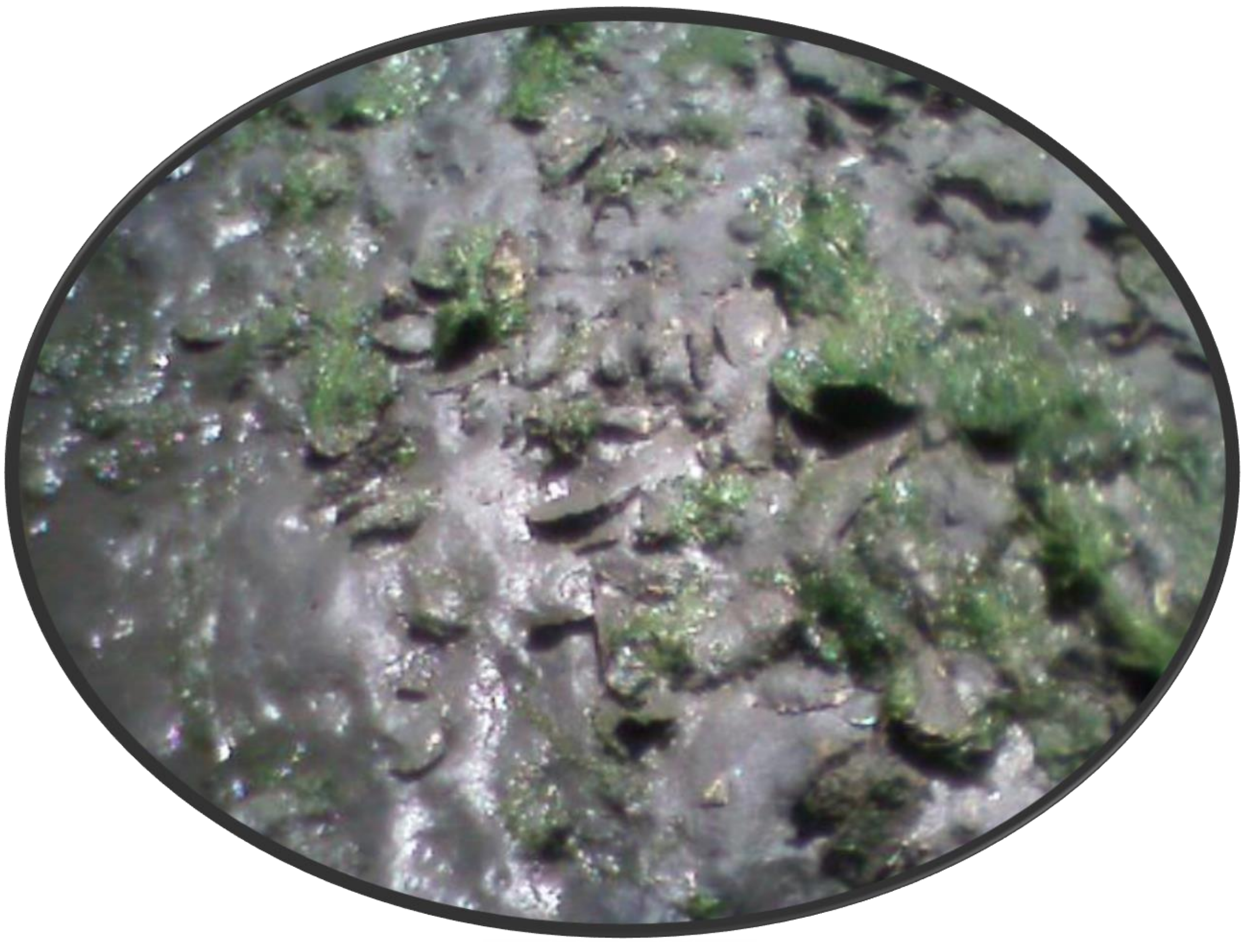
Sand Wars. Excessive Sedimentation on Grays Harbor Oyster Beds: Likely Causes and Recommended Mitigation.



Prepared for the Grays Harbor Conservation District, June 2015

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Executive Summary

Grays Harbor has some of the largest commercial oyster culture production in the nation, producing approximately $12 million in net revenue annually. Sixty-six percent of oysters produced in WA State are grown here or in neighboring Willapa Bay. However, farmers are struggling with excessive deposits of sediment on their oyster beds, smothering both juvenile and fully-grown animals. Cumulative losses to growers due to sediment deposition over the last five years alone number several million dollars. This includes important labor income for a relatively poor economy, as well as taxes and lease income for the county, the state, and state agencies. Many commercial producers have already shut down or limited operations due to these excessive sedimentation events. Many previously prime oyster tidelands have been washed away or sanded in to the extent that they are unusable. Whitcomb Flats, which previously migrated eastward at approximately 15 meters per year, has been migrating at an average rate of 73 meters (nearly 240 feet) per year since 1990, a sure sign that something is wrong in the hydrodynamics and related sediment flux in Grays Harbor. Without funds for prompt intervention and mitigation of these sediment problems, Grays Harbor oyster tidelands and commercial oyster cultivation will continue to degrade and eventually vanish. High wave energy and accompanying sediment loads caused by dredging and navigational channel improvements have caused the oyster beds to be repeatedly smothered by sediment. Reports on this problem have been ongoing since 1990, and several attempts have been made to receive grants to help resolve it, but we are now at a turning point which requires immediate action.

Recommended Actions:

- **Stabilize Whitcomb Flats and reduce sedimentation using a combination of**
    1. **Artificial reefs built of seeded shell bags or seeded Reef Balls**
    2. **Build-up of sand on Whitcomb Flats to prevent wave overtopping**
    3. **Structural interventions of rock, concrete, or pilings**

- **Test alternative oyster culture methods (while not a permanent solution, it may provide temporary relief for shellfish growers)**
    1. **Adjustable Longline Systems**
    2. **Rack and Bay Culture**

- **Perform hydrodynamic modeling to better understand the mechanisms that are influencing sedimentation, identify potential new shellfish beds, and to decide the best possible next steps**

June 30, 2015

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Abstract

The Grays Harbor estuary has long been one of the most productive oyster production areas in the nation. Twenty five percent of US oysters are cultivated here and in neighboring Willapa Bay. Oyster aquaculture and related jobs are key parts of the local and regional economy, and ecological benefits to the estuary include water filtration, juvenile fish and crustacean habitat, and healthy benthic fauna. However, for several decades, o[1]yster growers have been increasingly affected by deposition of sediment on shellfish beds. While some sediment movement and management is to be expected in oyster aquaculture, the increased amount of sediment deposition in Grays Harbor since the 1990s has caused the degradation and/or closure of hundreds of acres of once prime tidelands, and unsustainable losses for many shellfish operators. Unless this sedimentation problem is mitigated or resolved, it is very likely that Grays Harbor oyster tidelands will continue to degrade, leading to progressively worse conditions for oyster growers, and associated evacuation of aquatic leases, loss of jobs, and business closures. We have identified the cause of the sedimentation to be increased wave energy created by the building of the North and South Jetties in the early 1900s and their ongoing reconstruction and maintenance throughout the century, with these effects worsened by completion of the US Army Corps of Engineers 1991 Deep Dredge project. That deepening of the navigational channel has caused Whitcomb Flats (the most productive oyster culture area) to migrate at an average rate of 73 meters/year since the project began in 1990, and waves often overtop the Flats, bringing with them high wave energy and large sediment loads. We have examined options for sediment intervention techniques and adaptive oyster culture methods and summarized these in a risk/benefit matrix of possible interventions. We conclude that while additional modeling should be performed for some of the more permanent interventions, a pilot test of sediment mitigation should be conducted using artificial reef construction, as well as testing of adaptive aquaculture methods for high energy environments.

Introduction

The Grays Harbor Conservation District commissioned Global Ocean Health to study the sediment deposition that has been increasingly affecting oyster growers in Grays Harbor Estuary for the last several decades. The harmful sediment deposits follow storm events and/or large ocean swells that can bring several feet of sand deposits with them. Sedimentation events cause abandonment of oyster leases, the closure of oyster farms, mortality of both juvenile and adult organisms, and the loss of jobs and the associated economic activity they provided. Shellfish growers directly and indirectly generate over 200 jobs in Grays Harbor County, accounting for $6 million in labor income to the County (Northern Economics Inc, 2013). While sediment flux is a natural part of any estuary system, the introduction of

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man-made structures at the turn of the 20th century, combined with the deep-draft dredging of the early 1990s has begun to change the state of the bay, particularly the oyster tideflats, in ways that create undesirable impacts for shellfish (Osborne, 2003). These changes enabled high ocean wave energy to enter the bay, bringing with it large amounts of sediment (Osborne 2003, GeoEngineers, 2015). This sand often ends up deposited on oyster beds, particularly in the South Bay area. Previously Class II prime oyster farming tracts are being washed away or submerged by sand.

Since active oyster farming began in Washington State over a century ago, Grays Harbor and its neighbor, Willapa Bay, have been known for their near-perfect oyster growing conditions (OSU Sea Grant, 1957). With little industrial or residential development, they have maintained conditions not found in other areas of Washington State. The tideflats of the south part of Grays Harbor, below Whitcomb Flat (known as South Bay), in particular, have been home to generations of oyster growers, and many multi-generational oyster operations still farm there. “These beds are beautiful and pristine, and worth saving. A diamond that still hasn’t been discovered. My father considered Grays Harbor to have the best oyster beds in the state, and beyond, and I agree with him,” says Erika Buck, of FMO Aquaculture (pers comm, 5/20/15).

Global Ocean Health assembled a small team of investigators to analyze available evidence and evaluate options for response. Team members conducted interviews and site visits and reviewed relevant government documents, including previous discussion of mitigation options between the Washington Department of Natural Resources (DNR) and the US Army Corps of Engineers (USACE). We also reviewed the scientific literature, data sets that record changes in the hydrodynamics and sediment fluxes in the estuary, and research on adaptive strategies used by shellfish growers around the world to mitigate effects of sedimentation. We interviewed growers regarding actively farmed land and used this information to create an updated map of oysterlands that reflects the massive losses of formerly leased or owned beds. We identified and evaluated shellfish industry practices for mitigating sedimentation impacts based on interviews, a query via a large shellfish industry listserv, and a search of technical and trade literature. We arrived at a list of possible sediment intervention options, described in-depth in the Mitigation section, and how these are likely to be used in combination. Regulatory permitting is a major obstacle to many options, and has been considered in our final recommendations. We have also created a matrix showing types of mitigation options and their comparative levels of risk and benefit (attached as Excel spreadsheet).

Background

Since the 1990s many growers have abandoned their leases and given up on the area (and in many cases on oyster growing entirely), solely or in large part because of the sedimentation issues that have been dumping sand on shellfish beds in unmanageable quantities (see Figure 1).

Figure 1 Oyster beds and eelgrass smothered by sediment deposits

In 2009, the Department of Natural Resources (DNR) estimated it was losing annual revenue from Grays Harbor Aquatic Leases in the amount of $57,000/yr (see Appendix A). That amount has since increased as more leases have been returned or reduced in valuation. DNR further reported that at least eight separate growing operations had to modify or abandon existing leases due to damages caused by increasing amounts of sand deposition in growing areas.

Despite these problems, Grays Harbor oyster cultivation generates approximately $12 million in net revenue annually (Northern Economics Inc, 2013), a significant portion of total economic activity for a rural coastal economy and an important source of jobs.

In addition to its economic benefits, shellfish farming also provides significant ecosystem services. As filter feeders, shellfish remove nitrogen and bacteria from the water, improving water quality and lowering turbidity. Oyster beds are natural breakwaters, protecting shorelines from storm surge and erosion. They support accelerated nutrient cycling that helps prevent buildup of harmful phytoplankton blooms and resulting impacts on dissolved oxygen. The most productive Grays Harbor oyster beds, the tideflats immediately to the southeast of, and connected to, Whitcomb Flat are highly productive habitat for benthic infauna and epifauna, including polychaetes and nemerteans (marine worms), bivalve mollusks (softshell and hardshell clams), and various small crustaceans, which are an important food resource to shorebirds and fish. These flats also serve as habitat for juvenile fish and Dungeness crabs and produce significant quantities of microalgae which are important food for oysters and hardshell clams. They also provide carbon sequestration services and stabilization of adjacent habitats and the shoreline (Grabowski & Peterson 2007, Lenihan et al. 2001, Rothschild et al. 1994, Coen et al. 1999, Grabowski et al. 2005). While the value of these ecosystem services can be difficult to quantify, some studies put the cost of alternative methods of water filtration as high as $1 million (Northern Economics, 2010).

Whitcomb Flats is a Natural Area Preserve (NAP), identified in 1976 because of important Caspian tern breeding grounds. However, it is no longer used as habitat by terns because the sand shoal is now completely covered at high tide. Because of this loss of elevation, it no longer supports vegetative growth either. The loss of elevation since naming as a NAP in 1981 is thought to be due the migration and erosion of the flat (Osborne, 2003). Most of the productive shellfish farming in Grays Harbor is in

South Bay, and those beds sited closest to Whitcomb Flat experience the most sedimentation (see map of area, Figure 2). Oyster beds further south of the spit are progressively less vulnerable to sudden sedimentation events, although none of them are unaffected. The migration of Whitcomb Flats has already destroyed some of the most historically productive beds in the estuary, and more leases are being returned to DNR as unviable for oyster culture. The last two hold-out leases that were farmed just south of Whitcomb Spit were returned to DNR in 2013 (pers comm, Hollingsworth, 6/8/15). Currently, the 132 acre lease farmed by FMO Aquaculture LLC is in the most vulnerable position and suffered sediment-related losses of approximately $210,000 this year (pers comm, Erika Buck, 6/17/15).

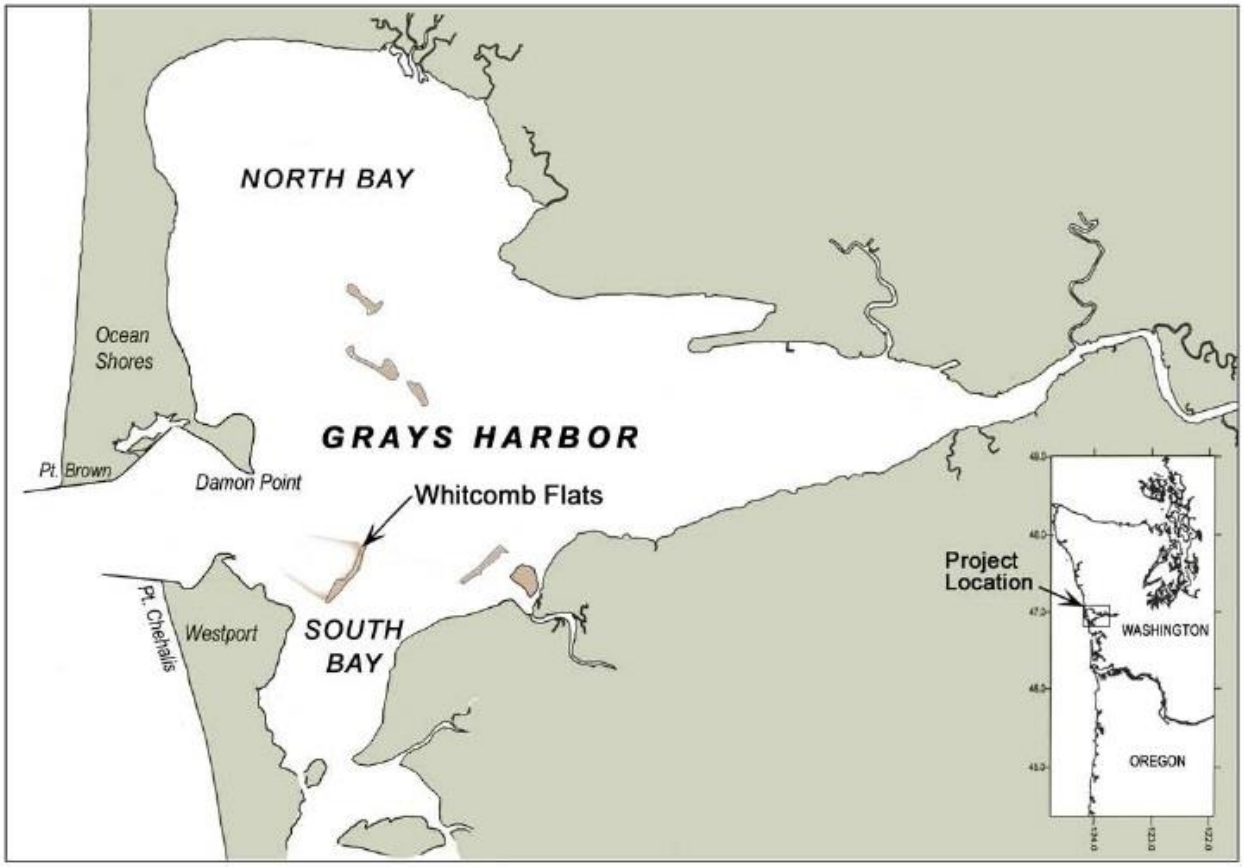

Figure 2 Location of South Bay and Whitcomb Flats in Grays Harbor

If no action is taken to stabilize the flats and prevent the continuing deposition of sediment on the oyster beds, it is likely that the once-prized tideflats of South Bay will become unviable to oysters and other mudflat organisms. This would involve loss of all the associated benefits of oyster beds, resulting in a cascade of both economic and ecological consequences.

The Migration of Whitcomb Flats

Sediment flux is a natural part of any estuary system, and even in the absence of anthropogenic changes it is normal to observe formation and dissolution of beaches, spits, tideflats, and other estuarine habitats over time. However, the evidence is clear that events starting with the construction of the

North and South Jetties over a hundred years ago, followed by a series of additional interventions since then, particularly the US Army Corps of Engineers' (USACE) Deep Dredge project of 1991, have drastically changed the state of the bay and degraded its oyster tideflats (Osborne, 2003; USACE, 2014b). For example, an immediate and startling drop in the amount of suitable oyster habitat (sticky mudflats) followed immediately after completion of the USACE's Deep Dredge project in 1991. Both oyster growers and the Department of Natural Resources (DNR) noted that gritty sand began covering oyster beds, and, in extreme cases, smothering the oysters. Bed managers noted an increase in large waves overtopping Whitcomb Flats, carrying sand and disrupting longline culturing gear (see Appendix B, Exhibit B, a 3/12/09 letter written by DNR describing meetings between DNR, USACE, and local growers). Because even a few inches of sediment can remove a bed from production, influx of additional sediment can pose severe problems. In the mid 1990s growers documented feet of new sediment build-up that destroyed productive beds that had been farmed for decades (see Appendix B, a video taken by growers in the mid 1990s documenting the migration of the flats and the deposition of sand on oyster beds).

Although oysters often live in conditions with suspended sediment in the water (turbidity), and in fact have a mechanism for decreasing turbidity and filtering suspended particulates, both juveniles and adults are adversely affected by sediment deposition. Heavy sediment loads that fill the interstitial spaces within oyster beds can cause high mortality of oysters and the loss of forage organisms for fish and crustaceans (Wilber & Clarke, 2010). Sedimentation associated with the maintenance of navigational channels is commonly cited as having an adverse effect on oysters (Kennedy, 1989, Coen 1995). A higher susceptibility to disease has also been linked to sedimentation (Lenihan et al. 1999, Volety et al. 2000). Sedimentation from oyster dredging has been the subject of lawsuits in other areas, including the closure of commercial oyster culture in one area of Scotland (Kirby, 1994). A dredging project in Louisiana was found to increase oyster mortality by 40% within 595 meters of the dredge spoils site (Rose, 1973), and destruction of oyster grounds near Buzzard's Bay, MA, was reported when dredging operations caused 8 to 12 inches of sediment deposition (Galtsoff, 1964).

A time series of photographs of Whitcomb Flats from 1967 to 2001 is used by Pacific International Engineering in their technical report to the Port of Grays Harbor, "Dynamics of Whitcomb Flats" (see Appendix C). In order to accurately use the photographs to measure the migration of Whitcomb Flats, Ground Control Points (GCP) were used to ortho-rectify the photographs. The resulting ortho-rectified photo mosaic was then digitized to create polygons representing the placement of the Flats over the time series. The resulting illustration is shown below (Figure 3).

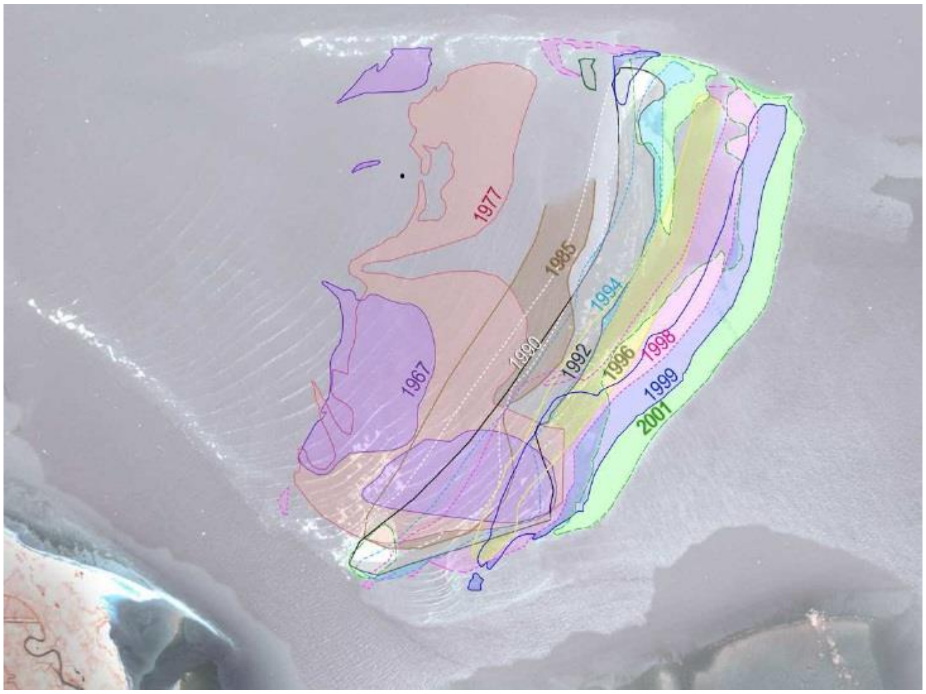

Figure 3 Ortho-rectified photo time series of the migration of Whitcomb Flats

Data presented in the report showed a steady eastward migration. In the time period from 1967 to 1977, Whitcomb Flats migrated at an average rate of 16-22 meters/yr. From 1977 to 1990, it migrated at a rate of 15 meters/yr. The rate of eastward migration dramatically increased after completion of USACE Deep Dredge project in 1991. From 1990 to 2001 it accelerated to 73 meters/yr. Therefore, the rate of migration quintupled in the immediate aftermath of the Deep Dredge project. These data demonstrate that the channel deepening and maintenance activities from 1990 are largely responsible for the eastward movement of Whitcomb Flats, and concomitant destruction of shellfish beds. We highly recommend a similar study of photographs from 2001-present to document the continuing trend of migration and erosion in this area. Technical study of the dynamics of sediment deposition in South Bay is a data gap that needs to be addressed to fully understand why these costly and excessive sediment events are occurring.

Statements from Growers

Both current and former shellfish growers have suffered extremely high impacts as a result of the recurring deposition of sand on their bed. Most are traditional bottom cultch growers – just a few inches can smother a young oyster – and year after year in some of the worst affected areas they see entire beds destroyed. “This year [2015] we’ve lost beds 4 and 7,” says Erika Buck, “We had set the seed in 2011, and spread the oysters in 2012. We expected to harvest this fall. Total expected income lost is $210,000. These were nearly full-grown oysters, that we went to check on after high swells, and they’d been buried to the lips in sand. Despite desperately attempting to harrow the sand, we lost both beds. We’re lucky that we can survive that kind of loss; not everyone can” (pers comm, 6/17/15). Another prominent grower in Grays Harbor, Mike Linn, lost 46 acres in Central Bay due to sand movement that he estimates costs the company $441,600 annually in revenue. He also states that the approximately 150 acres he operates around Whitcomb Flats in South Bay are threatened by sediment transport. Without mitigation, these sedimentation issues could cost the company $1.4 million annually. He further states that, “There’s a lot more sediment coming in the North Bay too – we had deep sea beds there with a shelly bottom, and now in the past 10-15 years it’s covered in sediment. We’re almost ready to abandon them, but need the room. This is likely the last year (2015) we’ll risk using it, and as it is we’re transporting large oysters there for final growth, because young oysters would be smothered by the sand” (pers comm, 6/2/15, Appendix C, 4/8/14).

Kevin Hatton, formerly of Hatton Oysters, used suspended culture (longline) methods. He reported that increased and prolonged wave activity had deteriorated the ropes he cultured his oysters on. The resulting breakage of culture longlines and loss of oysters led him to reevaluate the financial productivity of the land parcel he leased (Appendix C, Exhibit B, letter from DNR to USACE) and to eventually cease operations in Grays Harbor. Floyd Ruggles also attributes closing of his oyster growing operations to sedimentation. He reports that within a few years of the Deep Dredge project, his shellfish beds experienced recurring sedimentation events. “They were buried with sand. I was in it and doing quite well for a good while, on the east coast of Whitcomb Flat, but right after the Deep Dredge it became impossible to continue. I got out of the area and out of oysters. It’s a creature that cleans the water, and lets you know when there’s a problem in the water – it’s the first to know when things are going wrong, and to lose it because of these sand issues that started after the Deep Dredge, it’s a real shame” (pers comm, 6/22/15).

“I’ve seen bags of oysters stacked three-high buried in sand after a large storm and wave event,” says Mark Ballo, another grower in the South Bay area, “all growers here are affected – some to different degrees, but all of us are suffering the effects [of increased sediment movement] (pers comm, 5/13/15).”

Dave Hollingsworth reports that they abandoned beds that had been productive for his family since 1978, and that produced $250,000-$350,000 per year in income, because, “It is too high a risk to replant.” Due to the eastward migration of Whitcomb Flats the company determined that the farm would become unviable (pers comm, 6/8/15).

Mitigation

To inform an evaluation of options for intervention, we examined culture methods that are commonly used on the West Coast and in Grays Harbor Estuary. We also gathered information on methods that are reported to be suitable for high-energy marine environments or resistant to sediment impacts.

Shellfish culture methods for high-energy, sediment-prone environments

Growers in Grays Harbor use one of two culture methods: bottom culture and longline. Because the temperature in Grays Harbor never reaches the warmth needed for oysters to spawn naturally, all growers rely on purchasing seed or seeded bags. The seed is cultured on crushed or whole oyster shell (cultch). Bottom culture involves placing the seeded shell (either directly or in bags) on the bottom of the bed. Longline culture strings oysters from ropes that are slotted into short stakes embedded in the ground, keeping them elevated from the mud, and less susceptible to sediment. However, high wave energy frequently knocks longline oysters from the rope, or breaks the rope, causing the oysters to fall to the ground, where they are frequently smothered by the sediment accompanying the powerful swells.

Reliance on methods that keep the crop on or near the seabed may leave growers vulnerable to heavy sand deposition. Culture methods intended to reduce that risk can be classified into two fundamental approaches: elevation and defense. Elevation involves raising oysters above the seafloor to avoid burial under mobile sediment. Defense involves installing barriers (temporary or permanent) on the seabed to protect the crop. The two approaches merit testing in Grays Harbor Estuary.

Adaptations in Aquaculture. In several locations around the world, a class of modern oyster culture technology has been developed and tested using posts or pilings to suspend oyster cages on cables in the water. One example is the BST system, an adjustable longline technology developed by Australian growers who report that it is robust in high-energy marine conditions. However, important questions remain about the suitability of such methods for Grays Harbor conditions, both physical and institutional. Growers have expressed misgivings about whether the pilings and dock-like structures used in the BST system (described below) and comparable technologies could be permitted readily. Brady Engvall, a prominent local oyster grower, also has expressed doubt whether a culture system suspended on thick, tall posts would function properly in the shallow waters available for oyster growing in Grays Harbor Estuary.

Defense – Sediment Intervention Techniques. Meanwhile previous studies and local experimentation by growers have converged on a "defense" approach that may ease risk of sand deposition for bed culture: deployment of temporary shell-bag berms or other, more permanent structural interventions that function as a barrier to migrating sand. One challenge for this method is that sand may migrate from different directions at different times, depending on variable winds and currents. Growers note that this likely requires that placements be temporary and subject to periodic relocation. However, hydrodynamic modeling of sediment transport can help to assess the ideal locations for structural interventions.

Both forms of intervention merit further investigation and experimentation to assess whether locally appropriate design adaptations are possible and to assess costs, risks, and benefits. (For example, a short post is used in some applications of the BST system; whether this would work in Grays Harbor Estuary remains unknown). Costs of permitting, construction, and operation are not yet known. Before pursuing either approach at large scale, a logical next step would be to conduct consultative design and site evaluation studies and pilot deployments. It is likely that useful information on adaptation methods for growers can be developed by adapting and testing variations of the two concepts.

Elevated Culture in High-Energy and Sediment-Prone Environments

Shellfish growers in many parts of the world face challenging marine environments, notably in exposed waters that experience high seas and strong winds. Growers in Australia have responded by engineering robust off-bottom culture methods designed to hold animals in cages secured on cables or monofilament lines that run between large posts. These and other robust approaches do show promise in some environments (see below). As noted above, growers in Grays Harbor Estuary expect that such an approach would encounter complicated permit requirements and might not be allowed.

Potential for permitting reform may be a precondition for testing of potentially important physical options. Before approaching any daunting permit hurdles, however, growers are likely to ask for evidence of the physical capabilities of alternative culture systems to withstand strong wave action and prevent storm-induced loss of oysters.

We found published reports and industry promotional materials on off-bottom shellfish culture systems in high-energy environments in Europe, the Gulf of Mexico, and Australia. While methods focused on several species and life stages—including nursery operations — we have summarized findings that pertain to the capability of systems to operate under harsh environmental conditions.

BST System Tested in Solway Firth, UK. From June 2007 to September 2010, Stirling University aquaculture researcher Janet Brown and Solway Marine Oysters tested an oyster culture technology known as the BST system, one of at least two similar technologies originally developed in Australia. Brown et al. (2010) reported mixed but useful results, showing that system orientation relative to tide can be an important variable in determining robustness to storms.

The project was intended to monitor growth of oysters in an extremely exposed area, the west shore of Cumbria, where Solway Firth (a large bay) opens into the Irish Sea along the boundary of England and Scotland.

Resilience in high-energy conditions improved with adjustments over the course of the study, but could not be firmly established from the data. Brown et al. noted that the BST technology was previously untested such rough waters, and never before used in the UK. They tested it to learn whether this technology could enable growers to operate in conditions that are too rough for bottom bottom culture or bags.

“The BST system was totally untested in such an exposed area, to the extent that the developers themselves were uncertain as to how it would perform,” Brown et al. observed. “In Europe the traditional culture method for *Crassostrea gigas* has been either bottom culture or bags on trestle” (AKA “rack and bag” in the US). “There are potential disadvantages to bottom culture and this is not used in Scotland at all and bags and trestles can be costly in time [ie, time intensive]. Bags need regular turning to prevent buildup of algae and sediment that could affect oyster feeding and ideally they also benefit from regular grading as growth can be uneven in the flat bags. On the exposed beaches such as the west coast of Cumbria bags and trestles could not possibly survive the first storm; they require sheltered conditions.”

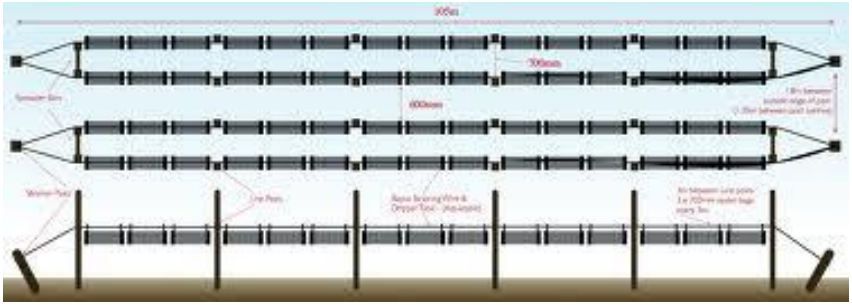

Figure 4 Illustration of BST Longline System

The BST system suspends cylindrical plastic mesh baskets on highly tensioned cable or monofilament line supported by posts. The mesh size of the baskets can be selected according to the size of the stock to be held. The height of the cable can be adjusted using plastic risers attached to the post, “so the farmer can control (to a degree) the hours of immersion the stock receives and so can potentially control the growth rates of a stock to meet market demand,” Brown wrote. The baskets are suspended from the cable by plastic arms that allow movement with water flow, an approach that Brown noted has potential to “endure greater wave exposure than traditional methods and so allow a wider range of sites to be exploited” while also reducing fouling and therefore time and labor required. Within the rigid baskets, oysters can move freely, “which is thought to prevent misshapen oysters.” Brown reported that this system had been used in Cowell, southeast Australia by its developer, Ashley Turner, “for 19 years with considerable success. BST suggest that their system cuts down management tasks by 80%.”

The test at Solway Firth was the first large-scale deployment of the BST system in the UK, but Brown reported that since the project started, several other farms adopted the method, including a large grower in the south of England (Brown et al., 2010).

Additional reports of using adjustable longline systems (ALS) like the BST system have been evaluated in other high energy areas, including the Gulf of Mexico where it survived Hurricane Isaac, and in the North Sea, where rough offshore conditions were evaluated for aquaculture (Casas et al., 2011, Beck 2007). Another option that is used throughout oyster aquaculture, but not currently employed in Grays Harbor, is “rack and bag” growing, where rebar racks are made approximately one foot tall, and shellfish grow-out bags are attached using clips. One prominent grower, Brady Engvall, is now constructing a rack and bag system for initial testing. Although a much higher investment cost is associated with these systems, they are worth evaluating in comparison to the similarly high costs of barrier-style mitigation measures.

Floating culture methods using racks, bags, trays, buoys, and floats, such as lantern nets, floating bags, suspended trays, cages on floats, Floating Upwelling Systems (FLUPSYs) nursery systems, etc, were all examined and found to be unlikely to be a fit for Grays Harbor, where the depth of the water is only appropriate for such applications within the navigation channel. We feel the other alternative culture methods are more deserving of pilot testing.

Defensive Applications for Sediment Intervention

There are a variety of methods to create a barrier that prevents wave energy and sediment loads from reaching vulnerable oyster tidelands. The most popular method is an artificial reef. The ability of artificial oyster reefs (using shell bag berms, Reef Balls, or other constructions) has been well documented. Oysters are well-known for their ability to reduce turbidity in water, and reefs act as breakwaters for wave energy (NOAA & TNC, 2011, Dehon, 2008). Oyster reefs (both natural and artificial) are natural ecosystem engineers, and they act as sediment accumulators and stabilizers, influencing hydrodynamics and geomorphology (Paiva et al., 2014).

One Grays Harbor grower already experimented with one of the most recommended methods: a seeded shell bag berm. In this case, using extra heavy-weight mesh bags and stacking them four feet high to protect the oyster bed beyond it. This method was successful in mitigating the worst effects of sedimentation. The bags quickly absorbed sediment and sand began to pile against the berm. By the end of the commercial growing season, only the top foot and a half had not been entirely sanded in. The berm successfully protected the bed behind it during that season from the worst effects of sedimentation. It was allowed to remain in place, where it eventually became completely buried. Then as wave energy shifted in the estuary, it became partially unburied, and again acted as a barrier against the worst of the high-energy waves. When they were eventually removed, the grower reports that they were like bags of concrete, because they had become so firmly impacted with sand (pers comm Erika Buck 6/15/15). Because of ecological considerations, as well as comparative ease of permitting, a pilot project using a shell bag berm running along the north edge of the South Bay shellfish beds would be our first suggestion for mitigation attempts (although we would not recommend that it be allowed to remain in place if completely covered by sediment). This was also a top recommendation of DNR and USACE in 2009, when they worked together on a sediment mitigation planning document (see Continuing Authorities Fact Sheet, Appendix B, Exhibit A).

Figure 5 Reef Balls fully settled by oysters

Reef Balls (Reefball.org) are another possible method of building an artificial reef. In some ways they are superior to seeded bags: made of concrete specially treated to an appropriate pH, and designed to provide habitat to not only oysters but also habitat and foraging space for fish and crustaceans. They have been adapted through thousands of experimental restoration projects to best imitate natural reefs, with a rough surface to aid attachment by seed, holes designed to create small whirlpools that bring additional nutrients to animals and plants living on the surface, and protective void spaces for fish. Reef Balls come in many different sizes and styles, can be molded on-site, and floated out behind a boat using their internal bladder. Used extensively in restoration efforts throughout the world, the only drawback is that because there is no natural oyster spawning within Grays Harbor, they need to first be seeded, and would only be fully effective during the life span of the original seed set. However, since the Pacific oyster can live up to 30 years if left unharvested, we believe that both the seed bag and Reef Ball approaches (or a combination of both) merit strong consideration. Figure 5 shows an artificial oyster reef using Reef Balls.

Placement of piles of loose oyster shell has also been shown to have some potential for mitigation in other areas, but considering the high wave energy, lack of natural spawning, and sheer amount of sedimentation deposits occurring in Grays Harbor, we don't feel that it would be effective enough there. A grower reports that in the 1970s her father combined loose shell piles with furrows to successfully manage sedimentation in Grays Harbor, but as described earlier changes in wave energy and amount of deposition has changed drastically since then (pers comm., Erika Buck 6/2/15). A study was conducted in Grays Harbor that showed enhancement of substrate using loose shell was effective in aiding Dungeness crab settlement and survival, but no examination was made of its effects on sedimentation or oysters (Vissner, 2010). Overall, placement of loose shell may be worth considering in combination with shell bags or other mitigation measures.

Other options, which, due to their more permanent nature, should first be evaluated using hydrodynamic modeling, fall into two categories: rocks held within mesh (Gabion Baskets, Reno Mattresses, and Triton Marine Mattresses), and concrete structures (CoreLoc and Dolos).

Structures using rock held within mesh (like Gabion Baskets and Triton Mattresses), are used as an alternative to rip-rap (which can be scattered by high wave energy), and are used for scour protection, erosion control, and embankment stability. They are normally filled with rock at the site. The rock type or layering of rock types is determined by specific application requirements. Gaps between rocks allow for the capture of sediment, and form habitat spaces for both animals and vegetation. Available in either a box or a mattress shape, they use reinforced steel wire mesh or geogrid panels to ensure durability. Mattresses are suggested to be no more than a maximum of 35 feet in length, 5 feet wide, and 8-12 inches tall, and can be filled and then hoisted into place. They are designed to blend with the environment as the voids become filled, and can be layered to suit specific applications. In the case of Whitcomb Flats, rock mattresses could be used to stabilize the flat, act as a breakwater for wave energy, and capture sediment. Typical installed mattress cost in water, in breakwater applications, is $15 per square foot. See figure 6, a picture of Triton Marine Mattresses.

Figure 6 Stack of filled marine mattresses staged for placement on National Shoreline Erosion Control Development and Demonstration Program project in Seabrook, NH (photograph by Kevin Knuuti, CHL)

Figure 7. CoreLoc being deployed in marine environment

Designed by the US Army Corps of Engineers, Coreloc are a type of concrete breakwater and shoreline protection structure, using interlocking, symmetrically tapered, octagonal structures. They are designed for high wave energy environments, and claim to dissipate the maximum amount of wave energy with the least amount of concrete. Dolos are a variant of Coreloc, both of which originate from the Kellner concrete jack design in the 1920s. Although most often used in riverine contexts, they have been used in ocean environments with success, with appropriate modeling and correct deployment. Their unique design is reminiscent of the childhood game of "jacks," so they are often referred to as such. The USACE is anecdotally said to have recommended the use of such concrete structures in Grays Harbor, although it is not included in the Continuing Authorities Project Fact Sheet, a joint effort between DNR and USACE to address Whitcomb Flats migration and sedimentation problems (Appendix B, Exhibit A). These types of structures allow for some sediment to be captured as well as diverted, and create habitat for fish and crustaceans within their crevices. These structures are permanent, so must be carefully modeled before placement to prevent unintended consequences. However, they should be considered as a method of permanently stabilizing Whitcomb Flats, rather than just mitigating the effects of its migration, erosion, and associated sedimentation.

In the same way that concrete structures might be deployed, piling arrays could be considered (as opposed to the traditional low piling wall, which is not recommended in this scenario). While pilings are generally considered undesirable in today's estuaries, they are an alternative to heavier and more expensive concrete options. Both concrete and piling structures will be difficult to receive permitting for, making them less desirable from an initial point of view. Shellfish growers in Grays Harbor may not have years to wait for mitigation of sediment deposition: they are suffering unsustainable losses now. That is why we recommend the use of a shell bag berm or similar to provide temporary relief while more permanent options are considered.

Finally, Whitcomb Flats could be built up with sand of sufficient height to prevent most overtopping of waves. As mentioned above, it is a Natural Area Preserve because it was once important breeding grounds for Caspian terns. This sediment intervention technique could have the double benefit of perhaps restoring breeding, roosting, stop-over and foraging grounds for birds. Because of this potential for restoring important habitat, the build-up of Whitcomb Flats, in combination with a structure to combat wave energy, was thought by DNR to be the least-cost, most environmentally beneficial solution; that would both restore habitat and reduce or eliminate damaging impacts of sediment to the tidalflats (Appendix B, Exhibit A, Continuing Authorities Project Fact Sheet).

The risk is that without further study of the exact hydrodynamics that are causing the migration and erosion of the flats, the deposition of more sand on Whitcomb Flats could simply result in a larger supply of sand to be deposited on shellfish beds. Until we can identify exactly what is causing the unraveling of natural sediment flux in the estuary, it's important to be cautious in attempting to rebuild Whitcomb

Flats to its former height. That could result in feeding the source of much of the sand, and recreating the effects of the last two decades.

Close monitoring and management of mitigation measures should be included in any planned mitigation project. From a permitting perspective, the US Corps of Engineers is dredging a large part of the harbor based on environmental impact documents that do not appropriately address oyster impacts (See Appendix B, comment letter to USACE from PCSGA). Therefore, the project should be clearly framed as mitigation, not as a new project to be permitted.

Other Impediments to Sediment Mitigation in Grays Harbor

Habitat competition from ghost shrimp will worsen challenges to Grays Harbor farmers

Further burdening farmers' ability to successfully cultivate oysters is the activities of ghost shrimp. Until recently, the harmful effects this animal has on tideflats were controlled by the use of pesticide spraying (carbaryl). However, a better solution was sought, and after many years and millions of dollars of research, USEPA issued a permit for the use of imidacloprid (a less harmful pesticide) to control ghost shrimp. However, a public outcry against the use of this new pesticide ensued in 2015, and the growers requested USEPA to withdraw the permit (Seattle Times, 4/30/15, 5/3/15). Within the next one to two years the last effects of the spraying of carbaryl will stop inhibiting ghost shrimp activity, and growers will have to face the double challenge of destruction of oyster bed habitat by both sedimentation and ghost shrimp.

"The burrowing and feeding behavior of the ghost shrimp is vigorous enough to cause substantial alterations in surface sediment characteristics over time, decreasing organic content and shifting the particle size distribution upwards," noted Hornig et al. (1989). "Sediment in dense ghost shrimp beds often has a soft, quicksand quality."

Kim Patten, of Washington State University, writes that "Ghost shrimp re-suspend sediment in the process of feeding and of constructing and maintaining burrows. This results in a continuous mixing of deep and shallow layers of sediment (bioturbation), which causes surface organisms (eelgrass to oysters) to literally sink and die. In Willapa Bay, it is estimated that 15,000 to 20,000 of the bay's 80,000 acres (45,000 of which are intertidal) are dominated by burrowing shrimp. Over 3,000 acres of privately owned oyster growing tidelands are estimated to have been permanently destroyed for not only oyster culture but also as habitat for nearly all other estuarine biota, including eelgrass, clams, and other sediment-dwelling organisms (Patten 2003).

Washington Department of Ecology (2014) observed, "Since at least the 1940s, two native species of burrowing shrimp (ghost shrimp, *Neotrypaea californiensis* and mud shrimp, *Upogebia pugettensis*) have caused impacts to Pacific coast commercial clam and oyster production by disrupting the structure and composition of the substrate, causing these shellfish to sink and suffocate."

In addition, Ecology observed that the region's nationally important shellfish harvests depend on a relatively narrow band of subtidal and intertidal land: "The combined oyster harvest from Willapa Bay and Grays Harbor constitutes approximately 24 percent of total oyster landings in the United States. The majority of oysters are raised directly on the substrate from subtidal elevations to about the +3.5-foot mean lower low water (MLLW) elevation level in the intertidal region."

Other Data Gaps in Grays Harbor

In the course of our study, it also became clear that there are large data gaps regarding the presence of beneficial eelgrass and other sub-aquatic vegetation (SAV), as well as the location and extent of salt marsh. Sub-aquatic vegetation is important for several reasons: it brings valuable photosynthesis activities and carbon absorption to an estuary, habitat and cover for both prey and predator creatures, helps small fish and invertebrates to achieve greater size and density, encourages bird activity, can help aerate water, has some sediment mitigation properties, and can also help in reducing the effects of ocean acidification by influencing the local pH (Hosack et al., 2006, Scigliano, 2012). Juvenile fish abundance in SAV can be compared to that of restored oyster reefs (Grabowski et al., 2005).

Native salt marshes are also important habitat and crucial for the natural functions of an estuary, including water filtration. They are also the best known natural carbon sink– outperforming tropical rainforests up to 17x (Laffoley & Grimsditch, 2009).

However, existing surveys of Grays Harbor SAV and salt marsh are quite inaccurate. In fact, both the data from DNR and the National Wetlands Inventory is wildly optimistic, showing SAV present in 70% or more of the bay, which current aerial photographs and on-the-ground observation show to be false. Worse yet, they show invasive species *japonica* and *Spartina alterniflora* as beneficial eelgrass and salt marsh. A new vegetative survey should be undertaken in order to understand the full health and challenges within Grays Harbor.

Policy Constraints on Intervention in a Changing Estuary

Options to mitigate "sanding in" of oysters in Grays Harbor Estuary may be constrained both by policies intended to protect shoreline functions (including natural sediment transport), as well as by physical conditions within the estuary itself.

An extensive body of law, policy and regulatory guidance has evolved (and is still evolving) to restrain human attempts to "control" the natural processes of coasts and rivers in Washington. These policies focus mainly on shoreline armoring, flood control, and other measures taken by people attempting to prevent damage to property, homes, or public facilities. Protection of natural coastal processes is an important goal—including for many oyster growers; however, the problem faced by Grays Harbor oyster growers presents a different case.

Extensive human modifications, especially navigational improvements, are believed to have altered Grays Harbor Estuary, profoundly changing patterns of water and sediment movement and possibly unraveling spits and other major morphological features of the bay. As a result, protecting oyster farms from sand overburden in this estuary today may be viewed in a different light: not as an attempt to arrest or block natural processes, but as a mitigation against harm caused by human activities. Although the migration of Whitcomb Flats is conclusive, as well as the higher wave energy overtopping the flats, the precise origin of the "sanding in" problem has not been definitively proved; although considerable evidence suggests that the problem likely amounts to an unintended consequence of past human actions such as dredging and jetty developments.

The role of natural sediment flux in healthy coastal processes is well recognized and extensively documented. Much of the literature and policy centers on protecting these processes —and the neighbors—from the unintended consequences that follow when people build fixed structures and assert fixed property boundaries too close to shorelines. Within the naturally fluctuating "migration zones" and "drift cells" that define coastal processes, the hard reality is that human property lines and structures sooner or later face defeat; but this eventual certainty hasn't stopped people from arguing with the inevitable.

Over generations, this tension between fixed human boundaries and mobile natural boundaries has led to extensive degradation of coastal ecosystems and human properties. Damming, diking, and seawall construction can and do produce a chain-reaction of flooding, erosion, and channel migration along neighboring shorelines. They damage habitat and diminish habitat-forming coastal processes. This reduces the capacity of shorelines and nearshore waters to support healthy ecosystems and even to buffer storm surges, a natural service that can protect coastal towns and homes, notably in large estuaries.

As a result of this history, oyster farmers in Grays Harbor Estuary are operating in a policy environment that evolved mainly to manage problems that are wholly distinct from the challenge they face today.

On one hand, a large portion of relevant policy and technical literature focuses on activities that inadvertently starve downstream environments of sediment. The authors of a National Research Council assessment of geospatial information needs for coastal planning observed, "Certain coastal environments such as beaches, dunes, flats and wetlands are sediment dependent. For instance, tidal lagoon substrates are populated by sessile filter feeding communities that depend on material flux as a food source. The same communities are vulnerable to excess sediment flux from upland land use related to agriculture or development. Conversely, coastal marshes need sediment input to keep up with sea level rise. Too much upland sediment control and damming of rives can starve these vital resources of the sediment necessary for their survival" (NRC 2004).

On the other hand, Washington policies for protection of estuarine and coastal ecosystems that we reviewed for this study are primarily focused on shoreline modifications and marine construction projects that might permanently interfere with natural processes.

Policy requirements and implications for response strategy

Sediment intervention options for oyster grounds are affected by a suite of state laws and policies, but certain exemptions for agriculture exist, and shellfish aquaculture enjoys some latitude under the law.

Washington's Shoreline Management Act (SMA), the state's key law governing shoreline projects, requires a Substantial Development Permit for any project costing over $5,000 that involves "driving of piling" and for any use interfering with "normal public use of the surface waters," according to information presented by the Department of Ecology to the state's Shellfish Aquaculture Regulatory Committee (Washington Department of Ecology SARC presentation, Nov. 26, 2007). Conditional Use Permits are normally required for any "unclassified use" that is not specifically addressed in a local Shoreline Master Program. Permit requirements can vary by county.

Rules governing marine construction could significantly limit options for mitigating sediment impacts on shellfish production. Floating culture and tall structures to elevate oysters above the seafloor would likely be restricted, for example, because they would interfere with navigation channels, which the Coast Guard and other agencies have jurisdiction over. In its guidance on aquaculture for local governments updating their Shoreline Master Programs, the Department of Ecology (2012) cites the Washington Administrative Code on this point: "Docks, piers, bulkheads, bridges, fill, floats, jetties, utility crossings, and other human-made structures shall not intrude into or over critical saltwater habitats" except when a series of conditions are met. The required conditions include:

- "The public's need for such an action or structure is clearly demonstrated and the proposal is consistent with protection of the public trust, as embodied in RCW 90.58.020;
- Avoidance of impacts to critical saltwater habitats by an alternative alignment or location is not feasible or would result in unreasonable and disproportionate cost to accomplish the same general purpose;
- The project including any required mitigation, will result in no net loss of ecological functions associated with critical saltwater habitat;
- The project is consistent with the state's interest in resource protection and species recovery. "

However, specific permit exemptions may be available for some of the potential interventions to protect oyster grounds. For example, it may be useful to investigate whether SMA exemptions for watershed restoration could simplify the approval process for some inventions intended to protect oysters from harmful sedimentation impacts.

Under the SMA, Conservation Districts are among the authorities that can sponsor watershed restoration plans, which define "a general program and implementation measures or actions for the preservation, restoration, re-creation, or enhancement of the natural resources, character and ecology of a stream, stream segment, drainage area, or watershed." (RCW 89.08.460)

The state classifies commercial aquaculture as "critical saltwater habitat," a designation that may be relevant in pursuing strategies to reduce sediment impacts arising from human activities. In its guidance on aquaculture for local governments, the Department of Ecology (2012) recorded that the Washington Administrative Code defines "critical saltwater habitat" to include "subsistence, commercial and recreational shellfish beds; mudflats, intertidal habitats with vascular plants, and areas with which priority species have a primary association." The agency's guidance document states, "Critical saltwater habitats require a higher level of protection due to the important ecological functions they provide. Ecological functions of marine shorelands can affect the viability of critical saltwater habitats. Therefore, effective protection and restoration of critical saltwater habitats should integrate management of shorelands as well as submerged areas."

Other exemptions and protections also may be provide some latitude for response to the sedimentation problem. Exemptions to permit requirements under SMA include "normal maintenance and repair" and "farming practices," according to Ecology's presentation to the SARC. Additionally, the SMA includes a broad exemption for agriculture: it stipulates that agency guidelines and Shoreline Master Programs adopted to implement this law "shall not require modification of or limit agricultural activities occurring on agricultural lands" (RCW 90.58.065, 2002).

The Washington Administrative Code (WAC) also recognizes aquaculture as a "preferred use" of water areas and an "activity of statewide interest." In its guidance for local governments engaged in SMP updates, Ecology (2012) cites WAC 173-26-241(3)(b), which states: "This activity is of statewide interest. Properly managed, it can result in long-term over short-term benefit and can protect the resources and ecology of the shoreline. Aquaculture is dependent on the use of the water area and, when consistent with control of pollution and prevention of damage to the environment, is a preferred use of the water."

Agency's guidance notes that Washington law also recognizes that aquaculture locations "are relatively restricted due to specific requirements for water quality, temperature, flows, oxygen content, adjacent land uses, wind protection, commercial navigation, and, in marine waters, salinity." In that context, the agency cites a WAC provision stating that: "Local government should ensure proper management of upland uses to avoid degradation of water quality in existing shellfish areas."

Permitting needs to be met by potential mitigation projects

Any project undertaken to change the effects of wave energy and sediment flux within the estuary would need to comply with the following:

1. Views of Federal, State, and Regional Agencies – Department of Natural Resources, the Shellfish Interagency Permitting Team, Dept of Ecology, Tribal, and Federal interests will need to be considered.

2. Environmental Statutes Compliance -

a. National Environmental Policy Act (NEPA) 42 USC 4321 et seq. An environmental assessment of the recommended plan and alternatives would need to be prepared. Subsequently either a Finding of No Significant Impact (FONSI) or an environmental impact statement will be prepared.

b. Endangered Species Act 16 USC 1531 et seq. A biological evaluation will be prepared and coordinated with NOAA Fisheries and U.S. Fish & Wildlife Service.

c. Clean Water Act, Section 404. Project will need to be consistent with Section 404(b)(1) of the Clean Water Act

d. Clean Water Act, Section 401. Project will need a 401 Water Quality Certification from EPA.

e. Coastal Zone Management Act (CZM). The project will need to comply to the maximum extent practicable with the approved state coastal zone management program.

f. National Historic Preservation Act. Requires Federal agencies to identify and protect historic properties.

g. Clean Air Act. Section 176 prohibits Federal agencies from approving any action that does not conform to the approved state or federal implementation plan.

h. Environmental Justice, Executive Order 12898. Requirement to identify and address disproportionately high and adverse human health or environmental effects on minority or low-income populations.

However, some preliminary testing of mitigations such as alternative culture methods and the placement of seeded shell bags may be allowed without requiring permitting in advance. This would need to be confirmed, but the placement of seeded shell bags is already permitted on DNR aquaculture leases, so a preliminary test to measure effects (like the one already performed by a Grays Harbor grower) could be attempted.

Conclusion

It is clear from the evidence studied and stakeholder interviews conducted that oyster tidelands in Grays Harbor are in a near-crisis situation, with many productive beds already lost to sedimentation and high wave energy, and more becoming unproductive every year. Since the effects of the Deep Dredge project were first felt by growers in 1990, they have been documenting and reporting on the effects of sudden sediment deposition events and high wave energy (see Appendix C). DNR has extensive files and documentation of the sedimentation problems, and has lost lease income and formerly productive shellfish beds (Appendix B, Exhibit B). Several attempts have been made in the past by DNR, the US Army Corps of Engineers, and local growers to work on mitigation options, and to apply for assistance grants, but none were successful. As local farmers have continued to suffer major losses to their operations, many of them have found the situation untenable and either closed their businesses, moved away, or reduced operations.

Through the formation of the Washington Shellfish Initiative, launched by Governor Gregoire in December 2011, Washington State has emphasized the importance of shellfish aquaculture. The Washington Shellfish Initiative specifically recognizes “the extraordinary value of shellfish resources on the coast. As envisioned, the initiative will protect and enhance a resource that is important for jobs, industry, citizens, and tribes.” It also states that shellfish “help filter and improve the quality of our marine waters, therefore being part of the solution to restore and improve the health of endangered waters (State of Washington, 2011).” Sixty-six percent of Washington’s oysters are produced in Grays Harbor and nearby Willapa Bay collectively. If Washington State wishes to encourage a thriving oyster aquaculture industry, then addressing the sediment problems in Grays Harbor is an important step.

While the stabilization of Whitcomb Flats and the mitigation of high wave energy and excessive sedimentation will not be easy, it is clear from the evidence reported herein that doing nothing is no longer an option. Hydrodynamics within the bay are unraveling the geomorphology, and the local economy and shellfish farmers are carrying the financial burden of the consequences, while the estuary experiences ecological losses.

In their Supplemental Environmental Impact Statements (SEIS) the US Army Corps of Engineers does not appropriately address the environmental impacts to oyster beds of their ongoing dredging projects (Appendix B and USACE, 2014b). Although they acknowledge the migration of Whitcomb Flats, by framing pre-1990 Corps projects as "baseline information," rather than something they are responsible for, they have avoided taking responsibility for the consequences. In fact, they never analyzed shellfish populations, sediment transport dynamics in Grays Harbor, and their impacts on shellfish beds in any of their SEIS. Since application to USACE by DNR for an Estuary Habitat Restoration Council grant in 2009 failed, the Corps has stopped participating in talks to contribute to mitigation efforts in any way. However, without further extensive study, the USACE cannot be found legally liable for the sedimentation of oyster beds in Grays Harbor. The funds and planning for mitigation efforts must be looked for elsewhere.

The economic and ecological benefits provided by oyster cultivation in Grays Harbor cannot be overstated: it is a key industry in an otherwise little developed area, and oysters are unmatched in the ecological benefits they provide to the estuaries they live in. We highly recommend that funds be sought to allow for planning of recommended mitigation options to begin as soon as possible.

Note: we strongly suggest that all materials contained in this report's Appendices be thoroughly examined.

Figure 8 Nearly grown oysters completely smothered by sand in 2015 – 100% mortality

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