TBNEP Oyster Report

Eelgrass Ecology and Commercial Oyster Cultivation in Tillamook Bay, Oregon

A literature review and synthesis by
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EXECUTIVE SUMMARY

Eelgrass beds are critical elements of the ecology of Pacific Northwest estuaries, including Tillamook Bay. They provide habitat for juvenile fish and shellfish, food for waterfowl such as the black brant, spawning areas for fish including the Pacific herring, and play an important role in nutrient cycling. Recent investigations suggest that commercial oyster farming has a negative impact on eelgrass meadows in Pacific Northwest estuaries. However, oyster ground culture (the type predominant in Tillamook Bay) coexists to some extent with eelgrass, and provides good habitat for many marine invertebrates, fish, and waterfowl. The relative habitat value of eelgrass versus oyster beds and the role that each plays in the estuarine system must be better understood as the Tillamook Bay National Estuary Project develops its comprehensive conservation and management plan.

This report synthesizes the current literature regarding the interaction of commercial oyster culture and eelgrass meadows, examines potential limiting factors to eelgrass health in Tillamook Bay, discusses burrowing shrimp, and makes recommendations for further research and management options. This report concludes that:

* Physical disturbances and other environmental factors can adversely affect eelgrass beds;
* Commercial oyster farming and/or its associated activities cause a decrease in the amount eelgrass in the immediate vicinity of the oyster farming operation;
* Oyster beds can provide suitable habitat for a number of estuarine species;
* The presence of burrowing shrimp can negatively affect oyster cultivation and eelgrass beds; and
* There is a need to better understand the interactions between oyster farming, eelgrass meadows, burrowing shrimp, and the various natural and anthropogenic influences in Tillamook Bay.

INTRODUCTION

The Tillamook Bay National Estuary Project (TBNEP) is developing a comprehensive conservation management plan (CCMP) for Tillamook Bay and its watershed. This plan will be used by state and federal agencies, industry representatives, and private citizens to manage the bay and its natural resources for sustainability, while addressing the needs of user groups. One of the most important natural resources in Tillamook Bay is eelgrass (Zostera marina). Eelgrass meadows provide shelter and structure for a variety of fish and invertebrates, supply the estuarine food web with detrital matter, and help to stabilize benthic sediments. One of Tillamook Bay's user groups is the commercial oyster industry. The role that oyster farming plays in the ecology of the bay is poorly understood, especially the effects of oysters and oyster farming on sediment dynamics, benthic and epibenthic animal species, and the bay's flora; particularly eelgrass. This report reviews the scope of published and unpublished information regarding these issues. Specifically, the report will:

* Describe eelgrass distribution, biology, and the role that eelgrass plays in estuarine systems of the Pacific Northwest;
* Provide an overview of the commercial oyster industry and the issues affecting it; and
* Describe the short and long term effects of oyster farming on eelgrass beds.

Most Pacific Northwest estuaries share similar ecosystems, and the information in this report is therefore somewhat applicable to the entire Pacific Northwest. However, each bay and estuary is unique, and this report focuses on Tillamook Bay. The information can be applied cautiously, but not carelessly, to other Pacific Northwest estuaries.

EELGRASS AND ITS IMPORTANCE TO PACIFIC NORTHWEST ESTUARIES

Eelgrass meadows represent a vital part of estuarine habitat. They provide shelter for juveniles of many species of fish and shellfish, and contain a high level of species diversity (Phillips 1984, Pregnall 1993, Triani 1995, Sayce 1997). Juvenile salmonids (Chinook salmon, Oncorynchus tshawytscha, chum salmon, O. keta, coho salmon, O. kisutch, steelhead, O. mykiss, and sea-run cutthroat trout, Salmo clarki clarki) utilize eelgrass habitat en route to the sea. Pacific herring, Clupea harengus pallasi, spawn in eelgrass although they will also deposit their eggs on other surfaces. Detritus (dead plant material) and small aquatic organisms are food for larval and juvenile fish and shellfish. Eelgrass itself is a primary food source for waterfowl such as the black brant (Waddell 1964, Reiger 1982, Baldwin and Lovvorn 1994, Wilson and Atkinson 1995). Phillips (1984) lists eelgrass' high productivity, habitat stabilization, and nutrient effects as other important functions within an estuarine system.

Distribution and Abundance

The historical extent of eelgrass in Tillamook Bay is not well documented. Figures 1 - 5 have been reproduced from their original form to more easily compare eelgrass distribution. They are not intended to be highly accurate. Rather, they are intended to provide a qualitative comparison of eelgrass distribution over time in Tillamook Bay. The earliest map of eelgrass distribution (Figure 1) is from 1971 (Tillamook Bay Task Force 1978). The bay had already been influenced by human activities for many years prior to this first inventory, and we have no record of eelgrass distribution in the bay's pristine state. Eelgrass inventories were completed and maps produced in the 1970s (Forsberg et al. 1977, Tillamook Bay Task Force 1978, Hancock et al. 1979, and ODLCD 1987), and a detailed inventory using multispectral airborne imagery was completed in 1995 (Strittholt and Frost 1996). [Note that Oregon Land Conservation and Development (ODLCD 1987) contains eelgrass distribution maps from 1979, and that Forsberg et al.(1977) contains eelgrass distribution maps from 1975]. Of these, only Hancock et al.(1977) and Strittholt and Frost (1996) were exhaustive enough to provide serviceable information. These two surveys describe detailed, intensive methods, while the other three do not describe the methods used to generate the maps. Nonetheless, this report will utilize the maps to make general comparisons between current eelgrass distribution and that of 20 - 25 years ago.

All five inventories show eelgrass presence in several areas of the bay:

* West bay, south of Crab Harbor;
* Hobsonville Point and the Ghost Hole area; and
* Portions of Miami Cove.

Aside from these three areas, there is considerable spatial and temporal variation in eelgrass distribution in Tillamook Bay. Hancock et al. (1979) and Strittholt and Frost (1996) show eelgrass presence in the extreme south end of the bay, but the other three studies do not. Strittholt and Frost (1996) and Hancock et al. (1979) show little or no eelgrass in the central part of the bay, but the other three studies indicate significant stands of eelgrass. Tillamook Bay Task Force (1978) and Forsberg et al. (1977) show no eelgrass in the area adjacent to the Garibaldi marina and the old Coast Guard pier, while the other three do. Despite the fact that these maps were generated using differing methods, and that eelgrass abundance (measured in density and biomass) is more difficult to assess than distribution, it seems clear that eelgrass distribution in Tillamook Bay has changed significantly over the past 20 years. This conclusion is corroborated in Ellis (1997). Distribution maps are found in Figures 1 - 5.

Eelgrass abundance varies seasonally, with winter die-off and spring/summer regrowth (Kentula and McIntire 1986, Phillips 1984). The literature suggests that while eelgrass does not readily colonize new areas (Dumbauld 1997, Phillips 1984, Sayce 1997), there is considerable annual variation in abundance due to a variety of factors. These factors include (but are not limited to) physical and chemical disturbance, changes in nutrient availability, and changes in water quality paramters such as turbidity and salinity (Phillips 1984, Pregnall 1993, Simenstad and Fresh 1995). It follows that these factors can result in long term changes in eelgrass abundance if the unfavorable conditions persist. It is possible that mesoscale changes in watershed and oceanic conditions can affect annual eelgrass regrowth. Rumrill and Christy (1996) suggested that as part of the ongoing El Niño event in 1996, overall eelgrass abundance in the South Slough portion of Coos Bay was in a state of decline.

EELGRASS BIOLOGY AND PHYSIOLOGICAL REQUIREMENTS

This section will briefly describe eelgrass growth strategies and several factors that affect the growth, reproduction, and distribution of eelgrass. Those factors will then be addressed in terms of their impact on eelgrass in Tillamook Bay. Refer to Table 1 for a timeline of growth and reproductive events, and to Table 2 for a summary of environmental conditions suitable for eelgrass growth and reproduction.

Growth and Reproduction

Eelgrass growth is seasonal, with new growth appearing mainly in spring and summer. New growth of roots, rhizomes, and leaves typically begins in February, with vegetative growth bursts occurring in June through July. There is a less prolific phase in early winter that generates narrower, shorter, and fewer leaves, as compared with spring/summer growth (Phillips 1984).

Eelgrass is a facultative annual. That is, it usually acts as a perennial utilizing vegetative growth, but will depend heavily on seed dispersal during times of stress. Stress factors include extreme water temperatures, and low salinity (Felger and McRoy 1975, Keddy and Patriquin 1978, Bayer 1979, Jacobs 1982, Phillips and Lewis 1983, as cited in Phillips 1984). Seed germination, production, and dispersal occurs all year, but primarily from April to October (Table 1). Intertidal eelgrass depends more on sexual reproduction than subtidal plants, which depend almost entirely on vegetative propagation. Most likely, this is due to the greater variety of environmental stresses that intertidal eelgrass is subjected to, such as physical disturbance and desiccation (Phillips 1984).

Temperature

Optimum temperature for eelgrass growth is between 100C and 200C (500F and 680F), but it can tolerate a much wider temperature range. In most areas where the plant is established, temperatures range between 50C and 270C (410F and 80.50F) (Phillips 1972, 1984). There is some evidence that genotypic variations have allowed selective adaptation to specific conditions. Temperate coastal Oregon does not experience great temperature extremes, so eelgrass adapted to this climate may not be able to survive in a warmer or colder climate where a local species of eelgrass thrives. Conversely, eelgrass from the extreme northern and southern end of its range are more tolerant of higher and lower temperature variations than eelgrass from the middle of the range (Phillips 1974).

Temperature does not appear to be a limiting factor for eelgrass growth in Tillamook Bay. The water temperature in the central part of the bay ranges between 70C and 140C (44.60F and 57.20F), with extremes reaching 2.80C and 200C (370F and 680F (ODEQ 1993). These temperatures are within the acceptable ranges cited in the literature.

Salinity

Eelgrass is tolerant of a wide salinity range, and experiences varying salinity levels according to the tide and level of fresh water input (Phillips 1984) (Table 2). During low tide in the upper end of Tillamook Bay, salinity will be very low; essentially fresh water. In the mid portion of the estuary during high tide, the salinity can reach near-oceanic conditions, but can also fall to near fresh water levels during low tide or rainfall events (normal oceanic salinity is approximately 34 ppt). In Puget Sound, eelgrass grows best between 20 ppt and 32 ppt, although lower salinity plays a role in seed germination (Phillips 1984). Phillips (1972) found that seed germination occurred optimally between 4.5 ppt and 9.1 ppt, and other researchers have found a similar correlation between salinity and seed germination (Arasaki 1950, Tutin 1938).

Salinity does not appear to be a limiting factor in eelgrass growth or reproduction in Tillamook Bay. In the central part of the bay, salinities range from 11 ppt to 26 ppt, with extremes ranging between 3 ppt and 32.2 ppt. In the extreme upper portion of the bay, salinities range between 0 ppt and 26 ppt (ODEQ 1993). There are significant stands of eelgrass in this part of the bay, and according to current literature, the eelgrass has a wide enough tolerance range to grow and reproduce here.

Substrate and Sediment

Eelgrass preferentially inhabits mixed substrates, but will colonize sediments varying from firm sand and gravel to soft mud (Ostenfeld 1908; Phillips 1974, 1984; author's personal observations). As eelgrass colonizes an area, it develops its own microenvironment. When individual leaves die, they contribute organic and inorganic material to the sediment. Shoot density increases, and rhizomes extend horizontally within the substrate, stabilizing the sediment. As plants become more established, they reduce current velocity, thereby allowing fine particles to settle out of the water column. This results in a silty yet stable sediment layer (Stout 1976, Burrell and Schubel 1977, Orth 1977, Churchill et al. 1978, Fonseca 1981, Fonseca et al. 1982, and Kenworthy et al. 1982, as cited in Phillips 1984). As this occurs, an anoxic layer forms near the sediment surface (Fenchel and Riedl 1970). Bacteria colonies develop, and according to Phillips (1984), "The developing sediment-microbial-nutrient-seagrass complex thus develops as a system." He adds that physical disturbances have serious effects on the substrate as a suitable site for seagrass growth, but does not explain what types of physical disturbances.

As stated above, eelgrass can colonize a variety of substrate types. This could lead one to think that suitable substrate is therefore not limiting to eelgrass. However, Phillips (1984) states that because eelgrass rhizomes are not capable of vertical growth, the plant is restricted to habitats where there is no net loss or gain of sediment. Tillamook Bay is prone to sedimentation problems (sedimentation is a priority issue of the TBNEP). Recent floods have likely scoured parts of the bay, and caused sediment deposition in other parts. There is no data from which to draw conclusions, but it is possible that excessive erosion and/or sedimentation could negatively affect eelgrass in the estuary. Phillips (1984) cites sedimentation from logging and road construction as one of the six activities that has affected eelgrass in Willapa Bay.

Light

Light is the greatest factor in limiting eelgrass growth. Numerous studies have shown a positive correlation between eelgrass production and radiative energy (Dillon 1971, Phillips 1972, Stout 1976, Thayer et al. 1975, Backman and Barilotti 1976, Dennison 1979, Dennison and Alberte 1982). Conversely, eelgrass becomes decreasingly productive as the amount of radiative energy decreases. Light limitation may result from turbidity, epiphytic growth, plankton blooms, shading from algae (such as Ulva spp. or Enteromorpha spp.), or self shading (Waddell 1964, Kentula and McIntire 1986, Pregnall 1993).

The maximum depth at which eelgrass grows is dependent on the availability of suitable substrate, acceptable current velocity (see following section), and light penetration (Thayer et al. 1975, Phillips 1984). Turbidity plays a major role in light penetration. Phillips (1984) states that light penetration is a limiting factor in Puget Sound and in Oregon in the winter. OSU (1977) cites turbidity as the most important limiting factor related to eelgrass.

In estuaries that are impacted by human use, the amount of light reaching eelgrass can be influenced by human activities. Heavy sediment loads resulting from logging and streamside erosion increase turbidity, thereby decreasing the amount of light reaching the eelgrass. High nutrient input from fertilizers and fecal material can result in excessive epiphyte growth on the eelgrass blades, which also deprives the eelgrass of light. Preliminary data from the TBNEP's water quality sampling program do not indicate excessive nutrient input into the estuary (Sullivan 1997). However, nutrient sampling has not been completed during low flow summer months, when eelgrass grows most prolifically.

The extent to which eelgrass in Tillamook Bay is affected by light is not known. OSU (1977) points to turbidity as limiting light penetration in Tillamook Bay, but turbidity data, measured in FTUs (flourometric turbidity units) from ODEQ (1993) does not indicate consistently high turbidity in the central part of the bay. FTU levels from zero to five indicate low turbidity. From six to 15 FTUs is moderate/borderline, and above 15 FTUs indicates very high turbidity (Pettit 1997). Periodically, readings from the central part of the bay exceed five FTUs, but the vast majority are between one and five FTUs (ODEQ 1993), indicating little if any light limitation.

Current Velocity

Moderate currents (less than 3.5 knots) are ideal for eelgrass growth. If the current is too fast, it tears leaves from the plant and can erode the substrate. If the current is too slow, algae dominates and eelgrass growth is poor (Phillips 1984).

Tillamook Bay has become increasingly channelized since the latter part of the 19th Century. The channel portions of the bay (-9 to -18 meters MLLW) have become deeper, and the channels have changed positions. The shallower portions of the bay (from +1 to +2 meters MLLW) have become shallower (Coulton and Williams 1996, Tillamook Bay National Estuary Project 1996). The effect this phenomenon has on eelgrass habitat is not clear. However, the flow through the channels has possibly increased due to channelization, and the flow in the intertidal areas has possibly decreased for the same reason (TBNEP 1996). Such a change in flow patterns and current velocity could hypothetically affect the suitability of portions of the estuary in terms of eelgrass habitat, however, data are not currently available to support or refute this conclusion for Tillamook Bay.

OVERVIEW OF THE OYSTER INDUSTRY

History

The Pacific Northwest oyster industry saw its beginnings in Puget Sound in the mid-1850s with the harvest of the native oyster, Ostrea lurida. The industry flourished and soon, up to 200,000 bushels were being harvested annually from Puget Sound alone (WDFE 1992). By 1895, the stocks were seriously depleted, but the industry was revived with the introduction of the Pacific oyster, Crassostrea gigas, from Japan. This oyster is hardy and grows quickly in these waters. Originally, seed was purchased from Japan, but there are many hatcheries now in operation in the Pacific Northwest, so oyster seed is locally available. O. lurida are not native to Tillamook Bay. Pacific oysters (Crassostrea gigas) were introduced experimentally in the 1920s, and in 1932, the first oysters intended for commercial production were placed in the bay (Coulton and Williams 1996).

Current Status

About 3,400 acres of intertidal and subtidal land in Oregon is leased to oyster growers. 2,461 acres are leased to nine oyster growers in Tillamook (ODA 1995). The oyster leases are shown in Figure 6. Tillamook Bay is divided into six Commercial Shellfish Management Areas (Figure 7) by the ODA, with most oyster culture taking place in the Main Bay and Cape Meares areas (ODA 1996).

Oyster production has decreased dramatically since the mid-1980s, when up to 31,000 gallons were produced annually (Figure 8). In 1995 Tillamook Bay produced 4,069 gallons with a value of $138,000 (ODA 1996). The reasons for the decrease in production are unclear, but are likely a combination of the following:

- burrowing shrimp problems (Hayes 1997, Mercer 1997);
- closure days (Hayes 1997, Mercer 1997);
- shutdown of a major leaseholder (Ellis 1997); and
- flooding in 1996 (Mercer 1997, Pacific Seafood 1997).

Methods of Oyster Culture

The predominant method of oyster farming in Tillamook Bay is ground culture. In this system, cultch (oyster shells with oyster spat growing on them) are taken by boat or barge to their destination, where they are distributed over the oyster plot. Sometimes, these oysters are collected and moved to fattening grounds after two to three years, although this is not practiced in Tillamook Bay. After three to four years, the oysters are harvested and prepared for market. Most oysters are harvested by hand. This involves transporting large metal baskets to oyster grounds at high tide by boat or barge. At low tide, the oysters are hand picked and placed into the baskets, to be retrieved during high tide (Hayes 1997).

In stake culture, wooden stakes are driven into the intertidal sediment, then cultch shell is attached to the stakes. An advantage of stake culture is that the oysters are completely surrounded by water rather than lying with one side facing the sediment. This method minimizes the possibility of the oysters sinking into extremely soft sediment, which is a problem with ground culture. The primary disadvantage of stake culture is that it is labor intensive (Pregnall 1993). Stake culture is not currently practiced in Tillamook Bay (Faudskar 1997).

Other culture methods include rack and raft culture. In rack culture, racks are placed horizontally one to two feet above the intertidal sediment. Bags of cultch are then attached to the racks. Rack culture is currently being practiced by one oyster grower in Tillamook Bay (Faudskar 1997). Raft culture requires deeper water because the oysters are attached to ropes which hang down from a floating raft. It is not currently practiced in Tillamook Bay.

The industry faces difficulties from several sources including burrowing shrimp, increasingly-frequent closures due to excessive levels of fecal coliform bacteria, sedimentation, and for the last two winters, severe flooding.

Bay Closures

The Oregon Department of Agriculture (ODA) is responsible for closing certain areas of the bay to commercial shellfish harvesting when fecal coliform (fc) bacteria levels exceed Food and Drug Administration standards. Bacterial sources include manure from dairy pastures, human waste via failed septic systems, and effluent from the area's six sewage treatment plants (Kruckenberg 1996).

There are four management designations under the current commercial shellfish management plan. These are "Approved," "Conditionally Approved," "Restricted," and "Prohibited." The designations are based on the correlation between freshwater input and the level of fc bacteria. Therefore, the decision to close given areas is based primarily on the level of the Wilson River, but also on rainfall and any other potential negative impacts such as sewage treatment plant failure or an oil spill. An approved area is open to shellfish harvest virtually any time. conditionally approved areas are closed to oyster harvest if the Wilson River reaches the seven foot level. The area remains closed for five days after the Wilson River peaks. Restricted areas are closed if the Wilson River reaches the seven foot level, or if more than one inch of rain falls within a 24 hour period. The area is closed for five days after the Wilson River peaks. Prohibited areas are completely closed to oyster harvest (Cannon 1997a).

The bay is divided geographically into six shellfish management areas (Figure 7). The Main Bay and Cape Meares management areas are classified as conditionally approved. The Flower Pot area is classified as restricted. These three management areas are where oyster culture takes place in Tillamook Bay.

Since 1993, the Main Bay and Cape Meares areas have averaged up to 90 days of closure annually. The Flower Pot area has averaged up to 120 days of closure (Cannon 1997a). The ODA acknowledges that using the level of the Wilson River as the criteria for bay closures is less than ideal due to poor correlation between river level and bay bacteria level (Cannon 1997a). However, direct water quality sampling has shown that the level of bacteria in Tillamook Bay sometimes exceeds federal standards regardless of fresh water input (ODA 1996). If the ODA revises its commercial shellfish management plan to more accurately reflect the amount of bacteria in the bay, it may result in even more bay closures (Cannon 1997a).

The Habitat Value of Oyster Beds

Oyster beds provide habitat for many species of benthic and epibenthic invertebrates. In fact, species diversity is higher in oyster beds than in eelgrass meadows (Brooks 1995, Sayce 1997). Pregnall (1993) suggested that "oyster clumps...support a larger and more diverse mobile macrofaunal community...than do eelgrass meadows." Algae grows on oyster shell, providing food and shelter for macrofauna. Because oyster beds provide habitat for crustaceans, decapods, amphipods, and finfish such as gunnels (Armstrong et al. 1989, Pregnall 1993, Brooks 1995, Rumrill and Christy 1996), predators (such as blue herons and other foraging birds) would likely also benefit by the presence of oyster beds.

The potential negative effects of harvesting oysters should be considered in the context of habitat value. Pregnall (1993) noted that the abundant macrofaunal community disappeared after oyster harvest. She did not hypothesize whether the animals were killed or simply moved elsewhere, but she did observe large numbers of blennies (Stichaeidaeand Pholidae spp.) and crabs killed during processing (Pregnall 1993).

BURROWING SHRIMP

The two species of burrowing shrimp present in Tillamook Bay are the ghost shrimp, Neotrypaea californiensis, and mud shrimp, Upogebia pugettensis. Both dig burrows 10 to 20 inches or deeper, although ghost shrimp build more extensive burrows, while mud shrimp construct less complex, more permanent burrows (WDFE 1985, 1992). Burrowing shrimp can be a hindrance to oyster farmers because the shrimp dig into the intertidal sediment, causing it to become very soft and unable to physically support oysters. The oysters then sink into the sediment and suffocate. Ghost shrimp are a more serious threat to oyster growers than mud shrimp because they are more active burrowers, but both species are capable of displacing large amounts of sediment and are viewed by oyster growers as pests (Hayes 1997; Simenstad and Fresh 1995; WDFE 1985, 1992).

Burrowing shrimp populations exhibit significant population changes over time (MacGinitie 1934, as cited in WDFE 1992, Dumbauld et al. 1996), and shrimp presence was noted and cited as a problem to oyster farmers in the region as early as 1929 (Simenstad and Fresh 1995). Burrowing shrimp have been identified as a problem in Tillamook Bay since the late 1950s or early 1960s (Faudskar 1997). WDFE (1985, 1992) cited the El Niños of 1957-58 and 1982-83 as resulting in a large increase in burrowing shrimp populations in Willapa Bay and Grays Harbor, Washington. However, the author has noted from many conversations with commercial oyster farmers that burrowing shrimp are viewed as a continual problem rather than an occasional impediment.

The correlation cited by the Washington Departments of Fisheries and Ecology (1985, 1992) between El Niño and an increase in burrowing shrimp abundance indicates that variable oceanic conditions affect shrimp populations. However, it is not clear whether the effect is direct or indirect. Other factors contributing to an increase likely include a decline in predator populations, (specifically sturgeon, Acipenser transmontanus, cutthroat trout, Salmo clarki clarki, Pacific staghorn sculpin, Leptocottus armatus, starry flounder, Platichthys stellatus, and Pacific salmon, Oncorynchus spp.) and an increase in suitable habitat due to sedimentation. Although a decline in predator populations has not been documented, it follows a trend of fisheries decline in most Pacific Northwest estuaries. In addition, Simenstad and Fresh (1995) suggests that long term disturbance of eelgrass beds may result in the creation of suitable burrowing shrimp habitat. He cites dredging, harrowing, and leveling as possibly "arresting successional development of the eelgrass community in favor of repeated invasions and dominance by burrowing shrimp." Harrison (1987) demonstrated this phenomenon experimentally. Dredging is not generally used as a harvest method in Tillamook Bay, although it was used as a harvest method prior to 10-15 years ago (Faudskar 1997).

Ghost shrimp do not readily colonize established, healthy eelgrass beds (WDFE 1985, Simenstad and Fresh 1995, Sayce 1997). Mud shrimp and eelgrass can co-exist to some degree, and mud shrimp may affect eelgrass density (Dumbauld 1997, author's observations). However, if an eelgrass bed is compromised in some way, via physical, chemical, or biological disturbance, it faces a greater chance of becoming colonized by both ghost and mud shrimp. Once ghost shrimp colonize an area, the area becomes unsuitable for either oysters or eelgrass (Sayce 1997, Dumbauld 1997).

In Washington, the burrowing shrimp problem is addressed with the application of the pesticide carbaryl (trade name Sevin), which has been used for over 30 years to rid the oyster beds of shrimp (Dumbauld 1997). It is currently illegal to use carbaryl for shrimp control in Oregon.

INTERACTION OF OYSTER CULTIVATION AND EELGRASS

The few studies that have investigated the effect of oyster culture on eelgrass beds conclude that the presence of an oyster farming operation results in decreased eelgrass abundance (Waddell 1964, Carlton et al. 1991, Everett, et al. 1995, Pregnall 1993, Rumrill and Christy 1996). The general findings of these studies are presented in Table 3. (The findings of Waddell (1964) are not included in Table 3 because he found dredging to be the only factor in eelgrass disturbance. Dredging would probably not be a significant negative impact on eelgrass in Tillamook Bay because oyster harvest is done by hand). These studies have documented decreased shoot density and percent cover, as well as poor natural recovery after the cessation of oyster culture in a given area. Two of the studies (Carlton et al. 1991, Everett et al. 1995, Pregnall 1993) investigated rack and/or stake culture, which may have very different mechanisms and effects than ground culture. The other two studies (Waddell 1964, Rumrill and Christy 1996) investigated the impact of ground culture on eelgrass, and found that ground culture causes a decrease in eelgrass abundance. Waddell (1964) attributes the decline in eelgrass to dredging oysters during harvest or transplanting of the oysters, but noted a decrease in eelgrass in adjacent, non-dredged control sites as well. Unfortunately, no control sites were selected away from oyster culture areas, so we do not know if the decline in eelgrass on the control sites was a result of the oyster culture activities, or if it was part of a estuary-wide phenomenon. Waddell (1964) was the only study to examine dredging impacts. The other studies investigated non-dredging impacts such as shading, competition for space, erosion, and accretion.

A decrease in benthic surface area and direct physical disturbance have been cited as the probable cause of eelgrass depletion at ground culture sites (Pregnall 1993). Off-bottom oyster culture, particularly rack culture, results in shading and either erosion or sedimentation that appear to be the primary cause of eelgrass depletion in those areas. Both rack and stake culture cause a decrease in eelgrass, but stake culture results in an increase in algae such as Ulva (sea lettuce) and Enteromorpha. These species in turn are suspected of having a negative effect on eelgrass (Waddell 1964, Geyer et al. 1990, Cowper 1978).

DISCUSSION

Past research indicates that all types of oyster culture, including ground culture, negatively affect eelgrass density and percent cover. However, the degree of impact depends on the method of oyster culture employed. Research also shows that although eelgrass density and distribution decrease in response to oyster cultivation, the eelgrass is not necessarily eliminated. (Waddell 1964, Carlton et al. 1991, Pregnall 1993, Everett et al. 1995, Rumrill and Christy 1996).

There is conflicting information regarding the extent that eelgrass and oysters coexist. Pregnall (1993) noted that outside her study area, "in areas of commercial oyster culture, eelgrass was absent or rare, while areas immediately surrounding these plots support dense beds of Zostera marina." However, personal comments (Dumbauld 1997, Hayes 1997, Leonard 1997) and the author's observations indicate that eelgrass can and does exist in commercial oyster grounds (Figure 9). It is up to the regulatory agencies to determine where the balance lies between utilization and conservation within the estuary.

Pregnall's (1993) observations that oysters provide good habitat for benthic and epibenthic fauna bring up an important question: What value does oyster habitat have if it is eliminated after three or four years? The question should be addressed if the habitat value of oyster ground is to used for making management decisions.

That eelgrass beds are vital to Tillamook Bay and should be a high priority is inarguable. There is limited information regarding the past extent of eelgrass beds, but judging from the information available, it appears that the overall distribution is more limited than historical levels. With that in mind, a concerted effort should be made to preserve what is left, and (if it is deemed a reasonable course of action) to explore the possibility of using restoration and enhancement to maintain and/or increase the total abundance of eelgrass in Tillamook Bay.

LITERATURE CITED1

Arasaki, M. 1950. Studies on the ecology of Zostera marina and Zostera nana. Bulletin of the Japanes Society of Science and Fisheries; 16: 75-76.

Armstrong, D.A., B. Dumbauld, and D. Doty, 1989. Oyster culture and crab habitat: Conflicts over use of the insecticide Sevin in coastal estuaries. The Northwest Environmental Journal Vol. 5, No. 1.

Armstrong, D.A. and R.E. Millemann, 1974. Effects of the insecticide carbaryl on clams and some other intertidal mud flat animals. Journal Fisheries Research Board of Canada, Vol. 31, No. 4.

Backman, T.W. and D.C. Barilotti, 1976. Irradiance reduction: Effects on standing crops of the eelgrass Zostera marina in a coastal lagoon. Marine Biology; 34:33-40.

Bakalian, A. 1985. Use of Sevin on estuarine oyster beds. Coastal Zone Management Journal Vol. 13 No. 1.

Baldwin, J.R. and J.R. Luvvorn 1994. Habitats and tidal accessibility of the marine foods of dabbling ducks and brant in Boundary Bay, British Columbia. Marine Biology 120:627-638.

Bayer, R.D. 1979. Intertidal zonation of Zostera marina in the Yaquina estuary, Oregon. Syesis 12: 147-154.

Bird, E.M. 1982. Population dynamics of the Thalassinidean shrimps and community effects through sediment modification. Ph.D. Thesis. University of Maryland. 150pp.

Brooks, K. 1995. Long term response of benthic invertebrate communities associated with the application of carbaryl (Sevin) to control burrowing shrimp, and an assessment of the habitat value of cultivated Pacific oyster (Crassostrea gigas) beds in Willapa Bay, Washington, to fulfill requirements of the EPA carbaryl data call in. 69 pp.

Burrell, D.C. and J.R. Schubel. 1977. Seagrass ecosystem oceanography. Pages 195-232 in C.P. McRoy and C. Helfferich, eds. Seagrass ecosystems: a scientific perspective. M. Dekker, New York.

Cannon, D., 1997(b). Personal communication, Oregon Department of Agriculture, March 31.

Cannon, D., 1997(a). Personal communication, Oregon Department of Agriculture, April 8.

Carlton, J.T., G.M. Ruiz, and R.A. Everett. 1991. The sturcture of estuarine communities associated with suspended populations of the introduced japanese oyster Crassostrea gigas: Years 1 and 2. Oregon Institute of Marine Biology, Charleston, Oregon.

Caspers, H. 1957. Black Sea and Sea of Azov. Pgs 801-899 in J.W. Hedgpeth, ed. Treatise on marine ecology and paleoecology. No. 1. Geo. Soc. Am. Mem. 67.

Cheney, D. and T. Mumford, Jr. 1986. Puget Sound publication series: Harvest of shellfish and seaweeds in Puget Sound. Washington Sea Grant. 180 pp.

Churchill, A.C., A.E. Cok, and M.I. Riner. 1978. Stabilization of subtidal sediments by the transportation of the seagrass Zostera marina L. New York Sea Grant, NYSSGP-RS-78-15. 48 pp.

Cottam, C. and D.A. Munro. 1954. Eelgrass status and environmental relations. Journal of Wildlife Management 13:449-460.

Coulton, K.G. and P.B Williams. 1996. An environmental history of the Tillamook Bay estuary and watershed.Tillamook Bay National Estuary Project Technical Report.

Cowper, S.W. 1978. The drift algal community of seagrass beds in Redfish Bay, Texas. Contributions to Marine Science 21:125-132.

Dennison, W.C. 1979. Light adaptations of plants: A model based on the seagrass Zostera marina L. M.S. thesis. University of Alaska, Fairbanks.

Dennison, W.C. and R.S. Alberte. 1982. Photosynthetic Responses of Z. marina L. (eelgrass) to in situ manipulations of light intensity. Oecologia 55: 137-144.

Dillon, C.R. 1971. A comparative study of the primary productivity of estuarine phytoplankton and macrobenthic plants. PhD dissertation. University of North Carolina, Chapel Hill. 112 pp.

Dumbauld, B. 1997. Comments at a Tillamook Bay National Estuary Project meeting, Garibaldi, March 11.

Dumbauld, B.R., D.A. Armstrong, and K.L. Feldman, 1996. Life-history characteristics of two sympatric Thalassinidean shrimps, Neotrypaea californiensis and Upogebia pugettensis, with implications for oyster culture. Journal of Crustacean Biology, 16(4):689-708.

Ellis, R. 1997. Draft scientific and technical report on the biological resources of Tillamook Bay. Unpublished Tillamook Bay National Estuary Project technical report.

Everett, R.A., G.M. Ruiz, and J.T. Carleton, 1995. Effect of oyster mariculture on submerged aquatic vegetation: An experimental test in a Pacific Northwest estuary. Marine Ecology Progress Series vol. 125: 205-21.

Faudskar, J. 1997. Oregon State University Extension Service. From comments on draft report, July 2.

Felger, R. and C.P. McRoy 1975. Seagrasses as potential food plants. Pages 62-74 in G.F. Somers, ed. Seed-bearing halophytes as food plants. Proceedings of a Conference, University of Delaware. DEL-SG-3-75, June 10-11, 1974.

Fenchel, R. and R.J. Riedl, 1970. The sulfide system in a new biotic community underneath the oxidized layer of marine sand bottoms. Marine Biology 7: 255-268.

Fonseca, M.S. 1981. The interaction of a seagrass, Zostera marina l. with current flow. M.S. Thesis. University of Virginia, Charlottesville. 35 pp.

Fonseca, M.S., J.S. Fisher, J.C. Zieman, and G.W. Thayer, 1982. Influence of the seagrass, Zostera marina L. on current flow. Estuarine Coastal and Shelf Science. 15: 351-364.

Forsberg, B., J. Johnson, and S. Klug. 1977. Identification, distribution and notes on food habits of fish and shellfish in Tillamook Bay, Oregon. Research Section, Oregon Department of Fish and Wildlife, Federal Aid Progress Report, Fisheries 117 pp.

Geyer, H.E., L.A. Deegan, J.T. Finn and S.G. Ayvazian, 1990. The effects of macroalgae on the abundance of eelgrass (Zostera marina) in the Waqoit Bay Estuary. Biological Bulletin 179:223.

Hancock, D.R., T.F. Gaumer, G.B. Willeke, G.P. Robart, and J. Flynn, 1979. Subtidal clam populations: Distribution, abundance, and ecology. Oregon State University Sea Grant College Program publication number ORESU-T-79-002. 243 pp.

Harrison, P.G. 1987. Natural expansion and experimental manipulation of seagrass (Zostera spp.) abundance and the response of infaunal invertebrates. Estuarine, Coastal and Shelf Science 24:799-812.

Hayes, J. 1997. Hayes Oyster Company. Personal communication. March 12.

Hinzman, R. 1997. Personal communication, Tillamook Bay National Estuary Project. April 28.

Hinzman, R. 1997. Personal communication, Tillamook Bay National Estuary Project. June 24.

Jacobs, R.P.W.M. 1982. Reproductive strategies of two seagrass species (Zostera marina and Z. noltii) along west European coasts. P. 150-155 in J.J. Symoens, S.S. Hooper, and P. Compere, eds. Studies on aquatic vascular plants. Royal Botanical Society Belgium, Brussels.

Johnson, J. Oregon Department of Fish and Wildlife; from comments at a March 11 1997 meeting; Garibaldi, Oregon.

Keddy, C.J. and De.G. Patriquin 1978. An annual form of eelgrass in Nova Scotia. Aquat. Bot. 5: 163-170.

Kentula, M.E. and C. D. McIntire 1986. The autecology and production dynamics of eelgrass (Zostera marina L.) in Netarts Bay, Oregon. Estuaries Vol. 9 No. 3, p. 188-199.

Kenworthy, W.J. J.C. Zieman, and G.W. Thayer. 1982. Evidence for the influence on the benthic nitrogen cycle in a coastal plain estuary near beaufort, North Carolina (U.S.A.) Oecologia 54: 152-158.

Kruckenberg, J. 1996. Evaluation of the Management Framework for Tillamook Bay National Estuary Project Priority Problems - Phase II of the Base programs Analysis. TBNEP Technical Report #08-96.

Leonard, D. 1997. Maryland Department of Marine Resources. Personal communication. April 8.

Lewis, J.B., and C.E. Hollingworth. 1982. Leaf epifauna of the seagrass Thalassia testudinum. Marine Biology 71:41-49.

MacGinitie, B.E. 1934. The natural history of the Callianassa californiensis Cana. Am. Midl. Nat. 15:16-177.

Mercer, H. 1997. Cape Meares Oyster Company. Personal communication. April 2.

ODA (Oregon Department of Agriculture) 1996. Shellfish growing area annual evaluation.

ODA (Oregon Department of Agriculture) 1995. Agriculture and Fisheries Statistics, ODA, Salem, Oregon.

ODEQ (Oregon Department of Environmental Quality) 1993. Summary of water quality sampling data between 1960 and 1993.

ODLCD (Oregon Department of Land Conservation and Development) 1987. The Oregon Estuary Plan Book.

O.S.U. 1977. Environmental impacts of dredging in estuaries. Schools of Engineering and Oceanography, Oregon State University, Corvallis Oregon. 675 pp.

Orth, R.J. 1977. The importance of sediment stability in seagrass communities. Pgs. 122-138 in B.C. Coul, ed. Ecology of marine benthos. University of South Carolina Press, Columbia.

Ostenfeld, C.H. 1908. On the ecology and distribution of grasswrack (Zostera marina) in Danish waters. Rep. Danske Biological Station 16: 1-62.

Pettit, G. 1997. Personal communication, Oregon Department of Environmental Quality, June 26.

Pacific Seafood 1997. Personal communication, Pacific Seafood Group, June 30.

Phillips, R.C. 1972. Ecological life history of Zostera marina L. (eelgrass) in Puget Sound, Washington. PhD dissertation, University of Washington, Seattle, 154pp.

Phillips, R.C. 1974. Temperate Grass Flats in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds. Coastal Ecological Systems of the United States. The Conservation Foundation, Washington, D.C.

Phillips, R.C. 1984. The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile.U.S. Fish and Wildlife document number FWS/OBS - 84/24.

Phillips, R.C. and R.R. Lewis 1983. Influence of environmental gradients on variations in leaf widths and transplant success in North American seagrasses. Marine Technology Series Journal 12: 59-68.

Posey, M.H. 1985a. The effects upon the macrofaunal community of a dominant burrowing deposit feeder, Callianassa californiensis, and the role of predation in determining its intertidal distribution. Ph.D. Thesis. University of Oregon 199 pp.

Posey, M.H. 1985b. Community changes associated with dense beds of a burrowing deposit feeder. Estuaries. vol. 8 no. 2B, p. 62A.

Pregnall, M.M. 1993. Regrowth and recruitment of eelgrass (Zostera marina) and recovery of benthic community structure in areas disturbed by commercial oyster culture in the South Slough National Estuarine Research Reserve, Oregon. A thesis; Bard College, Annandale-On-Hudson, New York.

Quayle, D.B. 1988. Pacific oyster culture in British Columbia. Canadian Department of Fisheries and Oceans, Bulletin Fish and Aquatic Sciences, No. 218.

Reiger, C. 1982. Return of the sea goose. Field and Stream 87:66-67, 141-144.

Rumrill, S. and J. Christy, 1996. Ecological impacts of oyster ground culture within estuarine tidelands: South Slough National Estuarine Research Reserve. Prepared for the Oregon Department of Land Conservation and Development.

Sayce, K., 1997. Comments at a Tillamook Bay National Estuary Project meeting, Garibaldi, March 11.

Simenstad, C.A. and K.L. Fresh, 1995. Influence of intertidal aquaculture on benthic communities in Pacific northwest estuaries: Scales of disturbance. Estuaries vol. 18, no. 1A, p. 43-70.

Stevens, B.S. 1929. Ecological observations on Callianassidae of Puget Sound. Ecology 10:399-405.

Stout, H., ed. 1976. The natural resources and human utilization of Netarts Bay, Oregon. NSF Student Originated Studies Program. Oregon State University, Corvallis. 247 pp.

Strittholt, J.R. and P.A Frost, 1996. Determining abundance and distribution of eelgrass (Zostera spp) in Tillamook Bay estuary, Oregon using multispectal airborne imagery.

Sullivan, T. 1997. E & S Environmental Chemistry. Personal communication of July 21.

Techet, K. 1906. Uber die marine vegetations des Trieste Golfes. Abhardl. K.K. Zool. Bot. Res. Wien 4:1.

The Research Group, 1992. An investigation of restoration and enhancement projects to achieve environmental and economic progress at Tillamook Bay, Oregon. 144 pp.

Thayer, G.W. D.A. Wolfe, and R.B. Williams. 1975. The Impact of Man on Seagrass Systems. American Scientist 63:288-296.

Tillamook Bay National Estuary Project. 1996. Changes in Tillamook Bay bathymetry (bay depth). Tillamook Bay National Estuary Project information bulletin.

Tillamook Bay Task Force, the Oregon State Water Resources Department and the United States Department of Agriculture, Soil Conservation Service, Forest Service-Economics, Statistics, and Cooperative Service, 1978. Tillamook Bay drainage basin erosion and sediment study summary report.

Triani, M.S. 1995. The influence of commercial oyster culture activities on the benthic infauna of Arcata Bay. Master's thesis, Humboldt State University, Arcata, California. 91pp.

Tutin, T.G. 1938. The autecology of Zostera marina in relation to its wasting disease. New phytology; 37: 50-71.

Waddell, J.E. 1964. The effect of oyster culture on eelgrass (Zostera marina L.) growth. Masters Thesis, Humboldt State College. 48 pp.

WDF (Washington Department of Fisheries) 1990. 1990 Fisheries Statistical Report, Olympia, WA.

WDFE (Washington Departments of Fisheries and Ecology) 1985. Final environmental impact statement: Use of the insecticide Sevin to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor.

WDFE (Washington Departments of Fisheries and Ecology) 1992. Final supplemental environmental impact statement: Use of the insecticide Sevin to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor.

Wilson, U.W. and J.B. Atkinson 1995. Black Brant winter and spring staging use at two Washington coastal areas in relation to eelgrass abundance. The Condor; The Cooper Ornithological Society.

Footnote 1: Several citations are included that are not cited in the text. These are relevant sources that provided background and perspective for this report.