ECOLOGICAL INTERACTIONS
AMONG EELGRASS, OYSTERS, AND BURROWING SHRIMP
IN TILLAMOOK BAY, OREGON

YEAR 2 (1999) REPORT

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EXECUTIVE SUMMARY

In 1998, the Tillamook Bay National Estuary Project (TBNEP) contracted with Battelle Marine Sciences Laboratory (MSL) to investigate ecological interactions among eelgrass, oysters, and burrowing shrimp in Tillamook Bay, in response to the growing need for credible scientific data on which to base management decisions regarding these resources. Staff from TBNEP and MSL designed this research program as a four year effort (1998 – 2001), with the understanding that we would need to collect meaningful data, at minimum, during the typical oyster harvest rotation (3 – 4 years). Findings of our Year 1 (1998) research were summarized in Shreffler et al. (1999).

In conjunction with the staff of the Tillamook County Performance Partnership (formerly Tillamook Bay National Estuary Project), we established three specific objectives for our Year 2 (1999) research:

Objective 1. Perform a patch-edge study to identify and characterize the major forcing factors affecting the temporal and spatial variability in eelgrass distribution at three locations in Tillamook Bay.

Objective 2. Conduct manipulative experiments to evaluate whether current oyster ground culture practices have long-term effects on eelgrass distribution within the Bay.

Objective 3. Provide recommendations for a cost-effective, long-term ecological monitoring and mapping strategy for the Bay.

Below we briefly highlight some of the key findings relative to each of these three objectives. We caution the reader that the "key findings" we present here for Objectives 1 and 2 are preliminary findings, not conclusions. By comparing the Year 1 (baseline) and Year 2 data, we can begin to make some observations about possible trends.

Key Findings Relative to Objective 1

Eelgrass patch-edge transects

Our 1999 monitoring revealed the most dramatic changes in eelgrass (*Zostera marina*) density and distribution at the Crab Harbor site. The overall mean eelgrass shoot density and eelgrass percent cover were 63% and 87% lower, respectively, in May 1999 than in June 1998. We documented the deposition of up to 82.5 cm of fine sand on top of the former eelgrass bed. Future sampling at new stations, which we added along each of the five transects at Crab Harbor, will enable us to document whether the sediment accumulation has stabilized, or whether eelgrass continues to be buried as the sediment advances seaward.

We observed increases in mean eelgrass density between June 1998 and May 1999 at both the South Channel and Schweizer Lease sites. Shrimp burrow densities appear to fluctuate dramatically, both seasonally and inter-annually at all sites. Oyster densities remain low at all sites. The mechanisms of interaction among eelgrass, oysters, and burrowing shrimp are still unclear.

Based on the dramatic loss of eelgrass at the Crab Harbor site, we suggest that episodic physical disturbances, such as the large-scale deposition of sediment we observed at Crab Harbor, may be one of the most significant controlling factors that determines eelgrass shoot densities and distribution in the Bay.

Water Quality Monitoring

Water quality standards for temperature, pH, and turbidity in the Bay under Oregon Administrative Rules were consistently met for the period April 20 through October 20, 1999. Standards for dissolved oxygen (DO) were not. However, we attribute this to a malfunction of the DO probe on the Hydrolab unit, rather than actual problems with low dissolved oxygen. As in 1998, our data indicate that water quality in the Bay remains high during the summer relative to the requirements of eelgrass growth and survival. Secchi depth and turbidity measurements indicate that the eelgrass beds at our study sites are probably not light limited during the period from April to October. Mean salinities and mean temperatures for all sites are well within the optimal range of conditions within which eelgrass flourishes in the Pacific Northwest (Table 6.1, Shreffler et al. 1998). The Bay temperature was typically cooler (mean range = 11.16-13.56° C) than the optimum range (15 – 18° C) for Pacific oyster somatic growth.

Elevation Changes at Crab Harbor

Between June 1998 and May 1999, we estimate that up to 82.5 cm of fine sand accumulated on top of the former eelgrass beds at the Crab Harbor site. We suspect that the sand that accumulated at Crab Harbor is probably of marine origin, rather than from the five rivers that enter the Bay, based on the findings of McManus et al. 1998. In 1952, the ocean breached the Bayocean spit, depositing up to one meter of marine sand in some areas of the Bay. Regardless of the source of the sand that accumulated between 1998 and 1999 at the Crab Harbor site, such large-scale deposition of sand is detrimental to the existing eelgrass beds at this site. We estimate that the sand deposition at our Crab Harbor site reduced the overall area of the eelgrass bed by approximately 1/3 between June 1998 and May 1999.

Sediment Elevation Monitoring

In May 1999, we established one sediment elevation monitoring station at each of the three eelgrass patch-edge sites and also the manipulative experiment site. The 1999 monitoring data from May and July will provide a baseline for future comparison and evaluation of sediment elevation changes. Subsequent monitoring will enable us to document trends in intra-annual and inter-annual changes in sediment accretion or erosion at each of these sites. These monitoring stations should enable us to detect both small scale (a few centimeters) and large scale (up to 0.5 meters) changes in sediment elevations, both between monitoring periods within the same year and between years.

Burowing Shrimp Characterization

In an effort to quickly characterize the relative numbers of mud shrimp (*Upogebia pugettensis*) vs. ghost shrimp (*Neotrypaea californiensis*), we used a hand pump to excavate burrowing shrimp within sampling pits approximately 0.3m in diameter at eight random locations within the patch-edge transects at the Crab Harbor site and four random locations within the patch-edge transects at the Schweizer Lease and South Channel sites. This rapid assessment confirmed our suspicion that mud shrimp appear to be more abundant than ghost shrimp at each of the eelgrass-patch edge sites. The implications of this finding are potentially important, because ghost shrimp pose the most significant threat to oyster culture operations and can cause much higher siltation and initial mortality than mud shrimp (Dumbauld et al. 1997). This statement is not intended to imply, however, that the effect of mud shrimp on oysters and eelgrass is not significant. We caution that a systematic and larger scale effort would be required to more definitively quantify and characterize the burrowing shrimp populations at each of these sites.

Key Findings Relative to Objective 2

Monitoring of Manipulative Experiment Plots

To better understand the ecological interactions among eelgrass, oysters, and burrowing shrimp, we initiated, in July 1998, a series of controlled removal and transplant experiments on a portion of the oyster lease owned by Pacific Oyster Company. Within the oyster lease, we established three replicate 3m x 3m experimental plots at Strata B (B1, B2, B3), at Strata C (C1, C2, C3), and at Strata D (D1, D2, D3), and three replicate 9m x 9m experimental plots at Strata A. In May and July 1999, we returned to each of the experimental plots at all four strata to record the same data that was gathered in the 1998 baseline survey (Shreffler et al. 1999). For each strata, we want to determine the effect of certain manipulations (treatments) on either the manipulative variable or the existing biological community at that strata. Below we summarize our 1999 findings relative to each treatment:

1. The effect of an environment without eelgrass on transplanted eelgrass density (Treatment EE1): eelgrass shoot densities clearly decreased between July 1998 (mean shoot density =60 shoots/m^2) and May 1999 (mean shoot density =32.3 shoots/m^2) in all of the plots where only eelgrass was transplanted.

2. The effect of an environment without oysters on transplanted oyster density (Treatment EE2): undetermined at this time. Our transplanted oyster clusters were moved (presumably by tidal currents) from one subplot to another, or completely out of our study area. However, because the oysters that we originally transplanted were not tagged or marked in any way, it is now difficult to distinguish between those oysters from our study and other oysters that have been transported into the experimental plots from the surrounding area.

3. The effect of an environment without eelgrass or oysters on the density of transplanted eelgrass and oysters (Treatment EE3): based on the data we have to date, we are unable to distinguish between effects the environment may have on the transplanted eelgrass and transplanted oysters vs. effects transplanted eelgrass and transplanted oysters may have on each other.

4. The effect of transplanted oysters on transplanted eelgrass density (Treatment AE1): a preliminary indication is that transplanted oysters had a negative effect on the density of transplanted eelgrass. In all plots where the two were transplanted together, eelgrass survival was 1.1% compared to 53.9% in adjacent plots where only eelgrass was transplanted.

5. The effect of transplanted eelgrass on transplanted oyster density (Treatment AE2): a preliminary indication is that the transplanted eelgrass had no effect on transplanted oyster density. Future monitoring could indicate whether eelgrass has an effect on oyster growth.

6. The effect of transplanted eelgrass on existing oyster density (Treatment BE1): our monitoring at Strata B indicates that the transplanted eelgrass had no effect on existing oyster density. Future monitoring could indicate whether eelgrass has an effect on oyster growth.

7. The effects of oyster harvest on existing eelgrass density (Treatment CE1): no data in 1999.

8. The effect of transplanted oysters on existing eelgrass density (Treatment DE1). Mean eelgrass density decreased by 57.4% at the Strata D subplots where oysters were transplanted into existing eelgrass, compared to only 26.8% decrease at the adjacent control subplots.

9. The effect that transplanting has on transplanted eelgrass density (Treatment TE1): we know from our monitoring at plot D4 within Strata D that the effect transplanting had on transplanted eelgrass was a 38.4% decrease in survival. Thus, under the best possible transplanting scenario (i.e., plants are excavated and then replanted in the same hole), we can only expect 61.6% of the plants to survive.

10. The effect that transplanting has on transplanted oyster density (Treatment TE2): no observed effect on the density of the transplanted oysters.

At all four strata, shrimp burrow densities changed dramatically (both increases and decreases) between 1998 and 1999. No trends are apparent yet, but we hope that continued monitoring may help us to discern patterns in burrow counts and also potential implications (negative or positive) of shrimp burrow densities for oysters and eelgrass.

Quantitative Sampling of Burrowing Shrimp

With the assistance of Brett Dumbauld from Washington Department of Fish and Wildlife, we determined that mud shrimp are the dominant burrowing shrimp species at the manipulative experiment site. Mean mud shrimp densities were 23 times higher than ghost shrimp densities for the seven samples we collected. The high densities of burrowing shrimp in Tillamook Bay will continue to be a major source of concern for oyster growers, until non-chemical methods of shrimp control are developed and implemented. The effect of high densities of burrowing shrimp on eelgrass has not been studied in Tillamook Bay, but is expected to be significant, especially for ghost shrimp, based on studies elsewhere (Harrison 1987, Suchanek, 1983).

Oyster Weights at Manipulative Experiment Plots

Following the 1998 field season, several oyster growers voiced concerns that we needed to be monitoring oyster growth, not just oyster survival, at the manipulative experiment plots. In August 1999, we tagged and weighed two or three oyster clusters from several experimental plots within each strata. These data will serve as the baseline for future monitoring of changes in oyster growth. By monitoring these tagged oyster clusters of oysters, we also hope to gain an indication of how often and how far oysters are moved by tidal currents.

Key Recommendations Relative to Objective 3

In 1998, we developed a long-term monitoring program for the intertidal and shallow subtidal portions of Tillamook Bay (Shreffler et al. 1999). The program focused specifically on eelgrass meadows, and their associated fauna, including burrowing shrimp and oysters. Based on the results of our Year 2 (1999) research, we offer the following suggested revisions to the monitoring plan:

- We know based on our 1999 monitoring at the Crab Harbor site, that large-scale sediment movements can be detrimental to eelgrass. Table 6.1 in the Year 1 final report lists the range of conditions within which eelgrass flourishes in the Pacific Northwest. This table should be revised to reflect our understanding that actively eroding or accreting substrates are not conducive to long-term eelgrass survival.

- We recommend that sediment elevation needs to be added to the list of parameters to be measured. Based on our 1999 observations of the dramatic sedimentation event(s) at Crab Harbor, sediment transport may play a profound role in structuring the eelgrass meadows and their associated fauna including burrowing shrimp and oysters.

- We also recommend that oyster weights need to be measured at the manipulative experiment plots. Interactions with eelgrass or burrowing shrimp may not effect oyster survival, but could have an effect on oyster growth. Oyster growth and condition are major concerns of the local oyster growers in the Bay.

- We reiterate the importance of taking aerial photographs annually during a mid-summer low tide series. These photographs, in conjunction with adequate groundtruthing, are the single most important tool for evaluating inter-annual changes in eelgrass distribution in the Bay.

- We recommend continued monitoring of percent cover, eelgrass shoot density, oyster density, and shrimp burrow density at the three established eelgrass patch-edge study sites (Schweizer Lease, Crab Harbor, South Channel) 3x/year (spring/summer/fall) for 2 more years (through 2001). The methods should follow those we used in 1999.

- We also recommend continued monitoring of eelgrass shoot density, oyster density, and shrimp burrow density, at the manipulative experiment plots at Strata A, B, C, D of the Pacific Oyster Lease site, 3x/year (spring/summer/fall) for 2 more years (through 2001). The methods should follow those we used in 1999.

- Once each sampling year, percent cover should be monitored at all the manipulative experiment plots.

- Once each sampling year, weights of the tagged oysters at the manipulative experiment plots should be measured.

- Once each sampling year, photographs should be taken at the permanent photo stations at Strata C, preferably in fall. This was not done in 1999.

- Once each sampling year, at the same time of year, changes in sediment elevations should be recorded at the three patch-edge sites and the manipulative experiment site.

- We recommend continuing to measure water properties (temperature, salinity, turbidity, DO, pH, and secchi depth) at the surface and near bottom at the three eelgrass patch-edge sites and one location at the manipulative experiment site biweekly from spring through fall of each year.

- We recommend that daily weather data should continue to be compiled from the nearest weather monitoring station to the Bay.

The continued success of our research program is dependent upon local volunteers, who are willing to assist with monitoring at the eelgrass patch-edge sites and manipulative experiment sites, and with collecting water quality and weather data.

ACKNOWLEDGMENTS

We wish to thank Roxanna Hinzman, former scientific technical coordinator of TBNEP, and Rich Felley, new director of the Tillamook Bay County Performance Partnership, for their support and encouragement during the second year of this research program. The implementation of our ongoing research program continues to rely on numerous, unpaid volunteers. Jaylen Jones, Anu Gupta, Phaedra Bennett, Michael Styllas, David Revell, Rich Felley, and Tim Moore assisted with monitoring of the eelgrass patch-edge study plots and manipulative experiment plots. Ron Thom provided a peer review of the draft report.

We especially wish to thank Brett Dumbauld from Washington Department of Fish and Wildlife, who made a valuable contribution to our research by characterizing the species, sexes, and sizes of burrowing shrimp at the manipulative experiment site.

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1.0 INTRODUCTION

In 1998, the Tillamook Bay National Estuary Project (TBNEP) contracted with Battelle Marine Sciences Laboratory (MSL) to investigate ecological interactions among eelgrass, oysters, and burrowing shrimp in Tillamook Bay (the Bay), and assist the staff of TBNEP with establishing and meeting management goals for the Bay. Following the completion of the Comprehensive Conservation and Management Plan (CCMP) for Tillamook Bay, a new entity, the Tillamook Bay County Performance Partnership (the Partnership), was formed in 1999 to implement the CCMP. Our overall mandate is to provide the Partnership with credible scientific data and objective recommendations that will foster better management of eelgrass, oysters, and burrowing shrimp in Tillamook Bay.

Staff from TBNEP and MSL originally designed this research program as a four year effort (1998 – 2001), with the understanding that we would need to collect meaningful data, at minimum, during the typical oyster harvest rotation (3 – 4 years). Background information on our state of knowledge relative to eelgrass, oysters, and burrowing shrimp in Tillamook Bay are summarized, along with the findings of our Year 1 (1998) research, in Shreffler et al. (1999).

In conjunction with staff from the Tillamook Bay County Performance Partnership, we established three primary objectives for Year 2 (1999) of this research program. We have organized the remainder of this report around these three stated objectives:

Objective 1. Perform a patch-edge study to identify and characterize the major forcing factors affecting the temporal and spatial variability in eelgrass distribution at three locations in Tillamook Bay.

Objective 2. Conduct manipulative experiments to evaluate whether current oyster ground culture practices have long-term effects on eelgrass distribution within the Bay.

Objective 3. Provide/revise recommendations for a cost-effective, long-term ecological monitoring and mapping strategy for the Bay.

2.0 METHODS

The methods we used in Year 2 of our research are outlined below for each of the three main research objectives. Unless noted otherwise, our methods in 1999 were the same methods we established in 1998, as reported in Shreffler et al. (1999).

2.1 Eelgrass Patch-Edge Study

2.1.1. Eelgrass Patch-Edge Transects

We established three long-term monitoring sites in May 1998 that were selected to represent a range in eelgrass shoot density, oyster density, and shrimp burrow density. All of these sites are within the Main Bay Shellfish Management Area. We permanently marked plots at these sites using a combination of hand-held, differential global positioning system (dGPS) coordinates and compass triangulations to stationary landmarks. The three sites are designated Crab Harbor, South Channel, and Schweizer Lease and are distributed in the northwest portion of the Bay near the Cape Meares Peninsula (**Figure 2.1**). Based on our reconnaissance surveys in May 1998, the northwest region of the Bay supports the largest intertidal eelgrass beds and is also the region most actively used for oyster growing. However, none of our eelgrass patch-edge sites are within portions of oyster leases that are presently being used for oyster culture. The Crab Harbor site is not within or near any oyster leases. The South Channel site is next to, but not within, several leases that are presently being used either for oyster ground culture or line culture. The Schweizer Lease site is within an oyster lease that is being used for rack and bag culture, but our eelgrass patch-edge transects are in an unused portion of that lease. The oysters in the area encompassed by our patch-edge transects at the Schweizer Lease site remain from a previous lease holder's ground culture operation.

Within each site, we established five parallel 30-m long transects that extend from approximately 10m outside of the eelgrass patch to the interior of the patch. We marked the head and tail of each transect with 1-inch diameter PVC pipe, which we pounded approximately 1m into the sediment. We then capped the exposed ends. We spaced the five transects (T1 – T5) at 20m intervals at the Schweizer Lease site, and 30m intervals at the Crab Harbor and South Channel sites. In May 1999, we replaced missing PVC pipes at the head of transects T2 and T3 at the Crab Harbor site, all the pipes at the other sites were still in place.

Along each transect, we recorded at low tide: eelgrass percent cover, eelgrass shoot density, shrimp burrow density, and oyster density. In May, July, and September 1999, we recorded these data within $1m^2$ quadrats placed at five meter intervals (i.e., 1m, 6m, 11m, 16m, 21m, 26m) along each transect line at each of the three patch-edge study sites.

2.1.2 Water Quality Monitoring

For each of the three sites, we also recorded water quality parameters—temperature, dissolved oxygen, salinity, pH, secchi depth, and turbidity—every other week from May through October, 1999. All of these parameters (except secchi depth) were recorded using a Hydrolab instrument in both surface water and bottom water at high tide. In addition, we used a Hatch turbidity meter from August 5, 1999 through October 20, 1999 when the turbidity probe on the Hydrolab was malfunctioning. A summary table of all of our 1999 field efforts is provided in **Table 2.1**.

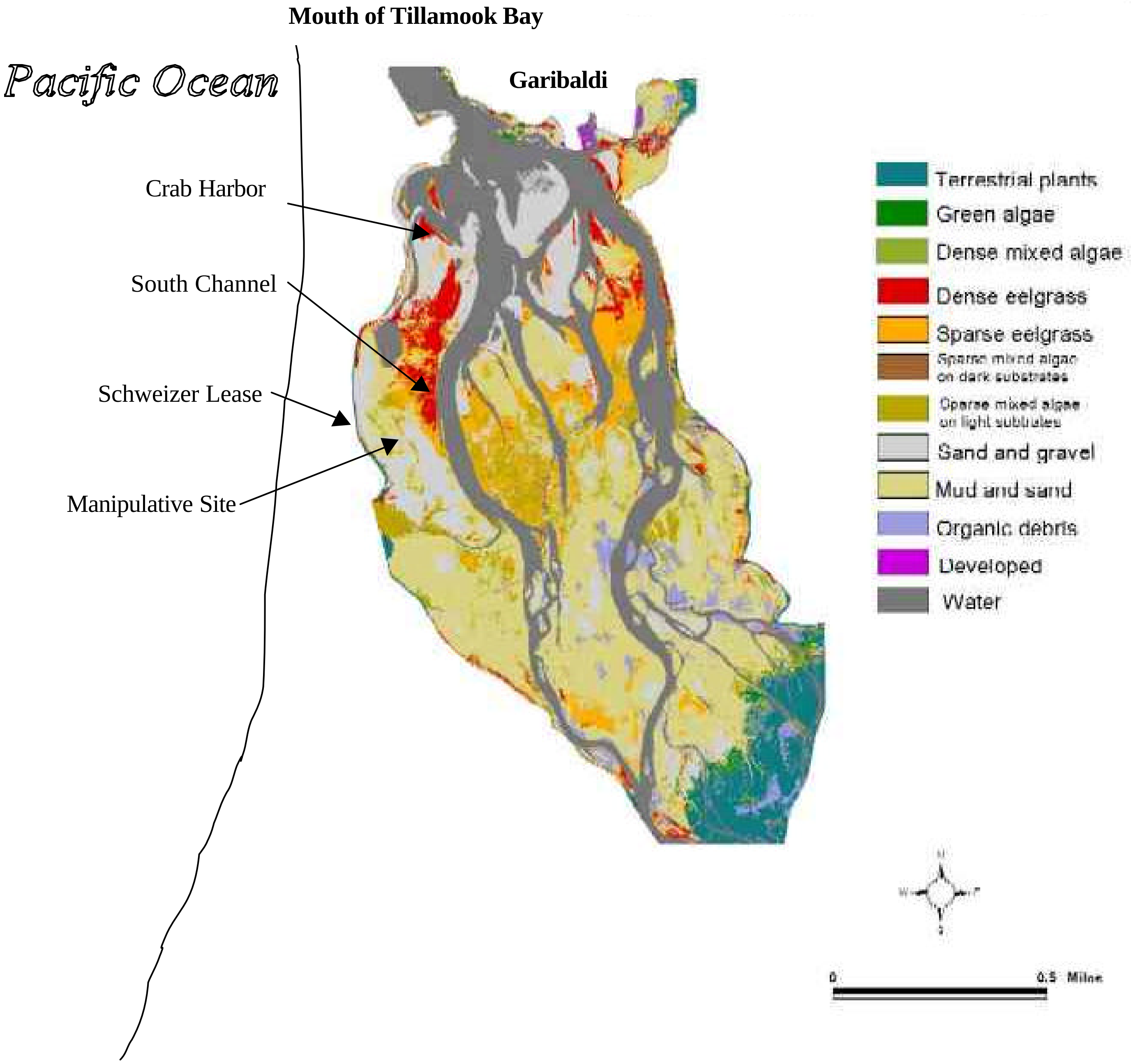

Figure 2.1 Multispectral habitat map of Tillamook Bay (modified from Earth Design Consultants 1996) showing the three locations of our eelgrass patch-edge study sites and the location of our manipulative experiment site. This image was captured at a -2.0 foot level, allowing for a clear view of benthic habitats.

Table 2.1 Summary of 1999 field efforts in Tillamook Bay.

Date	Field Effort
4/20/99 – 10/20/99	Biweekly water quality monitoring at eelgrass patch-edge sites and manipulative experiment site
5/17/99	Eelgrass patch-edge monitoring at Schweizer Lease Site
5/18/99	Eelgrass patch-edge monitoring at South Channel and Crab Harbor Sites
5/19/99	Monitoring at manipulative experiment plots, quantitative burrowing shrimp samples (Brett Dumbauld), qualitative burrowing shrimp samples (Kerry Griffin, Dave Shreffler)
5/20/99	Established sedimentation monitoring stations at each site; measured elevation changes at Crab Harbor site
7/14/99	Sedimentation monitoring at Crab Harbor, South Channel, Schweizer Lease, and manipulative experiment sites
7/15/99	Monitoring at manipulative experiment plots
8/13/99	Oyster clusters tagged and weighed at manipulative experiment plots
9/8/99	Eelgrass patch-edge monitoring at Crab Harbor Site (T4 , T5 only)
9/9/99	Eelgrass patch-edge monitoring at Schweizer Lease Site (T1, T2 only)

2.1.3. Elevation Changes at Crab Harbor

In May 1999, we used a sight level to estimate differences in elevation between the head and tail of each patch-edge transect at the Crab Harbor site. The sight level has a vial bubble and crosswire, which when properly aligned establishes a true level line of sight. The sensitive vial bubble, the crosswire, and the object on which you are sighting can all be seen through the eyepiece at the same time. The observer simply records the position of the sighted object in relation to the level line of sight as seen through the instrument; this is the same principle of operation as used in engineers' surveying instruments. Using a sight level is an inexpensive, quick way to determine differences in elevation.

2.1.4 Sediment Elevation Monitoring

We also established in May 1999 one sediment elevation monitoring station at each of the three eelgrass patch-edge sites and also the manipulative experiment site. The purpose of these stations was to allow us to monitor inter-annual and intra-annual changes in sedimentation. We know from our conceptual model of factors that control eelgrass growth or survival (Figure 6.1 in Shreffler et al. 1999), that physical disturbances, such as large-scale sediment movements (i.e., erosion or accretion), are often deleterious to eelgrass.

We positioned two 1.5m-long PVC pipes vertically at a distance of just under 1.0m so that we could lay a 1.0m wood measuring stick horizontally on top of the two vertical pipes and parallel to the sediment surface. We then drove each pipe approximately 1.0m into the sediment and verified that the measuring stick would sit level in a horizontal position on top of the two vertical pipes. Using this simple arrangement, we could then use another measuring stick to record vertical distances (cm) between the horizontal measuring stick and the sediment surface at intervals of 10cm, 20cm, 30cm, 40cm, 50cm, 60cm, 70cm, and 80cm along the horizontal measuring stick. We recorded changes in sediment elevation in May and July 1999 at each of the three patch-edge sites and one location at the manipulative experiment site.

2.1.5 Burrowing Shrimp Characterization

In an effort to quickly characterize the relative numbers of mud shrimp (*Upogebia pugettensis*) vs. ghost shrimp (*Neotrypaea californiensis*) at each of the three eelgrass patch-edge sites, we used a hand pump to excavate burrowing shrimp within sampling pits approximately 0.3m in diameter. We sampled shrimp at eight haphazardly selected locations within the patch-edge transects at the Crab Harbor site, and four haphazardly selected locations within the patch-edge transects at the Schweizer Lease and South Channel sites. We determined the species of each individual burrowing shrimp we excavated, returned all the identified shrimp to the sampling pit, and then covered the pit with the excavated sediment. We intended for this effort to be a rapid assessment of relative numbers of the two species of interest, not a quantitative characterization of the burrowing shrimp populations at each of our eelgrass patch-edge sites.

2.2 Manipulative Experiments

2.2.1 Monitoring of Manipulative Experiment Plots

To better understand the ecological interactions among eelgrass, oysters, and burrowing shrimp, we initiated, in July 1998, a series of controlled removal and transplant experiments on a portion of the oyster lease owned by Pacific Oyster Company (**Figure 2.1**). We selected this site because the distribution of eelgrass, oysters, and burrowing shrimp could be divided within four distinct strata on the mudflat adjacent to a tidal channel: Strata A contained bare mud and burrowing shrimp, Strata B contained mud, oysters, and burrowing shrimp, Strata C contained mud, oysters, eelgrass, and burrowing shrimp, and Strata D contained mud, eelgrass, and burrowing shrimp. Because these four strata occur at approximately the same elevation and distance from the channel edge, we made the assumption that these strata shared the same physical attributes, such as depth, light, turbidity, temperature, salinity, and substrate type.

Within the oyster lease, we established three replicate 3m x 3m experimental plots at Strata B (B1, B2, B3), at Strata C (C1, C2, C3), and at Strata D (D1, D2, D3), and three replicate 9m x 9m experimental plots at Strata A (A1, A2, A3) (**Figure 2.2**). Prior to initiating the experiments, we gathered baseline data within the experimental plots at all four strata between June 15 and July 21, 1998. We recorded data on percent cover and densities of existing eelgrass, oysters, and shrimp burrows within the entire area enclosed by each of these experimental plots (Shreffler et al. 1999).

In May and July 1999, we returned to each of the experimental plots at all four strata to record the same data that was gathered in the 1998 baseline survey. For each strata, we want to determine the effect of certain manipulations (treatments) on either the manipulated variable (e.g., transplanted oysters or eelgrass) or the existing biological community at that strata. All of the treatments and expected effects we are testing through these manipulative experiments are summarized in **Table 2.2**.

2.2.2 Quantitative Sampling of Burrowing Shrimp

On May 19, 1999, Brett Dumbauld from Washington State Department of Fisheries and Wildlife (WDFW) joined us at the manipulative experiment plots to take quantitative samples of burrowing shrimp. Using a stainless steel coring device (40-cm diameter by 60-cm deep), he excavated, by shovel and hand, seven pits at randomly selected locations (see photo, **Figure 2.3**). Sediment was excavated from the core, sieved (3-mm-pore-size mesh), and sorted for burrowing Thallassinid shrimp (*Upogebia pugettensis* and *Neotrypaea californiensis*). Shrimp collected within each core were placed in labeled Ziploc bags and then transported back to his laboratory. For each individual burrowing shrimp, he recorded the species, sex, and carapace length (nearest 0.1 mm) from the posterior mid-dorsal margin to the tip of the rostrum. He also made shrimp burrow counts within a 40-cm-diameter ring before taking each core.

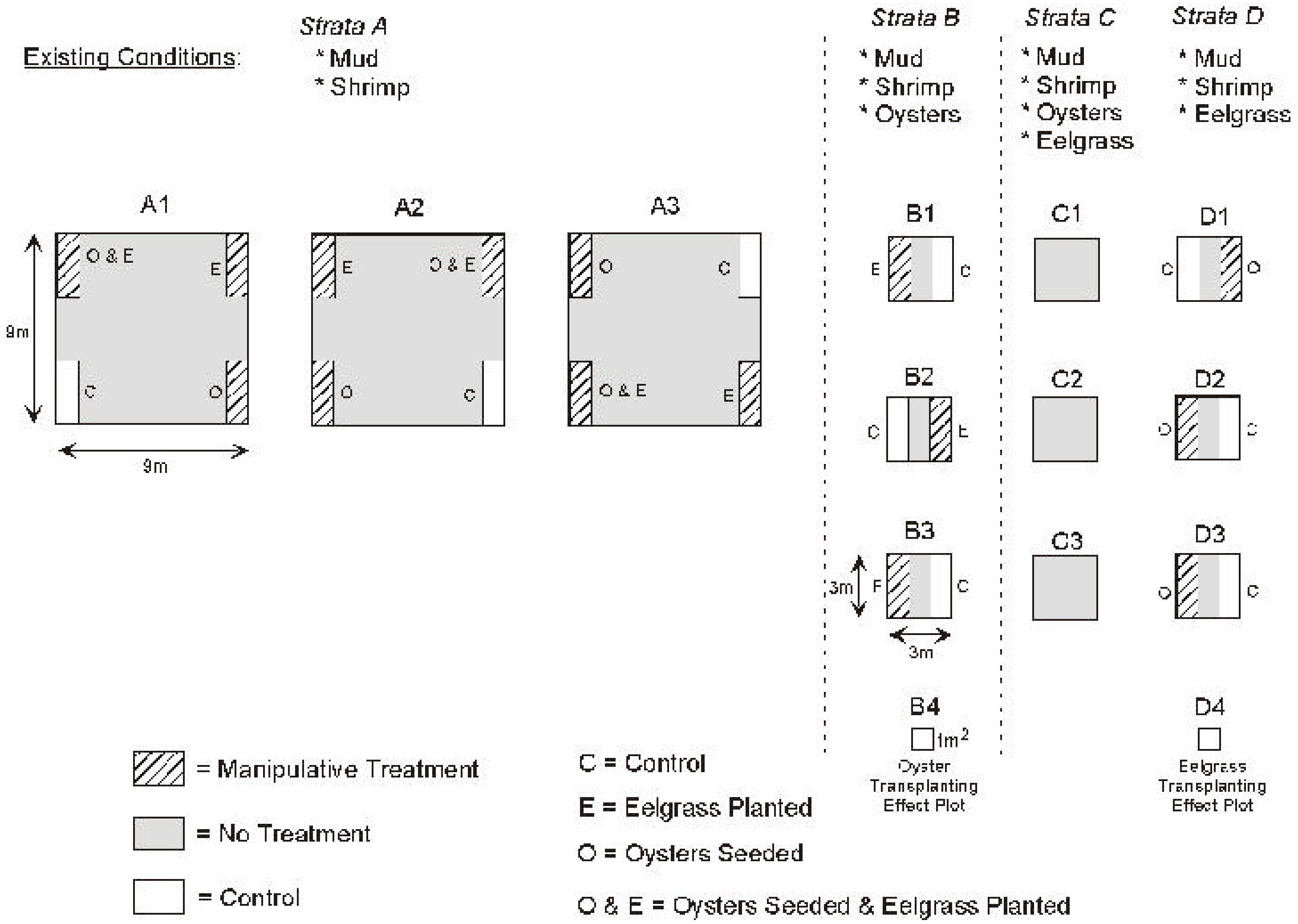

Figure 2.2 Diagram of our manipulative experiment plots established in July 1998 within four strata: Strata A-D.

Table 2.2 Summary of treatments implemented and post-treatment monitoring performed for the manipulative experiments initiated in July 1998 at Tillamook Bay.

Treatment BE1:	We transplanted eelgrass into existing mud, shrimp, and oysters at Strata B (B1, B2, B3).
Monitoring:	We will monitor the effect of transplanted eelgrass on existing oyster density.
Treatment CE1:	None; We collected baseline (pre-harvest) data and took photos at Strata C.
Monitoring:	We will monitor the effects of oyster harvest on existing eelgrass density.
Treatment DE1:	We transplanted oysters into existing mud, shrimp, and eelgrass at Strata D (D1, D2, D3).
Monitoring:	We will monitor the effect of transplanted oysters on existing eelgrass density.
Treatment EE1:	We transplanted eelgrass into mud and shrimp at Strata A (A1, A2, A3).
Monitoring:	We will monitor the effect of an environment without eelgrass on transplanted eelgrass density.
Manipulation:	We transplanted oysters into mud and shrimp at Strata A (A1, A2, A3).
Effect EE2:	We will monitor the effect of an environment without oysters on transplanted oyster density.
Manipulation:	We transplanted eelgrass and oysters into mud and shrimp at Strata A (A1, A2, A3).
Effect EE3:	We will monitor the effect of an environment without eelgrass or oysters (i.e., Strata A) on the density of transplanted eelgrass and oysters.
Manipulation:	We transplanted oysters only, eelgrass only, or both at Strata A (A1, A2, A3).
Effect AE1:	We will monitor the effect of transplanted oysters on transplanted eelgrass density.
Manipulation:	We transplanted oysters only, eelgrass only, or both at Strata A (A1, A2, A3).
Effect AE2:	We will monitor the effect of transplanted eelgrass on transplanted oyster density.
Manipulation:	We dug up eelgrass and re-inserted the plants into the same hole (D4).
Effect TE1:	We will monitor the effect that transplanting has on transplanted eelgrass density.
Manipulation:	We picked up oysters, put them in a bucket, and returned them to the same location (B4).
Effect TE2:	We will monitor the effect that transplanting has on the transplanted oysters' density.

Figure 2.3 Photo of Brett Dumbauld (WDFW) sampling burrowing shrimp within a stainless steel coring device at the Tillamook Bay manipulative experiment site in May 1999.

2.2.3 Oyster Weights at Manipulative Experiment Plots

Following the 1998 field season, oyster growers in the Bay voiced concerns that we needed to be monitoring oyster growth, not just oyster survival, at the manipulative experiment plots. In August 1999, we randomly selected 2 or 3 oyster clusters from several experimental plots within each strata. We then rinsed the mud off each cluster in a bucket of seawater, weighed each cluster using a Chatillon digital field scale (to the nearest 0.05 pound), and counted the number of individual oysters in each cluster. Finally, we tagged each cluster using colored cable ties and placed the clusters back in their original locations within the experimental plots. Prior to weighing the oyster clusters at the next monitoring period, we will scrape off any barnacles or other encrusting organisms.

2.2.4 Oyster Harvest at Strata C

After repeated attempts in both 1998 and 1999, we have not yet been able to get Pacific Oyster Company to harvest their oysters within Strata C. At Strata C, which contains oysters, burrowing shrimp, and eelgrass, we wanted to determine what effect(s) oyster harvesting has on existing eelgrass. We intended to monitor eelgrass survival and recovery, in both the control and treatment areas of three plots (C1, C2, C3), over the next two to three years. Pacific Oyster Company continues to express willingness to assist with our research program. The difficulty has been coordinating with them to get some of their already overworked personnel into the field. Although we have been granted permission to hand harvest the oysters ourselves, we prefer to work with the company to ensure that the harvest is done by professionals, using the same methods that they routinely employ at their other lease sites.

2.3 Monitoring Recommendations and Adaptive Management Plan

In the final report for Year 1 (1998) of this research program, we developed recommendations to TBNEP regarding relevant biological, chemical, and physical indicators that could facilitate adaptive management of eelgrass, oysters, and burrowing shrimp over the long term (Shreffler et al. 1999). Many of these recommendations were incorporated into the comprehensive conservation and management plan (CCMP) for Tillamook Bay. Based upon insights we gained from our 1999 field studies, we revisited these recommendations to see whether changes are needed. We present our recommendations for revisions to the monitoring and adaptive management plan in section 4.3 of the discussion.

3.0 RESULTS

3.1 Eelgrass Patch-Edge Study

3.1.1. Eelgrass Patch-Edge Transects

In May 1999, we documented changes in eelgrass percent cover, eelgrass shoot density, shrimp burrow density, and oyster density at three eelgrass patch-edge monitoring sites: Crab Harbor, South Channel, and Schweizer Lease. In September 1999, we performed monitoring only at transects T4 and T5 at the Crab Harbor site and transects T1 and T2 at the Schweizer Lease site. We collected no data at the South Channel site in September 1999. Our September 1999 monitoring was limited by foul weather and boat engine problems that could not be resolved during the scheduled sampling period. The results of our May and September monitoring for each transect at these three eelgrass-patch edge sites are provided as raw data in **Appendix A.**

A comparison of the 1998 vs. 1999 data for eelgrass percent cover, eelgrass shoot density, shrimp burrow density, and oyster density at the three monitoring sites is provided in **Table 3.1**. Between 1998 and 1999 sampling, we observed the most dramatic changes in eelgrass percent cover and shoot density at the Crab Harbor site. In May 1999, the upper elevations of every transect (T1-T5), at distances of 1m, 6m, and 11m from the transect head pins, were devoid of eelgrass. The mean eelgrass shoot density for transects T1-T5 (29.2/m^2) was significantly less than in June 1998 (78.3/m^2). Similarly, the mean percent cover for transects T1-T5 was also significantly lower in May 1999 (5.7 %) compared to June 1998 (42.4%). Even without the benefit of these data, we could visually observe the dramatic loss of eelgrass at the Crab Harbor site between 1998 and 1999 (see photos, **Figure 3.1**). We observed that the upper elevations of our Crab Harbor transects that previously supported eelgrass appeared to be buried under fine sand. In order to further characterize ongoing changes to the eelgrass beds at the Crab Harbor site, we extended each of the five transects by 20m and added four new monitoring stations along each transect at 31m, 36m, 41m, and 46m from the head pins.

In contrast to 1998, when the Crab Harbor site had the highest eelgrass shoot densities of the three sites (June mean =78.3 shoots/m^2; September mean = 123.4 shoots/m^2), we observed the highest eelgrass shoot densities in 1999 at the Schweizer Lease site (May mean = 113.2 shoots/m^2; September mean = 149.7 shoots/m^2) (**Table 3.1**). The Schweizer Lease site also had the highest shrimp burrow densities (May mean = 431.5/m^2; September mean = 205.7/m^2) and individual oyster densities (May mean = 1.1/m^2; September mean = 0.6/m^2) in 1999. As of September 1999, it appears that the Schweizer Lease site has the highest eelgrass densities, followed by the South Channel site and the Crab Harbor site. The Schweizer Lease site also has the highest burrowing shrimp densities, followed by the South Channel site and the Crab Harbor site. Finally, the Schweizer Lease site has the highest oyster densities, followed by the Crab Harbor site and the South Channel site.

We also plotted the eelgrass shoot density data as spatial data, so that we could better visualize changes between 1998 and 1999 (**Figures 3.2, 3.3, and 3.4**). Each of these diagrams shows two different depictions of eelgrass shoot densities for our two most complete datasets from September 1998 and May 1999. We developed these eelgrass shoot density diagrams from the survey data we collected along the same transects at each site in 1998 and 1999.

We show four ranges of eelgrass shoot densities: high (>160 shoots/m^2); medium (80 - 160 shoots/m^2); low (< 80 shoots/m^2); and none (0 shoots/m^2). We used our best professional judgment to assign high,

Table 3.1 Summary of 1998 and 1999 eelgrass patch-edge monitoring data for Tillamook Bay.

	Means for all Transects			
Site-Date	**Percent cover Eelgrass**	**Eelgrass Shoot Density (no./m ^{2})**	**Shrimp Burrow Density (no./m ^{2})**	**Oyster Density (no./m ^{2})**
Crab Harbor-6/98	42.4	78.3	9.6	0.0
Crab Harbor-5/99	5.7	29.2	26.8	0.2
Crab Harbor-9/98	50.9	123.4	5.3	0.0
Crab Harbor-9/99 (a)	28.4	44.7	17.8	0.4
South Channel-6/98	17.3	34.3	278.8	0.0
South Channel-5/99	13.5	63.9	307.5	0.0
South Channel-9/98	45.3	49.7	143.6	0.0
South Channel-9/99	nd(b)	nd	nd	nd
Schweizer Lease-6/98	38.0	63.4	504.9	0.9
Schweizer Lease-5/99	16.1	113.2	431.5	1.1
Schweizer Lease-9/98	46.0	101.7	400.4	0.6
Schweizer Lease-9/99 (c)	61.0	149.7	205.7	0.6

(a) data for transects T4 and T5 only

(b) nd = no data collected

(c) data for transects T1 and T2 only

Figure 3.1 Photos of eelgrass distribution at the Crab Harbor site in 1998 (top) and 1999 (bottom).

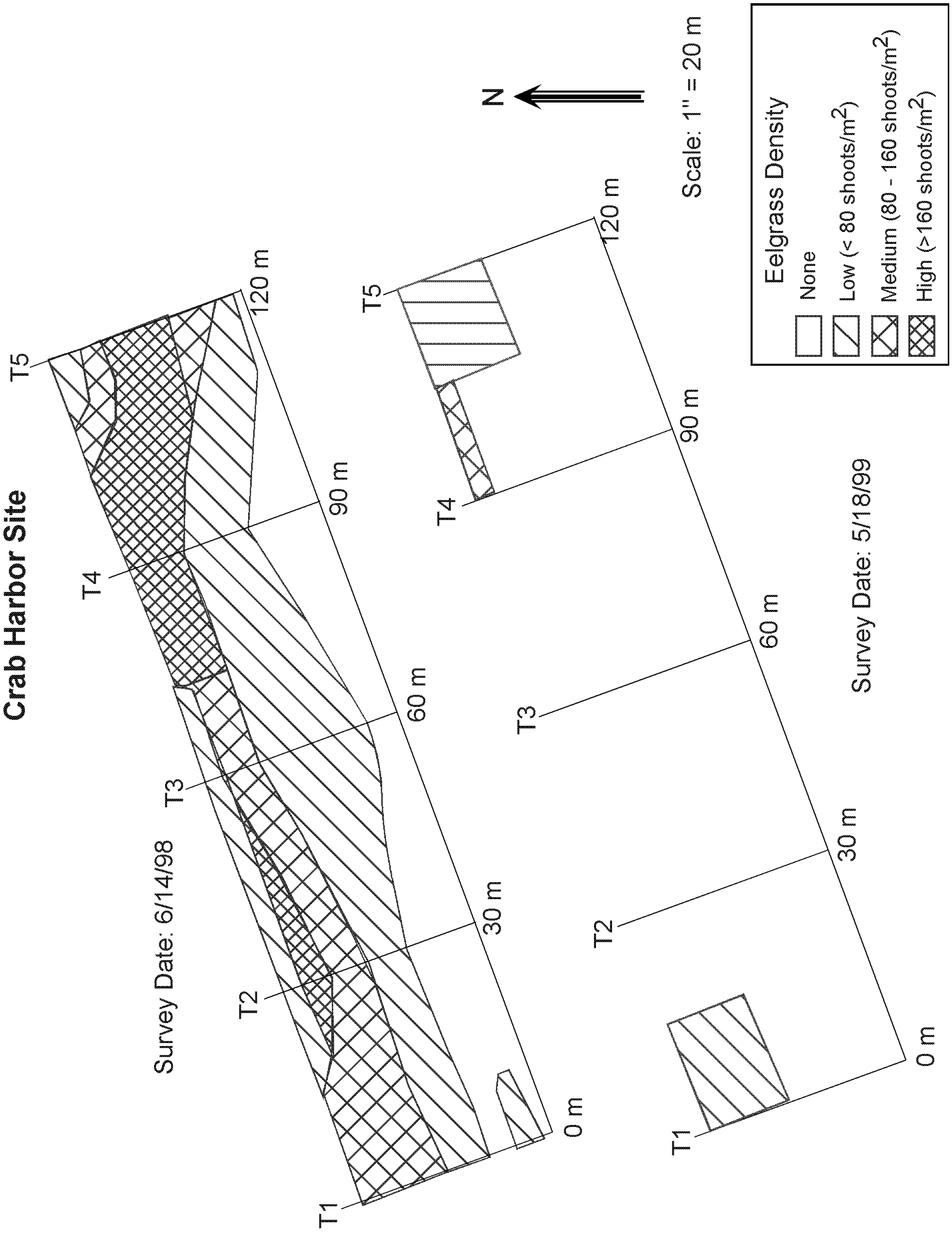

Figure 3.2 Eelgrass densities observed on 6/14/98 and 5/18/99 at the Crab Harbor site.

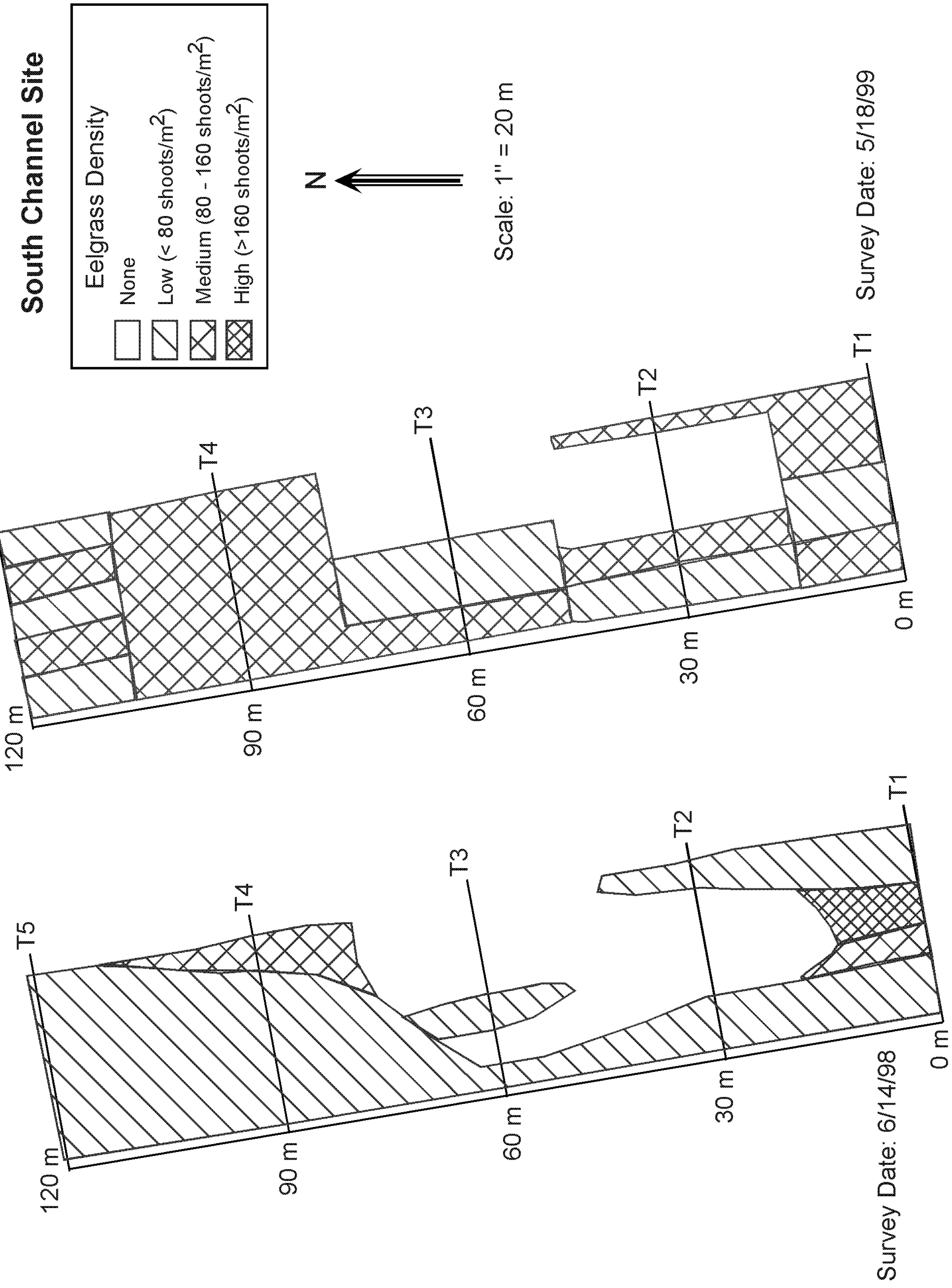

Figure 3.3 Eelgrass densities observed on 6/14/98 and 5/18/99 at the South Channel site.

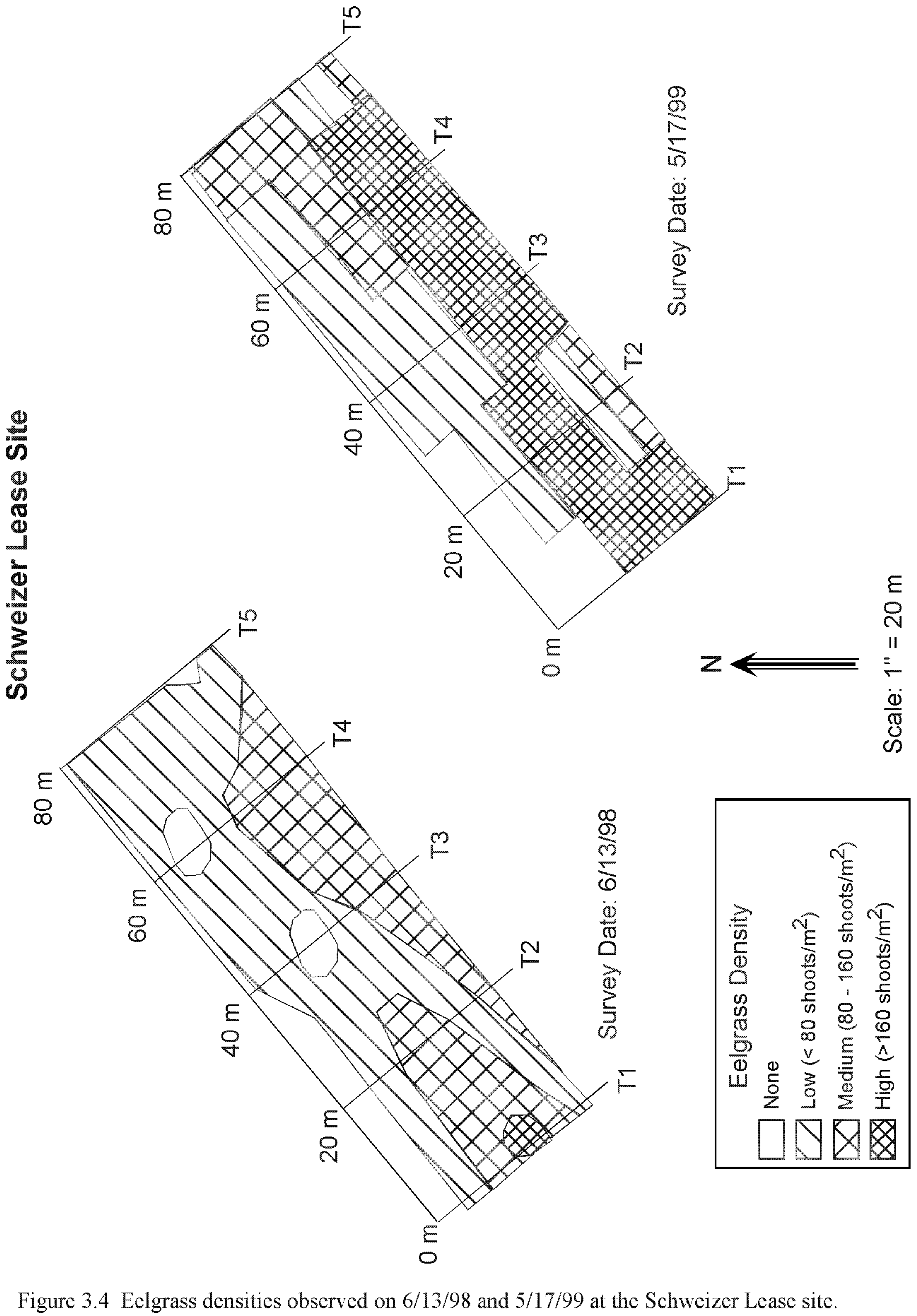

Figure 3.4 Eelgrass densities observed on 6/13/98 and 5/17/99 at the Schweizer Lease site.

medium, and low ranges of shoot densities, after carefully evaluating all available data from the three sites, and based on our previous experience with mapping eelgrass densities in Puget Sound, Washington. The eelgrass shoot densities depicted between the transects were interpolated from data at known points on the transects. We estimated that the eelgrass shoot densities continued from a known point along a transect to the midpoint between the transects. Therefore, each resulting diagram shows an estimation of the actual eelgrass shoot densities at a particular site.

By visually comparing the eelgrass densities we observed in June 1998 to the densities we observed in May 1999, we can once again see the dramatic loss of eelgrass that occurred at the Crab Harbor site (**Figure 3.2**). Only a few patches of the extensive eelgrass present in 1998 remained in 1999, and those patches were of lower overall density than in 1998. At the South Channel site, most of the area that supported no eelgrass in 1998 still did not support eelgrass in 1999 (**Figure 3.3**). Many patches that we classified in 1998 as low density were medium density in 1999. This observation is consistent with the increase in mean density from 34.3 shoots/m^2 in June 1998 to 63.9 shoots/m^2 in May 1999 that we reported in Table 3.1. At the Schweizer Lease site, the most obvious changes are that much of the area that we classified as medium density in June 1998 was high density in May 1999 and some of the area that was formerly low density in 1998 we classified as medium density in 1999 (**Figure 3.4**). Again, this observation is consistent with the 44% increase in mean eelgrass shoot density between June 1998 and May 1999 that we reported in Table 3.1. Plots of eelgrass shoot density data from September in both years was not possible, because we were unable to collect data at all transects for all three patch-edge sites in September 1999.

3.1.2 Water Quality Monitoring

Under Oregon Administrative Rules, the following water quality standards have been established for the Tillamook Basin: water temperature shall not exceed 18°C, pH shall not be lower than 6.5 nor higher than 8.5, and dissolved oxygen (DO) for estuarine waters must exceed 6.5 mg/L (Hinzman and Nelson 1998, Table 4-1). There are no rules for turbidity or salinity in Tillamook Bay. Because sediment can have a high impact on salmonid reproduction (Lloyd 1987), the state of Washington established that background turbidity plus a 5 ntu increment is the standard that cannot be exceeded when background turbidity is 50 ntu or less.

We collected water quality data in estuarine waters of Tillamook Bay between April 20 and October 20, 1999 (**Table 3.2**). As in 1998, the temperature criterion was never exceeded in 1999. In 1999, the highest recorded water temperature at any of the four monitoring sites was 15.8°C in surface water at the South Channel site on 7/1/99; the lowest recorded water temperature was 9.20°C in bottom water at the Crab Harbor site on 9/23/99. Over the April to October monitoring period, the mean surface water temperature (11.16°C) and bottom water temperature (10.84°C) at the Crab Harbor site were lower than at the other three sites. The range of pH we observed never exceeded the water quality criterion on the two dates that we measured pH. We were only able to collect pH data on 4/20/99 and 5/5/99, subsequently the pH probe on the Hydrolab unit was determined to be malfunctioning. Dissolved oxygen fell below the criteria of 6.5 mg/L on multiple dates at multiple sites. We also suspect that the DO probe was malfunctioning. A post-field season diagnosis of the Hydrolab functions revealed an estimated $1,700 worth of repairs required on the unit. Thus, we do not have confidence in the reported pH, and DO values in Table 3.2.

Secchi depth was consistently the same as the water depth for all sites on all sampling dates. Mean secchi depths for the four sites ranged from 1.26 m to 1.64 m. Turbidity was substantially below the 5 ntu threshold for effects on salmonid reproduction at all sites on all sampling dates. Mean turbidity for the four sites ranged from 1.83 ntu to 2.63 ntu. Over the six-month sampling period, mean surface salinities ranged from a low of 28.37 ppt at the Manipulative Experiment site to a high of 31.83 ppt at the Crab Harbor site. Mean bottom salinities over the same time period ranged from a low of 30.58 ppt at the Manipulative Experiment site to a high of 32.23 ppt at the Schweizer Lease site. The highest salinity we measured was 34.10 ppt in bottom water at the Manipulative Experiment site on 6/3/99; the lowest salinity we measured was 16.40 ppt in surface water at the Manipulative Experiment site on 5/5/99.

3.1.3 Elevation Changes at Crab Harbor

Because of the dramatic sediment accumulation we observed at the Crab Harbor site, we decided to make some field measurements of the elevation changes. Using a sight level, we measured elevation differences between the head and tail pipe for each of the five transects (T1-T5). We determined that in less than one year (between June 1998 and May 1999) 76.0 cm of fine sand had accumulated at the head pipe for T1, 82.5 cm at the head pipe for T2, 79.5 cm at T3, 75.5 cm at T4, and 81.5 cm at T5. These measurements confirmed our observations that fine sand appeared to have accumulated on top of the former eelgrass bed at the upper elevations of all five transects at the Crab Harbor site.

3.1.4 Sediment Elevation Monitoring

We constructed sediment elevation monitoring stations at all three eelgrass patch-edge sites and one location at the manipulative experiment site to help us document changes in sediment elevations. At this time, we only have data from May and July 1999 (**Table 3.3**). The mean change in sediment height between May and July 1999 was -6.9 cm at the Crab Harbor site, -0.4 cm at the South Channel site, -2.0 cm at the Schweizer Lease site, and +1.3 cm at the Manipulative Experiment site. It appears that even over a short time period (i.e., 3 mos), both small and large changes occur in sediment elevations.

3.1.5 Burrowing Shrimp Characterization

At the Crab Harbor site, we found no ghost shrimp in any of the eight test pits. We collected a total of 26 mud shrimp. At the Schweizer Lease site, we collected a total of 56 mud shrimp and 7 ghost shrimp in four test pits. At the South Channel site, we collected a total of 44 mud shrimp and 7 ghost shrimp in four test pits.

Table 3.2 Summary of water quality data collected at four sites in the Bay (4/20/99 – 10/20/99)

WATER QUALITY PARAMETERS

Monitoring Site, Date, & Time		**Temperature (C)**		**DO (mg/L)**		**Salinity (ppt)**		**pH**		**Secchi (m)**	**Turbidity (ntu)**	**Depth (m)**
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom			
Crab Harbor												
4/20/99	1720	9.93	9.93	nd[a]	nd	32.00	32.10	7.39	7.30	nd	nd	1.8
5/5/99	1730	11.47	11.41	7.65	7.90	27.50	28.20	6.62	6.75	1.0	nd	1.0
5/19/99	1445	11.81	11.76	nd	nd	28.00	28.50	nd	nd	1.0	0.23	1.0
6/3/99	1700	10.13	9.95	nd	nd	34.00	34.20	nd	nd	1.0	nd	1.0
6/17/99	1630	11.55	11.51	14.25	16.75	32.60	32.60	nd	nd	1.8	nd	1.8
7/1/99	1545	14.50	13.00	nd	nd	28.70	30.30	nd	nd	nd	nd	nd
8/5/99	0840	11.40	11.20	nd	nd	32.70	33.30	nd	nd	1.0	2.23[b]	1.0
8/12/99	1500	11.40	11.30	nd	nd	33.00	33.00	nd	nd	nd	1.16	nd
8/25/99	1200	12.10	10.80	nd	nd	33.10	33.50	nd	nd	1.0	3.52	1.8
9/8/99	1315	10.10	10.00	nd	nd	33.70	33.70	nd	nd	2.3	1.47	2.3
9/23/99	1315	9.30	9.20	nd	nd	33.60	33.90	nd	nd	2.0	2.62	2.0
10/20/99	1100	10.20	10.00	nd	nd	33.10	33.20	nd	nd	1.9	2.00	1.9
	mean	**11.16**	**10.84**	**10.95**	**12.33**	**31.83**	**32.21**	**7.01**	**7.03**	**1.44**	**1.83**	nd
South Channel												
4/20/99	1720	11.31	10.76	4.60	4.90	28.00	30.90	7.28	7.30	nd	nd	1.8
5/5/99	1730	12.13	11.15	7.20	8.20	23.50	28.30	6.69	6.62	1.6	nd	1.6
5/19/99	1445	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
6/3/99	1700	12.00	9.70	nd	nd	30.80	34.50	nd	nd	1.3	nd	1.3
6/17/99	1630	14.39	12.62	16.50	17.00	30.10	31.80	nd	nd	2.1	nd	2.1
7/1/99	1545	15.80	13.10	nd	nd	27.80	30.20	nd	nd	nd	nd	nd
8/5/99	0840	14.20	12.50	nd	nd	32.20	33.20	nd	nd	nd	nd	nd
8/12/99	1500	13.60	11.80	nd	nd	31.70	32.70	nd	nd	nd	2.29	nd
8/25/99	1200	15.40	15.10	nd	nd	30.70	31.60	nd	nd	1.5	3.48	1.5
9/8/99	1315	13.60	10.30	nd	nd	32.20	33.70	nd	nd	2.0	2.11	2.0
9/23/99	1315	10.00	9.40	nd	nd	33.50	33.80	nd	nd	1.7	1.71	1.7
10/20/99	1100	10.80	10.60	nd	nd	32.30	32.50	nd	nd	1.3	2.76	1.3
	mean	**13.02**	**11.55**	**9.43**	**10.03**	**30.25**	**32.11**	**6.99**	**6.96**	**1.64**	**2.47**	nd
Schweizer Lease												
4/20/99	1720	10.81	10.44	4.30	4.50	28.90	30.70	7.21	7.22	nd	nd	1.6
5/5/99	1730	13.03	11.24	8.10	8.10	18.90	27.80	6.79	6.65	1.2	nd	1.2
5/19/99	1445	13.43	13.43	16.81	14.20	18.80	19.00	nd	nd	1.0	0.17	1.0
6/3/99	1700	12.24	10.70	7.90	13.00	30.20	33.40	nd	nd	1.0	nd	1.0
6/17/99	1630	14.22	13.87	16.75	nd	30.20	30.40	nd	nd	1.6	nd	1.6
7/1/99	1545	15.00	15.00	nd	nd	28.20	28.10	nd	nd	nd	nd	nd
8/5/99	0840	15.00	15.00	nd	nd	31.90	31.90	nd	nd	0.75	2.76	0.75
8/12/99	1500	13.60	11.80	nd	nd	31.70	32.70	nd	nd	nd	2.29	nd
8/25/99	1200	13.80	13.50	nd	nd	31.90	32.10	nd	nd	1.15	nd	1.15
9/8/99	1315	13.60	12.90	nd	nd	32.20	32.60	nd	nd	1.6	2.45	1.6
9/23/99	1315	12.00	12.00	nd	nd	32.20	32.20	nd	nd	1.8	2.30	1.8
10/20/99	1100	11.40	11.20	nd	nd	31.70	31.80	nd	nd	1.2	2.81	1.2
	mean	**13.18**	**12.59**	**10.77**	**9.95**	**28.90**	**30.23**	**7.00**	**6.94**	**1.26**	**2.13**	nd
Manipulative Site												
4/20/99	1720	10.86	10.35	3.97	4.26	28.9	31.1	7.21	7.18	nd	nd	1.0
5/5/99	1730	13.15	11.17	9.20	8.40	16.40	28.30	6.74	6.59	1.6	nd	1.6
5/19/99	1445	13.82	13.83	16.00	nd	18.20	18.50	nd	nd	1.5	nd	1.5
6/3/99	1700	12.15	9.96	8.10	13.00	30.20	34.10	nd	nd	1.4	nd	1.4
6/17/99	1630	15.38	14.65	14.00	14.00	28.60	29.50	nd	nd	2.0	nd	2.0
7/1/99	1545	15.70	15.20	nd	nd	28.70	30.30	nd	nd	nd	nd	nd
8/5/99	0840	15.30	14.70	nd	nd	31.50	32.30	nd	nd	1.0	nd	1.0
8/12/99	1500	13.90	12.60	nd	nd	31.30	32.30	nd	nd	nd	3.17	nd
8/25/99	1200	14.80	14.60	nd	nd	31.60	31.70	nd	nd	1.2	3.00	1.7
9/8/99	1315	13.60	12.20	nd	nd	32.10	32.90	nd	nd	2.0	2.28	2.0
9/23/99	1315	12.30	10.90	nd	nd	31.80	33.10	nd	nd	1.9	1.93	1.9
10/20/99	1100	11.70	10.40	nd	nd	31.10	32.80	nd	nd	1.6	2.78	1.6
	mean	**13.56**	**12.55**	**10.25**	**9.92**	**28.37**	**30.58**	**6.98**	**6.89**	**1.57**	**2.63**	nd

[a] nd = no data collected [b] turbidity recorded with Hatch turbidity meter 8/5/99-10/20/99

3.2 Manipulative Experiments

3.2.1 Monitoring of Manipulative Experiment Plots

We have summarized 1998 vs. 1999 post-treatment monitoring data at the manipulative experiment plots for Strata A (**Table 3.4**), Strata B (**Table 3.5**), and Strata D (**Table 3.6**).

Table 3.3 Sediment elevation changes at four stations in Tillamook Bay (May and July 1999).

Site	**Horizontal distance from stake (cm)**	**5/20/99 Height (cm)**	**7/14/99 Height (cm)**	**Change in Height (cm)**
Crab Harbor	10	60.0	60.3	0.3
	20	60.0	61.0	1.0
	30	59.0	61.0	2.0
	40	59.5	61.1	1.6
	50	60.0	59.5	-0.5
	60	60.0	60.4	0.4
	70	60.0	30.0	-30.0
	80	60.0	30.0	-30.0
			mean	**-6.9**
South Channel	10	62.5	60.2	-2.3
	20	59.0	60.5	1.5
	30	60.5	58.4	-2.1
	40	59.5	59.4	-0.1
	50	59.5	59.4	-0.1
	60	59.0	59.4	0.4
	70	59.5	59.6	0.1
	80	60.5	59.6	-0.9
			mean	**-0.4**
Schweizer Lease	10	61.5	59.6	-1.9
	20	61.0	60.6	-0.4
	30	60.0	58.5	-1.5
	40	61.0	56.8	-4.2
	50	59.5	59.4	-0.1
	60	60.0	59.4	-0.6
	70	61.5	58.4	-3.1
	80	61.5	57.5	-4.0
			mean	**-2.0**
Manipulative	10	52.0	52.5	0.5
	20	51.5	51.5	0.0
	30	50.0	58.0	8.0
	40	50.0	50.2	0.2
	50	52.0	53.4	1.4
	60	52.0	52.5	0.5
	70	53.0	53.0	0.0
	80	53.0	52.5	-0.5
			mean	**1.3**

Table 3.4 Summary of monitoring at manipulative experiment plots within Strata A, 1998 vs. 1999.

			Jul-98	May-99	Jul-98	May-99	Jul-98	May-99	May-99
Plot #	**Subplot #**	**1998 Treatment**	**Eelgrass Shoot Density (no/m^2)**	**Eelgrass Shoot Density (no/m^2)**	**Shrimp Burrov Density (no/m^2)**	**Shrimp Burrow Density (no/m^2)**	**Oyster Clusters (no/m^2)**	**Oyster Clusters (no/m^2)**	**Oyster Individs (no/m^2)**
A1	1	Oys + eel(a)	60	0	192	148	10	16	2
	2	Oys + eel	60	1	224	248	10	7	1
	3	Oys + eel	60	0	176	204	10	11	1
	4	Control	0	0	288	188	0	0	0
	5	Control	0	0	212	276	0	0	0
	6	Control	0	0	216	252	0	0	0
	7	Oys only	0	0	244	280	10	7	1
	8	Oys only	0	0	232	164	10	8	8
	9	Oys only	0	0	168	204	10	13	1
	10	Eel only	60	7	224	296	0	1	0
	11	Eel only	60	35	224	376	0	0	0
	12	Eel only	60	38	224	152	0	0	0
A2	1	Eel only	60	67	348	236	0	0	0
	2	Eel only	60	34	348	268	0	0	0
	3	Eel only	60	14	348	248	0	0	0
	4	Oys only	0	0	200	212	10	7	1
	5	Oys only	0	0	224	168	10	10	0
	6	Oys only	0	0	128	164	10	6	0
	7	Control	0	0	132	144	0	0	0
	8	Control	0	0	136	204	0	0	0
	9	Control	0	0	152	224	0	0	0
	10	Oys + eel	60	0	120	172	10	7	1
	11	Oys + eel	60	1	132	184	10	8	1
	12	Oys + eel	60	2	152	188	10	12	1
A3	1	Oys only	0	0	364	244	10	17	3
	2	Oys only	0	0	260	240	10	6	1
	3	Oys only	0	0	200	296	10	4	0
	4	Oys + eel	60	1	272	240	10	8	1
	5	Oys + eel	60	1	180	136	10	10	3
	6	Oys + eel	60	0	188	304	10	3	3
	7	Eel only	60	36	388	384	0	0	0
	8	Eel only	60	39	388	352	0	0	0
	9	Eel only	60	21	388	304	0	0	0
	10	Control	0	2	236	204	0	0	0
	11	Control	0	0	140	156	0	0	0
	12	Control	0	0	128	156	0	1	2

(a) oys=oysters; eel=eelgrass

Table 3.5 Summary of monitoring at manipulative experiment plots within Strata B, 1998 vs. 1999.

Plot #	**Subplot #**	**1998 Treatment**	**Jul-98 Eelgrass Shoot Density (no/m^2)**	**May-99 Eelgrass Shoot Density (no/m^2)**	**Jul-98 Shrimp Burrow Density (no/m^2)**	**May-99 Shrimp Burrow Density (no/m^2)**	**Jul-98 Oyster Individs (no/m^2)**	**May-99 Oyster Individs (no/m^2)**
B1	1	Eel only	60	0	204	72	28	33
	2	Eel only	60	1	204	92	17	26
	3	Eel only	60	1	204	268	16	13
	5	Control	0	0	180	148	32	28
	6	Control	0	0	200	124	36	59
	7	Control	0	0	192	236	11	21
B2	1	Control	0	0	148	164	38	50
	2	Control	0	0	208	236	6	4
	3	Control	0	0	132	268	15	7
	5	Eel only	60	2	216	168	23	37
	6	Eel only	60	1	216	200	11	13
	7	Eel only	60	3	216	208	22	11
B3	1	Eel only	60	0	100	136	20	18
	2	Eel only	60	3	100	68	29	34
	3	Eel only	60	6	100	80	19	19
	5	Control	0	0	256	216	15	18
	6	Control	0	0	200	124	12	17
	7	Control	0	0	156	176	51	37
B4	na	Oys only	0	0	nd	nd	10C/9I (a)	9C/7I

(a) C = clusters; I = individuals

Table 3.6 Summary of monitoring at manipulative experiment plots within Strata D, 1998 vs. 1999.

Plot #	**Subplot #**	**1998 Treatment**	**Jul-98 Eelgrass Shoot Density (no/m^2)**	**May-99 Eelgrass Shoot Density (no/m^2)**	**Jul-98 Shrimp Burrow Density (no/m^2)**	**May-99 Shrimp Burrow Density (no/m^2)**	**Jul-98 Oyster Clusters (no/m^2)**	**May-99 Oyster Clusters (no/m^2)**	**May-99 Oyster Individs (no/m^2)**
D1	1	Control	66	74	380	592	0	0	0
	2	Control	105	41	304	344	0	0	0
	3	Control	72	59	396	356	0	0	0
	5	Oys only	71	0	512	304	10	10	0
	6	Oys only	29	12	392	224	10	9	0
	7	Oys only	35	4	488	348	10	6	0
D2	1	Oys only	60	0	256	348	10	8	1
	2	Oys only	16	0	436	236	10	11	0
	3	Oys only	23	16	392	404	10	4	0
	5	Control	4	18	396	396	0	0	0
	6	Control	42	25	332	548	0	0	0
	7	Control	33	27	304	408	0	0	0
D3	1	Oys only	51	3	440	176	10	12	0
	2	Oys only	99	29	212	204	10	0	0
	3	Oys only	89	34	312	140	10	6	0
	5	Control	67	38	468	244	0	0	0
	6	Control	68	45	436	408	0	0	0
	7	Control	63	54	440	260	0	0	0
D4	na	Eel only	112	69	nd	nd	nd	nd	nd

At Strata A, we observed that in all plots (A1-A3) where we transplanted oysters and eelgrass together (oys + eel), eelgrass shoot density decreased from the 1998 transplanting density of 60 shoots/m^2 to # 2 shoots/m^2 in May 1999 (**Table 3.4**). In Strata A plots where we only transplanted eelgrass (eel only) at a density of 60 shoots/m^2 in 1998, eelgrass shoot densities decreased by May 1999 to a mean density of 32.3 shoots/m^2. We transplanted oyster clusters (oys only) into subplots within plots A1, A2, and A3 at a density of 10 clusters/m^2 in July 1998. In May 1999, the mean density of oyster clusters increased in a few subplots (range = 11-17 clusters/m^2) and stayed the same or decreased in most others (range = 3-10 oysters/m^2). We also recorded the density of individual oysters in May 1999, because no individual oysters were transplanted in July 1998 at the start of the manipulative experiments and individual oysters were present in the experimental plots in May 1999.

At Strata B, we observed that in all plots (B1-B3) where we transplanted eelgrass, eelgrass shoot density decreased from the 1998 transplanting density of 60 shoots/m^2 to a mean density of 1.9 shoots/m^2 in May 1999 (**Table 3.5**). As we observed at Strata A, oyster densities at Strata B decreased in some subplots and increased in others.

At Strata D, we could see that eelgrass shoot densities were significantly less in the treatment plots than the control plots, even before we collected any data in 1999 (**see photo, Figure 3.5**). Our monitoring confirmed this observation. Eelgrass shoot densities decreased significantly (1998 mean = 52.6 shoots/m^2; 1999 mean =10.9 shoots/m^2) at all of the subplots (D1-D3) where oysters were transplanted into existing eelgrass (**Table 3.6**). In comparison, mean eelgrass shoot density at the control plots was 57.8 shoots/m^2 in 1998 and 42.3 shoots/m^2 in 1999. At subplot D4, eelgrass shoot density decreased from 112 shoots/m^2 in 1998 to 69 shoots/m^2 in 1999.

3.2.2 Quantitative Sampling of Burrowing Shrimp

We summarized the number and density of shrimp burrows, mud shrimp, and ghost shrimp sampled at the manipulative experiment site in **Table 3.7**. Based on the seven samples collected by Brett Dumbauld, the mean shrimp burrow density at the manipulative experiment site was 368.5/m^2. Mud shrimp (mean = 23.1/sample) were far more abundant than ghost shrimp (1.0/sample). Densities of mud shrimp (mean = 180.8/m^2) were also correspondingly higher than densities of ghost shrimp (mean = 7.8/m^2). A total of 162 mud shrimp were collected in the seven samples: 83 males, 70 females, and 9 unsexed. We present length-frequency histograms for total mud shrimp, male mud shrimp, and female mud shrimp in **Figure 3.6**. Male shrimp appeared to have three peaks in length around 10mm, 15mm, and 20mm probably representing three age classes (1, 2, and 3 year old animals, see Dumbauld et al 1996). Age classes for female shrimp were more difficult to discern, but the histogram for total shrimp indicates the presence of a larger age class (4 year olds?) at about 25mm CL.

3.2.3 Oyster Weights at Manipulative Experiment Plots

We weighed and tagged 3 clusters of oysters at plots C1 and C2, and two clusters at plots A2, A3, B1, B2, B3, D1, D2, and D3 (**Table 3.8**). These data will serve as the baseline for future monitoring of changes in oyster growth. By monitoring these tagged clusters of oysters, we also hope to gain an indication of how often and how far oysters are being moved by tidal currents.

Figure 3.5 Photo of Jaylen Jones and Kerry Griffin monitoring at treatment plots (right), where oysters were transplanted into existing eelgrass, and control plots (left) within subplot D1, Strata D, at the manipulative experiment site, May 1999. Note that eelgrass appears to be missing from the treatment plots (within the white quadrats) and present within the control plots (between the two stakes on the lower left of the photo).

Table 3.7 Summary of burrowing shrimp quantitative sampling at the manipulative experiment site in Tillamook Bay, May 19, 1999.

Sample #	Shrimp Burrow #	Shrimp Burrow Density (no./m2)	Mud Shrimp #	Mud Shrimp Density (no./m2)	Ghost Shrimp #	Ghost Shrimp Density (no./m2)
1	37	289	15	117	0	0
2	37	289	17	133	0	0
3	46	359	18	141	0	0
4	60	469	31	242	2	16
5	56	438	36	281	4	31
6	47	367	26	203	1	8
7	nd	nd	19	148	0	0
mean	47.2	368.5	23.1	180.8	1.0	7.8
sd	9.5	74.2	8.0	62.4	1.5	11.9

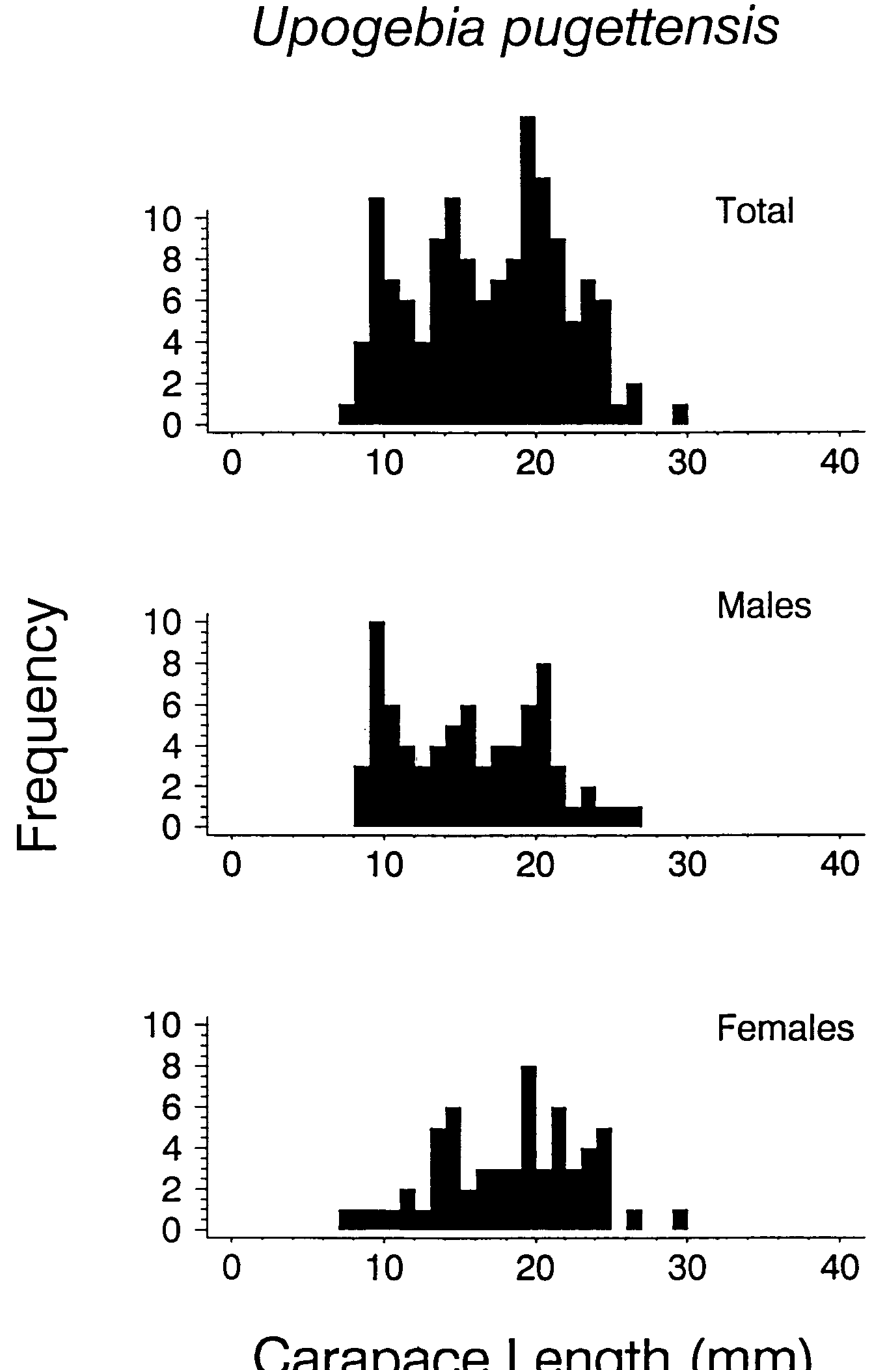

Figure 3.6. Length-frequency histograms for mud shrimp, *Upogebia pugettensis*, collected at the manipulative experiment site on May 19, 1999.

Table 3.8 Weights and number of individuals for tagged oyster clusters at each of the four strata at the manipulative experiment plots, August 1999.

Plot	**Tag Color**	**Weight (lbs)**	**# Individuals**
C1	Red	1.40	7
	Black	1.90	6
	Yellow	1.85	7
C2	Red	1.15	4
	Black	1.60	6
	Yellow	0.85	3
A2(4)	Black	0.95	3
	White	1.60	7
A3(1)	Black	1.65	9
	White	0.90	4
B1	Yellow	1.15	4
	White	2.05	8
B2	Yellow	1.00	3
	White	0.55	2
B3	Yellow	1.40	6
	White	1.90	8
D1	Red	1.60	7
	White	2.70	16
D2	Red	2.35	15
	White	1.00	5
D3	Red	1.80	2
	Black	1.55	9

3.3 Monitoring Recommendations and Adaptive Management Plan

We present our recommendations for revisions to the monitoring and adaptive management plan in section 4.3 of the discussion.

4.0 DISCUSSION

4.1 Eelgrass Patch-Edge Study

4.1.1 Eelgrass Patch-Edge Transects

Our 1999 monitoring revealed the most dramatic changes in eelgrass density and distribution at the Crab Harbor site. The overall mean eelgrass shoot density and eelgrass percent cover were 63% and 87% lower, respectively, in May 1999 than in June 1998. We suspect that the loss in eelgrass was likely due to deposition of up to 82.5 cm of fine sand on top of the former eelgrass bed. Future sampling at new stations (31m, 36m, 41m, and 46m), which we added along each of the five transects at Crab Harbor, will enable us to document whether the sediment accumulation has stabilized, or whether eelgrass continues to be buried as the sediment advances seaward. As discussed in greater detail below (Section 4.1.3), we believe that the deposited sand was probably of marine origin. We also believe that the sediment accumulation at our Crab Harbor site was most likely the result of natural processes, as opposed to human-induced factors in the upper watershed that resulted in increased rates of river-sediment accumulation in the Bay.

We observed increases in mean eelgrass density between June 1998 and May 1999 at both the South Channel and Schweizer Lease sites. Shrimp burrow densities appear to fluctuate dramatically, both seasonally and inter-annually at all sites. As expected, oyster densities remain low at all sites. No new oysters are being intentionally placed into our eelgrass patch-edge sites. Thus, year-to-year changes in oyster densities are likely due to oysters being transported either into or out of our patch-edge sites. The mechanisms of interaction among eelgrass, oysters, and burrowing shrimp are still unclear, but our first year of post-treatment monitoring at the manipulative experiment site indicates some interesting trends (see Section 4.2).

In 1998, we speculated that the most likely controlling factors for eelgrass in Tillamook Bay were turbidity, nutrients, physical disturbances, biological disturbances, temperature, and salinity. We see no evidence from the first two years of data that temperature and salinity are controlling factors. Temperature and salinity ranges were consistently within the optimal range for eelgrass growth from May to September in both 1998 and 1999 (see Section 4.1.2). We measured turbidity for the first time in 1999. These data will now serve as the baseline for comparison in future years, and may allow us to draw inferences about whether turbidity is a controlling factor for eelgrass. Based on the dramatic loss of eelgrass at the Crab Harbor site, we suggest that episodic physical disturbances, such as the large-scale deposition of sediment we observed at Crab Harbor, may be one of the most significant controlling factors that determines eelgrass shoot densities and distribution in the Bay.

4.1.2 Water Quality Monitoring

Water quality standards for temperature, pH, and turbidity were consistently met in the Bay for all sampling dates (4/20/99-10/20/99). Standards for dissolved oxygen (DO) were not. However, we attribute this to a malfunction of the DO probe on the Hydrolab unit, rather than actual problems with low dissolved oxygen. As in 1998, our data indicate that water quality in the Bay remains high relative to the requirements of eelgrass growth and survival. The upper portion of Tillamook Bay where we are conducting our research is relatively shallow, well flushed, and appears to be more influenced by the ocean than the five rivers that enter the lower bay. The average depth of the Bay is 2 meters, and intertidal flats comprise 50 to 60% of its surface area (McManus et al. 1998). Secchi depth was consistently the depth of the water column at the time of sampling. Secchi depth and turbidity measurements lead us to believe that the eelgrass beds at our study sites are probably not light limited during the period from April to October. Mean salinity and mean temperatures for all sites are well within the optimal range of conditions within which eelgrass flourishes in the Pacific Northwest (Table 6.1, Shreffler et al. 1998). The Bay temperature was typically cooler (mean range = 11.16-13.56° C) than the optimum range (15-18° C) for Pacific oyster somatic growth, as reported in Hinzman and Nelson (1998).

4.1.3 Elevation Changes at Crab Harbor

Between June 1998 and May 1999, we estimate that up to 82.5 cm of fine sand accumulated on top of the former eelgrass beds at the Crab Harbor site. Sand contributed by the five rivers that enter Tillamook Bay is not effectively moved through the Bay to the ocean, and river-sand is thought to dominate sediment accumulation within the eastern part of Tillamook Bay (McManus et al. 1998). In addition, sand is carried from the ocean beaches into the Bay by tidal currents flowing through the inlet to the Bay. While it is possible to distinguish between ocean-derived sand and river-derived sand, such an effort was beyond the scope of our research. McManus et al. 1998 found that, in general, river-sand dominates the eastern half of the Bay and beach-sand the western half. Furthermore, the authors' inferred sediment transport paths in Tillamook Bay indicate that the sediment in the Crab Harbor vicinity is primarily beach-sand. Thus, we suspect that the sand that accumulated at Crab Harbor probably entered the Bay from the ocean beaches. Regardless of the source of the sand that accumulated between 1998 and 1999 at the Crab Harbor site, such large-scale deposition of sand is detrimental to the existing eelgrass beds at this site. We estimate, visually, that the sand deposition at our Crab Harbor site reduced the overall area of the eelgrass bed by approximately 1/3 between June 1998 and May 1999. Future analysis of annual aerial photos should enable us to document year-to-year changes in eelgrass distribution.

4.1.4 Sediment Elevation Monitoring

The 1999 monitoring data from May and July will provide a baseline for future comparison and evaluation of sediment elevation changes. Subsequent monitoring will enable us to document trends in intra-annual and inter-annual changes in sediment accretion or erosion at each of these sites. These monitoring stations should enable us to detect small-scale (a few cm) and large-scale (up to 0.5 m) changes in sediment elevations, both between monitoring periods within the same year and between years.

We suspect that the largest change in sediment elevations that we observed between May and July 1999 (-30.0 cm at a distance of 70 cm and 80 cm from the monitoring stake at the Crab Harbor site) is likely due to a pit dug by recreational clam harvesters. We know that of the three eelgrass patch-edge sites, the Crab Harbor site is the most frequently visited by shellfish harvesters, and we commonly find pits within our transects.

4.1.5 Burrowing Shrimp Characterization

Our rapid, semi-quantitative assessment of burrowing shrimp confirmed our suspicion that mud shrimp appear to be more abundant than ghost shrimp at each of the eelgrass-patch edge sites. The implications of this finding are potentially important, because ghost shrimp pose the most significant threat to oyster culture operations and can cause much higher siltation and initial mortality than mud shrimp (Dumbauld et al. 1997). Since relatively few ghost shrimp were collected at any of the three eelgrass patch-edge sites, oyster ground culture at these sites is probably at less risk than if ghost shrimp were the dominant burrowing species. We caution, however, that a systematic and larger scale effort would be required to more definitively quantify and characterize the burrowing shrimp populations at each of these sites.

4.2. Manipulative Experiments

4.2.1 Monitoring of Manipulative Experiment Plots

Marine bivalves and especially oysters are proven monitors and indicators of ecosystem stress on the Atlantic coast (Dame 1996). The best, long-term field experiment data comes from the Chesapeake Bay ecosystem, and more recent short-term data is available for North Inlet, South Carolina (reviewed in Dame 1996). Similar ecosystem-scale field manipulations are conspicuously lacking for the Pacific coast. The drawbacks of field manipulations are the inability to exercise control over most of the variables in the system, the long monitoring periods required post-manipulations (i.e., years), the difficulty of replicating experiments, and the higher expense in comparison to mathematically-based ecosystem models or controlled laboratory experiments. Nevertheless, field manipulations are a powerful tool for understanding complex ecosystem processes and the ecosystem role of bivalves (Dame 1996).

In Tillamook Bay, we have designed our manipulative field experiments not to understand ecosystem-level processes, but rather, to understand the mechanisms of interaction among oysters, eelgrass, and burrowing shrimp. We can, however, draw upon the findings of the Atlantic coast ecosystem-scale studies in interpreting the results of our manipulative experiments. As noted by Dame (1996), the interpretation of manipulative experiments requires that two fundamental questions be answered: (1) did the manipulated ecosystem change following the manipulation, and (2) did the manipulation cause the change?

At Strata A of the Tillamook Bay manipulative experiment site, we are monitoring for five separate effects of our manipulations:

- The effect of an environment without eelgrass on transplanted eelgrass (Treatment EE1);
- The effect of an environment without oysters on transplanted oysters (Treatment EE2);
- The effect of an environment without eelgrass or oysters on transplanted eelgrass and oysters (Treatment EE3);
- The effect of transplanted oysters on transplanted eelgrass density (Treatment AE1); and
- The effect of transplanted eelgrass on transplanted oyster density (Treatment AE2).

Relative to treatment EE1, we know that eelgrass shoot densities clearly decreased between July 1998 and May 1999 in all of the plots where only eelgrass was transplanted (mean decrease = 46.1%). It is unclear, however, how much of this effect is due to the environment at the site vs. eelgrass losses that resulted from the stress of the transplanting effort. We know from our monitoring at plot D4 within Strata D that the effect transplanting had on transplanted eelgrass

(Treatment TE1) was a 38.4% decrease in shoot density. This suggests that under the best possible transplanting scenario (i.e., plants are excavated and then replanted in the same hole), we can only expect 61.6% of the plants to survive. The transplanted eelgrass at Strata A experimental plots was moved from nearby locations, and thus transplant survival could be expected to be even less than at plot D4.

Relative to Treatment EE2, we know that our transplanted oyster clusters were moved (presumably by tidal currents) from one subplot to another, or completely out of our study area. However, because the oysters we originally transplanted were not tagged or marked in any way, it is now difficult to distinguish between those oysters from our study and other oysters that have been transported into the experimental plots from adjacent oyster leases. We also do not know whether the individual oysters that were present in our experimental plots in 1999 had broken off the clusters we transplanted in 1998, or whether these "singles" were transported into our plots from elsewhere.

Relative to Treatment EE3, we are unable to distinguish at this time between whatever effects the environment may have on the transplanted eelgrass and transplanted oysters vs. effects transplanted eelgrass and transplanted oysters may have on each other. Relative to Treatment AE1, our preliminary indication is that transplanted oysters had a negative effect on the denstiy of transplanted eelgrass, because in all plots where the two were transplanted together, eelgrass survival was 1.1% compared to 53.9% in adjacent plots where only eelgrass was transplanted. We suggest that this effect could be primarily due to eelgrass blades being abraded by the sharp-edged oysters. We won't know until our monitoring in spring 2000 whether any of the eelgrass that was transplanted in 1998 into the treatment plots recovers. Relative to Treatment AE2, our preliminary indication is that the transplanted eelgrass had no effect on transplanted oyster density. Future monitoring of oyster weights may give us an indication of whether the transplanted eelgrass had any effect on oyster growth.

Our monitoring at Strata B indicates that transplanted eelgrass had no effect on existing oyster survival (Treatment BE1). We won't know until subsequent monitoring in 2000 and 2001 whether the transplanted eelgrass had an effect on oyster growth. Data from Strata B indicate a potential negative effect of oysters on eelgrass. Mean eelgrass shoot density decreased from 60 shoots/m^2 in 1998 to 1.9 shoots/m^2 in 1999. As we indicated above, we are convinced that oysters are being moved around by the tides from one year to the next, and perhaps intra-annually as well. We speculate that some of the observed eelgrass losses may be attributable to oysters being bounced along the bottom and across the eelgrass transplants by tidal currents. In August 1999, we tagged oyster clusters at each of the four strata; through subsequent monitoring, we hope to get an indication of how often and how far oysters are being moved.

The effect that oyster transplanting has on transplanted oysters (Treatment TE2) appears to be negligible. Within subplot B4, we observed a change in oyster density from 10 clusters and 9 individuals in 1998 to 9 clusters and 7 individuals in 1999. We think that the observed change in oyster density is due to oysters being removed from our experimental plots by the tides and not oyster mortality.

Based on our monitoring data from Strata D, we suggest that there may be a negative effect of transplanted oysters on existing eelgrass density (Treatment DE1). Eelgrass density decreased by 57.4% at the subplots where oysters were transplanted into existing eelgrass, compared to only 26.8% decrease at the control subplots.

At all four strata, shrimp burrow densities changed dramatically (both increases and decreases) between 1998 and 1999. No trends are apparent yet, but we hope that continued monitoring may help us to discern patterns in burrow counts and also potential implications of shrimp burrow densities for oysters and eelgrass. We also still hope to monitor the effects of oyster harvest on existing eelgrass survival at Strata C (Treatment CE1). This effort is dependent on the continued cooperation and participation of personnel from Pacific Oyster Company.

4.2.2 Quantitative Sampling of Burrowing Shrimp

With Brett Dumbauld's assistance, we determined that mud shrimp are the dominant burrowing shrimp species at the manipulative experiment site. Mean mud shrimp densities were 23 times higher than ghost shrimp densities for the seven samples we collected. As noted in Section 4.1.4, ghost shrimp pose a much more significant threat to oyster culture than mud shrimp. Nevertheless, mud shrimp still pose a threat, especially to oyster ground culture, because excavation and resuspension of sediments by mud shrimp can soften the sediment, bury oysters, and interfere with oysters' filter feeding (Dewitt et al. 1997). The mud shrimp densities we found at the manipulative experiment site (180.8/m^2) are significantly higher than maximum mud shrimp densities (100-125/m^2) observed in Willapa Bay, Washington (Dumbauld, pers. comm.). The populations of burrowing shrimp in Tillamook Bay will continue to be a major source of concern for oyster growers until non-chemical methods of shrimp control are developed, tested, and implemented.

4.3 Monitoring Recommendations and Adaptive Management Plan

In 1998, we developed a long-term monitoring program for the intertidal and shallow subtidal portions of Tillamook Bay (Shreffler et al. 1999). The program focused specifically on eelgrass meadows, and their associated fauna, including burrowing shrimp and oysters. Based on the results of our Year 2 (1999) research, we offer suggested revisions to the monitoring plan below, by sections of the original (1998) plan.

Purpose and Goal of the Monitoring Program

We suggest that the goal of the monitoring program should remain unchanged. The **purpose** of the eelgrass-monitoring program is **to provide strong and scientifically defensible information on the health of eelgrass meadow communities in Tillamook Bay**. The **goal** for the eelgrass subsystem is to **maintain and/or increase the aerial coverage of eelgrass meadows in the Bay in balance with other biological components of the Bay ecosystem** The *intent* embedded within this goal *is to assure that the eelgrass meadows are healthy and thriving in the Bay, and that their functions and associated fauna also thrive*.

Conceptual Model

We recommend no changes to the conceptual model of linkages between eelgrass, controlling factors, and the resources and functions associated with eelgrass. However, we note that "physical disturbances" and "biological disturbances" as presented in this model encompass both natural and human-induced disturbances.

We know based on our 1999 monitoring at the Crab Harbor site, that large-scale sediment movements can be detrimental to eelgrass. Table 6.1 in the Year 1 final report lists the range of conditions within which eelgrass flourishes in the Pacific Northwest. This table should be revised to reflect our recent documentation that actively eroding or accreting substrates are not conducive to eelgrass survival.

Parameter Selection

We recommend that sediment elevation needs to be added to the list of parameters to be measured. Based on our 1999 observations of the dramatic sedimentation event(s) at Crab Harbor, sediment transport may play a profound role in structuring the eelgrass meadows and their associated fauna including burrowing shrimp and oysters.

We also recommend that oyster weights need to be measured at the manipulative experiment plots. Interactions with eelgrass or burrowing shrimp may not effect oyster survival, but could have an effect on oyster growth. Oyster growth is a major concern of the local oyster growers in the Bay.

Performance Criteria

We recommend no changes at this time.

Methods, Timing, and Frequency

Eelgrass and other vegetation

- We reiterate the importance of taking aerial photographs annually during a mid-summer low tide series. These photographs are the single most important tool for evaluating inter-annual changes in eelgrass distribution in the Bay.

- We recommend continued monitoring of percent cover, eelgrass shoot density, oyster density, and shrimp burrow density at the three established eelgrass patch-edge study sites (Crab Harbor, South Channel, and Schweizer Lease) 3x/year (spring/summer/fall) for 2 more years (through 2001). The methods should follow those we used in 1999.

- We also recommend continued monitoring of eelgrass shoot density, oyster density, and shrimp burrow density, at the manipulative experiment plots at Strata A, B, C, D of the Pacific Oyster Lease site, 3x/year (spring/summer/fall) for 2 more years (through 2001). The methods should follow those we used in 1999.

- Once each sampling year, percent cover should be monitored at all the manipulative experiment plots.

- Once each sampling year, weights of the tagged oysters at the manipulative experiment plots should be measured.

- Once each sampling year, photographs should be taken at the permanent photo stations at Strata C, preferably in late summer or early fall when eelgrass is at its peak abundance. Photos were taken in 1998, but not 1999.

- Once each sampling year, changes in sediment elevations should be recorded at the three patch-edge sites and the manipulative experiment site.

Water Properties

- We recommend measuring water properties (temperature, salinity, turbidity, DO, pH, and secchi depth) at the surface and near bottom at the three eelgrass patch-edge sites and one location at the manipulative experiment site biweekly from spring through fall of each year.

Weather

- We recommend that daily weather data should continue to be compiled from the nearest weather monitoring station to the Bay.

Data Management

We recommend no changes at this time.

Adaptive Management

We recommend no changes at this time.

Community-Based Monitoring

The continued success of our research program is dependent upon local volunteers, who are willing to assist with monitoring at the eelgrass patch-edge sites and manipulative experiment sites, and with collecting water quality and weather data.

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APPENDIX A

Eelgrass Patch-Edge Monitoring Data for 1999

Eelgrass Patch-Edge Monitoring Data for Crab Harbor Site (5/18/99)

Transect #	Distance Along Transect (m)	Percent Cover (in a 1m ^{2} quadrat)				Eelgrass Shoot Density (no./m ^{2})	Shrimp Burrow Density (no./m ^{2})	Oyster Density (no./m ^{2})
		Eelgrass	Sand	Ulva	Enteromorpha			
T1	1	0	100	0	0	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	0	0	0
	16	4.5	95.5	0	0	16	0	0
	21	2.5	97.5	0	0	30	0	0
	26	2	98	0	0	2	0	7
	31	0	100	0	0	0	24	0
	36	1.5	98.5	0	0	5	12	0
	41	13	87	0	0	41	116	0
	46	11	89	0	0	34	56	0
T2	1	0	100	0	0	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	0	0	0
	16	0	100	0	0	0	0	0
	21	0	100	0	0	0	0	0
	26	0	100	0	0	0	0	0
	31	1	99	0	0	16	24	0
	36	39	61	0	0	152	48	0
	41	44.5	55.5	0	0	198	76	0
	46	47.5	52.5	0	0	152	68	2
T3	1	0	100	0	0	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	0	0	0
	16	0	100	0	0	0	0	0
	21	0	100	0	0	0	0	0
	26	0	100	0	0	0	0	0
	31	1	99	0	0	14	56	0
	36	5	95	0	0	65	64	0
	41	6.5	93.5	0	0	60	52	0
	46	3	97	0	0	45	84	0
T4	1	0	100	0	0	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	0	0	0
	16	0	100	0	0	0	0	0
	21	0	100	0	0	0	0	0
	26	9.5	89.5	2	0	102	32	0
	31	19	81	0	0	134	80	1
	36	1	99	0	0	28	72	0
	41	5	95	0	0	64	76	0
	46	3	97	0	0	46	164	0
T5	1	0	100	0	0	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	0	0	0
	16	0.5	99	0.5	0	2	0	0
	21	19.5	79	1.5	0	78	96	0
	26	23.5	76.5	0	0	61	32	0
	31	30.5	69.5	0	0	115	72	0
	36	63.5	36	0.5	0	149	60	5
	41	49.5	50.5	0	0	176	104	0
	46	63.5	36.5	0	0	146	52	3
	mean	5.7	94.2	0.1	0.0	29.2	26.8	0.2
	sd	17.1	17.1	0.4	0.0	56.2	39.8	1.3

Eelgrass Patch-Edge Monitoring Data for Crab Harbor Site (9/8/99)

Transect #	Distance Along Transect (m)	Percent Cover (in a 1m ^{2} quadrat)				Eelgrass Shoot Density (no./m ^{2})	Shrimp Burrow Density (no./m ^{2})	Oyster Density (no./m ^{2})
		Eelgrass	Sand	Ulva	Enteromorpha			
T1	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
	31	nd	nd	nd	nd	nd	nd	nd
	36	nd	nd	nd	nd	nd	nd	nd
	41	nd	nd	nd	nd	nd	nd	nd
	46	nd	nd	nd	nd	nd	nd	nd
T2	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
	31	nd	nd	nd	nd	nd	nd	nd
	36	nd	nd	nd	nd	nd	nd	nd
	41	nd	nd	nd	nd	nd	nd	nd
	46	nd	nd	nd	nd	nd	nd	nd
T3	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
	31	nd	nd	nd	nd	nd	nd	nd
	36	nd	nd	nd	nd	nd	nd	nd
	41	nd	nd	nd	nd	nd	nd	nd
	46	nd	nd	nd	nd	nd	nd	nd
T4	1	0	97	0.5	2.5	0	0	0
	6	0	100	0	0	0	0	0
	11	0	100	0	0	5	28	0
	16	0	100	0	0	0	0	0
	21	0	100	0	0	0	52	0
	26	11	88	1	0	0	32	0
	31	0	100	0	0	0	20	0
	36	5	95	0	0	nd	nd	nd
	41	0.5	99.5	0	0	0	16	0
	46	0.5	99	0.5	0	0	0	0
T5	1	0	100	0	0	0	0	0
	6	0	100	0	0	83	4	0
	11	0	100	0	0	176	12	0
	16	0.5	99	0.5	0	123	16	0
	21	95	4	1	0	98	36	2
	26	90	10	0	0	117	24	0
	31	94	6	0	0	113	44	5
	36	81	14	0	0	nd	nd	nd
	41	93	6.5	0	0.5	nd	nd	nd
	46	96.5	2.5	1	0	nd	nd	nd
	mean	28.4	71.0	0.2	0.2	44.7	17.8	0.4
	sd	41.6	41.9	0.4	0.6	59.8	16.5	1.3

Eelgrass Patch-Edge Monitoring Data for South Channel Site (5/18/99)

	Distance Along	Percent Cover (in a 1m^2 quadrat)						
Transect #	Transect (m)	Eelgrass	Mud	Ulva	Diatoms	Eelgrass Shoot Density (no./m^2)	Shrimp Burrow Density (no./m^2)	Oyster Density (no./m^2)
T1	1	19.5	80.5	0	0	94	248	0
	6	2	98	0	0	27	128	0
	11	19	81	0	0	71	440	0
	16	32	68	0	0	141	300	0
	21	38.5	61.5	0	0	123	272	0
	26	41.5	58.5	0	0	131	236	0
T2	1	5	95	0	0	27	280	0
	6	24.5	75.5	0	0	140	396	0
	11	0	98.5	0	1.5	0	288	0
	16	0	100	0	0	0	348	0
	21	0	100	0	0	0	128	0
	26	10	90	0	0	83	292	0
T3	1	27.5	72	0.5	0	80	228	0
	6	0	100	0	0	1	276	0
	11	1.5	98.5	0	0	15	300	0
	16	0	100	0	0	0	284	0
	21	0	100	0	0	0	124	0
	26	0	100	0	0	0	104	0
T4	1	13	87	0	0	103	332	0
	6	12.5	87.5	0	0	93	568	0
	11	32	68	0	0	150	432	0
	16	3.5	96.5	0	0	87	452	0
	21	15	85	0	0	150	660	0
	26	11.5	88.5	0	0	85	284	0
T5	1	34.5	65.5	0	0	62	220	0
	6	15	85	0	0	83	180	0
	11	4	96	0	0	20	420	0
	16	31	69	0	0	111	368	0
	21	9.5	80.5	10	0	32	244	0
	26	2.5	97.5	0	0	7	392	0
	mean	13.5	86.1	0.4	0.1	63.9	307.5	0.0
	sd	13.4	13.4	1.8	0.3	53.1	126.9	0.0

Eelgrass Patch-Edge Monitoring Data for Schweizer Lease Site (5/17/99)

	Distance Along	Percent Cover (in a 1m ^{2} quadrat)				Eelgrass Shoot	Shrimp Burrow	Oyster Density
Transect #	Transect (m)	Eelgrass	Mud	Ulva	Oyster	Density (no./m ^{2})	Density (no./m ^{2})	(no./m ^{2})
T1	1	0	97.5	1	1.5	0	336	4
	6	0	100	0	0	0	276	0
	11	35.5	63.5	0	1	255	464	7
	16	24.5	75.5	0	0	204	420	0
	21	16	84	0	0	163	376	0
	26	27	72.5	0.5	0	173	524	0
T2	1	0	100	0	0	0	484	0
	6	3.5	96.5	0	0	27	504	0
	11	36	64	0	0	178	540	0
	16	25.5	74.5	0	0	232	512	0
	21	15.5	84.5	0	0	50.5	472	0
	26	5.5	94.5	0	0	85	644	0
T3	1	2	98	0	0	30	224	0
	6	4	96	0	0	37	280	5
	11	8	92	0	0	22	524	6
	16	31	69	0	0	171	348	0
	21	35	64	0	1	256	364	5
	26	30	68.5	0	1.5	178	496	6
T4	1	2	97.5	0	0.5	34	452	0
	6	0	100	0	0	1	512	0
	11	11	89	0	0	149	412	0
	16	41.5	58.5	0	0	251	708	0
	21	12.5	87.5	0	0	172	312	0
	26	47	53	0	0	248	368	0
T5	1	17	83	0	0	118	516	0
	6	6.5	93.5	0	0	105	192	0
	11	13	87	0	0	90	336	0
	16	3	97	0	0	31	488	0
	21	0	93	7	0	0	388	0
	26	30.5	69.5	0	0	135	472	0
	mean	16.1	83.4	0.3	0.2	113.2	431.5	1.1
	sd	14.5	14.4	1.3	0.4	89.8	116.2	2.3

Eelgrass Patch-Edge Monitoring Data for Schweizer Lease Site (9/9/99)

Transect #	Distance Along Transect (m)	Percent Cover (in a 1m ^{2} quadrat)				Eelgrass Shoot Density (no./m ^{2})	Shrimp Burrow Density (no./m ^{2})	Oyster Density (no./m ^{2})
		Eelgrass	Mud	Ulva	Enteromorpha			
T1	1	0	9	91	0	0	84	4
	6	6.5	29.5	64	0	12	76	0
	11	93	2.5	4.5	0	388	316	3
	16	95	2	3	0	266	248	0
	21	76.5	6	17.5	0	176	280	0
	26	79.5	3.5	17	0	116	168	0
T2	1	0	40.5	36.5	23	0	208	0
	6	33.5	8	51	7.5	75	204	0
	11	86.5	9.5	4	0	252	304	0
	16	96.5	1	2.5	0	221	92	0
	21	74.5	5.5	20	0	122	164	0
	26	91	2.5	6.5	0	168	324	0
T3	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
T4	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
T5	1	nd	nd	nd	nd	nd	nd	nd
	6	nd	nd	nd	nd	nd	nd	nd
	11	nd	nd	nd	nd	nd	nd	nd
	16	nd	nd	nd	nd	nd	nd	nd
	21	nd	nd	nd	nd	nd	nd	nd
	26	nd	nd	nd	nd	nd	nd	nd
	mean	61.0	10.0	26.5	2.5	149.7	205.7	0.6
	sd	39.2	12.3	28.6	6.8	119.9	90.9	1.4