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Evaluation of Potential Eelgrass Restoration Sites: Methods, Results, and Recommendations

June 2014

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U.S. DEPARTMENT OF ENERGY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

This report outlines the field portion of a collaborative study undertaken by the Pacific Northwest National Laboratory (PNNL) and the Washington Department of Natural Resources (DNR) to identify and test areas around Puget Sound for eelgrass restoration. The intent was to assist DNR in reaching its goal to increase the abundance of eelgrass in Puget Sound 20% by the year 2020. The overall study used numerical modeling of Puget Sound to identify potential locations that could support eelgrass populations. This field task then evaluated a subset of those sites and provided recommendations for future actions including large-scale restoration at the most promising locations. This testing was a multi-step process that included evaluation of the model results, site visits, and test plantings of eelgrass shoots multiple locations around Puget Sound.

The first step took the potential locations generated by the model and evaluated their potential for supporting eelgrass restoration activities. Sites were evaluated against a number of criteria including historical evidence of eelgrass, known presence of eelgrass, potential stressors, size of the potential site, proximity to donor sites, and proximity to other potential sites. This process resulted in a list of 24 sites around Puget Sound to be visited and assessed by PNNL researchers. These site visits were designed to determine if eelgrass was already present at the site and whether certain environmental parameters (e.g., depth, substrate, and exposure) were appropriate to support eelgrass populations. Obvious stressors (e.g., mooring fields) detrimental to eelgrass were also noted during the site visits.

Based on the results of the site visits, five locations were chosen around Puget Sound for further testing. Small test plots were planted at the sites to determine if eelgrass would survive before large quantities of resources were committed to large-scale restoration activities. Two test plots between 30 and 45 m^2 in area were planted at each location except Zangle Cove (only one test plot). Each plot was planted with 448 to 872 eelgrass shoots and marked carefully for future visits. The test plots were evaluated after almost a year to determine the survival of the eelgrass. Of the nine test plots planted, three had survival greater than 60% (Joemma State Park shallow and deep sites and Zangle Cove). These sites were recommended for larger-scale restoration activities. A fourth site, the middle site in Westcott Bay, had adequate survival for this type of transplant study (17%) and it was recommended that further work be done to determine the extent to which the site could be restored with eelgrass.

Acknowledgments

This study required a good support team, and many people helped with the collection of data and preparation of the report. Jeff Gaeckle and Fred Short (Department of Natural Resources) were collaborators in all phases of the project from the planning to the field work to the data interpretation, and their insight has been invaluable. Volunteers from the Washington Conservation Corps – Puget Sound Corps team provided shore support bundling plants so the divers could continue their work on the water. Jerry Johannes allowed us to place an Odyssey light sensor on his property for the ambient air readings. Pema Kitaeff (University of Washington Friday Harbor Marine Lab) assisted in cleaning the Odyssey sensor in Westcott Bay. Kelly Andrews (NOAA Fisheries) and Randy Carman (Washington Department of Fish and Wildlife) reviewed this report and provided needed suggestions. To all we are grateful.

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Acronyms and Abbreviations

°M	degrees magnetic
cm	centimeter(s)
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
ft	feet
GPS	global positioning system
m	meter(s)
m^2	square meter(s)
MLLW	Mean Lower Low Water
MSL	Marine Sciences Laboratory
NE	Northeast
NW	Northwest
PAR	Photosynthetic Active Radiation
PNNL	Pacific Northwest National Laboratory
PVC	polyvinyl chloride
SCUBA	self-contained underwater breathing apparatus
SE	Southeast
SP	State Park

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1.0 Introduction

The populations of eelgrass (*Zostera marina* L.), which plays an important ecological role in nearshore habitats (as described below), are declining worldwide in response to human activities. For this reason, the Washington State Department of Natural Resources (DNR) has recommended that eelgrass coverage in the Puget Sound be increased 20% by 2020 (Dowty et al. 2010). This goal has been accepted by the Puget Sound Partnership (a state agency established to lead efforts to protect and restore Puget Sound and its diversity of life). Pacific Northwest National Laboratory (PNNL) and the DNR are supporting this goal by identifying favorable areas for eelgrass restoration in Puget Sound.

1.1 Background

Seagrasses are true flowering plants (i.e., angiosperms, not to be confused with seaweeds) found in the marine environment (for a general overview and review of the literature, see Larkum et al. 2006). Seagrasses are a group or clade of plants rather than a single taxonomic unit found generally in 4 families and approximately 12 genera. They are present throughout the world on all continents except Antarctica and can form large monoculture or multi-species meadows in favorable environments. These meadows have been shown to have many beneficial properties and are protected in most areas in recognition of their ecological worth. Seagrass meadows have one of the highest primary production rates of any habitat, provide multiple food sources for numerous food webs, stabilize the seabed, contribute to the local oxygen budget (both above and below ground), and form a complex habitat structure. As such these meadows can be foraging, spawning, nursery, and migratory areas for many animals including commercially important fish and invertebrates, marine mammals, and waterfowl.

Eelgrass (*Z. marina*) is the most widely distributed among approximately 60 seagrass species globally and spans temperate to subtropical waters in the northern hemisphere. Eelgrass can be found on both sides of the Atlantic and Pacific Oceans, although there is some debate about the exact classification of species or sub-populations throughout the range. In bays and estuaries of the Pacific Northwest it is a common species that can form very dense meadows. The visible part of the plant is a bundle of three to seven thin, narrow (~0.5 cm), and flattened leaves (or blades) that can reach 1.5 m or longer. These blades derive from a node along a buried stem-like structure, or rhizome, which serves to anchor the plants in the substrate. Roots grow from each node and assist in anchoring the plants to the substrata and facilitate nutrient and gas exchange. The rhizomes also function as an energy storage part of the eelgrass plant. The roots and rhizomes form complex mats under the sediments of eelgrass meadows and the spread of rhizomes provides for asexual reproduction of the species. Eelgrass can also reproduce sexually, forming seeds that can be transported short distances in the water or over greater distances if the more buoyant flowering shoot breaks off and drifts away (Ewanchuk and Williams 1996). Eelgrass in the Pacific Northwest is a perennial plant that may behave as an annual in more stressful environments such as the higher intertidal zone or in warm bays (Santamaría-Gallegos et al. 2000).

Seagrasses worldwide, however, are declining at a worrisome rate and usually due to anthropogenic activities. Although not easily quantified, locally it is believed that eelgrass area has been lost through physical changes in shorelines, periodic physical disturbances, and degradation of water quality (Thom 1995, Thom et al. 2011). Climate change effects are expected to further exacerbate eelgrass losses. Therefore all coastal areas of the United States afford some protection to native seagrass populations because of the recognized ecological role they play in nearshore ecosystems. Protection for eelgrass is afforded at the federal, tribal, state, and local levels. Various jurisdictions are attempting to eliminate the decline of eelgrass in their waters and many even have goals seeking to increase eelgrass coverage. For example, in Washington State, the DNR has recommended that eelgrass coverage in Puget Sound be increased 20% by 2020. It is toward that end that PNNL and the DNR have undertaken this project to identify favorable areas for eelgrass restoration.

1.2 Project Overview

The current project, 20% More Eelgrass by 2020: Restoration Site Selection and Testing, and Resolving Regulatory and Social Barriers to Conservation and Recovery, sought to provide DNR with viable suggestions about how to meet its goal for increasing eelgrass coverage in Puget Sound. The program strategy was to approach the problem in two different ways:

- First, work with stakeholders (e.g., shoreline managers, researchers, state agencies, tribes, etc.) to identify areas where better regulation/enforcement could help improve environmental conditions, reduce anthropogenic impacts, and facilitate eelgrass growth/survival (Task 3 in this study).
- Second, identify specific areas where active restoration (e.g., planting of eelgrass) could provide a viable population that can in turn increase local abundance (Tasks 2 and 4).

This second, more active, approach is a multiphase process designed to identify restoration options that offer the best chances for success. The first step was to use existing environmental data, current and historical eelgrass distributions, a basin-wide water-quality model, and an eelgrass biomass model to suggest appropriate locations for eelgrass transplantation (Task 2). Researchers evaluated the potential sites identified in the model along with the available data, and culled the list to those most likely to be candidate restoration areas. Researchers visited these sites to evaluate the presence or absence of eelgrass, sediment type, exposure, water clarity, abundance of macroalgae, and potential stressors to further narrow the list to sites best suited for eelgrass transplantation. Researchers then planted small plots of eelgrass shoots to see if eelgrass can indeed survive in these areas. These test plots are important in this process because the data sets used to evaluate the list were limited and the site visit only provides a snapshot into the conditions at each location. The test plots allow the biology to ultimately determine the suitability of the site. Sites where the test plants survive could then be recommended for aggressive restoration effort and large-scale planting. The site visit and test plantings (Task 4) are critical in the process to increase the chances for successful restoration on larger scales and provide the most efficient use of limited resources when trying to reach the ultimate goal of increasing eelgrass coverage.

1.3 Report Purpose and Contents

This report documents the results of Task 4 of the project, undertaken by Pacific Northwest National Laboratory and DNR to identify areas for restoring eelgrass to meet the Washington State goal of increasing the coverage of eelgrass in Puget Sound. While the overall study seeks to identify these areas with a combination of interactions with shoreline planners and managers, numerical modeling, site visits, and test plantings, this report focuses on the site visits and test plantings. The plantings were used to validate the appropriateness of the potential sites for large-scale restoration activities. The ensuing sections describe the study methods and materials, followed by site-specific results, discussion, and conclusions.

2.0 Methods and Materials

As described in Section 1.0, the methodology for recommending sites for large-scale eelgrass restoration involved a number of steps. First, the model results from Task 2 were evaluated by DNR and PNNL scientists. Then site visits were conducted in locations around Puget Sound to identify areas for test plantings. Finally test plots were established throughout Puget Sound to evaluate the most promising sites for eelgrass survival.

2.1 Evaluation of Model Results

The results of the eelgrass biomass model identified areas of Puget Sound that should have higher biomass production based on the best available data. These areas were discussed by a team of scientists with local knowledge to create a more manageable list of sites to visit. Some of the criteria used in the discussion included the following:

- **Historical evidence of eelgrass**. It was assumed that sites that used to have eelgrass should be better candidate sites than those that never seemed to support eelgrass historically.
- **Potential stressors at the site**. Current stressors at a site could explain why historical populations died or prevent reintroduction efforts. Stressors could include, but were not limited to, harbors, mooring areas, shoreline modifications, known sources of pollution or eutrophication, significant seasonal freshwater inputs, and macroalgal blooms.
- **Known presence of current eelgrass populations**. Areas with known populations of eelgrass were excluded because the idea of the restoration is to provide nuclei of eelgrass populations from which colonization of the areas could occur. For the purposes of this study, restoring areas already containing eelgrass was not considered an efficient use of resources.
- **Size of the site.** When possible, larger areas were given preference because they could ultimately lead to larger meadows and more progress toward the goal of 20% more eelgrass in Puget Sound.
- **Proximity to potential donor sites**. The restoration process requires plants to be harvested from donor sites. The closer the donor site the better plants should be adapted to the local environment, the less stress the plants should experience during the transplanting process, and the easier the logistics for the field crew in mobilizing and carrying out the required tasks.
- **Proximity to other potential sites**. Logistically, it was necessary at times to group sites spatially to maximize the limited time on the water for the site visits and evaluate as many sites as possible.

2.2 Field Observations at Potential Sites

The process above identified 24 sites to be surveyed for eelgrass presence, absence, and site conditions best suited for eelgrass transplantation in 5 regions around Puget Sound. The five regions were the South Sound, eastern Kitsap County, Discovery Bay/Quimper Peninsula/Upper Hood Canal, Whidbey Island, and the San Juan Islands. Specific sites for proposed survey locations in each region are depicted in Figure 1 through Figure 5 and listed below each figure.

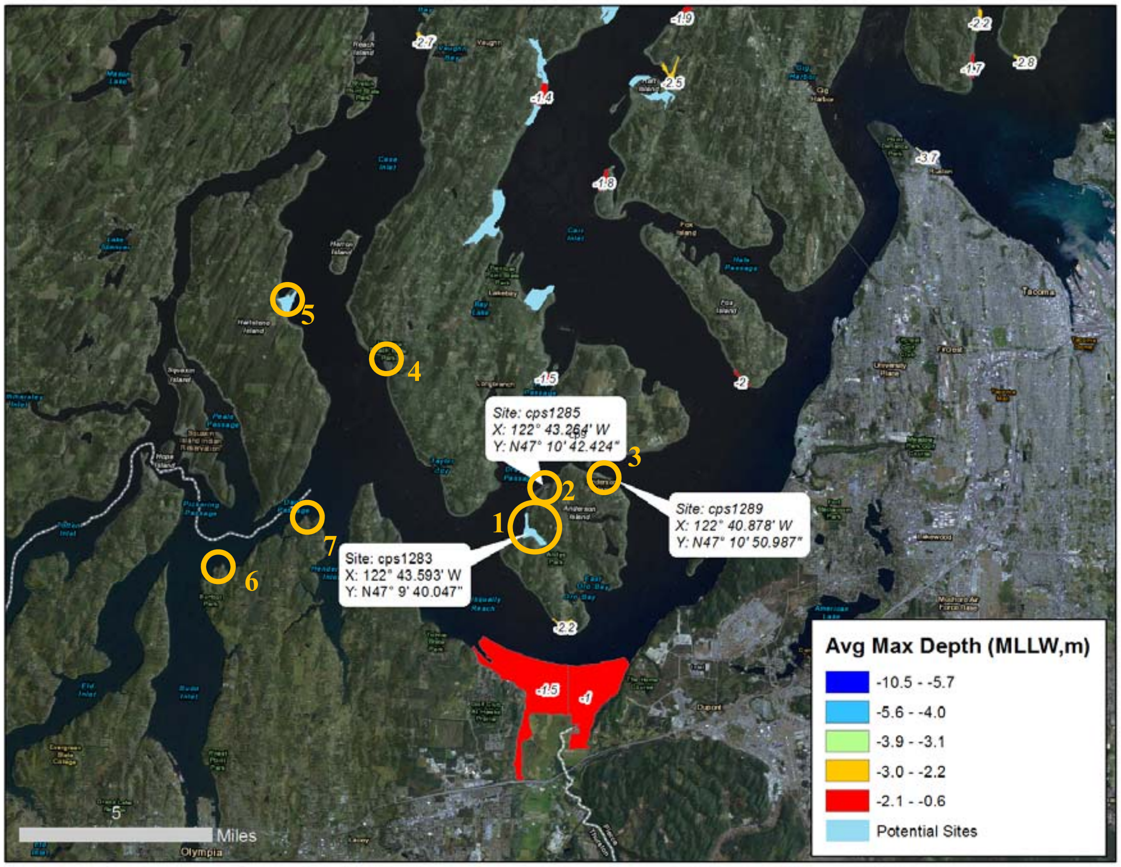

Figure 1. Proposed locations for surveys in the South Sound region (yellow numbers correspond to site names in the text). Average maximum depth shading is for eelgrass known to be in the region.

- South Sound
  - 1 - Amsterdam Bay (west side of Anderson Island)
  - 2 - NW Anderson Island
  - 3 - NE Anderson Island
  - 4 - Joemma State Park
  - 5 - Hartsten Island (by McMicken Island)
  - 6 - Zangle Cove (Dover Point)
  - 7 - Dickerson Point

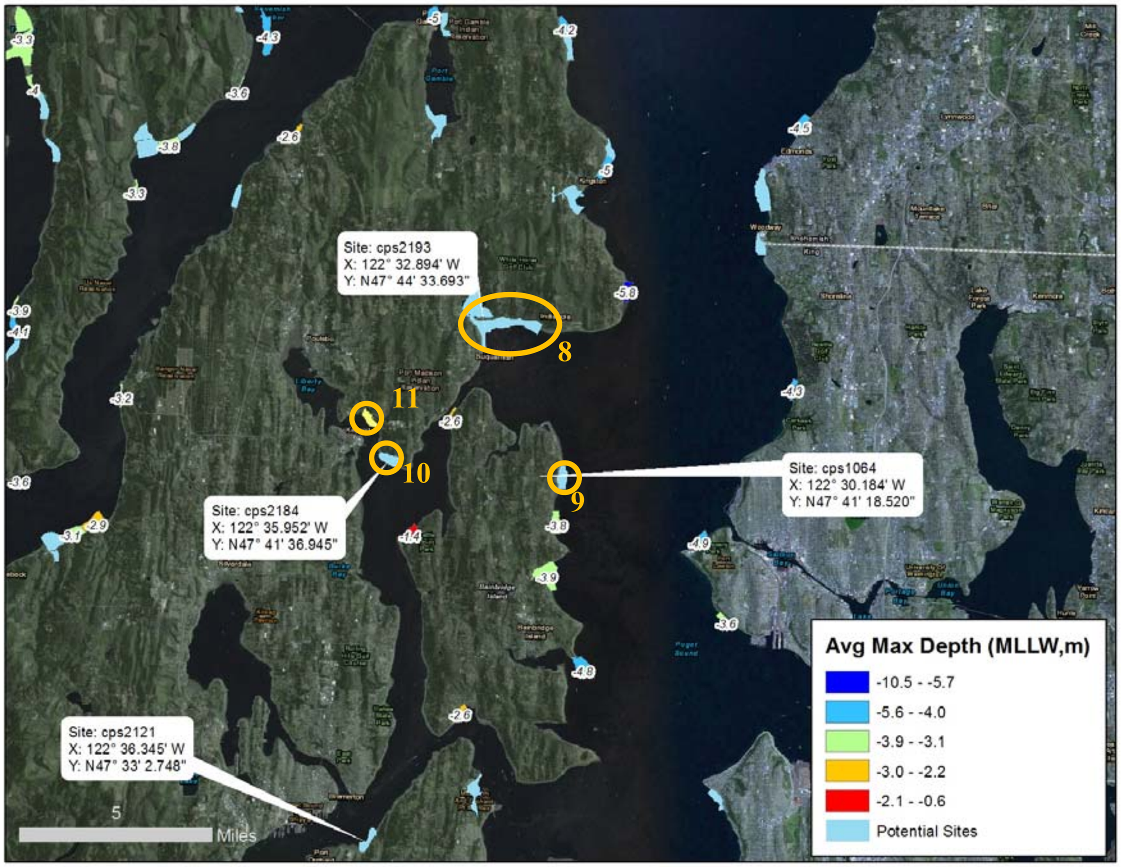

Figure 2. Proposed locations for surveys in the East Kitsap County region. Average maximum depth shading is for eelgrass known to be in the region.

- East Kitsap County
  - 8 - Miller Bay
  - 9 - Fay Bainbridge State Park
  - 10 - Liberty Bay Mouth (SE site)
  - 11 - Liberty Bay Mouth (NW "why not" site)

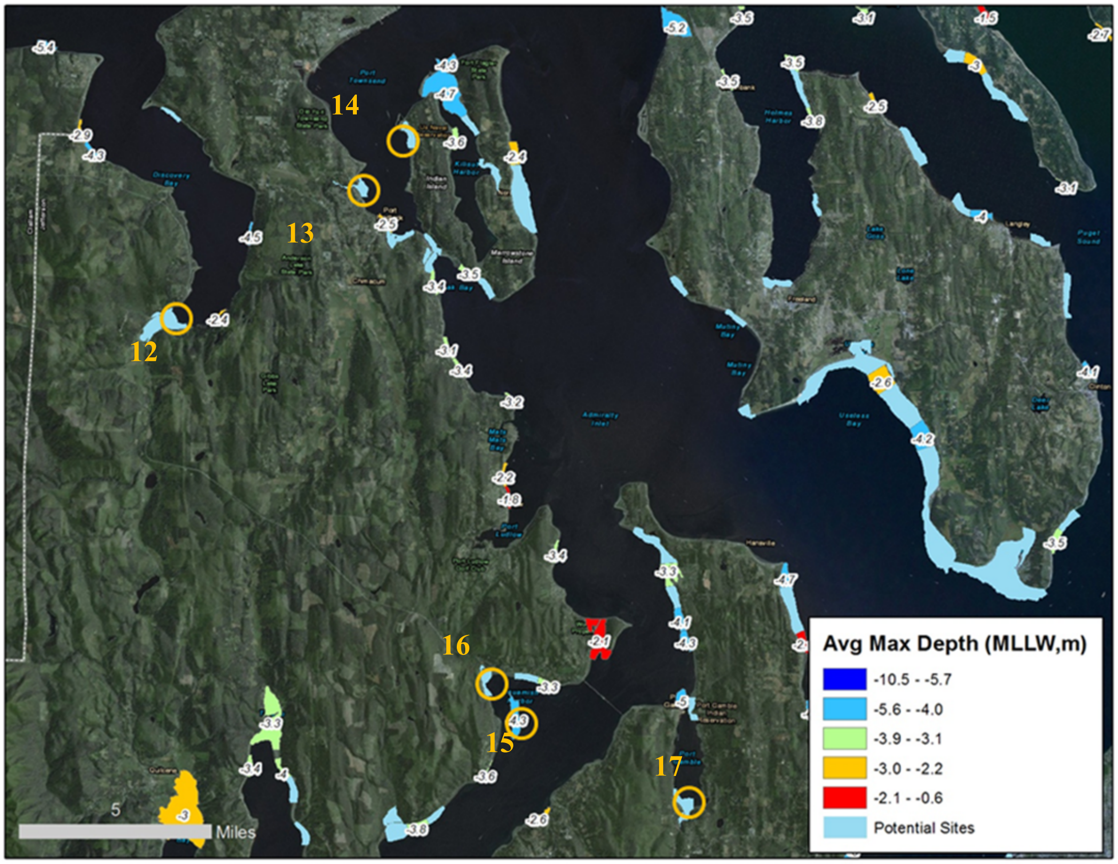

Figure 3. Proposed locations for surveys in the Upper Hood Canal/Quimper Peninsula region. Average maximum depth shading is for eelgrass known to be in the region.

- Discovery Bay/Quimper Peninsula/Upper Hood Canal
  - 12 - Discovery Bay
  - 13 - Port Hadlock/Irondale
  - 14 - Indian Island
  - 15 - Squamish Harbor (Case Shoal)
  - 16 - Squamish Harbor (head of the bay)
  - 17 - Port Gamble Bay

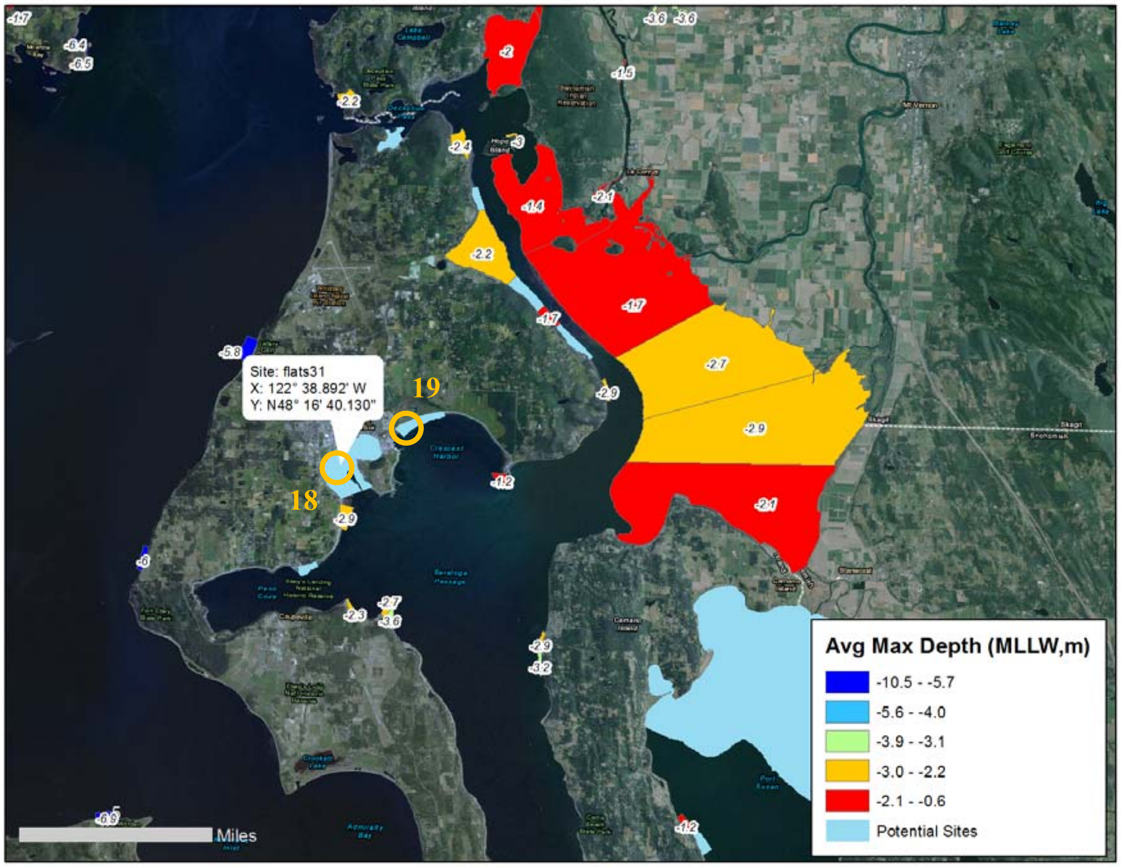

Figure 4. Proposed locations for surveys in the Whidbey Island region. Average maximum depth shading is for eelgrass known to be in the region.

- Whidbey Island
  - 18 - Oak Harbor
  - 19 - Crescent Harbor

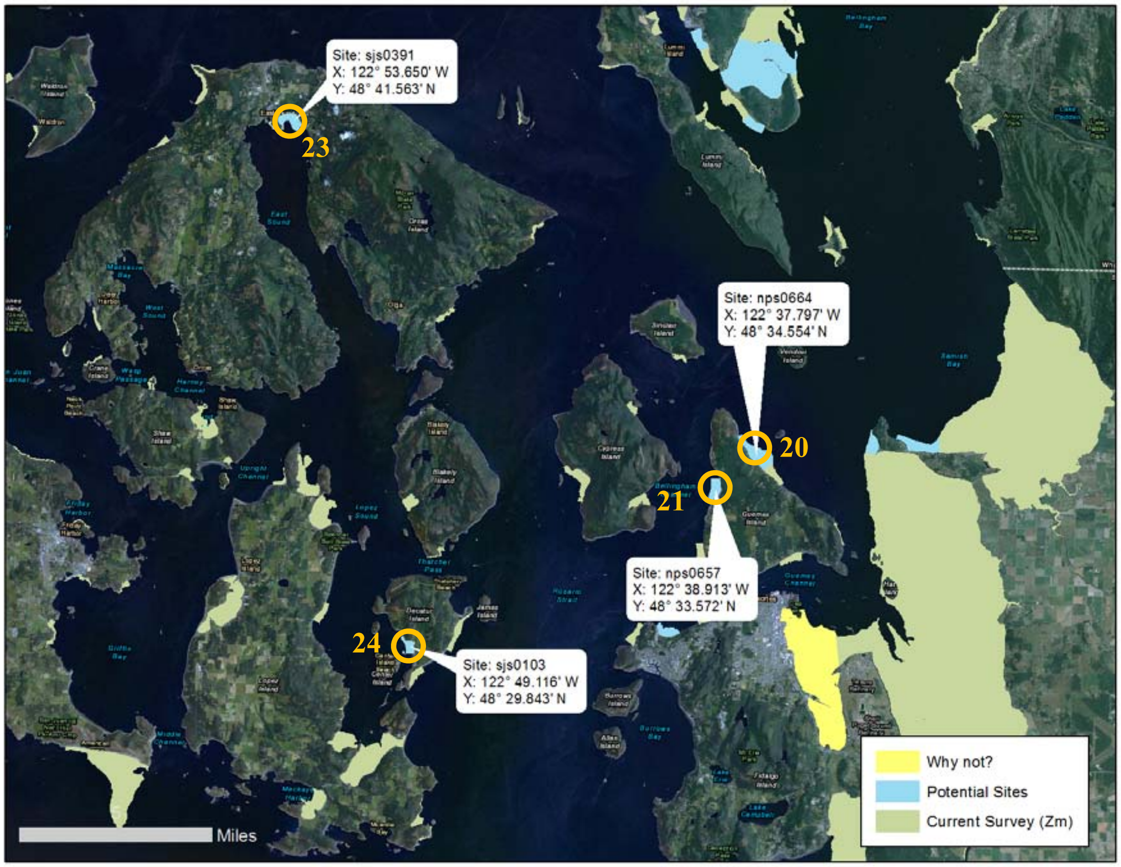

Figure 5. Proposed locations for surveys in the San Juan Island region.

- San Juan Islands
  - 20 - Guemes Island (east)
  - 21 - Guemes Island (west)
  - 22 - Orcas Island
  - 23 - Decatur Island

The site surveys were conducted using drop cameras from PNNL Marine Sciences Laboratory (MSL) research vessels. Diving was ultimately not conducted during these surveys for two reasons. First, the shortened length of the day meant the surveys had to be conducted efficiently while there was daylight. Diving is a time-consuming process and some of the sites would have been missed if divers had been deployed. Second, the drop cameras provided the necessary information for this step of the process.

The primary goal of the surveys was to look for the presence or absence of eelgrass at the site. At most sites with eelgrass, a sample was taken for DNR as part of a separate genetic analysis study. If eelgrass was not found at the site, other characteristics were evaluated to determine potential suitability for supporting eelgrass populations. These other factors included the following:

- **Depth**. Eelgrass is very sensitive to the available light and as such is usually found in discrete depth ranges. These ranges can vary with the region in response to variables such as average attenuation of light in the water column and tidal amplitude.
- **Sediment grain size**. Sediment composition is important for successful eelgrass growth and anchoring. While it can handle some coarser material, eelgrass prefers sediment that is sandy to muddy sand without too much organic material. Sites that were too muddy or too rocky were excluded.
- **Exposure**. Areas that appeared prone to being overly exposed to storm activity were given lower preference because higher wave energy can dislodge and uproot eelgrass plants, especially when they are newly transplanted and have not had time to develop an extensive rhizome mat. This was often subjective and often relied on other clues such as shoreline characteristics and substrate grain size.
- **Identification of potential stressors**. Areas with obvious stressors, such as a mooring field, were also ranked lower in this process. Reducing these potential stressors allows the best possible chance for success in any restoration activities.

2.3 Test Plantings

Using the results of the site surveys (see the Results section), nine test plots were chosen at five locations throughout Puget Sound. In all areas except Westcott Bay, the eelgrass was planted in a small rectangular plot (30 to 45 m^2) marked with screw anchors and polyvinyl chloride (PVC) stakes at the corners to be later identified for monitoring (see Figure 6). A summary of the sites can be found in Table 1. The summary indicates the individual test plot, the global positioning system (GPS) coordinates at the inshore corner on the left side facing the shore, the depth of the substrate at the marked corner corrected by the predicted tide to feet Mean Lower Low Water (MLLW), the length and magnetic direction (from the GPS point) of the sides parallel and perpendicular to the shore, and the estimated number of shoots planted.

In Westcott Bay, the design of the planting plots was modified slightly to cover a wider depth gradient (see Figure 7). A baseline was established perpendicular to shore, spanning the desired depth range, and marked at each end with a screw anchor. GPS coordinates were taken at both screw anchors to aid in reestablishing the baseline at a later time. At five predetermined depths along this baseline, a row 5 m wide, parallel to shore, was planted with eelgrass in the same manner described below (i.e., a cluster of five anchor staples per square meter). To locate these sites for monitoring, the distance along the baseline was noted and a PVC stake was placed on each end on the row. The summary of the coordinates, direction of the baseline, depths, and number of shoots planted for both sites in Westcott Bay is given in Table 2.

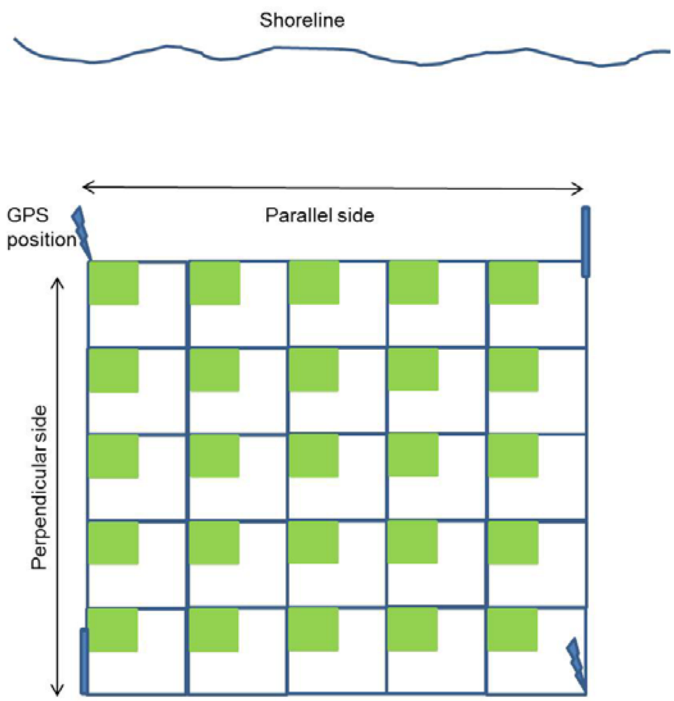

Figure 6. Schematic of a test plot used for the eelgrass test planting. Captions show the orientation identified in Table 1. The green filled squares indicate where eelgrass was planted. The corner of the plot where the GPS position and depth were taken is indicated. The angled corner marker (i.e., lightening) indicates the location of screw anchors, and the cylinder post indicates the location of a PVC stake. The actual dimensions of the plot varied with the number of plants available (see Table 1 for the details).

Table 1. Summary of the test plots planted in the South Sound and in Liberty Bay. A schematic of the plots can be seen in Figure 6 to explain the orientation of the data.

Location	Coordinates	Depth (ft MLLW)	Parallel Side	Perpendicular Side	# Shoots
Amsterdam Bay shallow	047° 09.636'N 122° 43.666'W	-3	6 m 225°M	6 m 315°M	720
Amsterdam Bay deep	047° 09.641'N 122° 43.669'W	-5	6 m 225°M	6 m 315°M	720
Joemma SP shallow	047° 13.337'N 122° 48.579'W	-3	6 m 102°M	6 m 198°M	712
Joemma SP deep	047° 13.321'N 122° 48.605'W	-5	6 m 102°M	6 m 198°M	712
Zangle Cove	047° 08.733'N 122° 53.594'W	-4	5 m 010°M	9 m 100°M	872
Liberty Bay 1	047° 42.227'N 122° 36.309'W	-5	6 m 165°M	6 m 255°M	720
Liberty Bay 2	047° 42.600'N 122° 36.841'W	-5.5	5 m 120°M	6 m 210°M	600

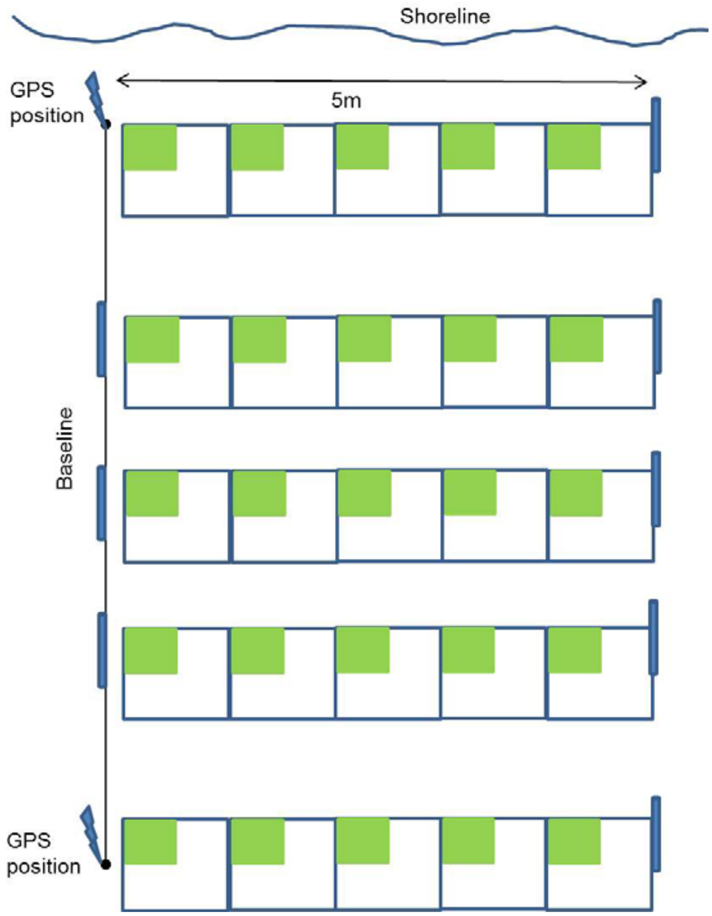

Figure 7. Schematic of a test plot for eelgrass test planting in Westcott Bay. Specifics for each site are summarized in Table 2. Markings are similar to those in Figure 6.

Table 2. Summary of the test plots planted in Westcott Bay. A schematic of the plots can be seen in Figure 7 to explain the orientation of the data.

Location	Inshore coordinates	Offshore coordinates	Bearing of baseline	Distance on baseline (m)	Depth (ft MLLW)	# shoots planted
Head of Westcott	048° 36.107'N 123° 08.364'W	048° 36.110'N 123° 04.443'W	255°M	0	-4.0	448
				18	-4.5	
				36	-5.0	
				50	-5.5	
				95	-6.0	
Middle of Westcott	048° 35.787'N 123° 09.652'W	048° 35.783'N 123° 09.608'W	90°M	0	-5.0	472
				16	-6.0	
				30	-7.0	
				44	-8.0	
				57	-9.0	

The eelgrass was planted using methods used by researchers at the MSL and proven successful in the Pacific Northwest. Eelgrass shoots, including rhizomes, were harvested from nearby healthy donor meadows (with the exception of Westcott Bay [see below]) and placed immediately into coolers of cold seawater. These coolers were brought to the shore for processing. The water in the coolers was periodically changed to keep the plants cool. Onshore, a sorting station was established with shaded tables containing trays periodically filled with fresh seawater to maintain cool temperatures. The eelgrass was then taken from the cooler, cleaned of sediment and excess material, and sorted for shoots with viable rhizome material (complete with root hairs). These roots are critical for successful transplantation. Shoots were separated, or kept in small bundles on the same rhizome, and placed into groups of four before being attached to turf staples by the rhizomes so the roots overlapped and the blades stuck out to the sides (see Figure 8). The eelgrass was attached using a paper tie that decomposes in a short period of time and allows the eelgrass to grow naturally. The staples help anchor the eelgrass shoots in place until the rhizomes can attach to the substrate. These staples are then planted by SCUBA divers at the site by lifting a small amount of sediment with a trowel, inserting the staple, and then covering the base of the plants with sediment. Plants were planted in clumps of five staples, resulting in a checkerboard pattern of 20 shoots/m^2, to act as nuclei for natural dispersal while covering a larger area.

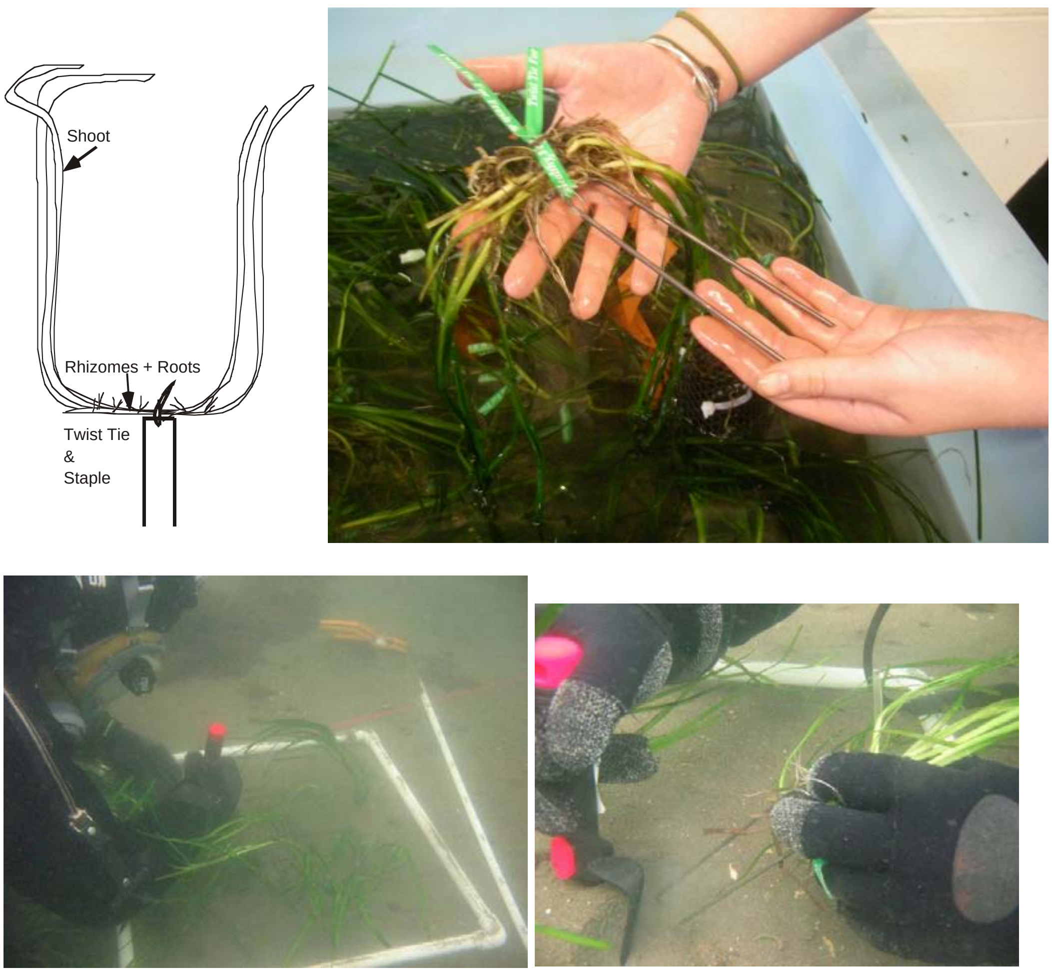

Figure 8. Diagram and photo of eelgrass attached to the turf staple for planting; examples of divers planting the eelgrass using a quadrat for reference.

Specifics for each of the sites chosen are given in the following sections grouped by region for simplicity, and a description of the site and planting conditions is provided to better describe the test plots.

2.3.1 South Sound Observations

Three locations were planted in the South Sound region north of Olympia, Washington (Figure 9) due to the uncertainty in eelgrass dynamics for the region. Eelgrass for all the sites was harvested in Thompson Cove on the southern point of Anderson Island on 4 June 2013 (Figure 9). Transplants were done on the two subsequent days in five test planting plots. Details for these sites are given in Table 1, but site-specific observations follow.

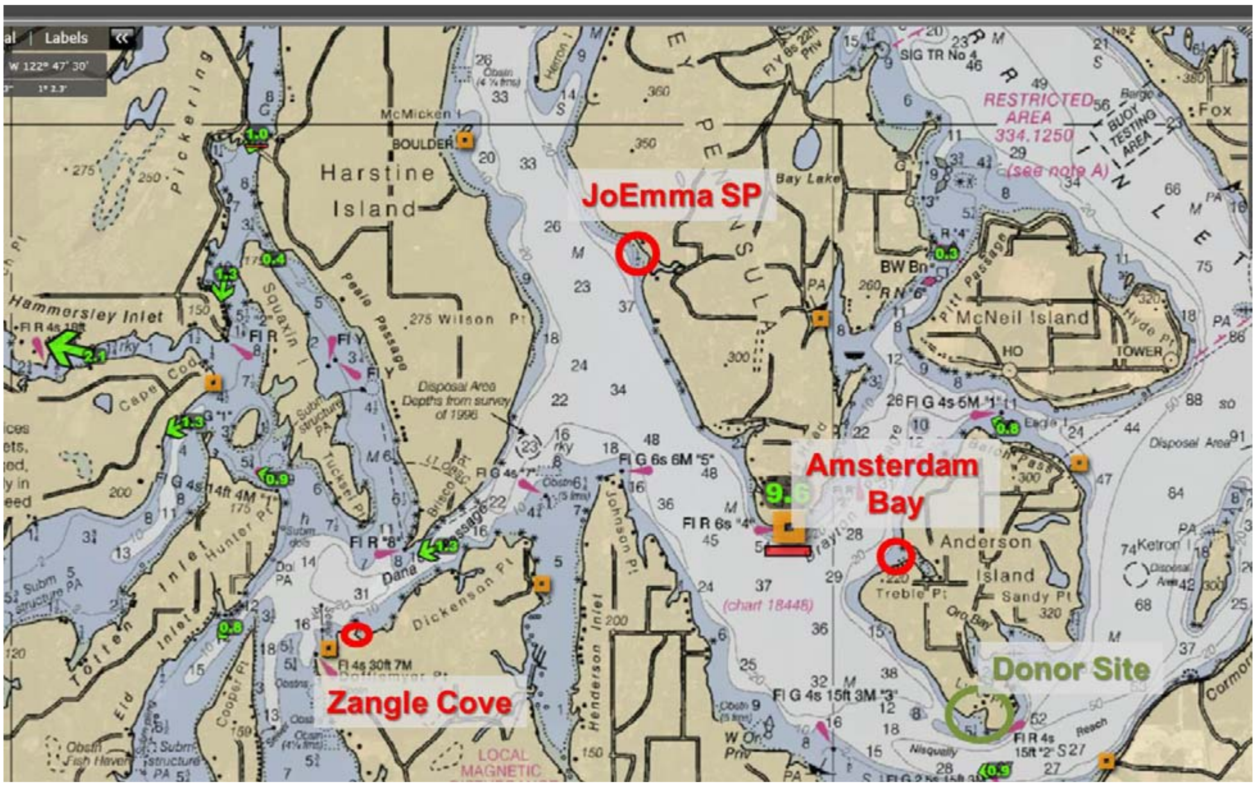

Figure 9. Specific locations for the eelgrass donor site and three transplanted test sites in the South Sound region.

Joemma State Park. Two test plots were planted in the waters off Joemma State Park on the west side of the Key Peninsula on 5 June. These plots were located at two different depths to the south of the park dock and mooring areas to minimize the impact of boaters on the test plantings. The sediment at the shallower plot was slightly more coarse (sandy gravel) than that of the deeper plot, indicating higher wave energies, but both were within acceptable ranges for eelgrass. At the time of planting, the divers experienced a noticeable current. Visibility was good throughout the dive and the site was easily visible throughout the planting process.

Amsterdam Bay. Two test plots were planted off Amsterdam Bay on the east side of Anderson Island. The sites are located on the shoreline shelf off the property of an interested landowner who offered to watch for potential disturbances. Like those at the state park, the two plots off Amsterdam Bay were placed at two different depths. The sediment was finer at both of these sites than at Joemma State Park, but there was no noticeable difference between the two plots. Visibility was not quite as good at these sites, but the site could be seen at times. Aa significant amount of drift *Ulva* was noticed at one point during the dive, but the site did not appear to be a depositional area. A light sensor array was also installed at this location.

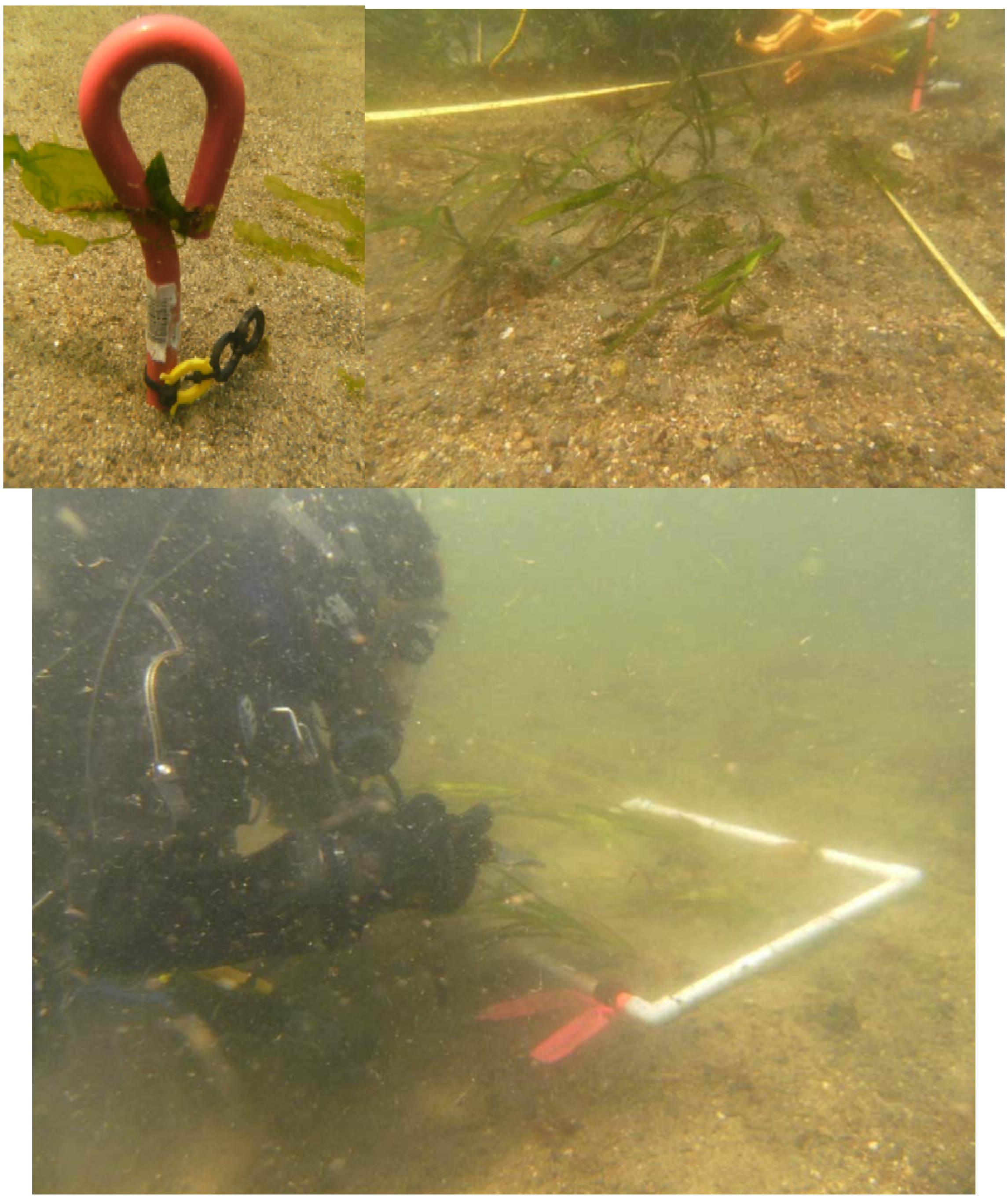

Figure 10. Planting eelgrass off Amsterdam Bay. Photos show a screw anchor used to mark the corner of the test plot, planted eelgrass next to a baseline tape, and a diver planting eelgrass using a 0.25-m^2 quadrat for reference.

Zangle Cove. Residents of this cove toward the mouth of Budd Inlet have expressed an interest in preserving and restoring eelgrass to DNR for some time. At least one small patch of eelgrass is located in the cove, and it was decided to do one test planting around the same depth as this patch. The test plot was established adjacent to the north side of the existing patch. It was observed that the offshore edge of the plot was slightly shallower and coarser than the inshore edge, which has more fines mixed into the sediment. It is thought that the plot was located on the edge of a sandy alluvial fan formed by the tidal slough/creek at the south end of the cove. The divers also noticed a current at this site, but by the end of the dive it had largely stopped. The visibility at the site worsened with the decrease in the tidal current, but was good enough to see the site. Some geoduck may be present at the site. Smaller crabs (>~10 cm), mostly *Cancer gracilis*, were also noted buried in the sediment.

2.3.2 Liberty Bay Observations

Eelgrass was harvested at a donor site off Miller Bay on the Kitsap Peninsula for the test plantings in Liberty Bay (Figure 11). Harvesting and planting were done on 7 June 2013. The test planting plots were located in a small cove near the mouth of the bay in a section of Poulsbo called Lomolo. Anecdotal data suggest eelgrass was historically located in this area. The site is a relatively flat section of the bay and questions about the water quality drive some of the uncertainty associated with the restoration of the area, so researchers decided to plant two shallow plots in different sections of the cove. The sediment was finer than that in the South Sound sites and contained some mud with the sand. This led to poor visibility at the site, especially when the divers were working, and it was difficult to see large sections of the site while planting. There is also a significant amount of drift algae (predominately brown algae) at the site, which may pose a disturbance for the eelgrass transplants, but the researchers do not know if this is an ephemeral or persistent feature of the site.

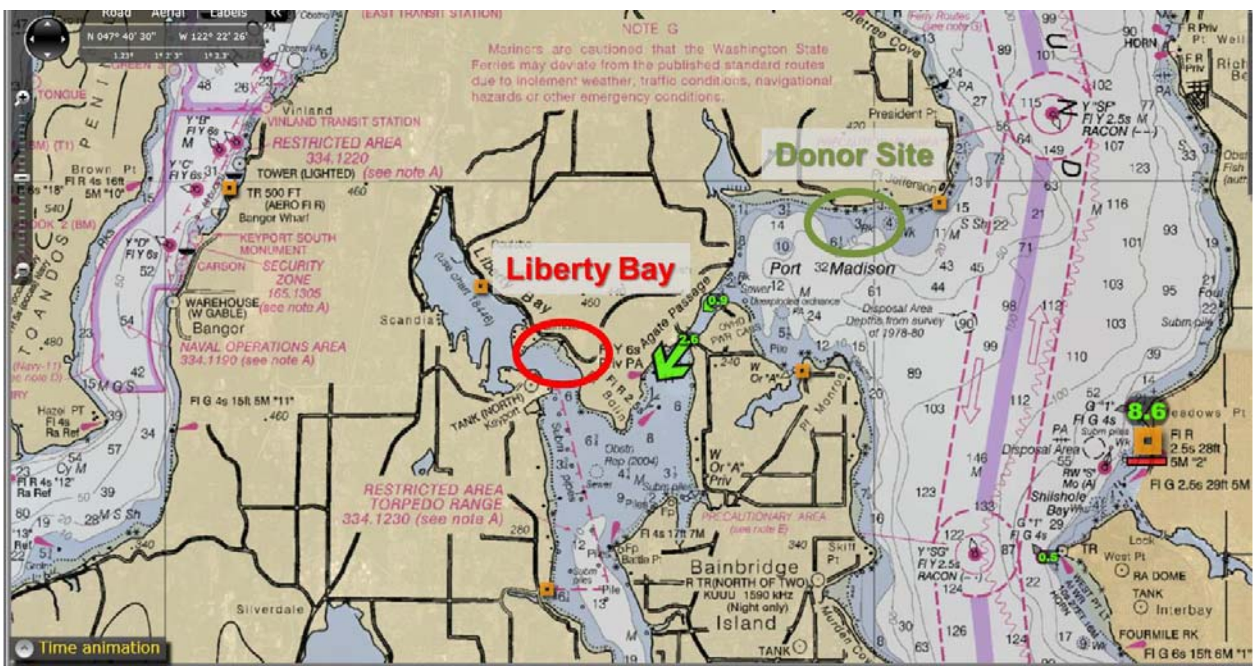

Figure 11. Locations of the donor and planting sites near Liberty Bay.

2.3.3 Westcott Bay Observations

Two test planting plots were established in Westcott Bay (Figure 12), an area with high historical eelgrass cover that experienced an unexplained eelgrass decline in recent years. The topography inside the bay is relatively flat, so the plots were modified to cover a wider depth range (as described above). Plots were therefore located in two areas of the bay; one at the head of the bay and one closer to the mouth near the termination of the natural meadows (according to DNR monitoring and observations during the planting). It was also decided to use plants from the MSL eelgrass tanks rather than harvest the larger plants outside the bay on San Juan Island that might be better adapted to deeper, clearer water. All planting was done on 14 June 2013. The plot at the head of the Westcott Bay had very soft sediment with a significant mud component. A shallower shoot depth was used during planting here to avoid anoxic sediment layers. The finer sediment also reduced visibility during planting to very short distances, making visibility at the site difficult. The second site was better for visibility and had sandier substrate. Some small boulders were placed randomly about at both sites, but none directly interfered with the planting.

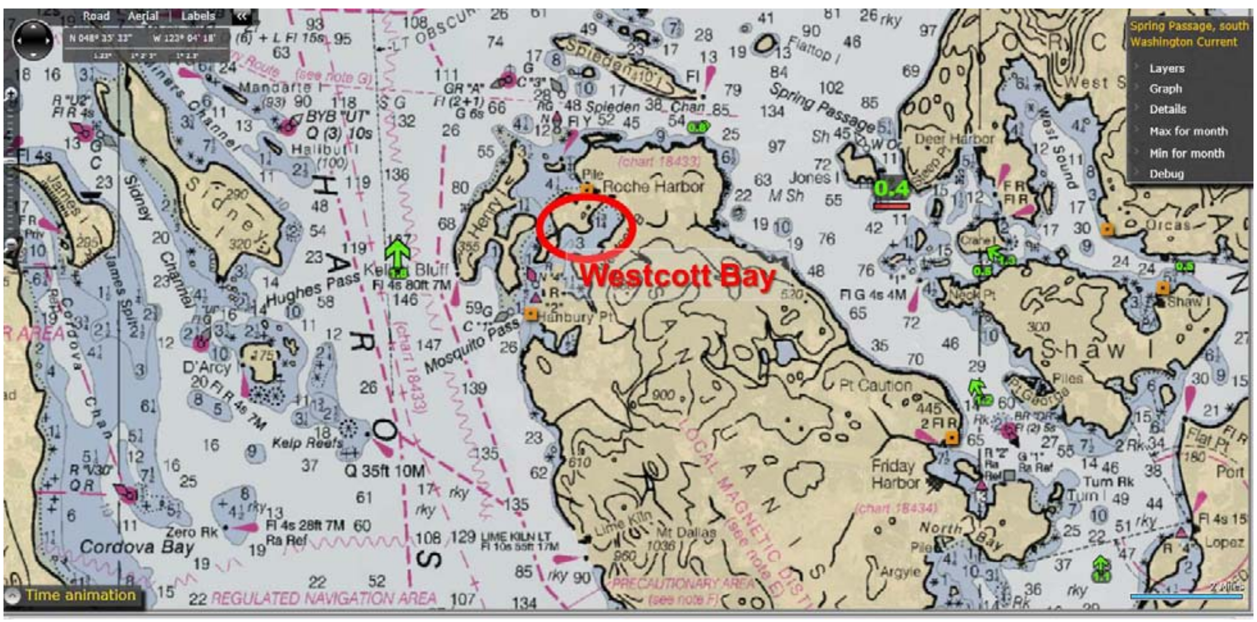

Figure 12. Location of the Westcott Bay test planting area on northern San Juan Island.

Two different sensors were deployed during the planting operations to monitor environmental conditions at the sites. The first, a HOBO Pendant (Onset, Bourne, MA USA) temperature/light data logger was attached to the inshore screw anchor of each test plot. While this data logger can record light levels, it was difficult to clean of biofoul and was therefore primarily deployed to record temperature fluctuations until the monitoring trip the next spring. To evaluate regional light availability and attenuation, Odyssey PAR (Photosynthetic Active Radiation) Recorders (Dataflow Systems, Christchurch NZ) were deployed in each region. These sensors were deployed in pairs 1 m apart in depth to calculate the attenuation of light in the water column (Figure 13). The lower sensor was located at approximately the same depth as the eelgrass canopy at each site. Sensors were placed in a holder that kept the sensors upright and oriented to the south, but also facilitated cleaning from a boat or person wading at lower tides. A third sensor was placed on land at Anderson Island to provide data about light reaching the surface of the Puget Sound. The intent was that these sensors would be used for a few months in the summer and hopefully a few months more in the winter. No sensors were deployed in Liberty Bay due to logistical difficulties. The other two sensors were placed at the following locations:

- Amsterdam Bay: 047° 09.632'N, 122° 43.671'W
- Westcott Bay: 048° 36.106'N, 123° 08.381'W.

2.4 Qualitative Surveys

At least once during the year after planting, research divers visited each transplant site to perform a qualitative evaluation of the site. While shoot counts were not conducted, the divers could obtain a general understanding of how the transplants were doing after the summer season. Divers located the site using the stakes and screw anchors placed during planting operations and swam the entire area. Observations were transmitted to surface support personnel on the research vessel (via wireless underwater communications) during the dive. These observations included comments about the apparent abundance and health of the plants, potential disturbances, water clarity, other biological organisms, and sediment changes. Photographs and videos were taken during these dives to document the site conditions. The light sensors, when present, were collected during these dives to retrieve the light data. These surveys were conducted in October 2013 in Liberty Bay and in December 2013 for the rest of the test plots.

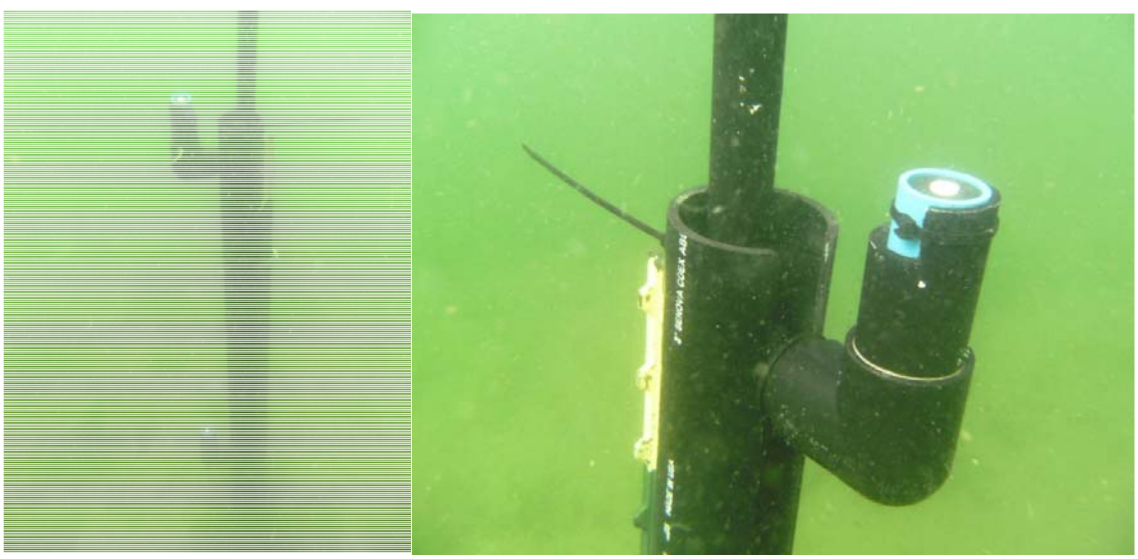

Figure 13. Odyssey light sensors deployed regionally near the eelgrass test plantings.

2.5 Quantitative Surveys

After approximately a year (i.e., March 2014), surveys were conducted at each of the test plots to determine the survival of the transplanted shoots. These surveys were conducted by research SCUBA divers counting all the shoots remaining at the test plots and determining the survival at each location. Divers first identified the site by locating the marking stakes/anchors and laying a transect tape to delimitate the perimeter of the plot (in Westcott Bay, the transect tapes were used to mark the baseline and perpendicular transects). A 1-m^2 quadrat was then moved along the plot such that every square meter of the plot was evaluated. All eelgrass shoots inside the quadrat were counted and the data recorded by support personnel on the research vessel. Other observations were also recorded during these surveys, especially if they might help explain the results of the survey (e.g., staples pulled out of the sediment or biological disturbances such as burrows).

3.0 Results

3.1 Field Observations at Potential Sites

MSL Scientific Dive Team scientists spent 5 days investigating each site on the list. The nature of these surveys was qualitative observation, so what follows in this section is a summary of the field notes for each location.

Amsterdam Bay (west side of Anderson Island). This site has two distinct locations: a flat shelf along the shoreline and a partially enclosed lagoon (Amsterdam Bay proper; see Figure 14), and neither had any signs of eelgrass. The lagoon entrance is protected by a shallow sand bar that could potentially contribute to recruitment limitation in the bay, preventing seeds or source plants from the protected waters. The sediment is primarily sand with a few finer grain sizes. Some small red and green algae were found in the lagoon. The site appears to be suitable to planting, but it could be a little shallow and exposed during summer spring low tides. The bay is also ringed by residential docks that could produce some boat traffic in the area. The outer shelf is similar in sediment composition with small patches of red and green macroalgae. Deeper there are more turfing macroalgae (probably Dictyota sp.) in large patches. Site appears to have good protection from most directions. Could be a candidate site for planting if a good handle on the appropriate depth for this area of South Sound can be determined. Might also be interesting to plant a couple of small test plantings at a few depths on the flat to experimentally determine the appropriate depth range.

Figure 14. Chart photo of Amsterdam Bay on Anderson Island.

NW Anderson Island. No eelgrass was found at this site. The substrate was sandy, but the slope and narrow depth range in this part of the Sound would only allow a very narrow fringe in this area if anything. The site is not necessarily recommended for planting, but it is a possibility.

NE Anderson Island. No eelgrass was found at this site. This site was obviously more exposed and the sediment reflected this with noticeably more cobble in the mix. The site is not recommended for planting.

Joemma State Park. No eelgrass was found at this site. The substrate was sandy and got a little coarser toward shore. It was largely devoid of autotrophs. There are some moorings and a dock at this site, but there is room along the shore away from these potential stressors for restoration. The site has potential as a transplant site.

Hartsten Island (by McMicken Island). No eelgrass was found at this site. We looked on both sides of McMicken Island. The sediment appeared to be sand along most of the depth gradient, but there were large deposits of *Ulva* covering the area. Under the drift algae there also appeared to be a layer of other organic material on the substrate, suggesting this may be a depositional area. Gut reaction is this would not be a good place for a test planting.

Zangle Cove/Dover Point. DNR identified this site as a site of some interest, particularly because the residents are interested in protecting the nearshore and the site is so deep into the Sound. No eelgrass was seen in the cove, only some scattered green and red algae. The substrate (sand) and grade seem appropriate for eelgrass, but the appropriate depth here is unknown and there may be significant exposure from storms from the north. A few private docks are near the mouth of the cove that may indicate some vessel traffic in the summer. The site could be considered for transplanting, but is not the highest on our list. (Note: a patch of eelgrass was later observed at the site when divers returned to plant the test plot.)

Dickerson Point. This site was also mentioned by DNR as a site of interest. Again no eelgrass was seen here, only some small macroalgae. A number of extensive sand dollar beds were inside the cove. This site has a number of moorings in addition to shoreline docks, suggesting there may be more traffic in the summer than other places. As with the cove at Dover Point, the substrate and grade seem appropriate for eelgrass, but there are uncertainties about the target depth, exposure of the cove, and the vessel traffic. The site could be targeted for transplanting if these concerns were explored more deeply.

Miller Bay. Eelgrass was found in a significant fringe between the shallow intertidal flat and deeper slope. While patchy in places, the eelgrass looked healthy and dense where present. The shallowest of the eelgrass may have been *Z. japonica* in a narrow band, but this was not confirmed. There were a number of moorings along this stretch of shoreline. An eelgrass sample was taken for genetic analysis.

Fay Bainbridge State Park. Like the Milwaukee Dock site south of Eagle Harbor where we are working on another project, this site had an extensive, healthy, dense eelgrass population along the shoreline. An eelgrass sample was taken for genetic analysis.

Liberty Bay Mouth. Potential site (SE site): No eelgrass was found at this site. The sediment was sand appropriate for eelgrass outside the little cove in deeper water, but once inside the points (headlands) defining the cove the sediment becomes very coarse with cobbles and a lot of shells. Suggests there is more energy inside the shallow cove and therefore not a good candidate site for transplanting.

Liberty Bay Mouth − Why not? site (NW site). Eelgrass was also absent at this site. The sediment was sandier than the cove immediately to the southeast; it had some fines and some shell hash. The sediment becomes coarser at the shallower edges, but could work for eelgrass. The divers will try to dive on this site when they return to Bainbridge at the end of November. It would be useful to run the model in this area with the new attenuation coefficients for Liberty Bay to determine if light could be limiting even at shallow depths here. This could be a potential site for planting though.

Discovery Bay. Eelgrass was seen in the flat at the head of Discovery Bay. The meadows were thick and looked healthy, but were patchy in their distribution. Substrate was sand with some organic matter on top. A sample of the eelgrass was taken here for genetic analysis.

Port Hadlock/Irondale. Eelgrass was also found at this location, but the population was patchy in distribution. Individual patches were not very big or densely populated, possibly due to adverse effects from the abundant *Ulva* seen at the site. The patches were thicker and more dense in shallower water. Sandy substrate. A sample was taken for genetic analysis, but only four plants were procured instead of the normal five.

Indian Island. Eelgrass was also found at this site. Distribution was patchy, but some of the patches were large and densely populated. The eelgrass seemed healthy, but there was a lack of animal life noticed on the camera (i.e., many fewer sea stars, crabs, and fish). Up shallow, one patch of eelgrass seemed shorter and may have been *Z. japonica*. Substrate overall was largely sand with some organic materials and at times patches of *Ulva*. No genetic sample was taken here.

Squamish Harbor (Case Shoal). This shoal is largely boulders and cobble on top with sandy sides. Eelgrass was found where the sand was present on both sides of the shoal. Kelp and other macroalgae were found on the harder substrates. Eelgrass meadows were sometimes large and contiguous and sometimes patchy, depending on the substrate. The eelgrass looked healthy.

Squamish Harbor (head of the bay). This area seemed to have the appropriate substrate, but very little eelgrass was found on this flat. The coarse sand substrate on the shallower flat only has some *Ulva* and sparse red macroalgae. It is a possible site for planting, but with the abundance of eelgrass in the vicinity, it is not likely to be recruitment limited. One hypothesis for the lack of eelgrass at this site is the geometry of the bay. There is a chance that any wind energy from the west to south-southwest concentrates waves onto the shallow flat at the head of the bay, creating periods of energy too great for the eelgrass.

Port Gamble Bay. The initial impression of this bay was of fine sediments and water probably too turbid for eelgrass. However, the shallower flat closer to the stream at the south end of the bay appeared to have better substrate that was sandier. No eelgrass was found, and only small clumps of red and brown macroalgal clumps were observed. It is a possible site for transplanting if it does not interfere with (or is interfered with by) other restoration options in the bay, because there may be recruitment limitation given the very narrow and shallow opening to the bay. We would probably want to explore the attenuation more in the area to gain a better understanding of the role light plays in limiting eelgrass growth.

Oak Harbor. Time was running short in the day for the sites on Whidbey Island, so only the area roughly indicated by the circle was sampled in Oak Harbor. However, healthy looking eelgrass was found at the site. While the eelgrass density was relatively thin at the deeper depths of its distribution, it became denser as the depth became shallower. Five shoots were collected for genetic analysis.

Crescent Harbor. Eelgrass was also present here, although it was much more sparse than at Oak Harbor. There may be more energy in this area because there were ripples in the sand substrate. This site is also relatively close to the Navy base and there are unidentified markers on the chart for the shoreline along the beach. This area should probably be avoided at this point. No genetic samples were taken here because of the proximity to Oak Harbor and the time limitations of the day.

Guemes Island – West. This site has extensive and apparently healthy eelgrass meadows, but at a relatively low-population density. The substrate is coarse sand with some shell material. There are many mooring balls (~24) at this site, suggesting vessel traffic in the summer. Shoots were collected here for genetic analysis.

Guemes Island – East. This site was quickly surveyed to establish the presence of eelgrass, but the strong breeze and potential for entanglement with moorings at the site prevented and extensive survey of the site. However, eelgrass was found at this site similar to the west side of the island (healthy but sparse coverage mixed with kelp). No genetic sample taken because of the obstacles at the site.

Orcas Island (East Sound). Eelgrass was found at this site in a very extensive and dense meadow. Eelgrass had many hooded nudibranchs on the blades. The upper edge of the eelgrass looked like it might have contained some *Z. japonica*, but all the shoots brought on board appeared to be *Z. marina*. Samples of the deeper *Z. marina* were taken for genetic analysis.

3.2 Qualitative Surveys of the Test Plots

Qualitative surveys were conducted in October 2013 at the two Liberty Bay sites and in December 2013 for the remaining seven test plots. Notes from each site are included below and while they are not quantitative the notes do provide insight into the condition of the test plots before the worst of the winter season had occurred.

Liberty Bay. The two sites were obviously different in their condition at the end of the summer. The northwestern plot appeared to be doing well and had significant amounts of eelgrass present. The original checkerboard planting pattern could still be seen throughout much of the plot and some of the plant clusters appeared to retain most of their shoots (others were maybe half the original number on average although quantitative counts were not made). The plants themselves looked healthy and many had grown to at least 0.5 m long or more. There were still some drift algae, mostly kelps, but not nearly as much as seen in the summer. In contrast, the southeastern plot had very little eelgrass. Divers only estimated 5 to 8 shoots *total* in the whole plot. The shoots seen were generally thinner than those at the other plot and definitely shorter (probably none were over 15 cm). The substrate looked similar and the drift algae was the same between the sites. Interestingly, there was a boat sunk on the bottom a body length away from one of the corner markers that was never seen while planting due to the poor visibility that day. There was no evidence that the boat has moved though, so it doubtful the boat is the cause of the eelgrass mortality. The boat was about 6 m long and 2 m wide. There are only two obvious differences between the sites from the surface. The northwestern site was along the northern shoreline facing south. It was also offshore of a small tidal creek. The other site was on the eastern shore with a westerly exposure and no input from shore.

Zangle Cove. Both the natural eelgrass outside the transplant plot and the planted shoots looked very good. The plants were larger (most 0.5 to 0.75 m) than expected for the time of year and appeared healthy and green. An abundance of crab parts were observed, as well as a live kelp crab, a couple of red rock crabs, and a few moon snails moving through the area. Divers guessed that of the original pattern planted between 75 to 90% of the plots still had eelgrass. Some of the clumps could have even spread out a little, but that could have been where they were close to the native bed or observer bias.

Anderson Island. The light sensors were located and not as fouled as expected. The eelgrass at the shallower site was largely gone; only one really good clump of eelgrass remain and then some isolated shoots. The plants present were generally short. There were small remnants of drift *Ulva*, but most of the mat observed by DNR in the summer and fall was gone. The deeper site looked much better and even though larger pieces of *Ulva* were still present there was approximately 50% (or less) of the original coverage. The plants looked healthier and were larger (some over 0.5 m) than those at the shallower site. There were a few kelp crabs in the plot and numerous snails on the eelgrass blades.

Joemma State Park. Again, eelgrass at the shallower site was not as abundant as at the deeper site. The divers estimated that the shallow site had less than 50% of the original coverage, and the plants were smaller (but healthy looking) and patchier than the deeper site. Some staples looked like they had the sediment scoured from around them or (more likely) had been partially pulled from the substrate. These were primarily located in the northwest corner of the plot. There were a lot of small snails. On the swim between the sites, the divers came across some debris that appeared to be some aquaculture or construction fencing. This was approximately 0.75 m wide by at least 8 m long. It was stationary during the dive, but certainly not cemented in and probably moved about in strong currents or wave action. The fencing was close to but not in the deeper transplant plot. Between this fence and the site we also found a number of large rebar "staples" normally used to anchor the aquaculture fencing. The deeper site appeared to have 75 to 80% of the original coverage with healthy looking plants. A few turf staples were partially exposed at the deeper site, but they were not as numerous as in the shallow site. A few moon snails were present as well as many of the smaller snails on the eelgrass blades.

Westcott Bay. At the head of the bay site, no plants were observed at any of the depths planted. One dead shriveled black blade was found still attached to a staple, but no other evidence of the eelgrass transplants was observed. The bottom was still very soft with a very fine layer of sediment on top that was easy to resuspend. There was also a lot of biological disturbance at this site—worm castings, burrows (shrimp?), and buried graceful and Dungeness crabs. There was no clear indicator of why the eelgrass disappeared (e.g., light, substrate, disturbance, etc.), but the divers were sure they were sampling the correct site because they were able to find all the stakes marking the sites and some staples. A number of staples were partially exposed (could indicate biological disturbance). The light sensors were intact and only partially fouled. Some eelgrass was found at each depth at the middle of the bay site and much of it appeared to be healthy. The average lengths went from approximately 0.25 m to over 0.5 m but did not really follow the depth gradient in pattern (e.g., the deepest site had some of the shorter plants but also had two clusters with the longest blades). While there were plants at each depth, overall survival did not appear that high. While this was a qualitative survey, the divers estimated between 70 to 80% mortality at each of the depths from what was planted. The grass left did not look bad but not all of it was there. All the site markers at each of the depth were located.

3.3 Quantitative Surveys of the Test Plots

The overall success of the test plantings is ultimately determined by the survival of the shoots transplanted to the site. These data, collected during the spring quantitative surveys, are summarized in Table 3. Of the nine plots planted, five had eelgrass mortality exceeding 90% and are probably not good candidates for large-scale planting. The two sites at Joemma State Park had excellent survival and actually had more shoots present in 2014 than planted in 2013. Two sites had some mortality as expected with the first year of this type of transplanting (e.g., Vavrinec et al. 2007), but did well enough to warrant further investigation for large-scale restoration at the site. Observations for each location are given below to put these survival estimates into perspective. Results for the temperature and light data are presented in a separate report.

Anderson Island. Both plots were largely devoid of eelgrass, and the few shoots present were very small and anemic. The sediment was finer here than at Joemma State Park and could be resuspended with ease, although it did settle out relatively fast. A few staples were exposed and raised above the sediment surface.

Joemma State Park. Both the plots had significant numbers of eelgrass present. The plants appeared to be slightly bigger in the deeper site and more numerous on the eastern side of the plot. Survival in the plots was not uniform; some sections of the plot only had eelgrass survival approach 50%, while other sections had survival estimated well over 100% (see Figure 15). In fact, some of the better portions of the deeper site had greater than 300% survival and portions of the planted checkerboard pattern had filled in enough to mask the patchy nature of the initial planting. A current was observed at this site during the survey and the sediment was coarser at both plots than it was at any other plot tested.

Zangle Cove. Eelgrass was present throughout the extent of the test plot and although there was an overall decrease in the eelgrass planted, the mortality was less than 40%. The plants looked healthy even early in the growth season. The planting was conducted on what appears to be the edge of a sandy alluvial fan from the stream on the southern part of the cove. So, while the site planted appears to be favorable for eelgrass restoration, it is uncertain how other parts of the cove will respond to large-scale restorations efforts.

Liberty Bay. While the northwest plot was doing well in October during the qualitative survey, both sites had lost most of the transplanted eelgrass when surveyed in the spring. Nothing was obvious during the surveys to explain this high mortality, but the water clarity in Liberty Bay has been questioned and may have contributed to the decline over the winter.

Table 3. Summary of survival at all the test planting plots and recommendations for future restoration at the location.

Site	Shoots planted	Area planted (m^2)	Shoots counted	Survival	Ave end density (shoots/m^2)	Recommendation
Joemma SP deep	712	36	930	130.6%	25.83	Larger planting
Joemma SP shallow	712	36	775	108.8%	21.53	Larger planting
Zangle Cove	872	45	539	61.8%	11.98	Targeted planting?
Westcott middle bay	472	25	81	17.2%	3.24	Trial planting
Anderson Is. deep	720	36	14	1.9%	0.39	Do not plant
Anderson Is. shallow	720	36	11	1.5%	0.31	Do not plant
Liberty Bay (NW site)	600	30	8	1.3%	0.27	Do not plant
Liberty Bay (SE site)	720	36	3	0.4%	0.08	Do not plant
Westcott head of bay	448	25	0	0.0%	0.00	Do not plant

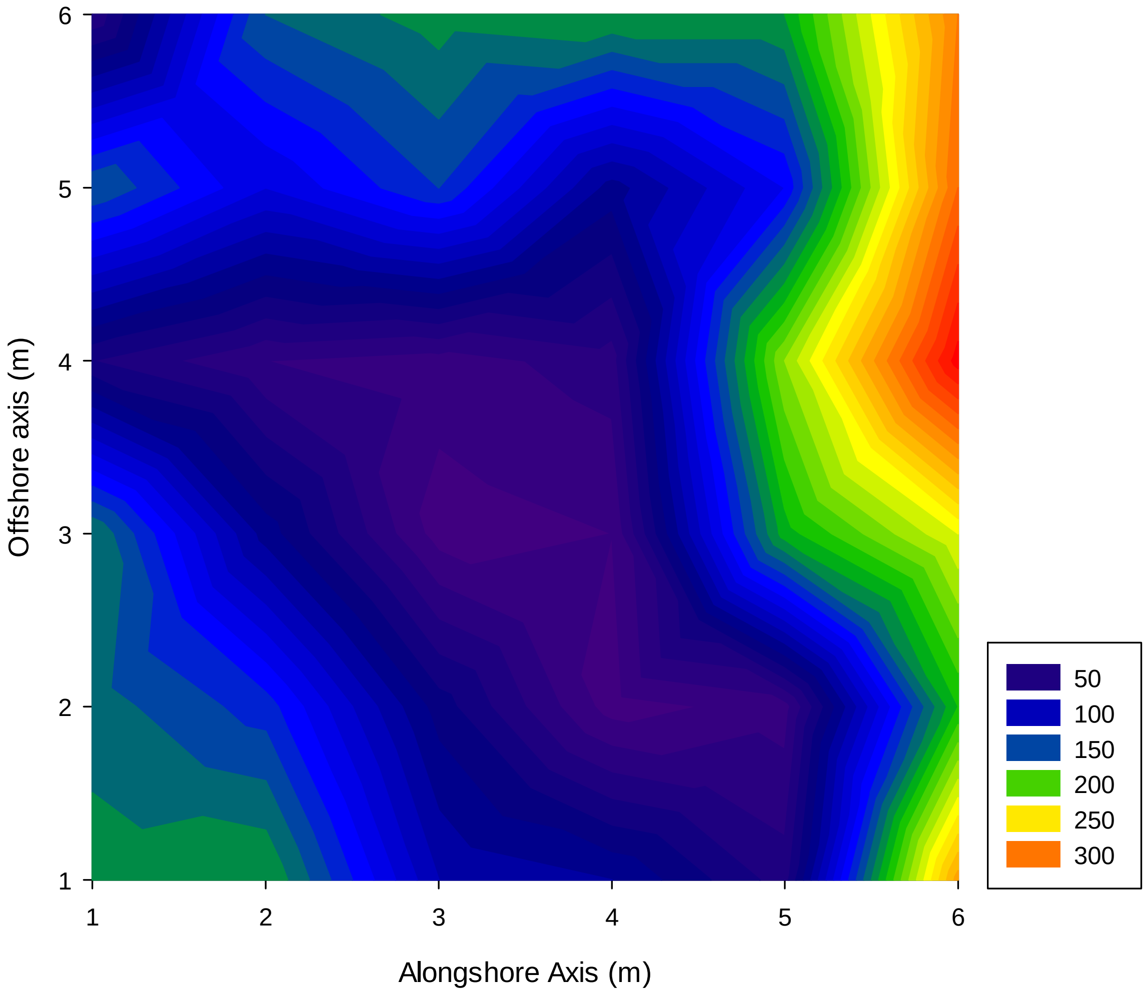

Figure 15. Percent survival of eelgrass at the Joemma State Park deeper test plot.

Westcott Bay. The head of the bay location had complete eelgrass mortality before the end of the summer and does not appear to be suitable for eelgrass at this time. The sediment was much finer and appeared to be slightly anoxic. There also appeared to be much biological disturbance at the site with many shrimp burrows and buried crabs. The middle of the bay site had better survival although the overall mortality was greater than 80%. Some eelgrass was found at each depth. The sediment was coarser at this site than at the head of the bay, and while there appeared to be less frequent biological disturbance, the magnitude may have been greater (e.g., larger crabs and much larger burrow mounds).

4.0 Discussion and Conclusions

The fact that this study is attempting to locate areas that are currently devoid of eelgrass but could support large-scale eelgrass restoration puts the process immediately at a disadvantage. Often the eelgrass is not present for a reason even if that reason is not readily apparent to researchers and managers. For this reason, part of the current study is to work with shoreline managers and state agencies to identify areas where better use management or environmental cleanup may open areas to supporting eelgrass populations. However, even given the difficulties involved, direct restoration (i.e., planting) can be an important tool in meeting the DNR goals for 2020. Restoration may be appropriate in these managed areas as they become suitable to support eelgrass. Planting is also a viable option in areas of low recruitment potential to initiate a population or supplement an ailing one. For the planting to be successful though, restoration specialists need to maximize the chances for success by minimizing stressors and testing the area before committing valuable resources to the task. It is therefore important to look at the test plot survival data and to identify patterns that may help guide future actions.

One of the original intents of the study was to study regional trends in eelgrass suitability, and the initial site visits spanned a large geographic area. In the areas north of the South Sound, many of the sites already possessed eelgrass and therefore the study was left with marginal sites to plant. It may therefore be difficult to draw large-scale regional inferences from these sites. For example, Liberty Bay did not do well in the test planting and we would not recommend large-scale restoration planting at the site due to the high mortalities observed in the test plots. However, large healthy eelgrass meadows are known to be in the region and relatively close to Liberty Bay off Miller Bay and Bainbridge Island. That said, the conventional wisdom going into this project was that South Sound was largely inhospitable to eelgrass and restoration would be hard in that area. Yet our data indicate that portions of the South Sound may be very good for supporting eelgrass growth, at least along a particular depth gradient along the shoreline. The decline on Anderson Island suggests that a strong southwest exposure may be undesirable in the region, so future work should focus on the north or east sides of land masses (e.g., Zangle Cove) or where the fetch is minimized (e.g., Joemma State Park). Joemma State Park also has significant flushing resulting in coarser sediments, and this may be beneficial in the South Sound where light penetration into the water column may be a concern. The larger sediment size would be harder to resuspend and further limit light availability. Patchy suitability and potential recruitment limitation may make parts of the South Sound ideal for restoration and meeting the goals established for 2020.

The Liberty Bay site is probably limited by water-quality issues. The water coming off the mudflats of upper Liberty Bay can be extremely turbid at times, as was the case when the site was planted. The fact that one of the sites was still doing well in December, despite the drift kelp in the area during planting, suggests that this drift algae was not the agent of mortality in the plots. It is more likely that light levels just became too low in the winter months to support the eelgrass and until the turbidity in the bay is improved the likelihood of producing eelgrass meadows such as those outside Liberty Bay is slim. Further investigation would be needed to verify this because no light sensor was deployed in Liberty Bay.

The Westcott Bay locations provide two distinct examples for the study. While the cause is unknown, it is obvious that the head of the bay site is unsuitable for eelgrass populations at this time. Very turbid waters, high biological disturbance, and sediment with high hydrogen sulfide were all observed at the site and could contribute to the inhospitable environment. The middle of the bay location had better survival and may be suitable for larger restoration. The remaining eelgrass was healthy and appeared to be doing well. Interestingly, some eelgrass was found at each depth suggesting the stressors on eelgrass at this site are not strongly associated with depth. And these results are supported by observations of natural eelgrass meadows on the southern side of the bay at approximately the same distance into the bay. Given the comparatively low survival at this site though, such a restoration should be undertake carefully and deliberately so as not to waste donor stock if something goes wrong.

The recommendations for moving forward with these sites can be seen in Table 3. It is not recommended that planting be done at the Anderson Island, Liberty Bay, or the head of Liberty Bay. Large-scale restoration planting is recommended at Joemma State Park. Planting may also be attempted at Zangle Cove and the middle of Westcott Bay, although more information may be needed to help ensure the best chances for success. In Zangle Cove, additional testing to ensure that changes in sediment type away from the alluvial fan will not compromise the probability of success would be beneficial. Likewise, the Westcott Bay site should be planted carefully because it may be just on the edge of suitability.

The results suggest a couple of other recommendations. First, the process outlined in this technique coupling modeling, local experience, and in situ testing is promising for maximizing the chances of large-scale restoration success and appears to be a good way to identify undesirable sites before extensive resources are wasted. Secondly, additional sites need to be identified in the South Sound that do not have a southwest exposure and have coarser sediment. These sites should be investigated and planted on a small scale to determine their appropriateness for planting and contributing to the larger restoration goal for 2020.

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