Videographic Eelgrass Survey of Island County Selected Areas

Final Report

by

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Submitted To:

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May 14, 2001

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Table of Contents

1 Introduction ... 1
2 General Methods ... 3
2.1 Overview ... 3
2.2 Eelgrass Parameters Measured ... 6
2.2.1 Basal Area Coverage ... 6
2.2.2 Patchiness Index ... 6
2.2.3 Maximum and Minimum Depth Characteristics ... 8
2.2.4 Mean Shoot Density ... 8
2.2.5 Leaf Area Index ... 9
2.3 Site Sampling Plan ... 9
2.4 Within-Site Transect Sampling ... 11
2.5 Plant Sampling ... 12
2.6 Water Quality Sampling ... 12
2.7 Data Analysis ... 12
2.7.1 Correcting Depths To MLLW ... 12
2.7.2 Videotape Post-Processing ... 13
2.7.3 Estimating Parameters ... 13
3 Utsalady (Skagit Bay South) ... 14
3.1 Site Definition and Description ... 14
3.2 Site Specific Methods ... 14
3.3 Results ... 14
4 Oak Harbor ... 24
4.1 Site Definition and Description ... 24
4.2 Site Specific Methods ... 24
4.3 Results ... 24
5 Penn Cove ... 32
5.1 Site Definition and Description ... 32
5.2 Site Specific Methods ... 32
5.3 Results ... 32
6 Holmes Harbor ... 43
6.1 Site Definition and Description ... 43
6.2 Site Specific Methods ... 43
6.3 Results ... 43
7 Maxwelton ... 50
7.1 Site Definition and Description ... 50
7.2 Site Specific Methods ... 50
7.3 Results ... 50
8 Summary ... 58
9 Discussion ... 61
10 Conclusions ... 66
11 Recommendations ... 66

12 References 68
13 Acknowledgements 72

Appendix A. Parameter estimation equations A-1
Appendix B. Underwater videographic survey methods B-1
Appendix C. Benthic grab sampling methods C-1

List of Tables

Table 1. Washington State Department of Fish and Wildlife preliminary eelgrass/macro algae habitat survey guidelines (Source: Washington State Department of Fish and Wildlife). 4
Table 2. Comparison of WDFW preliminary eelgrass/macro algae habitat survey guidelines, Submerged Vegetation Monitoring Project methods, and methods used in the Island County Eelgrass Survey. 5
Table 3. Tide prediction and reference stations used to correct depth measurements to the mean lower low water datum. 13
Table 4. Parameter estimates and 95% confidence limits for the three strata in Skagit Bay South. 20
Table 5. Parameter estimates and 95% confidence limits for two eelgrass beds in Oak Harbor. 30
Table 6. Estimated basal area coverage, variance, and confidence limits for Penn Cove. 39
Table 7. Patchiness indices and depth parameter estimates for Penn Cove. 40
Table 8. Estimated basal area coverage, variance, and confidence limits for Holmes Harbor. 47
Table 9. Patchiness indices and depth parameter estimates for Holmes. 48
Table 10. Parameter estimates and 95% confidence limits for Maxwelton. 56
Table 11. Summary of transect sampling parameter estimates for all sites. 59
Table 12. Summary of benthic grab sampling parameter estimates for the three sites sampled. 60
Table 13. Summary of water quality parameters for all sites. 60
Table 14. Site rankings by parameter and total “Relative Health Score.” 60

List of Figures

Figure 1. Location of sites surveyed during the December 2000 Island County underwater videographic eelgrass survey. 2
Figure 2. Schematic representation of two eelgrass beds with the same basal area coverage but different patchiness. 7
Figure 3. Sites sampled during the Washington Department of Natural Resources Submerged Vegetation Monitoring Project 2000 survey. 10
Figure 4. Illustration of the underwater videographic survey system. 11
Figure 5. Map showing the Skagit Bay South flats site defined by the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project. 16

Figure 6. Aerial photograph sequence showing the shoreline between Brown Point (a) and Utsalady Point (j). ... 17
Figure 7. Site map for Utsalady Bay. ... 18
Figure 8. Site map for Skagit Bay South. ... 19
Figure 9. Predicted tide heights for December 5, 2000 at three stations near the Skagit Bay South site (Stanwood, Crescent Harbor, and Ala Spit). ... 21
Figure 10. Depth records for transects 14 and 16 across Utsalady Bay. ... 21
Figure 11. Echosounder recordings taken from north-south transects across Skagit Bay on December 6, 2001. ... 22
Figure 12. Water quality profiles from Skagit Bay South. ... 23
Figure 13. An enlargement from a 1841 map drawn during the Wilkes Expedition. ... 26
Figure 14. A 1942 aerial photograph of Oak Harbor. ... 26
Figure 15. The dredged channel in Oak Harbor is clearly visible in this historical photograph (circa 1964). ... 27
Figure 16. A 1984 aerial photograph of Oak Harbor. ... 27
Figure 17. Aerial photographs taken in May 1993 of the small boat basin, Oak Harbor Marina and dredged spoils east of the spit. ... 28
Figure 18. Site map of Oak Harbor. ... 29
Figure 19. Water quality profiles from Oak Harbor. ... 31
Figure 20. Map of Penn Cove showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites. ... 34
Figure 21. Aerial photos of Penn Cove. ... 35
Figure 22. Aerial photo sequence of the northwest corner of Penn Cove where the largest and deepest eelgrass bed was observed. ... 36
Figure 23. Site maps for Penn Cove. ... 37
Figure 24. Photo of *Z. marina* and mussel beds in intertidal zone near Coupeville. ... 38
Figure 25. Photo of the varieties of *Z. marina* in the intertidal zone at Coupeville. ... 41
Figure 26. Water quality profiles for Penn Cove. ... 42
Figure 27. Map of Holmes Harbor showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites. ... 44
Figure 28. Aerial photo sequences for Holmes Harbor. ... 45
Figure 29. Site map for Holmes Harbor. ... 46
Figure 30. Water quality profiles for Holmes Harbor. ... 49
Figure 31. Map of the Maxwelton Watershed Shoreline showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites. ... 51
Figure 32. Aerial photos of the Maxwelton Watershed Shoreline region. ... 52
Figure 33. Site map for the Maxwelton Watershed Shoreline site. ... 53
Figure 34. Photo of a seagrass patch on the tide flat at Maxwelton Shoreline Watershed with a mixed stand of *Z. marina* and *Z. japonica*. ... 54
Figure 35. Histogram of depths where both *Z. marina* and *Z. japonica* were observed at the Maxwelton Watershed Shoreline site. ... 54
Figure 36. Photo of Black brant (*Branta bernicla*) grazing and resting on the tide flat at the north end the Maxwelton Watershed Shoreline site. ... 55
Figure 37. Photo of Mallard ducks (*Anas platyrhynchos*) and black brant at the Maxwelton Watershed Shoreline site. ... 55
Figure 38. Water quality profiles for the Maxwelton Watershed Shoreline site. ... 57

Figure 39. Historic eelgrass locations reported by Thom and Hallum (1990). 64
Figure 40. A 1841 map drawn during the Wilkes Expedition shows the depths in both Penn Cove and Oak Harbor, but does not report eelgrass. 65
Figure 41. Photographs of sampling equipment used during the Island County eelgrass survey. B-3
Figure 42. Sample screen from the real-time plotting system. B-4

1 Introduction

In 1998 the United States Congress passed the Northwest Straits Marine Conservation Initiative (HR 3461) to protect and restore degraded marine resources and habitats in the Northwest Straits (defined to be the open waters, nearshore areas and shorelines of the U.S. side of the Strait of Juan de Fuca and Strait of Georgia, as well as Puget Sound waters from the Canadian border to the south end of Whidbey Island). Scientific justification for the Initiative was based on observations of ecosystem stress in the Northwest Straits region:

- Declining salmon, bottom fish, and baitfish stocks;
- Closures of recreational and commercial shellfish beds;
- Degradation and losses of eelgrass bed, kelp forests, and other marine habitats;
- Dwindling populations of seabirds and marine mammals.

The Initiative established seven Marine Resources Committees (MRCs), one each in Clallam, Jefferson, Island, San Juan, Skagit, Snohomish, and Whatcom counties. These committees are citizen-based with representation from local and tribal governments, recreational and conservation groups and professional scientists and economists. The MRCs are guided and assisted by the Northwest Straits Commission, a thirteen member organizational body with seven MRC representatives and six members appointed by the Governor of Washington and the United States Secretary of the Interior.

The Northwest Straits Commission and the MRCs are not regulatory bodies. They must rely on existing authorities to implement their recommendations. Nevertheless, the success of the Initiative and individual MRCs will be evaluated using measurable standards of performance, including meeting the following benchmarks:

- A net gain in highly ecologically productive nearshore, intertidal, and estuarine habitat, and no significant loss of existing, high-value habitat; improve state, tribal, and local tools to map, assess, and protect nearshore habitat and prevent harm from upland activities;
- Measurable increases in factors that support bottomfish recovery, including sufficient amounts of quality protected habitat;
- Net reduction in the amount of shellfish areas closed to harvesting because of pollution;
- Establishment of scientifically based regional system of marine protected areas.

The Initiative is authorized for a six-year period, after which Congress must approve further funding. Presumably, MRCs must demonstrate progress in meeting the above benchmarks by 2004.

Demonstrating "net gains," "measurable increases," and "net reductions" requires baseline data. Thus, a primary objective of the Island County MRC is to acquire baseline information that describes the distribution of important habitats in the nearshore zone. Because the seagrass *Zostera marina* L. (eelgrass) provides critical habitat for outmigrating juvenile salmon (*Oncorhynchus* spp.) as well as other valued species (e.g., Pacific herring, *Clupea harengus pallasi*, Dungeness Crab, *Cancer magister* and black brant, *Branta bernicla*) (Phillips 1984; Simenstad 1994; Wilson and Atkinson 1995), this nearshore vegetation community was the primary target in the first year of habitat delineation.

The Island County MRC selected five priority sites for the first year study (Fig. 1): Utsalady, Oak Harbor, Penn Cove, Holmes Harbor, and the Maxwelton Creek Watershed Shoreline.

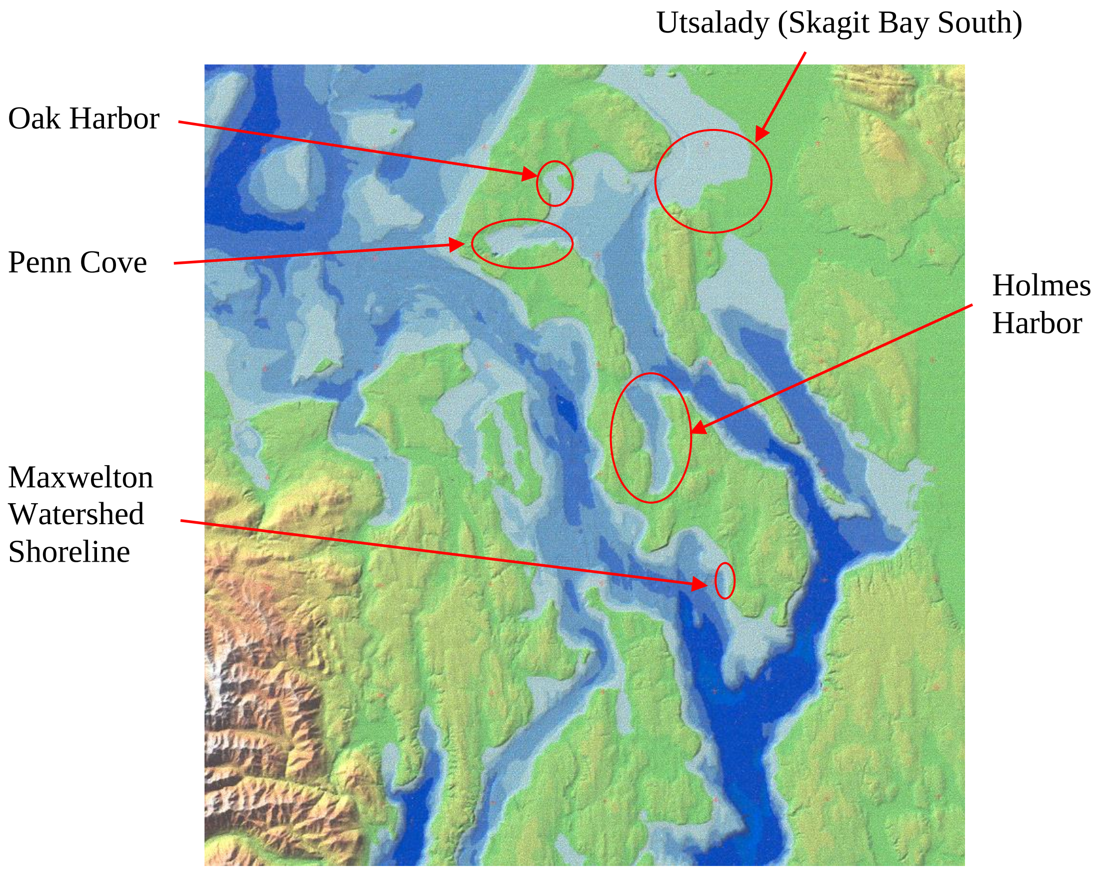


Figure 1. Location of sites surveyed during the December 2000 Island County underwater videographic eelgrass survey.

Utsalady is one of the most sensitive shorelines in Island County—it is ideal spawning habitat for surf smelt (*Hypomesus pretiosus*) (Pentilla 1999). It is the only stretch of shoreline in the County that is designated as an "Aquatic Conservancy" in the county's Shoreline Master Program. This designation was the result of a citizen petition to the County and severely limits certain types of future development.

Oak Harbor and Coupeville (in Penn Cove) are the two largest cities in Island County, and as such are subject to increased shoreline development. Coupeville is designated an Urban Growth Area under the State's Growth Management Act and has an existing sewage treatment plant. Surrounding Penn Cove also has a large mussel production enterprise.

In the Holmes Harbor region, Island County is exploring the possibility of designating Freeland (located at the south end of the bay) as an Urban Growth Area. Such a designation would result in higher residential densities and more intense commercial or industrial development, which in turn would require new local water, sewer and storm drainage infrastructures.

The Maxwelton Creek watershed is the largest watershed in Island County. Over the past decade the Maxwelton Salmon Adventure has been working to restore chum (*Oncorhynchus keta*) and coho (*O. kisutch*) salmon runs in Maxwelton Creek. Knowledge of seagrass distribution and density along the Maxwelton Creek Watershed Shoreline will contribute to a more comprehensive understanding of the habitability of this site for outmigrating the salmon.

The following chapter discusses the general methods used in this study. It is a somewhat detailed and lengthy chapter, but necessary to allow proper scientific review and replication of our work. At a minimum we recommend that all readers familiarize themselves with the methods overview (section 2.1) before proceeding to the five separate chapters (Chapters 3 through 7) containing descriptions, specific methods and results for each site.

2 General Methods

2.1 Overview

The contract between Island County and Marine Resources Consultants states that the Island County eelgrass survey shall use the same protocols as those being developed by the Washington State Department of Natural Resources. However, for the past decade the primary institutional guidelines for conducting eelgrass surveys in Puget Sound have been those set forth by the Washington State Department of Fish and Wildlife (WDFW). These guidelines were developed to help evaluate the potential impacts of site specific construction projects on nearshore eelgrass and macro algae habitats. Such projects are required to obtain a Hydraulic Project Approval from WDFW as part of the Department's "no net loss" policy for protecting eelgrass habitat.

WDFW publishes guidelines for four types of eelgrass/macro algae habitat surveys:

(1) <u>preliminary</u> surveys are applied to "proposed projects where eelgrass or significant macro algae habitats are suspected to be present in the vicinity of the proposed project";

(2) <u>intermediate</u> surveys are applied when a "proposed project is to be located within an area of documented eelgrass macro algae habitats, but where herring spawn has not been documented";

(3) <u>intensive</u> surveys are applied to "proposed projects located within an area of documented herring spawn";

(4) <u>post-project</u> monitoring surveys are applied to "those instances where statistical evaluation is deemed necessary."

Given the objectives for the Island County survey, we concluded that our methods also should follow, to the extent possible, the WDFW preliminary survey guidelines (Table 1). Note that preliminary surveys can be conducted at any time of year (all other types of surveys must be conducted between June 1 and October 1). The only preliminary survey guideline that seemed inappropriate for the Island County survey was the requirement to berth transects at 40 ft intervals. Violating this guideline seemed reasonable given the different objectives and geographic scope of the Island County survey.

Table 1. Washington State Department of Fish and Wildlife preliminary eelgrass/macro algae habitat survey guidelines (Source: Washington State Department of Fish and Wildlife).

Item	Guideline
1	The diver/biologist will survey transects perpendicular to and/or parallel to the shoreline including the outer extremities of the proposed project site.
2	Survey transects will include the entire project site and will be spaced at a maximum of 40 foot intervals.
3	Transect locations will be referenced to a permanent physical feature within the project site.
4	The qualitative distribution of macro algae species along each transect will be documented.
5	Substrate characterization along each transect will be documented.
6	A project site map will be developed indicating the qualitative distribution of eelgrass/macro algae species, substrate characterization, approximate depth contours and the approximate location of the proposed project features.
7	Approximate depth contours will be established for the project site based on mean lower low water equal to 0.00 (MLLW = 0.00). Tidal reference and correction should be noted.
8	Survey documentation will also include the time of survey, date of survey, turbidity/visibility, presence of invertebrate/vertebrate species and miscellaneous anecdotal observations pertinent to habitat characteristics of the project site.
9	Preliminary surveys may be conducted at any time during the year. Surveys from June 1 through October 1 most accurately reflect macro algae distribution and therefore preferable.
10	Results of preliminary surveys will be compiled and sent to the WDFW habitat manager for review.

The WDFW guidelines were designed for site specific projects and are not directly applicable for monitoring eelgrass resources over large geographic areas. On this larger scale, the primary monitoring effort for Puget Sound waters is the Puget Sound Ambient Monitoring Program (PSAMP). The geographic scope of the PSAMP includes all the inland marine waters of Washington State, from Cape Flattery to the west, Olympia to the south, and the Canadian border to the north. The Nearshore Habitat Program of the Washington State Department of Natural Resources (DNR) represents DNR as a component of the PSAMP and has responsibility to monitor temporal trends in submerged aquatic vegetation in Puget Sound. In 2000 DNR initiated the Submerged Vegetation Monitoring Project (SVMP) to assess spatial patterns and temporal trends in nearshore environmental indicators. The specific goal of this project is to monitor the temporal changes in maximum depth and Sound-wide distribution of eelgrass. The non-indigenous seagrass *Z. japonica* is not a target species for the SVMP.

The four specific objectives of the SVMP are: (1) capture temporal trends in eelgrass abundance and distribution in Puget Sound; (2) allow for analysis of trends over sub-areas that are defined by considering environmental and/or human use factors; (3) monitor vegetation parameters that are strong indicators of eelgrass extent and quality; and (4) consider environmental and anthropogenic gradients (stressors). The vegetation parameters measured are: basal area coverage (i.e., area of the seabed covered by at least one eelgrass shoot), patchiness index, minimum and maximum eelgrass depth statistics (range, mean, standard deviation), mean shoot density, mean leaf area, and leaf area index. If one substitutes “Island County” or a sub-region of Island County (e.g., “Holmes Harbor”) for Puget Sound, the four SVMP objectives are quite similar to those of the Island County eelgrass survey. The main difference is the geographic scope of the study area.

The methods used in this study follow the SVMP as required by the contract, and add features of the WDFW guidelines to make the final product acceptable to WDFW as a preliminary eelgrass/macro algae habitat survey (Table 2). The remaining sections of this chapter describe the methods in more detail.

Table 2. Comparison of WDFW preliminary eelgrass/macro algae habitat survey guidelines, Submerged Vegetation Monitoring Project methods, and methods used in the Island County Eelgrass Survey.

Item	WDFW Guidelines	Submerged Vegetation Monitoring Project	Island County Eelgrass Survey
Geographic scope	Site specific; usually less than 1,000 m of shoreline	Puget Sound Regional	Site specific (Maxwelton, Oak Harbor, Utsalady) Regional (Penn Cove; Holmes Harbor)
Survey design	Line transects	Line transects	Line transects
Transect berthing	Maximum 40 ft	Varies by site size	Varies by site size
Geo-referencing	Local permanent physical feature	Sub-meter differential global positioning system (DGPS)	Sub-meter differential global positioning system (DGPS)
Eelgrass (*Z. marina*) parameters	Qualitative distribution	Geo-referenced distribution, basal area coverage, patchiness index, mean minimum depth, mean maximum depth, mean shoot density, mean leaf area, leaf area index	Geo-referenced distribution, basal area coverage, patchiness index, mean minimum depth, mean maximum depth, mean shoot density, mean leaf area, leaf area index
Z. japonica parameters	None	None	Geo-referenced distribution, basal area coverage, patchiness index, mean minimum depth, mean maximum depth
Macro algae parameters	Qualitative description	None required; available depending on methods	None

Table 2. Concluded.

Item	WDFW Guidelines	Submerged Vegetation Monitoring Project	Island County Eelgrass Survey
Macro Invertebrates	Qualitative description	None required; available depending on methods	Green sea urchins, geoducks, mussels
Substrate parameters	Qualitative description	None required; available depending on methods	Geo-referenced qualitative categorization (sand, cobble/shell, rock)
Map	Required; showing eelgrass, macro algae, substrate, isobaths	Yes (eelgrass only)	Yes; showing eelgrass, macro invertebrates, substrate, isobaths
Vertical datum	Mean lower low water	Mean lower low water	Mean lower low water
Water quality data	Visibility/turbidity	Profiles for temperature, salinity, dissolved oxygen, pH, turbidity, photosynthetically available radiation (PAR)	Profiles for temperature, salinity, dissolved oxygen, pH, turbidity, photosynthetically available radiation (PAR)
Survey dates	Anytime	Preferred June - August	October 7; December 4 – 14

2.2 Eelgrass Parameters Measured

2.2.1 Basal Area Coverage

Basal area coverage is the number of square meters of the seabed that has eelgrass growing on it. For estimating this area we define the minimum mapping unit to be 1 m^2 and the minimum eelgrass density to be one eelgrass shoot (i.e., we are measuring eelgrass presence/absence regardless of density). An important feature of this parameter is that it can be estimated at the site, region, and Puget Sound level.

At the site level, we used methods described in Norris et al. (1997) and Norris and Hutley (1998) to estimate basal area coverage. Briefly, these methods involve the following steps: (1) conduct a series of line transects through the site and record all eelgrass locations; (2) draw a polygon around the eelgrass observations to define the bed perimeter and compute its area; (3) compute the average fraction of a transect that has eelgrass; and (4) multiply the average eelgrass fraction times the polygon area. When comparing basal area coverage over time, the polygon defining the bed perimeter must encompass all eelgrass observations from all time periods. The mathematical details are given in Appendix A.

2.2.2 Patchiness Index

A quantitative measure of “patchiness” (referred to as “grain” by Pielou 1977) can be computed by considering an eelgrass bed as a two-phase mosaic (i.e., a surface composed of two types of polygons—eelgrass and no eelgrass). Areas with eelgrass are called patches and those without are called gaps. Intuitively, the patchiness of an eelgrass bed is related to the length of the interphase boundary relative to the bed area. Beds with high patchiness have a high interphase boundary while those with low patchiness have a low interphase boundary (Pielou 1977).

Fig. 2 shows two rectangular eelgrass beds with the same basal area coverage, but much different patchiness. The interphase boundaries in the low patchiness (top) and high patchiness (bottom) beds are 36 and 132 units, respectively. In practice, it is not feasible to measure the length of the interphase boundary. However, a similar quantitative measure of patchiness is the number of interphase transitions that occur along a straight-line transect passing through the bed. In the example shown, both transects through the bed with low patchiness (top) have two transitions, while the two transects through the bed with high patchiness (bottom) have four and six transitions, respectively. We define the patchiness index to be the number of patch/gap transitions per 100 m of straight-line transect length.

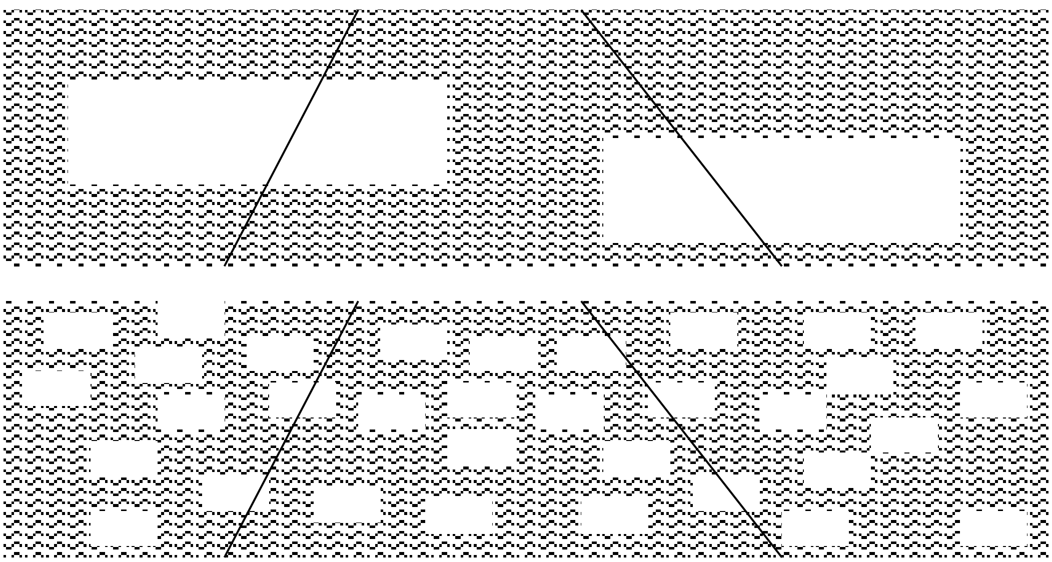


Figure 2. Schematic representation of two eelgrass beds with the same basal area coverage but different patchiness.

Basal area cover describes how much of an area is covered by eelgrass, but it does not provide information on the distribution within this vegetated zone. This issue is relevant as resource managers resolve controversies relative to the habitat value of a single large or several small (SLOSS) seagrass patches within particular estuaries (Robbins 1997). Clearly, the homogeneity of seagrass cover is disrupted by changes in the physical environment resulting in a gradient of patch dynamics from continuous cover to fragmented patches (Fonseca and Bell 1998). Because fragmentation of eelgrass patches can be a function of human-induced disturbance (e.g., deteriorating water quality, oil spills, toxic contamination) (Zieman et al. 1984; Short and Wyllie-Echeverria 1996), knowledge of this index’s trend could lead to an evaluation of site specific human activity in Puget Sound. Care must be taken in evaluating a one-time measure of patchiness, however. It may be difficult to determine if a patchy eelgrass bed is in the process of colonizing or retreating from a site.

2.2.3 Maximum and Minimum Depth Characteristics

Maximum and minimum depth characteristics refer to the shallow- and deepwater boundaries of eelgrass growth. Consider a straight-line transect oriented perpendicular (or oblique) to the bathymetry contours (e.g., running shallow to deep) and passing entirely through an eelgrass bed. If one records at regular intervals along the transect the depths at which eelgrass is observed along this transect, there will be both a maximum and a minimum depth observation. If similar measurements are taken from many such transects, one will have a number of maximum and minimum depth measurements. Our parameters of interest are the descriptive statistics (range, mean, standard deviation) of these collections of maximum and minimum depth measurements.

The distribution of eelgrass across a bathymetry gradient is dependent on both the amount of time plants are exposed to air in the shallows and the quality and availability of submarine light in the deeper regions. At the upper (shallow) perimeter of the seagrass zone, leaves can be negatively impacted by desiccation resulting from exposure to air, which can, in turn, reduce biomass and areal extent (Jenkins et al. 1992; Ramirez- Garcia et al. 1998). The minimum depth of seagrass distribution also can be affected by other factors, such as direct disturbance and temperature change (Short and Wyllie-Echeverria 1996). Thus, observed changes in this parameter may point to a need for investigating these potential stressors.

In deeper water, loss or gain in eelgrass cover is a function of the amount and quality of submarine light (Zimmerman et al. 1991; Dennison et al 1993). Koch and Beer (1996) noted that in estuaries with extreme tidal ranges the vertical distribution of eelgrass might be regulated in the shallows by exposure and at depth by light. Because maximum high tides and minimum low tides in spring and summer differentially expose and cover a large portion of the tide flats in the Puget Sound basin, a desiccation/light reduction model may control the vertical distribution of eelgrass in this estuary. Norris and Wyllie-Echeverria (1997) found that the maximum depth distribution of eelgrass in Willapa Bay, Washington increased as distance from river mouths increased. They suggested that the gradient in maximum depth distribution was correlated with turbidity and associated light availability. Dennison et al. (1993) discovered that system-wide trends in the lower limit of submerged aquatic vegetation growth (which includes eelgrass) over time can be a predictor of ecosystem health.

2.2.4 Mean Shoot Density

Defining mean shoot density at a given site is not a trivial matter because it requires specifying a reference seabed area. For example, mean shoot density can be expressed as the total number of shoots relative to: (1) the potential eelgrass habitat; (2) the area enclosed by a polygon drawn around all eelgrass (i.e., including bare patches of seabed within the polygon); or (3) the basal area coverage. We use option three and define mean shoot density at a site to be the total number of shoots divided by the basal area coverage.

The vegetative growth strategy of eelgrass is characterized by the spread of erect shoots or turions that support strap-shaped, foliage leaves (Tomlinson 1974; Dawes1981; Dennison 1991). Shoot densities can decrease or increase in response to seasonal and stress gradients (e.g., temperature, submarine light) and are therefore indicators of environmental change at local and regional scales (Phillips and Lewis 1983; Kentula and McIntire 1986; Olesen and Sand-Jensen 1994). Documenting shoot density changes is a common feature of eelgrass (and other seagrasses) investigations and thus, comparative analysis using data from the literature is possible (Neckles 1994).

2.2.5 Leaf Area Index

Leaf Area Index (LAI) is a measure of the leaf area per seabed area. Mathematically, LAI is defined to be the mean shoot density (shoots/m^2) times the mean leaf area (m^2; one side) per vegetative shoot (Bulthuis 1990). We define leaf area for a single shoot to be the area of the sheath (one side; measured from the root primordia to the end of the sheath) plus the area of all the leaves (one side; measured from the end of the sheath to the leaf tip).

Site specific values of LAI can be used to calculate aboveground biomass at these sites and provide trend analysis of this metric over time (Poumain-Tapa and Ibarra-Obando 1999). Also, because LAI integrates the value of leaf area and shoot density, the index is potentially more sensitive to environmental stress than leaf width (Neckles 1994). Finally, LAI values allow an estimate of surface available for epibenthic crustaceans, especially harpacticoid copepods, which are in turn important prey sources for juvenile chum salmon, Pacific herring, Pacific sand lance (*Ammodytes hexapterus*) and surf smelt (Simenstad et al 1988; Simenstad 1994).

2.3 Site Sampling Plan

The Submerged Vegetation Monitoring Project divides potential eelgrass habitat in Puget Sound into two types of sites: “flats” and “fringe.” Flats sites are shallow embayments, expansive tide flats, and river deltas (e.g., Skagit Bay, Dosewallips delta). There are 73 flats sites; seven are in Island County: Coronet Bay, Cultus Bay, Oak Harbor, Dugualla Bay, Port Susan West, Port Susan Middle, and Skagit Bay South.

Fringe sites are 1,000 m sections of shoreline (as measured by the –20 ft isobath), each with a relatively narrow band of potential eelgrass habitat; there are 2,353 fringe sites throughout Puget Sound. Fringe sites are further sub-divided into two strata based on eelgrass abundance noted in earlier surveys (Berry et al. 2001): “low eelgrass” (west of Dungeness Spit; 165 sites) and “high eelgrass” (east of Dungeness Spit; 2,188 sites). For organizational purposes, sites are assigned to one of five regions (Fig. 3): north Puget Sound (nps), San Juan/Straits (sjs), Saratoga/Whidbey (swh), Hood Canal (hdc), and central Puget Sound (cps). Note that portions of Island County are included in three of these regions—San Juan/Straits, Saratoga/Whidbey, and Central Puget Sound.

The SVMP non-randomly selected six “core” sites (four flats and two fringe) for sampling every year (Fig. 3). Of the remaining 69 flats sites, 10 were randomly selected for sampling in 2000; none were located in Island County. Among the 51 fringe sites sampled in 2000, four were located in Island County (sjs0819 near Partridge Point, swh0847 near Ala Spit, swh1556 near Sunset Beach, and swh1593 near Cornell).

In subsequent years, the SVMP uses a rotational design with partial replacement. This design calls for 20% of the sites sampled in a given year to be replaced the following year and a waiting period of five years before a site can rejoin the sampling pool. Thus, once a site is selected, it will be sampled for five continuous years, after which it must wait another five years before it can be selected again. If Island County contemplates a long-term eelgrass monitoring program, it may wish to consider using a rotational design.

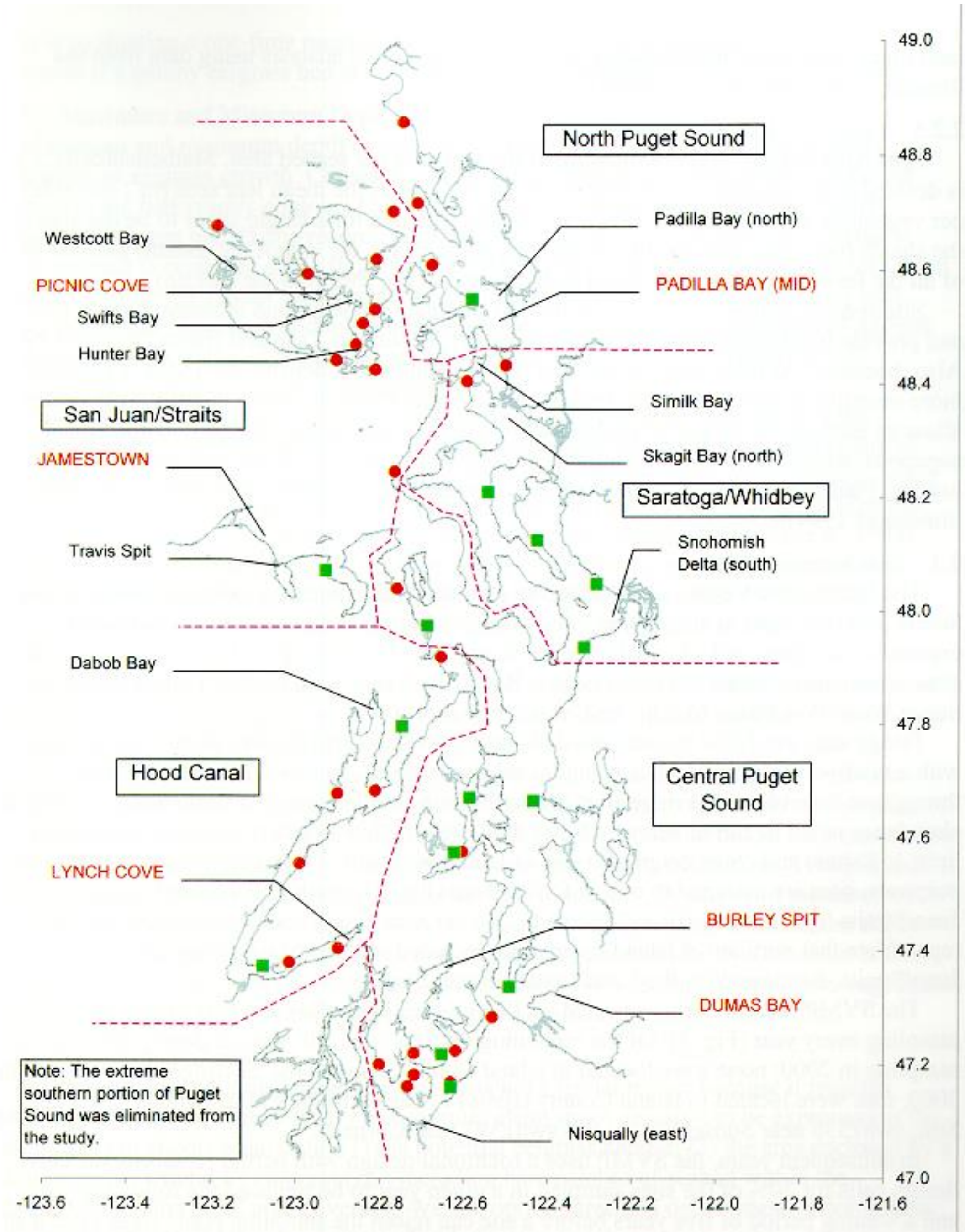


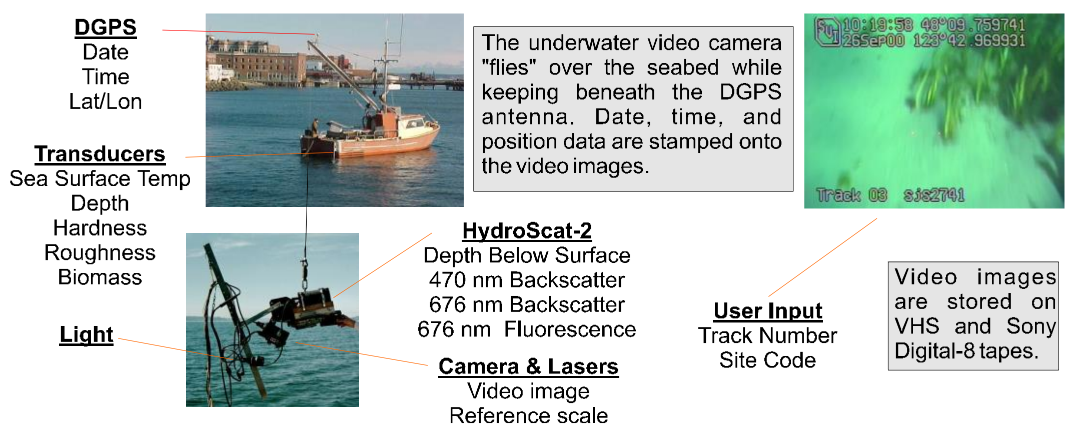
Figure 3. Sites sampled during the Washington Department of Natural Resources Submerged Vegetation Monitoring Project 2000 survey.
Note: "Core" sites are named in red. "Flats" sites are named in black. "Fringe" sites without grab sampling are shown as brown dots. "Fringe" sites with grab sampling are shown as green squares. Dashed pink lines delineate regions. No flats sites and four fringe sites were sampled in Island County.

For the Island County survey site sampling plan we used the same flats and fringe sample units as the SVMP. Thus, we used the Skagit Bay South (which contains the Utsalady area) and Oak Harbor flats sites to define the sampling boundaries for those areas. Similarly, we used a single fringe site (cps0761) to define the sampling boundaries for the Maxwelton Watershed Shoreline site. The Penn Cove and Holmes Harbor regions contain only fringe sites, but we did not sample all of them. Instead, within each of these regions we selected some fringe sites non-randomly (due to special interest, such as the areas near Coupeville and Freeland) and some randomly. For estimation purposes, the sites selected non-randomly can be treated like "core" sites in the SVMP, thus allowing us to use the estimation equations derived for the SVMP (see Appendix A for mathematical details). Further details of the sampling plans for each area are presented Chapters 3 through 7.

2.4 Within-Site Transect Sampling

Within-site transect sampling has two objectives: (1) delineate eelgrass beds at a site; and (2) collect data needed to estimate basal area coverage, patchiness index, and minimum and maximum eelgrass depth characteristics. The SVMP does not specify the specific methods of estimating these parameters. However, to estimate these parameters the survey equipment must be capable of simultaneously recording eelgrass presence/absence, position, and depth. Time of day may be required to correct depth measurements to the Mean Lower Low Water (MLLW) datum.

For both the 2000 SVMP and for the Island County eelgrass survey we used underwater videographic (UV) methods to conduct transect sampling (Fig. 4). A complete description of these methods is given in Appendix B.



Date	Time	Lat	Lon	SST	Depth	Hard	Rough	Bmass	bb470	bb676	fl676	Grass
09/26/00	10:19	9.76	42.97	8.30	17.90	113	0	183	0.0185	0.0164	0.0813	1
09/26/00	10:20	9.76	42.97	8.30	17.90	113	0	260	0.0184	0.0162	0.0829	1
09/26/00	10:20	9.76	42.97	8.30	18.10	113	0	260	0.0181	0.0158	0.0771	1
09/26/00	10:20	9.76	42.97	8.30	18.20	113	0	260	0.0181	0.0158	0.0783	0
09/26/00	10:20	9.76	42.97	8.30	18.50	113	0	260	0.0177	0.0153	0.0755	0

For flats sites, transects are conducted in a grid pattern; for fringe sites, transects are conducted perpendicular to the shoreline. At 1 to 2 sec intervals, data from all sources are integrated and stored in a database. During post-processing, depths are corrected to the Mean Lower Low Water vertical datum (using predicted tide heights adjusted for prediction errors) and eelgrass codes (presence/absence) are added to each record.

Figure 4. Illustration of the underwater videographic survey system.

2.5 Plant Sampling

We collected whole plant samples from ten randomly selected stations using a 0.1 m^2 van Veen benthic grab. The grab stations were randomly selected from the collection of eelgrass observations recorded during transect sampling. Shoot counts from each grab sample were used to estimate shoot densities, and up to 30 randomly selected plants were measured for leaf area (see Appendix C for more details).

2.6 Water Quality Sampling

At each site we selected a water quality sampling station near the deep-water edge of the observed eelgrass bed. We used a HydroLab DataSonde 4a to measure water column profiles of temperature, salinity, dissolved oxygen, pH, and photosynthetically active radiation (PAR). If the depth exceeded 3 m we took measurements every 1.0 m, otherwise we took measurements every 0.5 m. Light attenuation coefficients (K_d) were estimated from the PAR profiles as the slope of *ln*(PAR) regressed against depth below the surface. During transect sampling we also continuously measured backscatter at two wave lengths (470 nm and 676 nm) using an instrument attached to the underwater video camera towfish.

2.7 Data Analysis

2.7.1 Correcting Depths To MLLW

Depths collected in the field measure the distance between the seabed and the transducer. To correct these depths to the MLLW vertical datum, three corrections must be applied:

- transducer offset (i.e., distance between the transducer and the surface);
- predicted tidal height (i.e., predicted distance between the surface and MLLW);
- tide prediction error (i.e., difference between the predicted and observed tidal height).

Corrected depth equals depth below the transducer plus the transducer offset minus the predicted tidal height plus the tide prediction error.

The transducer was attached externally to the transom of the vessel and the offset was measured directly. It is impractical to establish a tide gauge at each site. Instead, we used the computer program Tides and Currents Pro 3.0 (Nobletec Corporation) to get predicted tide heights (6 min intervals) at one or more locations near the site. We averaged these heights to get the predicted heights for the site and date.

Each tide prediction station is based on a tide reference station at which the National Oceanic and Atmospheric Administration (NOAA) maintains tide gauges (e.g., Friday Harbor, Seattle, Tacoma, and Port Townsend). NOAA publishes the observed tide heights (6 min intervals) at these reference stations on their web site (http://www.co-ops.nos.noaa.gov/data_res.html). To determine the tide prediction error for each sampling day, we computed the difference between the tide height predicted by the Tides and Currents Pro 3.0 program and those observed and published by the National Oceanic and Atmospheric Administration. Table 3 lists the tide prediction station(s) and associated tide reference station(s) used for each site.

We created approximate isobaths at 2 ft intervals using a three step procedure. First, we selected positions from the database that were within 0.2 ft of the desired isobath (e.g., between –0.2 and +0.2 for the MLLW isobath). Second, we plotted these positions in AutoCad. Third, we drew a polyline through the plotted positions to create the isobath.

Table 3. Tide prediction and reference stations used to correct depth measurements to the mean lower low water datum.

Site	Tide Prediction Station(s)	Tide Reference Station
Skagit Bay South	Crescent Harbor (1139)	Seattle (1049)
	Ala Spit (1145)	
Oak Harbor	Crescent Harbor (1139)	Seattle (1049)
Penn Cove	Coupeville (1141)	Seattle (1049)
Holmes Harbor	Holly Farms Harbor (1135)	Seattle (1049)
Maxwelton	Hansville (1033)	Seattle (1049)

2.7.2 Videotape Post-Processing

The primary purpose of videotape post-processing is to accurately assign eelgrass codes (0 = absent; 1 = present) and video quality codes (0 = seabed is not visible; 1 = seabed is visible) to each time/position record stored every 1 s by the video overlay computer. Each record represents an area of the seabed; this area is determined by the speed of the vessel and the field of view of the camera. The field of view is a function of the camera height above the seabed. Video footage is recorded at 30 frames per second. For each time/position record we define "eelgrass presence" to mean that any part of a single eelgrass plant is visible in at least one of the 30 frames stamped with a specific time/position.

We converted the raw data to spreadsheet files containing a blank column for eelgrass code. A reviewer played the videotape for each transect, watched for changes in eelgrass status (present/absent), and entered the appropriate eelgrass code in the spreadsheet file records. The reviewer started and stopped the videotape as necessary to positively identify eelgrass. Video footage from the Maxwelton site also was coded for presence/absence of *Z. japonica*.

We reviewed the tapes multiple times to enter codes for other attributes: green sea urchins (*Strongylocentrotus droebachiensis*), geoducks (*Panope generosa*), mussels (*Mytilus edulis*), and sediment type (unknown, sand, cobble/shell, rock). When eelgrass cover was high, it often was not possible to identify these attributes. Also, since eelgrass was the target attribute, we did not extend transects into deep-water regions that may have contained these auxiliary attributes. Thus, the distribution and abundance of green sea urchins, geoducks, and mussels report here must be considered qualitative.

2.7.3 Estimating Parameters

We used equations developed for the Submerged Vegetation Monitoring Project to estimate basal area coverage, patchiness index, mean shoot density, mean leaf area, and leaf area index. Appendix A provides a complete description of these equations. Minimum and maximum depth statistics were computed using standard equations.

3 Utsalady (Skagit Bay South)

3.1 Site Definition and Description

Utsalady is included in the Skagit Bay South flats site (flats21) of the DNR SVMP (Fig. 5). Skagit Bay South is the largest flats site in the SVMP (18,377 acres), accounts for 16.7% of the total flats sites areas, and includes area from three counties (Island, Skagit, and Snohomish). After consultation with members of the Island County Marine Resource Committee we agreed to sample this entire area, even though only a portion of the site lies within Island County. The rationale was that sampling only the Island County portion of this site would not provide adequate baseline data for a complete understanding of the eelgrass resources in that area.

This site is composed of two general areas: Utsalady Bay and Skagit Bay. Utsalady Bay at the southern end of the site has a narrow and relatively deep channel close to the shoreline extending eastward from Utsalady Point (Fig. 5). We observed many private mooring bouys (many with vessels attached) in the bite just east of Utsalady Point, and aerial photos (taken in 1993) displayed on the Washington State Department of Ecology web site (www.ecy.wa.gov/apps/shorephotos) also show vessels anchored in this vicinity (Fig. 6). The channel shallows as the shoreline turns north toward Brown Point. The central portion of Utsalady Bay is shallow (approximately – 6 ft MLLW). Skagit Bay is a broad tide flat that extends for nearly 8,000 m in the east to west direction. It has several relatively deep channels in the southern portion apparently caused by river outflow from the Skagit and Stillaguamish Rivers.

3.2 Site Specific Methods

We sampled this site on December 5 and 6, 2000. We conducted four zig-zag UV transects (1 – 4) along the shoreline of Utsalady Bay starting 500 m east of Utsalady Point and ending 700 m south of Brown Point (Fig. 7). We also conducted two straight-line UV transects (14 and 16) extending across the entire Utsalady Bay. In Skagit Bay we conducted eight east-west straight-line transects extending from the MLLW isobath at the east end to the bathymetry break into deep water at the west end (Fig. 8). The first four of these transects (5, 6, 8, and 9; transect 7 was aborted) were at the same latitude and together constitute a single transect across the potential eelgrass habitat. We also conducted two straight-line transects (15 and 17) in the north-south direction over the southern edge of the eelgrass bed.

Water quality data were gathered near the western edge of the eelgrass located near the center of Skagit Bay (Fig. 8). Benthic grab samples were collected from ten randomly selected stations where eelgrass was observed during the underwater video survey (Fig. 8). Only nine vegetative shoots were collected of which seven were measured to estimate mean leaf area. To estimate tide heights during the sampling period we averaged the predicted tide heights from the Crescent Harbor and Ala Spit tide prediction stations. We did not include the tide predictions at Stanwood (which is also in the vicinity) because they seemed to be quite different from those at Crescent Harbor and Ala Spit (Fig. 9).

3.3 Results

Estimated total basal area coverage of eelgrass was 7,724,823 m^2 (772 hectares; 1,909 acres), which represents about 10% of the total area within the site boundary (Table 4). It should be noted that the site boundary includes all the area up to the DNR Water Level Line, which is approximately the mean high tide line. Thus, much of the site area is the higher tide flat at the mouth of the south fork of the Skagit River. The patchiness index in Skagit Bay was about half that for Utsalady Bay (Table 4).

Since maximum eelgrass depths became deeper from Utsalady Point to Brown Point and the Utsalady Bay maximum depths were shallower than those for Skagit Bay, we stratified (after sampling) the entire region into three strata. Stratum 1 included the western half of Utsalady Bay (transects 1, 2, and 16), stratum 2 included the eastern half of Utsalady Bay (transects 3, 4, and 14), and stratum 3 included all of Skagit Bay (transects 5-13, 15, and 17). Mean maximum eelgrass depths for strata 1, 2, and 3 were –4.3 ft, -5.7 ft, and –7.8 ft MLLW, respectively. These differences were statistically significant (two-tailed two-sample t-tests with unequal variances; $p = 0.0189$ between strata 1 and 2; $p = 0.0022$ between strata 2 and 3). There was no significant difference in the minimum eelgrass depths (all were -0.5 ft MLLW). The two transects crossing the central portion of Utsalady Bay did not have any eelgrass, despite the fact that over much of their length the depth was shallower than the mean maximum eelgrass depth observed for Skagit Bay (Fig. 10).

Transects running in the north-south direction across Skagit Bay crossed several relatively deep channels. Echosounder recordings of these transects revealed several types of eelgrass patch dynamics (Fig. 11). The “wedge effect” in which the top of the eelgrass canopy remains a constant distance below MLLW until the bed abruptly ends has been a common feature we have observed throughout Puget Sound.

Mean shoot density was 9 shoots/m^2, mean leaf area was 70.1 cm^2/shoot, and and leaf area index was 0.063 (based on m/m) (Table 4). Water quality data indicated a lens of cold fresh water at the surface (Fig. 12).

The final transect database had 24,298 time/position records, of which 0, 9, and 94 noted urchins, geoducks, and mussels, respectively. All of the geoducks and mussels were observed in the eastern shoreline of Utsalady Bay. For sediment types, only 310 and 58 records were categorized as cobble/shell and rock, respectively. The remaining 99% of the records were categorized as sand.

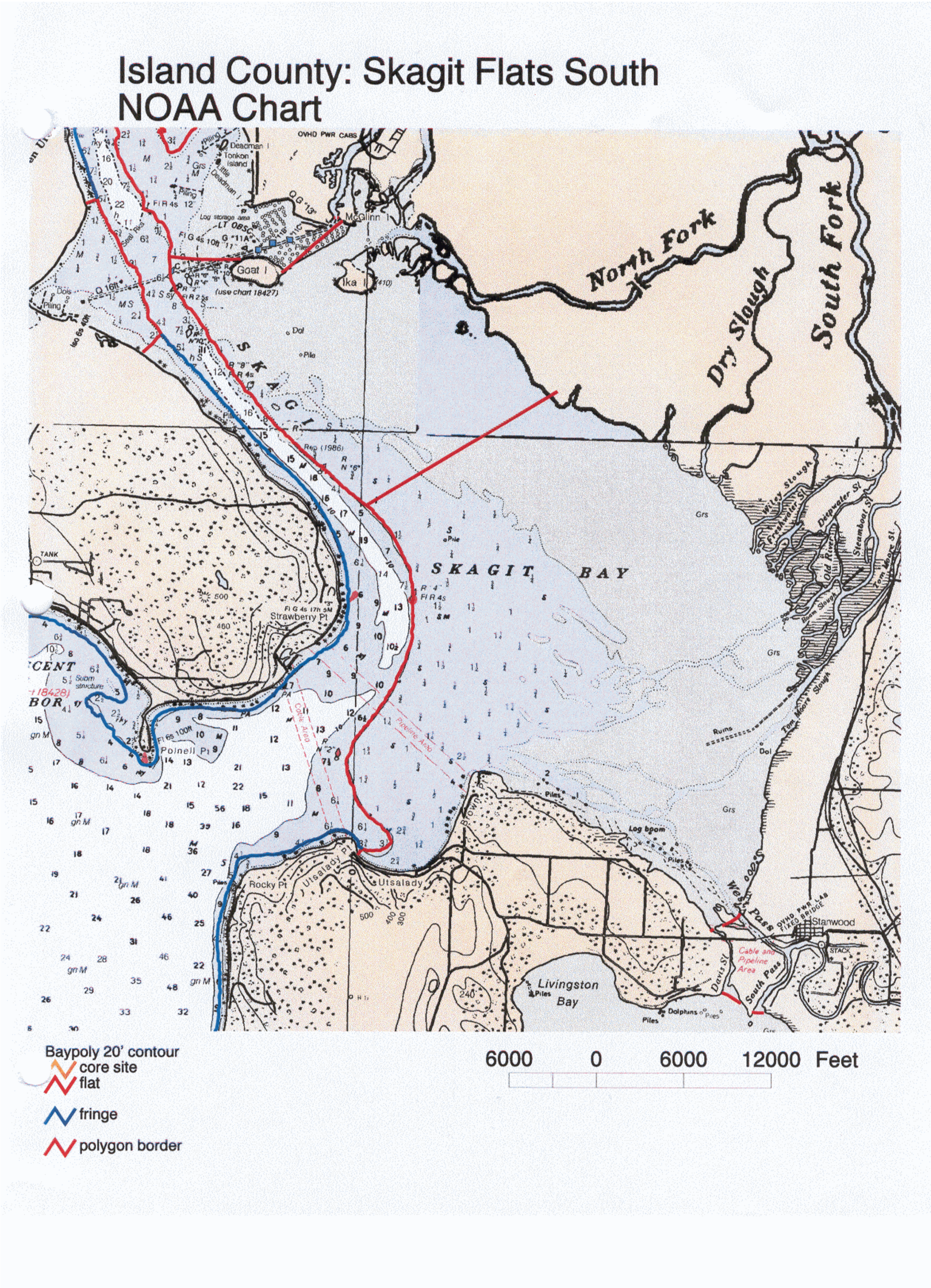


Figure 5. Map showing the Skagit Bay South flats site defined by the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project.

Figure 6. Aerial photograph sequence showing the shoreline between Brown Point (a) and Utsalady Point (j).

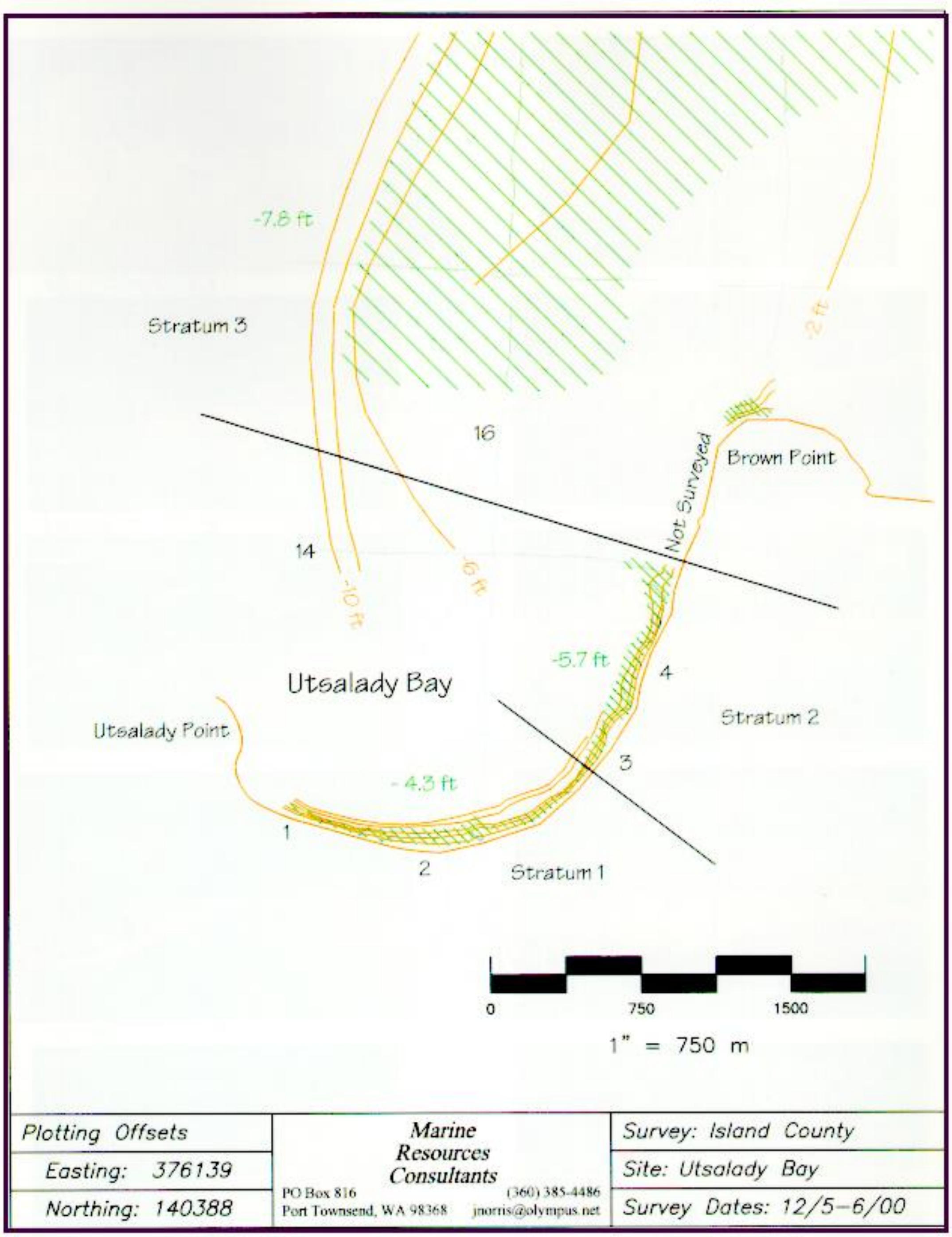


Figure 7. Site map for Utsalady Bay.

Note: UV transects are numbered (1-4, 14, 16). Eelgrass beds are in green. Estimated mean maximum eelgrass depths for three strata are labeled in green.

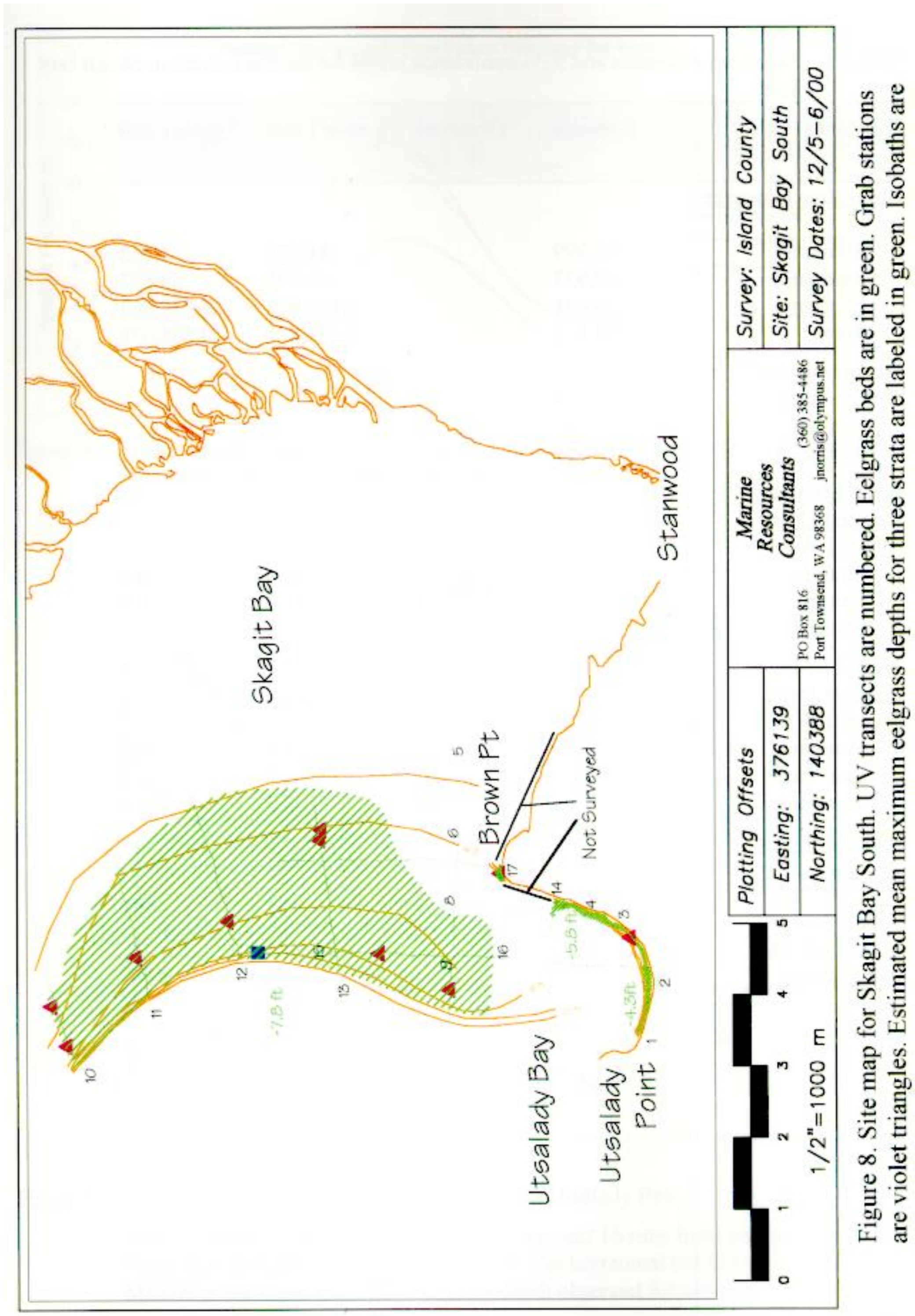


Figure 8. Site map for Skagit Bay South.

Note: UV transects are numbered. Eelgrass beds are in green. Grab stations are violet triangles. Blue square is the water quality station. Estimated mean maximum eelgrass depths for three strata are labeled in green.

Table 4. Parameter estimates and 95% confidence limits for the three strata in Skagit Bay South.

Parameter	Estimate	Observed Range	Lower Limit	Upper Limit
Basal Area Coverage (m^2)				
Stratum 1	48,399		41,275	55,523
Stratum 2	39,933		20,293	59,572
Stratum 3	7,636,491		6,119,998	9,152,983
Total	7,724,823		6,222,841	9,268,078
Patchiness Index				
Stratum 1	12.58			
Stratum 2	17.40			
Stratum 3	7.15			
Mean Minimum Eelgrass Depth (ft, MLLW)				
Stratum 1	-0.5	(-1.4, 0.1)	-0.9	-0.2
Stratum 2	-0.5	(-1.7, 2.2)	-1.3	0.4
Stratum 3	-0.5	(-1.0, 0.3)	-0.9	-0.1
Mean Maximum Eelgrass Depth (ft; MLLW)				
Stratum 1	-4.3	(-7.2, -3.0)	-4.8	-3.8
Stratum 2	-5.7	(-9.0, -4.0)	-6.9	-4.6
Stratum 3	-7.8	(-8.7, -6.8)	-8.2	-7.4
Mean Shoots/m^2	9	(0, 30)	0	15
Mean Leaf Area (cm^2)	70	(39, 95)	51	89
Mean Leaf Area Index (m/m)	0.063		0.046	0.080

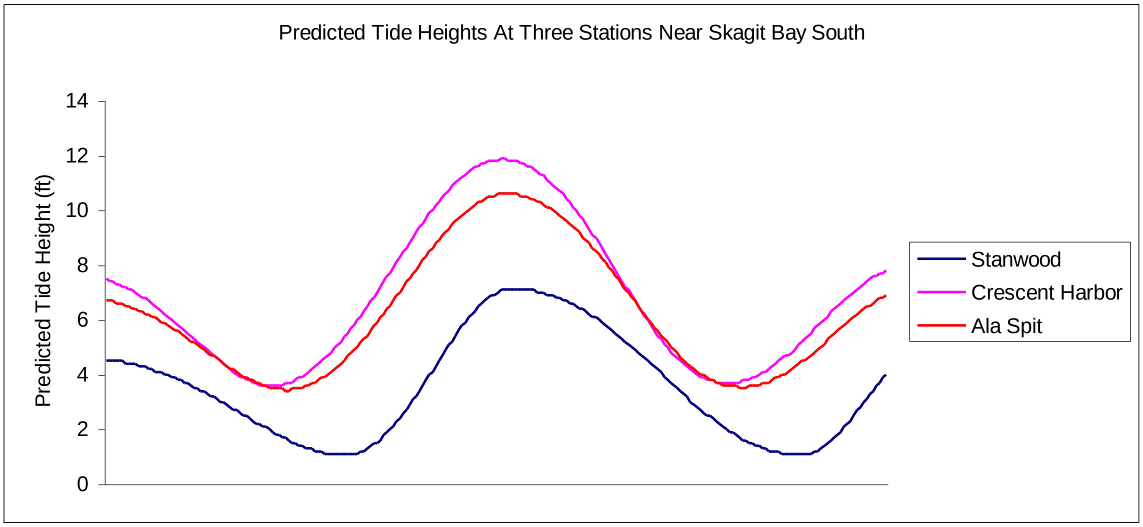


Figure 9. Predicted tide heights for December 5, 2000 at three stations near the Skagit Bay South site (Stanwood, Crescent Harbor, and Ala Spit).

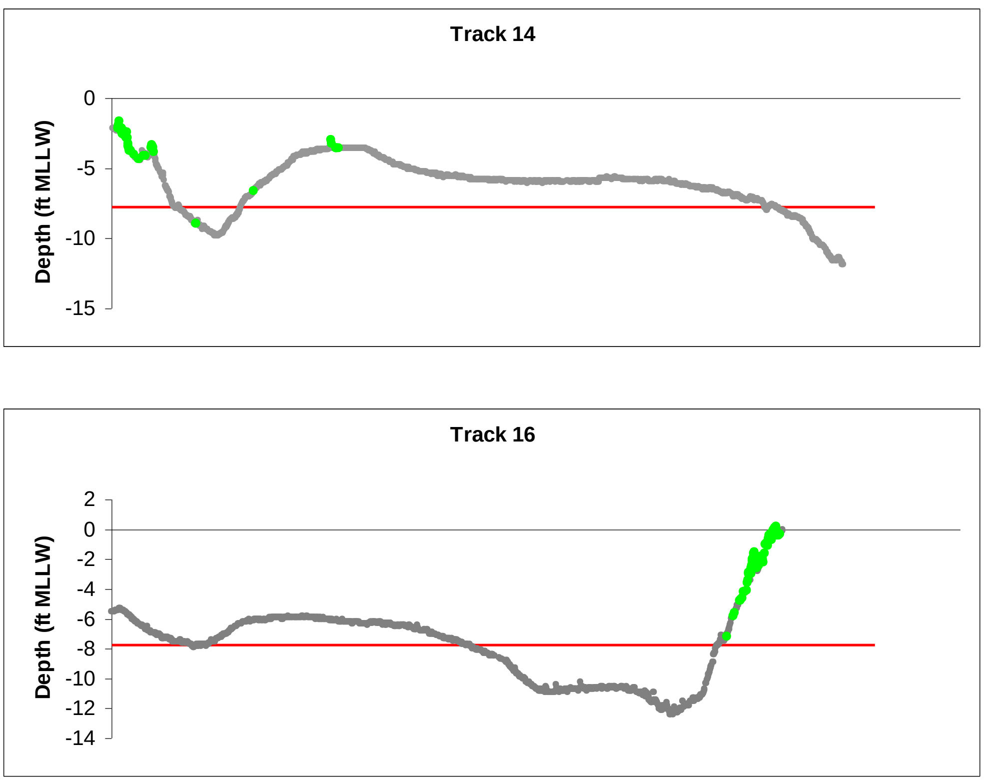
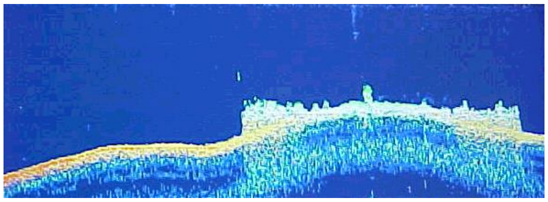
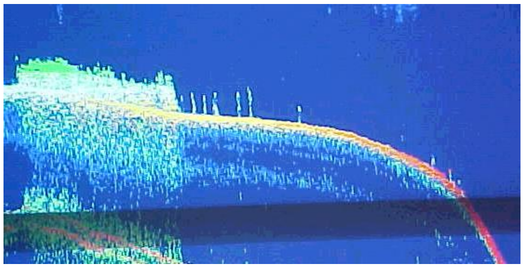
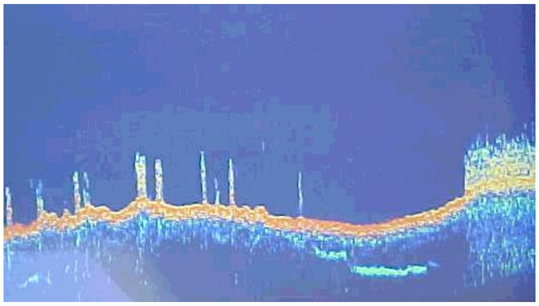


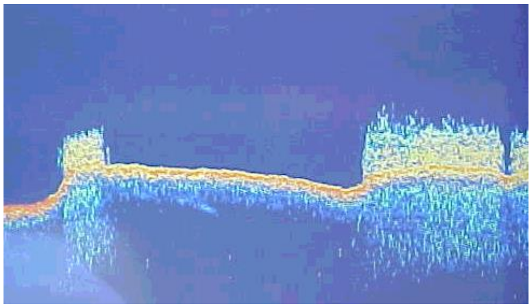
Figure 10. Depth records for transects 14 and 16 across Utsalady Bay.

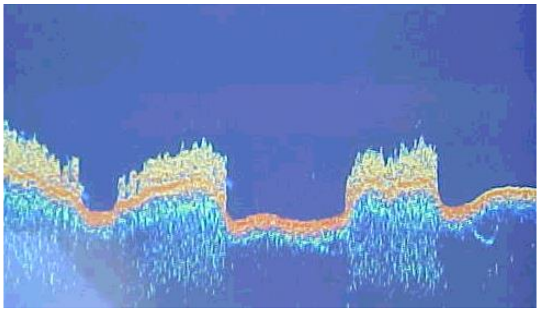
Note: Transect 14 runs from east to west; transect 16 runs from north to south. Green dots indicate eelgrass observations. The horizontal red line at –7.8 ft MLLW is the mean maximum eelgrass depth observed for stratum 3 (Skagit Bay).


"Wedge Effect." Canopy top a constant distance below MLLW until bed abruptly ends.


Abrupt edge of main bed with sparse plants distributed down the slope.


Abrupt edge of main bed with sparse plants distributed down the slope.


"Edge Effect." Plants located near the edge of a channel.


"Hummock Effect." Plants located on ridges between channels.

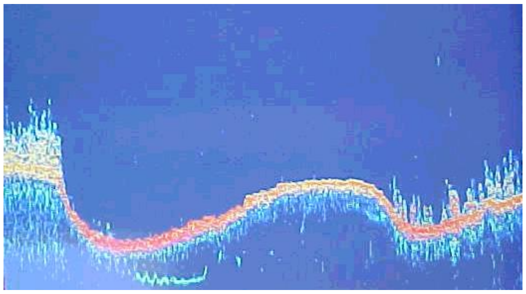

Inconsistent distribution of plants by depth.

Figure 11. Echosounder recordings taken from north-south transects across Skagit Bay on December 6, 2001.

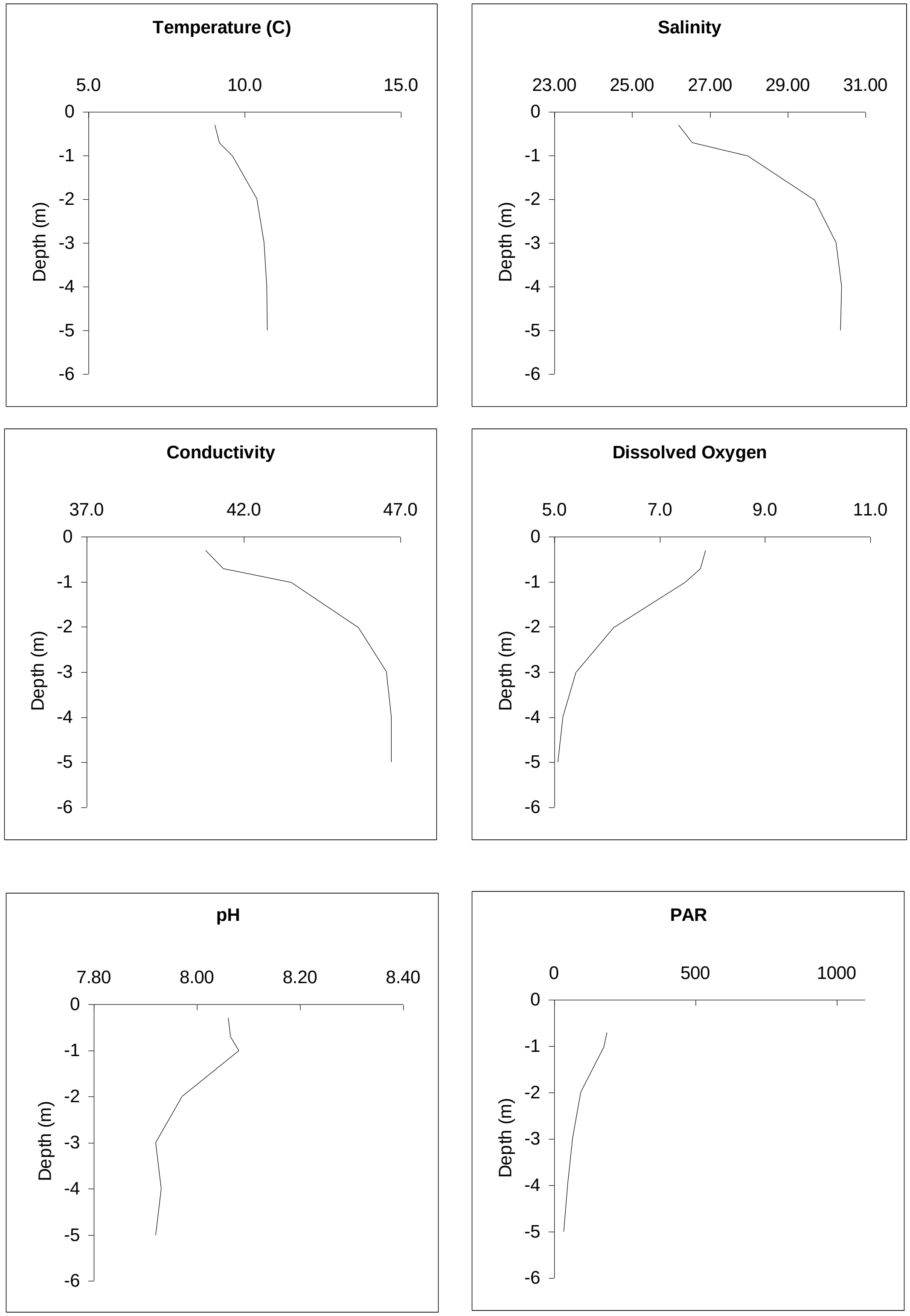


Figure 12. Water quality profiles from Skagit Bay South.

Note: Data were taken at 122:28.814 and 48:18.287 on December 6, 2000 at 2:08 pm. Tide was near high water slack and sky cover was hazy sunshine.

4 Oak Harbor

4.1 Site Definition and Description

Oak Harbor is a 954 acre flats site (flats31) in the DNR SVMP. The site extends from Oak Harbor Marina out to the red navigation buoy number 4 at the channel entrance. Oak Harbor is a shallow (maximum depth in the main bay is approximately 12 feet) mud and sand bay that has been extensively modified. Historical maps and photographs show a long sand spit extending from Maylor Point northward almost to the present town of Oak Harbor (Figs. 13 and 14). During the 1940s the mud flat east of the northern tip of this spit was dredged to create a navigation channel to the Navy seaplane base (Fig. 15). The dredge spoils appear to have been deposited east of the remaining portion of the spit to create the present marsh habitat (Figs. 16 and 17). Also, a small boat basin close to downtown Oak Harbor has been dredged (Fig. 17).

4.2 Site Specific Methods

We sampled Oak Harbor on December 4 and 8, 2000 (Fig. 18). We began with a coarse grid sampling pattern using straight-line transects over the entire site (transects 1 – 8; 16 – 20). These transects were oriented perpendicular to the isobaths and identified two eelgrass beds (a small northern bed and a larger southern bed) of sufficient size to warrant additional transects. We added additional straight-line transects over the large southern bed to create a finer grid pattern (transects 9 – 15; 23; 25). To delineate the shallow- and deep-water margins of the small northern bed we used a zig-zag transect (transect 22). Finally, we conducted a zig-zag transect through the dredged small boat basin near downtown Oak Harbor.

We collected benthic grab samples from 10 randomly selected stations (one station was in the small eelgrass bed; nine were in the larger eelgrass bed). Of the 100 plants collected at these ten stations, we measured 30 for leaf area. We collected water quality data at a station located along the eastern edge of the large eelgrass bed.

4.3 Results

The estimated basal area coverages for the small northern bed and the large southern bed were 5,353 m^2 and 86,489 m^2, respectively, for a total of 91,842 m^2 (9.18 hectares; 22.7 acres; Table 5). In addition to these two eelgrass beds, we observed individual plants, or small groups of plants, scattered throughout the site, including some north and east of the north end of the spit (one observation near the south end of transect 17, one near the north end of transect 19, and five along transect 20). No eelgrass was observed in the small boat basin near downtown Oak Harbor. There were small clusters of plants located between the two beds, but they did not cover enough area to justify computing areas.

The patchiness index for the small northern bed was double that for the large southern bed (21.24 vs 10.17). Minimum eelgrass depths for the small northern bed and large southern bed were –3.1 ft and –2.0 ft, respectively; this differences was signifcant at the 90% level (two-tailed two-sample t-test with unequal variances; $p = 0.0574$). Maximum eelgrass depths were extremely variable for the large southern bed, ranging from –14.8 to –2.9 ft MLLW, with a mean of –8.1 ft. Although this mean was over two feet deeper than that for the small northern bed (-5.7 ft), the difference was not significant at the 90% level (two-tailed two-sample t-test with unequal variances; $p = 0.1812$) due to the high variability.

Sea surface temperature in Oak Harbor was the coldest of any site (5.8 C). Weather during this sampling week was quite cold, dropping below freezing at night. There was a lens of fresh water on the surface (Fig. 19). Mean shoot density was 100 shoots/m^2 and mean leaf area per shoot was 63.66 cm^2; leaf area index was 0.637.

The final transect database had 24,298 time/position records, of which 660, 46, and 847 noted urchins, geoducks, and mussels, respectively. Almost all of the urchins were observed in the region east of the large southern eelgrass bed (Fig. 18). Because eelgrass obscures the view of the seabed, we could not determine if urchins were present beneath the eelgrass canopy. Most of the geoducks were observed just south of the large southern eelgrass bed, while most of the mussels were observed in shallow water at the northern portion of the site, including the region near the small boat basin.

For sediment types, 162 records were categorized as cobble/shell; no rock sediment type was observed. The remaining 99% of the records were categorized as sand.

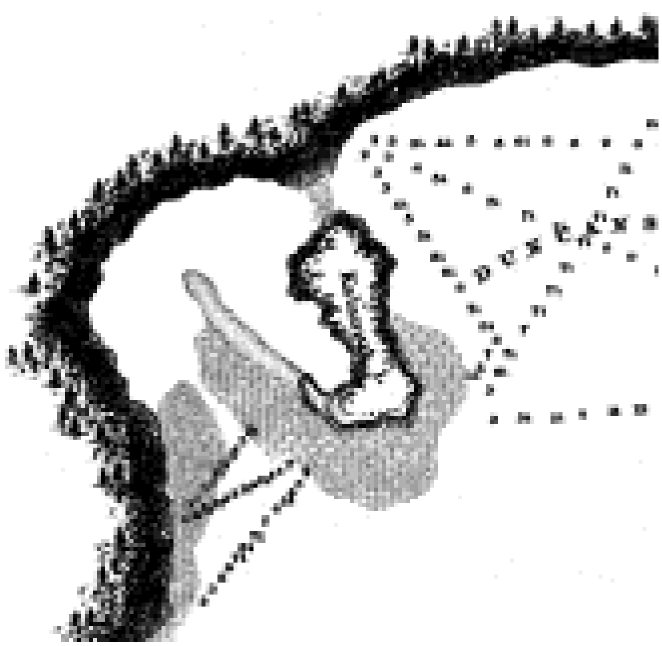


Figure 13. An enlargement from a 1841 map drawn during the Wilkes Expedition.

Note: (Map provided by the Mrs. Janet Enzmann, Archivist, Island County Museum, Coupeville, WA).

Figure 14. A 1942 aerial photograph of Oak Harbor.

Note: Photo provided by Tom Burdett, Director of Planning and Community Development, City of Oak Harbor. Digital image taken by T. Wyllie-Echeverria.

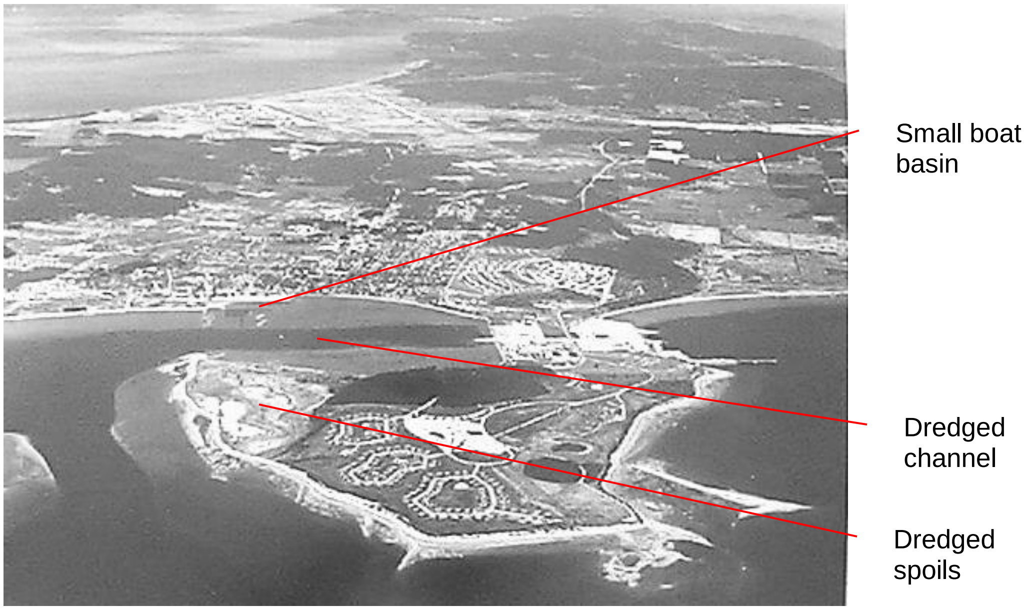


Figure 15. The dredged channel in Oak Harbor is clearly visible in this historical photograph (circa 1964).

Note: Dredged spoils are visible adjacent to the spit depicted in Fig. 14. Also note the dredged small boat basin near downtown Oak Harbor. (Photo provided by Tom Burdett, Director of Planning and Community Development, City of Oak Harbor. Digital image taken by T. Wyllie-Echeverria)

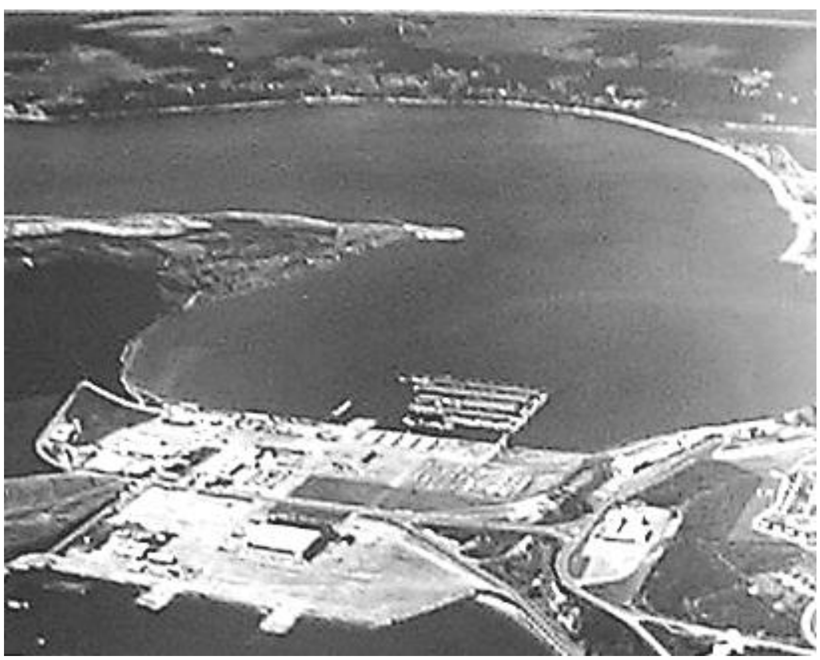


Figure 16. A 1984 aerial photograph of Oak Harbor.

Note: Digital photo by T. Wyllie-Echeverria of a picture provided by Dave Williams, Harbormaster, Oak Harbor Marina.

Small boat basin

Oak Harbor Marina

Spit and dredged spoils

Figure 17. Aerial photographs taken in May 1993 of the small boat basin, Oak Harbor Marina and dredged spoils east of the spit.

Note: Photos from the Washington State Department of Ecology web site: www.ecy.wa.gov/apps/shorephotos.

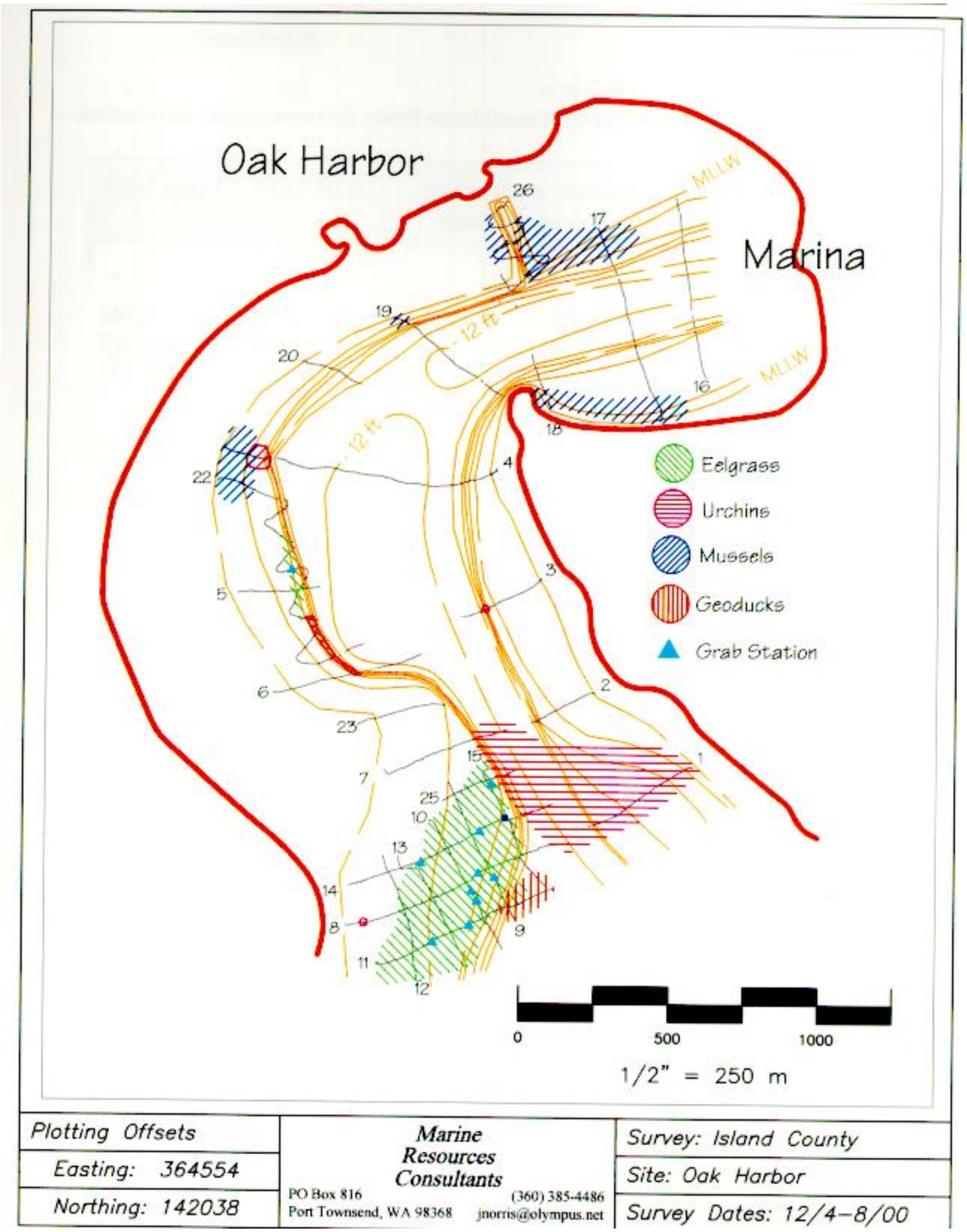


Figure 18. Site map of Oak Harbor.

Note: UV transects are numbered. Water quality station is the blue square. Isobaths are in 2 ft intervals.

Table 5. Parameter estimates and 95% confidence limits for two eelgrass beds in Oak Harbor.

Parameter	Estimate	Observed Range	Lower Limit	Upper Limit
Basal Area Coverage (m^2)				
Small north bed	5,353		4,139	6,566
Large south bed	86,489		72,391	100,587
Total	91,842		76,530	107,153
Patchiness Index				
Small north bed	21.24			
Large south bed	10.17			
Mean Minimum Eelgrass Depth (ft, MLLW)				
Small north bed	-3.1	(-3.7, -1.9)	-3.9	-2.2
Large south bed	-2.0	(-3.1, -1.6)	-3.1	-0.9
Mean Maximum Eelgrass Depth (ft; MLLW)				
Small north bed	-5.7	(-5.9, -5.4)	-5.7	-5.7
Large south bed	-8.1	(-14.8, -2.9)	-12.2	-4.1
Mean Shoots/m^2				
Large south bed	100	(0, 310)	21	172
Mean Leaf Area (cm^2)				
Large south bed	64	(12, 239)	43	84
Mean Leaf Area Index (m/m)				
Large south bed	0.637		0.418	0.855

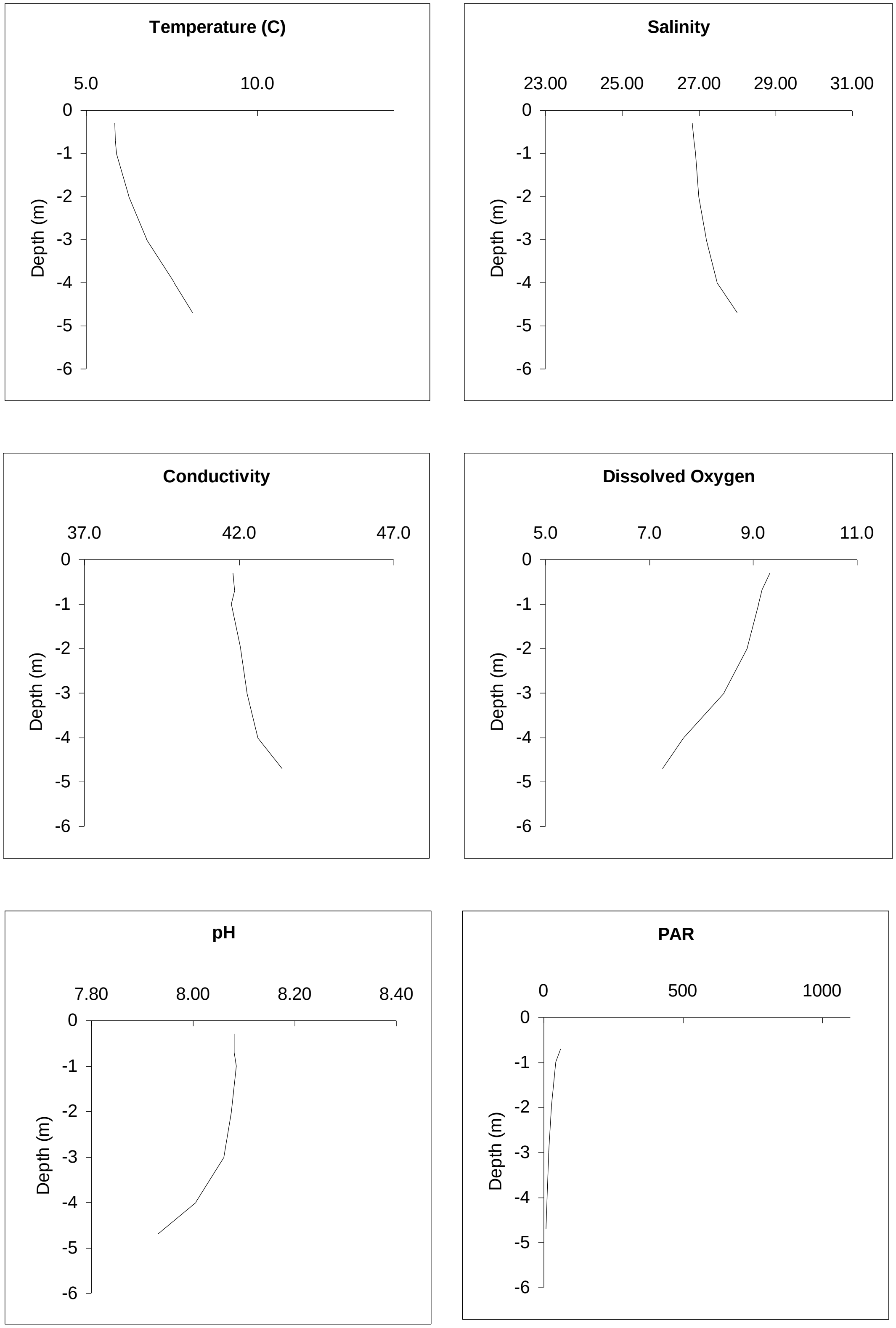


Figure 19. Water quality profiles from Oak Harbor.

Note: Data were taken at 122:38.693 and 48:16.100 on December 13, 2000 at 3:00 pm. Sky was very cloudy and overcast.

5 Penn Cove

5.1 Site Definition and Description

Just southeast of Oak Harbor, Penn Cove extends approximately 3.5 miles east from Saratoga Passage (Fig. 20). We defined the eastern end of this site to be Long Point. There are no large tide flats in the cove and the DNR SVMP categorizes the entire region as eelgrass fringe sites (swh0887 to swh0901; Fig. 20). The maximum depth in the bay is approximately 15 fm. The town of Coupeville is located midway along the southern shore (Fig. 21). Numerous commercial mussel growing rafts are located west of Coupeville near the southern head of the bay (Fig 21).

5.2 Site Specific Methods

Our sampling plan prioritized sampling into three categories—regions of known eelgrass; regions of potential human impact; and all other regions. To satisfy the first two categories we non-randomly selected three fringe sites for sampling (swh0887, swh0888, swh 0898). Previous eelgrass surveys indicated that the first two sites (located along the northeast shore) contained the only large eelgrass bed in Penn Cove (PSWQA 1992; Fig. 22). The third site contained the largest town—Coupeville. We used a systematic random sampling plan for the remaining sites in which we sampled all of the odd numbered sites. In summary, of the fifteen fringe sites located in Penn Cove, we selected three non-randomly, selected seven randomly using a systematic plan, and did not sample five sites.

We sampled Penn Cove on December 7 and 8, 2000. For sites swh0887 and swh0888 we conducted straight-line transects perpendicular to the shoreline. We sampled all other sites using a single zig-zag transect. We visited the area near the Coupeville dock on April 28, 2001 to verify the species identification.

During pre-survey discussions with the Island County MRC it was decided that we would not collect benthic grab samples in Penn Cove to allow more time to determine the distribution of eelgrass around as much of the bay as possible. Water quality data were collected at the outer edge of the eelgrass bed located just east of the Coupeville dock.

5.3 Results

As noted in previous surveys, eelgrass was most abundant at the northeast corner of the bay, and sparsely distributed around the remainder of the bay (Fig. 23). We observed eelgrass adjacent to the Coupeville dock (Fig. 24). With the exception of the northeast corner, eelgrass occurred in a very narrow and sparse band rarely growing deeper than the low intertidal zone. On two 1,000 m sites we did not observe any eelgrass (swh0891 and swh0895). Total estimated eelgrass area for Penn Cove was 158,351 m^2 (15.84 hectares; 39.1 acres; Table 6). Site swh0888 contained over a third of this total (57,608 m^2; 36%). The estimated total for the 1,000 m site in front of Coupeville was 10,953 m^2. Patchiness index was similar at all sites, ranging from 8.98 to 16.37.

Mean maximum eelgrass depths at the three sites in the northeast corner of the bay were –9.7 ft (swh0887), -6.3 ft (swh0888), and –0.8 ft (swh0889) (Table 7). These differences were statistically significant (two-tailed two-sample t-tests: $p = 0.06$; $p = 0.01$). Mean maximum eelgrass depth at the southeast corner of the bay was –4.6 ft (swh0901). Throughout the remainder of the bay, mean maximum eelgrass depths ranged from –1.9 ft to – 0.3 ft and mean minimum eelgrass depths ranged from 0.3 ft to 1.4 ft. During our site visit on April 28, 2001 we identified two varieties of *Z. marina*—var. *phillipsii* and var. *typica* (Fig. 25) and verified that *Z. japonica* was not present near the Coupeville Dock.

Penn Cove had the lowest salinity readings of any of the regions (23.80 at the surface and 24.86 at 4 m below the surface). Compared to the other regions on the east side of Whidbey Island, Penn Cove had higher dissolved oxygen and a similar K_d value.

Of the 18,968 time/position records, 10,041 (53%) had green sea urchin observed, 1,492 (8%) had geoducks observed, and 1,889 (10%) had mussels observed. The urchins were observed in large numbers everywhere except the southeast corner of the bay (Fig. 23). Geoducks were observed throughout the bay and mussels were more numerous on the northern shore than the southern (Fig. 23). The sediment type was mostly sand (86%) with cobble/shell accounting for 13% and rock accounting for 1%.

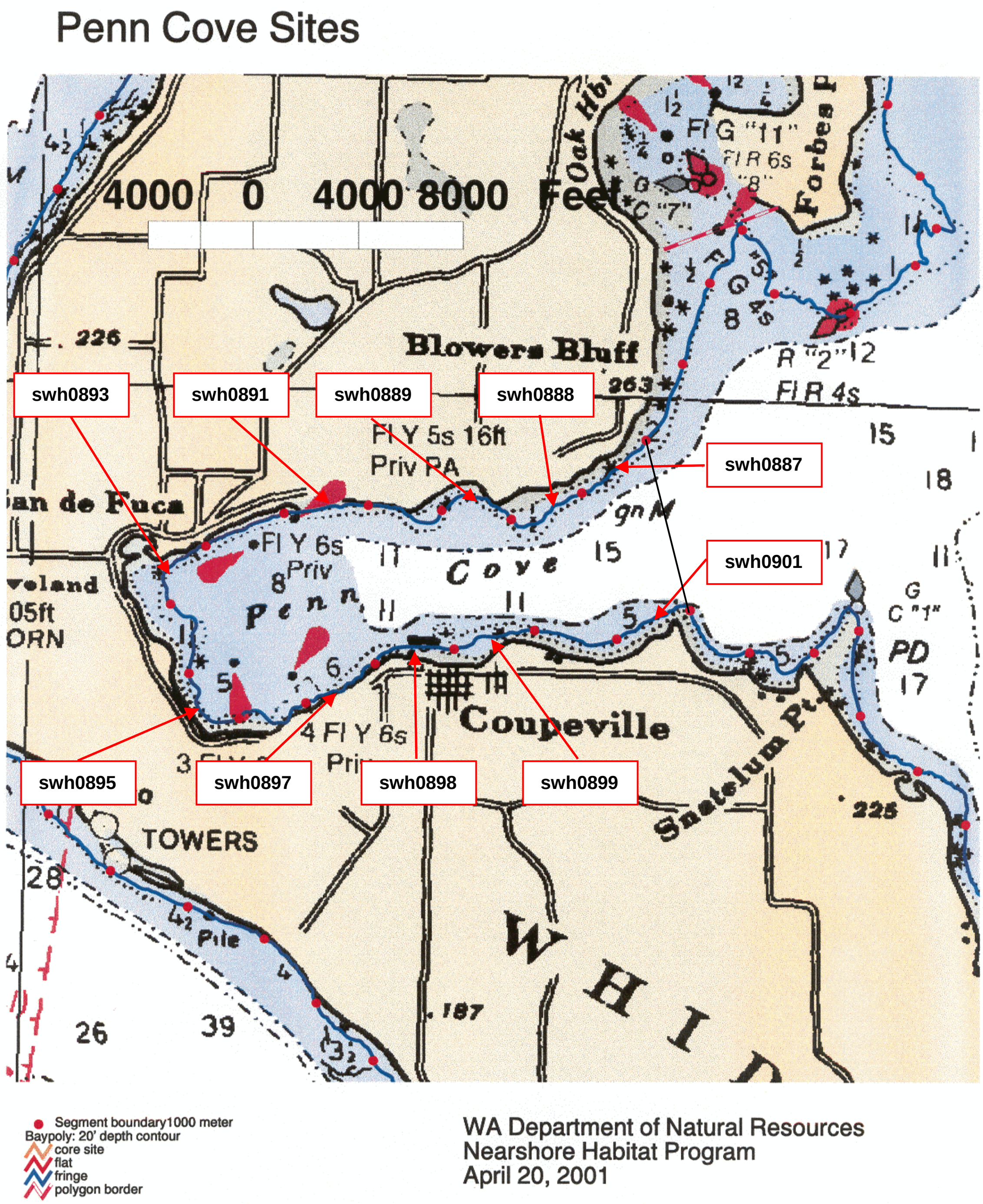


Figure 20. Map of Penn Cove showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites.

Note: Fringe sites are delineated by the blue line with red dots 1,000 m apart. The Island County eelgrass survey sampled sites swh0887, swh0888, swh0889, swh0891, swh0893, swh0895, swh0897, swh0898, swh0899, and 0901.

Figure 21. Aerial photos of Penn Cove.

Note: The two top photos are of the shoreline near Coupeville and the bottom photo shows the mussel growing rafts in the southwest corner of Penn Cove. (Source: Washington State Department of Ecology web site: www.ecy.wa.gov/apps/shorephotos.)

swh0087

swh0888

swh0887 and swh0888

swh0888 and swh0889

swh0888

Figure 22. Aerial photo sequence of the northwest corner of Penn Cove where the largest and deepest eelgrass bed was observed.

Note: Photos from the Washington State Department of Ecology web site: www.ecy.wa.gov/apps/shorephotos.

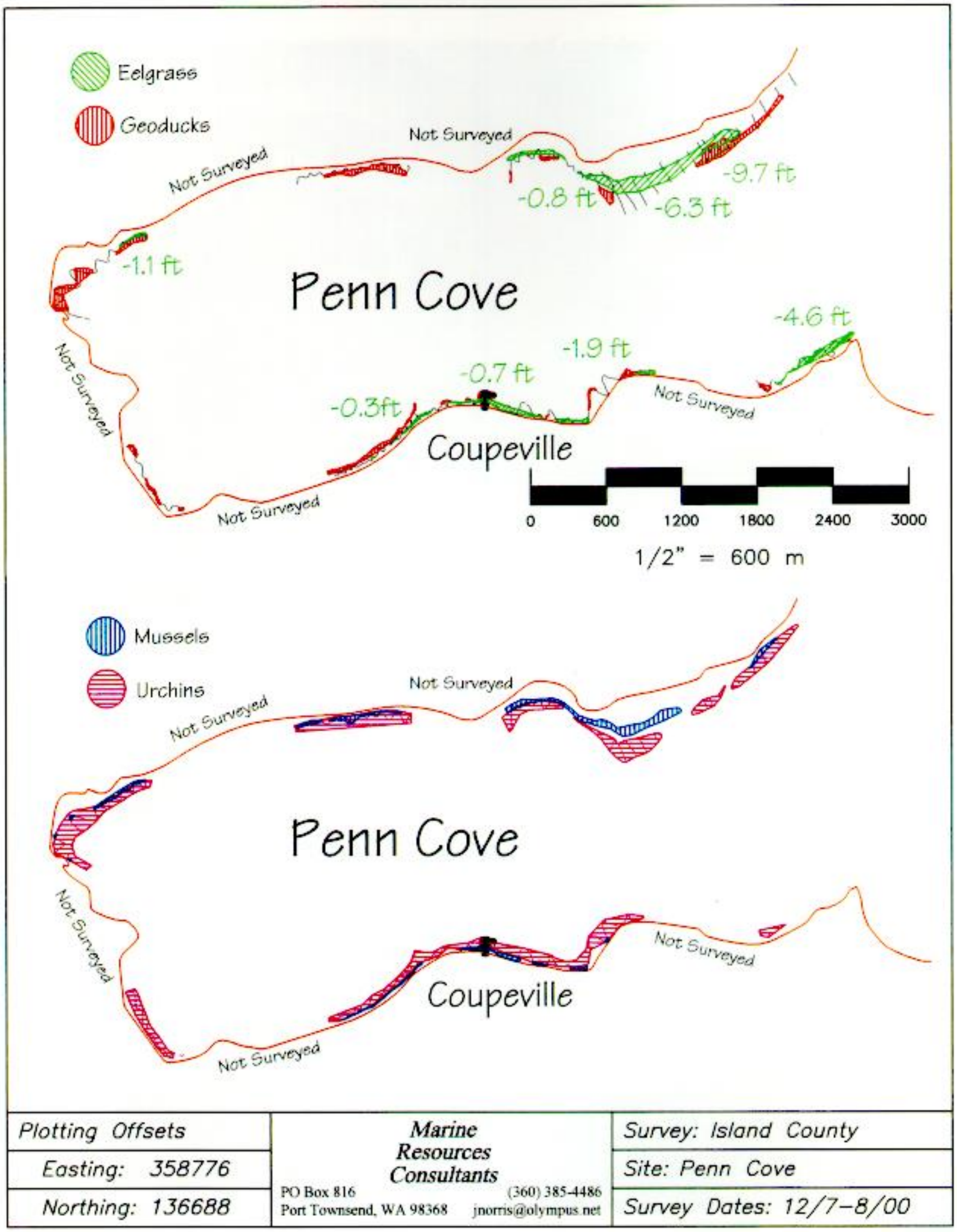


Figure 23. Site maps for Penn Cove.

Note: Mean maximum eelgrass depths are labeled in green (top map). Urchins and geoducks may also be distributed in deeper water than shown (we only surveyed to the deep water edge of the eelgrass beds).

Figure 24. Photo of *Z. marina* and mussel beds in intertidal zone near Coupeville.

Note: The top image is looking east away from the Coupeville Dock and the bottom is looking west. Note the presence of *Z. marina* high in the intertidal zone in both views. (Photos by T. Wyllie-Echeverria.)

Table 6. Estimated basal area coverage, variance, and confidence limits for Penn Cove.

Site	Estimated Eelgrass Area (m^2)	Estimated Variance	Lower Limit	Upper Limit
Non-Random Sites				
swh0887	15,579	1,045,213	13,575	17,583
swh0888	57,608	35,663,501	45,903	69,313
swh0898	10,953	247,837	9,977	11,929
Total	84,140	36,956,551		
Randomly Selected Sites				
swh0889	12,018	1,053,432	10,006	14,030
swh0891	0	0		
swh0893	2,619	124,520	1,927	3,310
swh0895	0	0		
swh0897	1,900	134,027	1,182	2,617
swh0899	5,246	679,845	3,630	6,862
swh0901	21,507	4,064,102	17,556	25,458
Total	43,290	6,055,926		
Mean	6,184			
Variance	62,875,887			
All Potential Random Sites	74,211	549,317,761		
Total (Random and Non-Random Sites)	158,351	586,274,312	205,809	110,894

Table 7. Patchiness indices and depth parameter estimates for Penn Cove.

Parameter	Estimate	Observed Range	Lower Limit	Upper Limit
Patchiness Index				
swh0887	15.80			
swh0888	8.98			
swh0889	12.29			
swh0891	N/A			
swh0893	9.21			
swh0895	N/A			
swh0897	10.93			
swh0898	10.68			
swh0899	10.11			
swh0901	16.37			
Mean Minimum Eelgrass Depth (ft, MLLW)				
swh0887	-1.8	(-3.8, -0.3)	-3.4	-0.1
swh0888	-0.1	(-0.6, 0.4)	-0.5	-0.3
swh0889	1.0	(-0.6, 2.1)	0.4	1.6
swh0891	N/A	N/A	N/A	N/A
swh0893	0.3	(-0.1, 0.8)	-0.2	0.7
swh0895	N/A	N/A	N/A	N/A
swh0897	1.3	(0.5, 2.3)	0.9	1.7
swh0898	1.4	(0.6, 2.5)	1.0	1.7
swh0899	0.4	(-0.9, 1.7)	0.0	0.9
swh0901	0.8	(0.0, 1.6)	0.5	1.2
Mean Minimum Eelgrass Depth (ft, MLLW)				
swh0887	-9.7	(-10.7, -7.4)	-11.5	-8.0
swh0888	-6.3	(-11.9, -1.9)	-9.8	-2.8
swh0889	-0.8	(-1.8, 0.0)	-1.2	-0.4
swh0891	N/A	N/A	N/A	N/A
swh0893	-1.1	(-2.1, -0.2)	-2.0	-0.2
swh0895	N/A	N/A	N/A	N/A
swh0897	-0.3	(-0.8, 0.5)	-0.6	-0.1
swh0898	-0.7	(-2.2, 0.7)	-1.1	-0.2
swh0899	-1.9	(-4.2, -0.6)	-2.7	-1.2
swh0901	-4.6	(-8.3, -1.7)	-6.3	-2.9

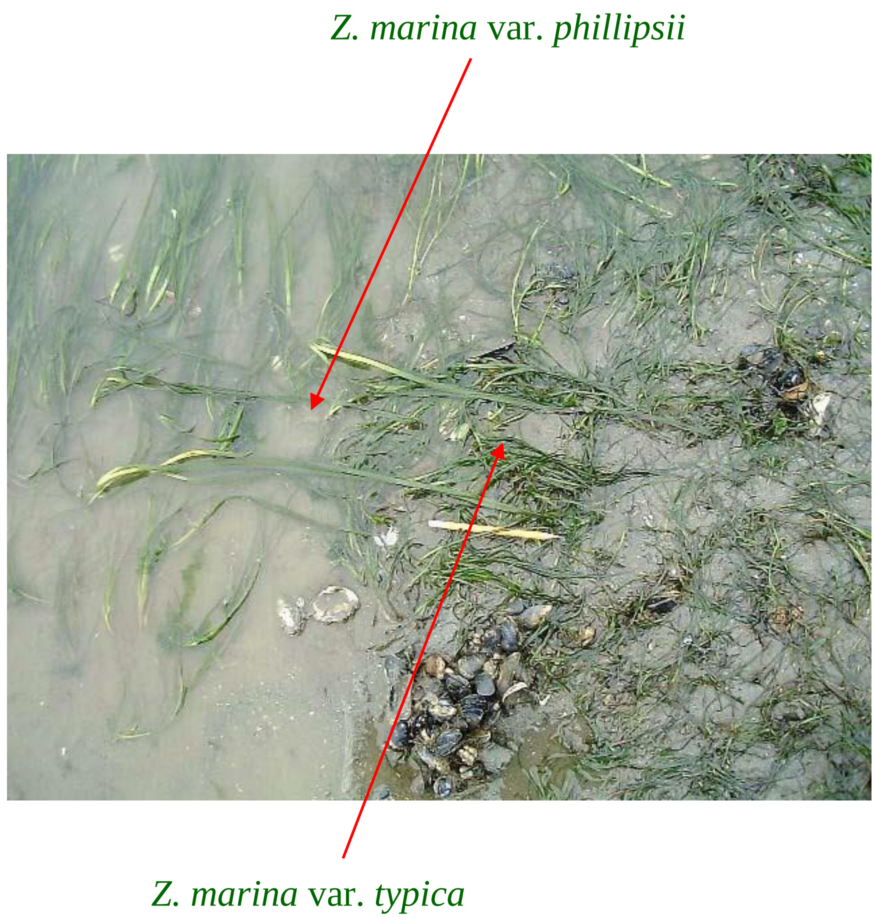


Figure 25. Photo of the varieties of *Z. marina* in the intertidal zone at Coupeville.

Note: *Z. marina* var. *phillipsii* grows in the depressions and is larger than *Z. marina* var. *typica* (note the pencil for scale). (Photo by T. Wyllie-Echeverria.)

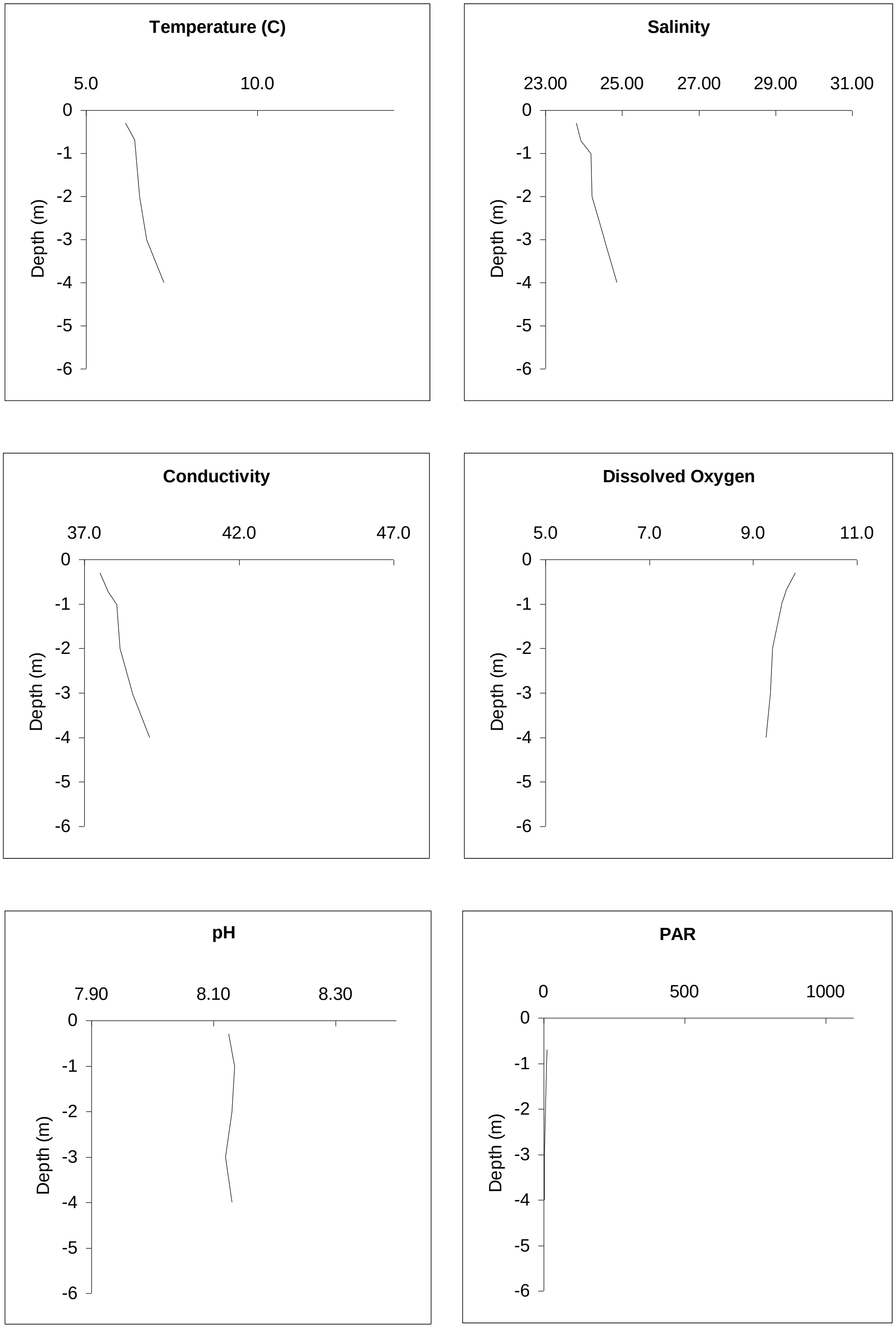


Figure 26. Water quality profiles for Penn Cove.

Note: Data collected at 122:41.201 and 48:13.328 (near Coupeville) on December 8, 2000 at 3:10 pm. Sky was very overcast.

6 Holmes Harbor

6.1 Site Definition and Description

Holmes Harbor is located at the southern part of Whidbey Island approximately 14 miles south of Oak Harbor (Figs. 27 and 28). It extends in a north-south direction for about six miles. Like Penn Cove, it does not have any extensive tide flats and its entire shoreline is categorized as fringe eelgrass habitat by the DNR SVMP (swh0920 to swh0942). Residential homes line much of the shoreline. The Nichols Brothers Boat Builders, Inc. is located at the southern end of the bay at the town of Freeland, but it does not have a dock or railway facility.

6.2 Site Specific Methods

During pre-survey planning we determined that seven of the 23 fringe sites in Holmes Harbor could be sampled during the one day allocated to this site. The Island County Marine Resource Committee gave the southern shoreline near Freeland its highest priority. Thus, we selected the three fringe sites at the southern end of the bay (swh0931, swh0932, and swh0933) for sampling, and then randomly selected four additional sites (swh0924, swh0928, swh0935, and swh0937).

We sampled Holmes Harbor on December 14, 2000 using one zig-zag transect at each site. No benthic grab samples were taken. We collected water quality data at the deep-water edge of the eelgrass bed at site swh0932 near Freeland.

6.3 Results

We observed significant eelgrass beds at all sites sampled (Fig. 29). The leaves appeared to be 3 to 4 ft long and percent cover appeared to be the highest of any region visited on this survey. Total estimated eelgrass area for Holmes Harbor was 1,538,158 m^2 (154 hectares; 380 acres; Table 8). Eelgrass area per 1,000 m fringe site ranged from 30,464 m^2 to 96,710 and averaged 70,841 m^2, implying an average eelgrass bed width of about 70 m. Patchiness index was relatively low at all sites, ranging between 0.97 (swh0924) and 7.58 (swh0933).

Mean minimum eelgrass depths ranged from –1.2 ft to 0.6 ft and mean maximum eelgrass depths ranged from –6.9 ft to –15.0 ft, with six of the seven sites having mean maximum depths over –11.2 ft (Table 9). The shallowest mean maximum depth was at swh0924 (north side of Dines Point). There was no apparent trend in mean maximum depths around the bay.

As with the other sites, water quality data indicate a layer of fresh water at the surface (Fig. 30). Of the 14,859 time/position records for Holmes Harbor, only 61, 17, and 16 of the records noted green urchins, geoducks, and mussels, respectively. However, due to the heavy eelgrass cover, it is possible that organisms were present but not seen. The sediment type was mostly sand (93% of the records) with the remainder (7%) being classified cobble/shell.

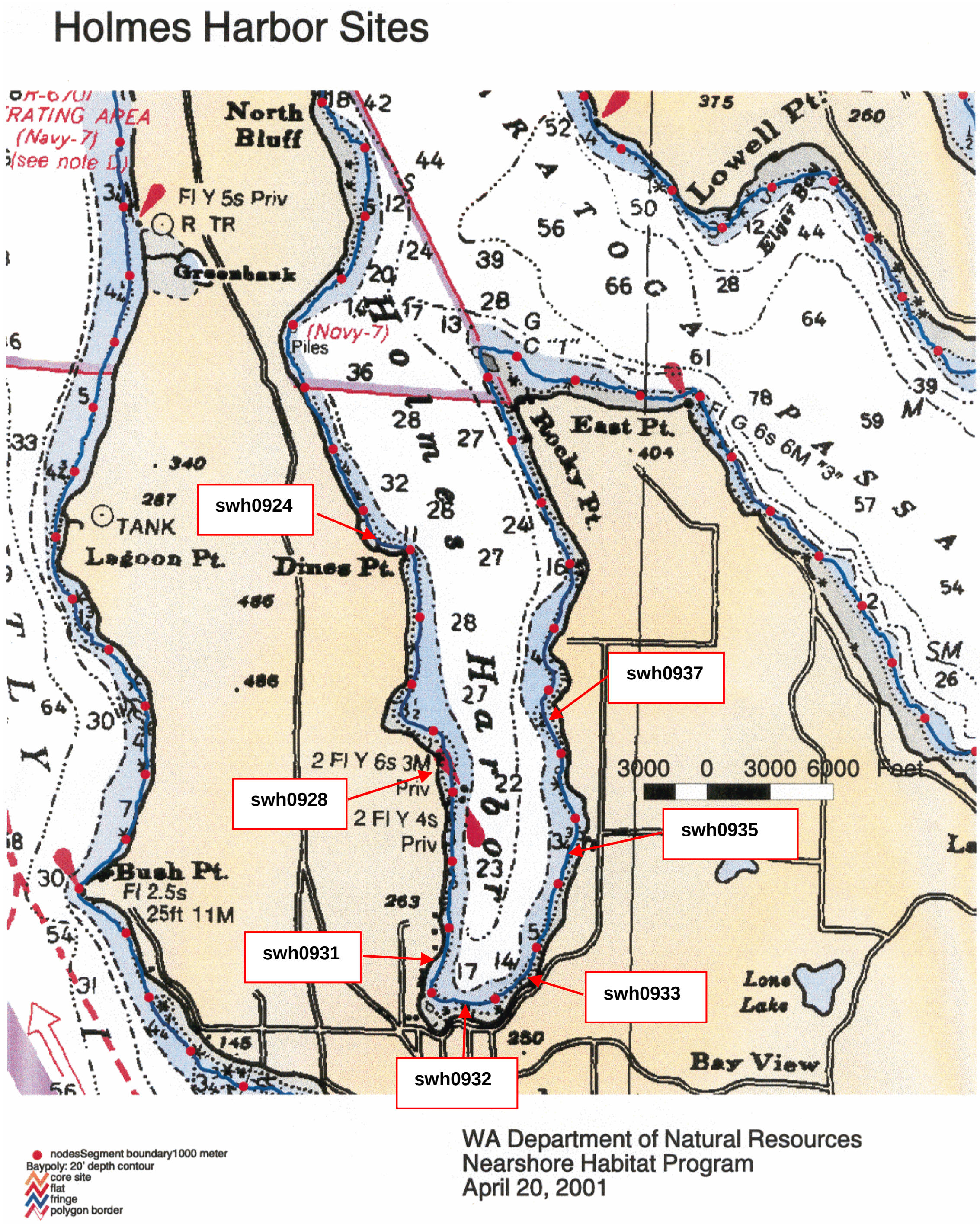


Figure 27. Map of Holmes Harbor showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites.

Note: SVMP fringe sites are delineated by the blue line with red dots 1,000 m apart. The Island County eelgrass survey sampled sites swh0924, swh0928, swh0931, swh0932, swh0932, swh0933, swh0935, and swh0937.


swh0924 (Dines Point)


swh0932 (Nichols Brothers Boat Builders, Inc.)


swh0924 (Dines Point)


swh0932 (Freeland)


swh0931


swh0933


swh0932 (Nichols Brothers Boat Builders, Inc.)


swh0933

Figure 28. Aerial photo sequences for Holmes Harbor.
Note: Photos from the Washington State Department of Ecology web site: www.ecy.wa.gov/apps/shorephotos.

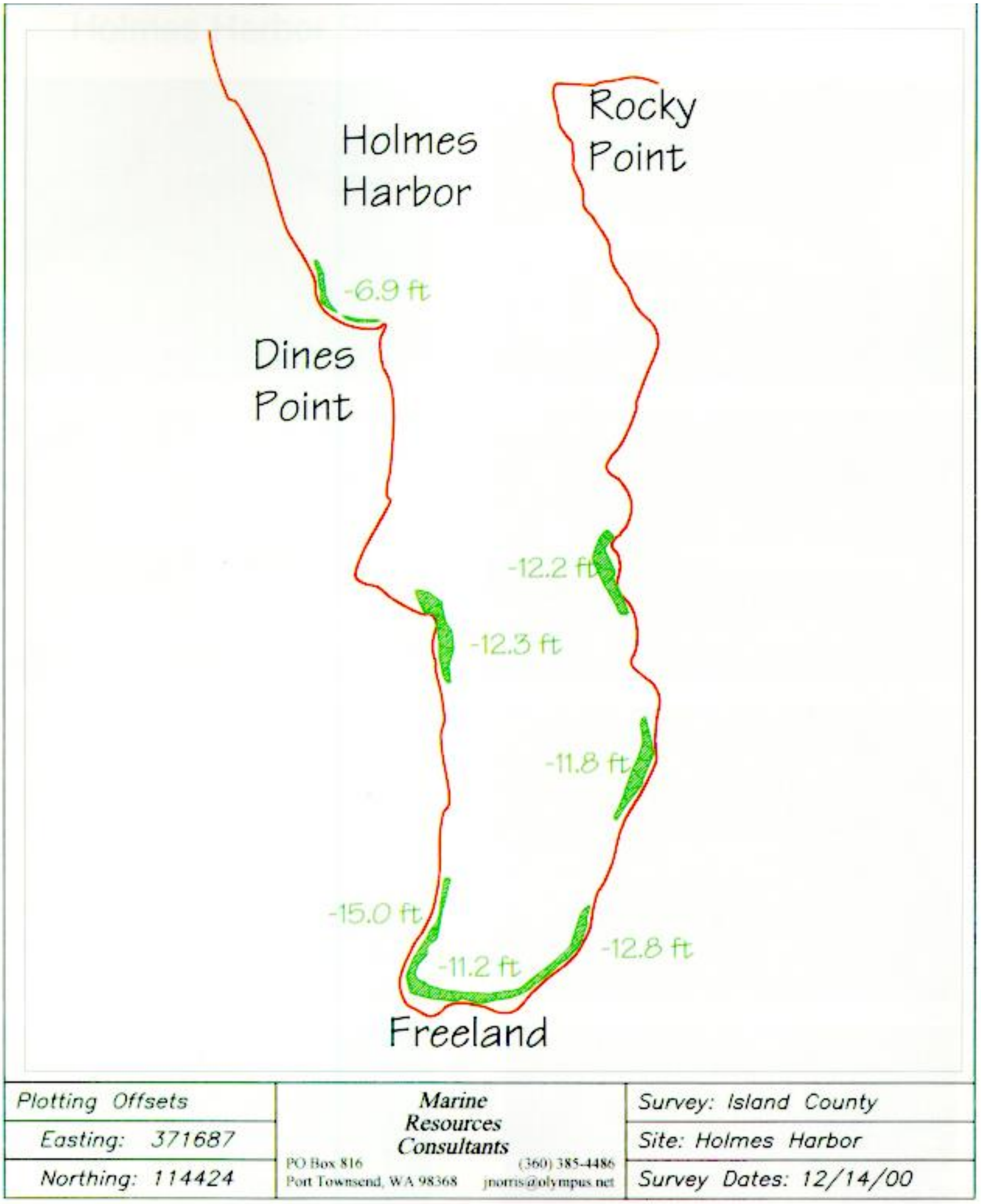


Figure 29. Site map for Holmes Harbor.

Note: Estimated mean maximum eelgrass depths are labeled in green.

Table 8. Estimated basal area coverage, variance, and confidence limits for Holmes Harbor.

Site	Estimated Eelgrass Area (m^2)	Estimated Variance	Lower Limit	Upper Limit
Non-Random Sites				
swh0931	61,999	1,207,549	59,845	64,153
swh0932	96,710	7,491,237	91,345	102,074
swh0933	59,243	11,367,008	52,635	65,852
Total	217,952	20,065,794		
Random Sites				
swh0924	30,464	628,224	28,911	32,017
swh0928	83,900	5,236,159	79,413	88,386
swh0935	81,285	30,106,961	70,530	92,039
swh0937	82,289	17,725,415	67,394	90,540
Total	277,938	53,696,759		
Mean	69,485			
Variance	677,871,027			
All Potential Random Sites	1,320,206	48,553,370,279		
Total (Random and Non-Random Sites)	1,538,158	48,573,436,073	1,106,186	1,970,129

Table 9. Patchiness indices and depth parameter estimates for Holmes.

Parameter	Estimate	Observed Range	Lower Limit	Upper Limit
Patchiness Index				
swh0924	0.97			
swh0928	2.01			
swh0931	1.74			
swh0932	6.79			
swh0933	7.58			
swh0935	2.57			
swh0937	2.72			
Mean Minimum Eelgrass Depth (ft, MLLW)				
swh0924	-0.1	(-1.3, 1.4)	-0.6	0.4
swh0928	0.3	(-2.3, 3.0)	-0.9	1.5
swh0931	-1.2	(-1.9, -0.1)	-1.7	-0.7
swh0932	-0.9	(-2.9, -0.2)	-1.7	-0.2
swh0933	-1.1	(-1.8, -0.3)	-1.5	-0.7
swh0935	0.6	(0.1, 1.3)	0.3	1.0
swh0937	-0.1	(-2.6, 0.8)	-0.9	0.7
Mean Minimum Eelgrass Depth (ft, MLLW)				
swh0924	-6.9	(-12.1, -3.1)	-8.2	-5.6
swh0928	-12.3	(-13.6,-9.2)	-13.1	-11.6
swh0931	-15.0	(-16.1, -13.1)	-15.5	-14.4
swh0932	-11.2	(-13.8, -2.9)	-13.7	-8.7
swh0933	-12.8	(-14.3, -10.6)	-13.5	-12.0
swh0935	-11.8	(-15.1, -3.7)	-14.6	-8.9
swh0937	-12.2	(-14.8, -5.9)	-14.2	-10.1

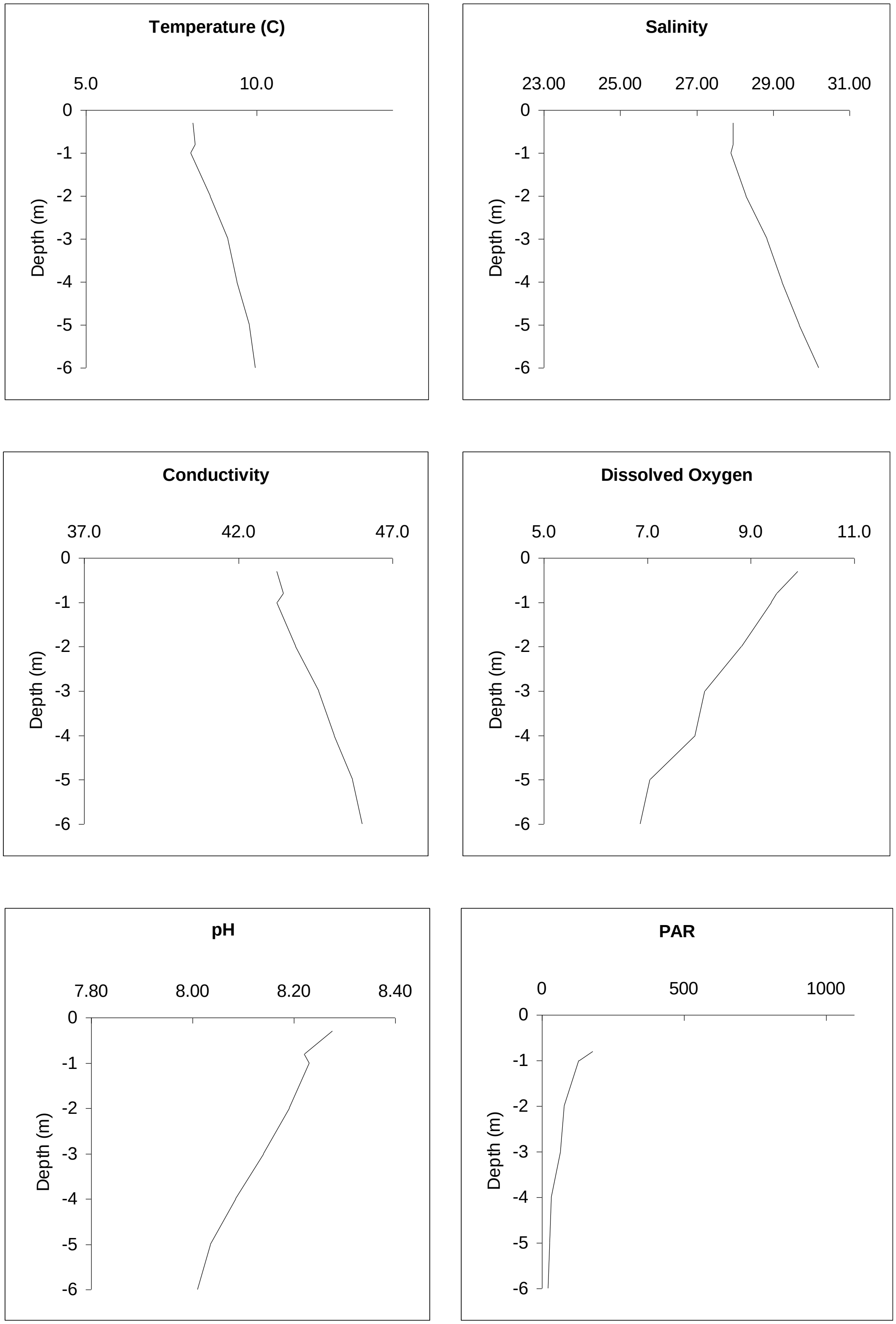


Figure 30. Water quality profiles for Holmes Harbor.

Note: Data were collected at 122:31.959 and 48:1.051 (near Freeland) on December 14, 2000 at 1:15 pm. Sky cover was cloudy.

7 Maxwelton

7.1 Site Definition and Description

Maxwelton is located at the southwestern end of Whidbey Island facing Admiralty Inlet. Maxwelton Creek drains the largest watershed in Island County and empties into Admiralty Inlet just north of the town of Maxwelton (Fig. 31). The tide flat directly off Maxwelton Creek extends approximately 500 meters to the west (Fig. 32). We selected fringe site cps0761 as our study site. Note that the DNR SVMP includes this site in the Central Puget Sound region. Maxwelton Creek empties into Admiralty Inlet approximately 200 m from the north end of this site.

7.2 Site Specific Methods

On October 7, 2000 we conducted 12 straight-line transects through this site—eight running perpendicular to the isobaths and four running parallel. Water quality data were collected at the deep-water edge of the eelgrass bed near the center of the site. We randomly selected 10 stations for benthic grab sampling. Of these 10 stations, three contained *Z. japonica*, but no *Z. marina*. Thus, we selected three additional stations from the *Z. marina* zone. Of the 260 plants collected during benthic grab sampling, we measured 30 for leaf area. During video tape post-processing we assigned attribute codes for *Z. japonica* as well as for *Z. marina*; we estimated basal area coverage for both species. On April 14, 2001 we visited the site at low tide to verify the distribution of these two species in the intertidal zone.

7.3 Results

The eelgrass bed at Maxwelton extends from the mid-intertidal zone to the bathymetry break at the end of the tide flat (Fig. 33). We observed no eelgrass in a semi-circle (approximately 150 m radius) extending from the mouth of Maxwelton Creek. *Z. japonica* occupies the nearshore portion of the bed and *Z. marina* occupies the deeper portion; there is a significant mixed zone where both species are present (approximately 65 m wide; Fig. 34). The estimated area for both species was nearly identical—65,635 m^2 for *Z. marina* and 63,215 m^2 for *Z. japonica*. The patchiness index for *Z. japonica* was slightly greater than that for *Z. marina* (Table 10).

Mean minimum depths for *Z. marina* and *Z. japonica* were 0.5 ft and 2.9 ft, respectively; mean maximum depths were –11.3 ft and 0.4 ft, respectively. Eighty time/position records were coded for both *Z. marina* and *Z. japonica*; the mixed zone included the depth range 0.0 ft to 2.5 ft (Fig. 35).

Estimated mean shoot density for *Z. marina* was 260 shoots/m^2, estimated mean leaf area was 48.64 cm^2, and estimated leaf area index was 1.26. We did not collect *Z. japonica* specimens. On our site visit on April 14, 2001 we observed a flock of approximately 2,500 black brant (*Branta bernicla*) and numerous other shorebirds feeding on the tide flat (Figs. 36 and 37).

Water quality data for Maxwelton are given in Fig. 38. In comparing these data to other sites, note that the Maxwelton data were collected in October while water quality data for other sites were collected in December. No urchins, geoducks, or mussels were observed at Maxwelton and the sediment type was all sand.

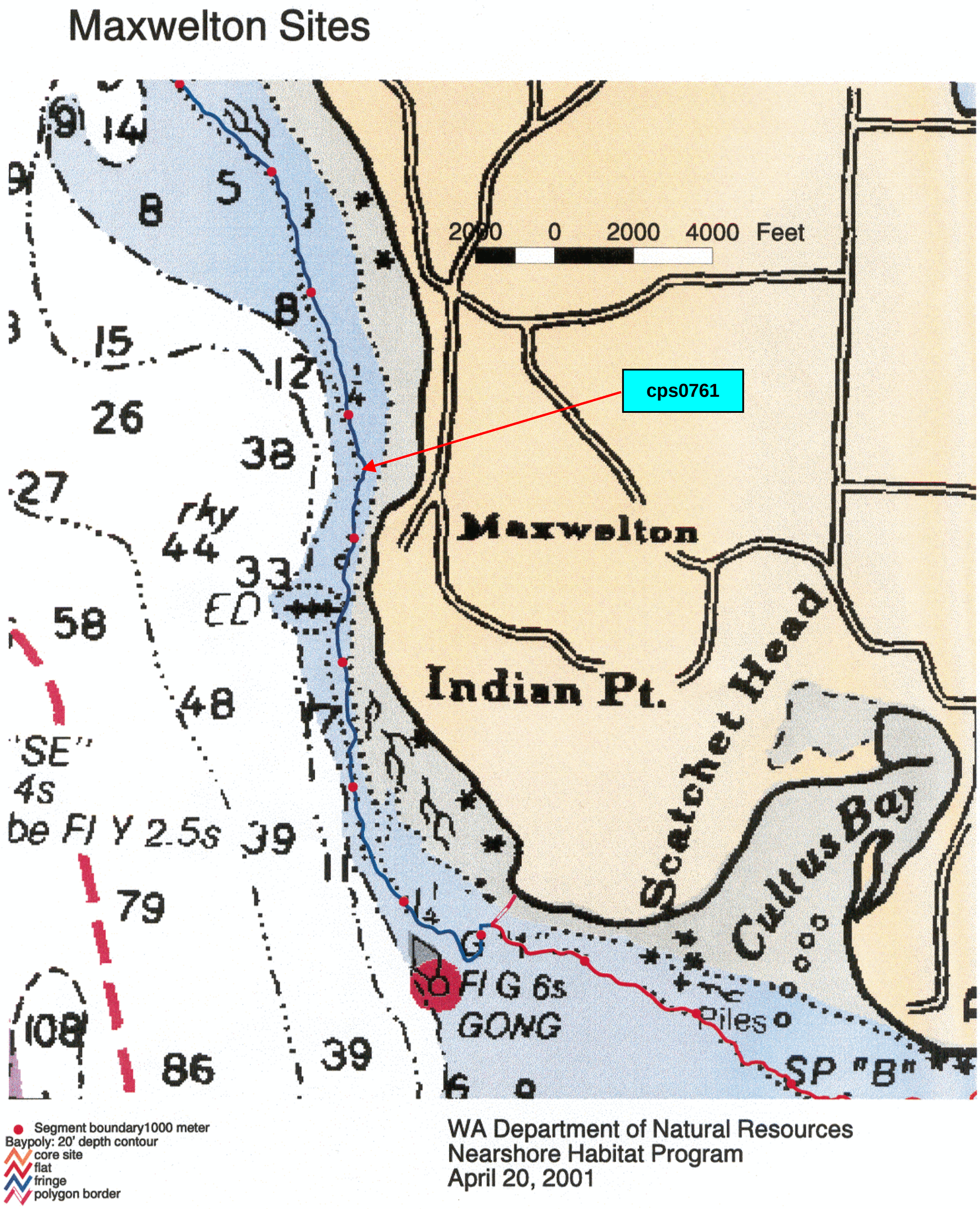


Figure 31. Map of the Maxwelton Watershed Shoreline showing the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project fringe sites.

Note: Fringe sites are delineated by the blue line with red dots 1,000 m apart. Site cps0761 was sampled for the Island County eelgrass survey.

Figure 32. Aerial photos of the Maxwelton Watershed Shoreline region.

Note: Photos from the Washington State Department of Ecology web site: www.ecy.wa.gov/apps/shorephotos.

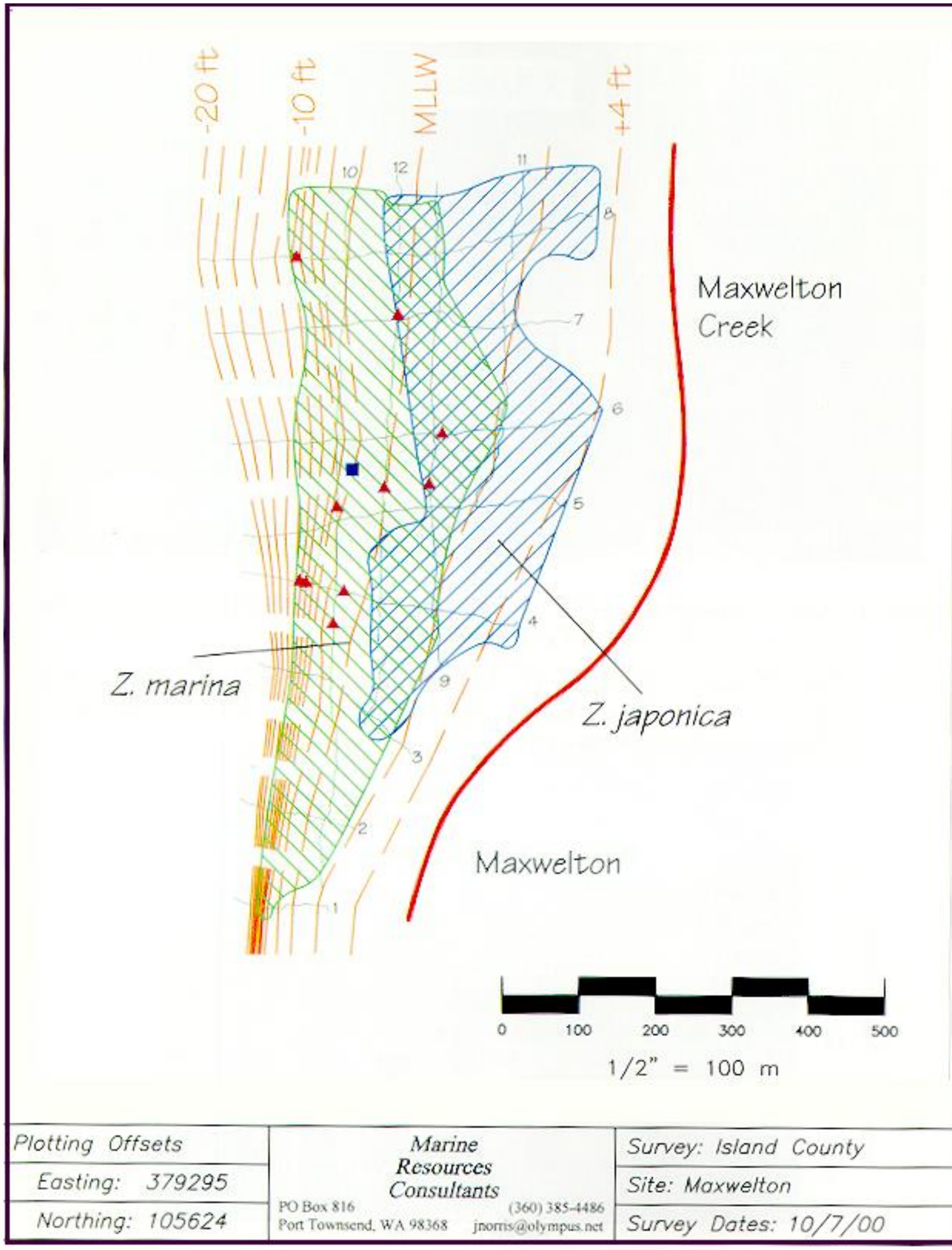


Figure 33. Site map for the Maxwelton Watershed Shoreline site.

Note: Grab stations are red triangles. Water quality station is the blue square. Isobaths are in 2 ft intervals.

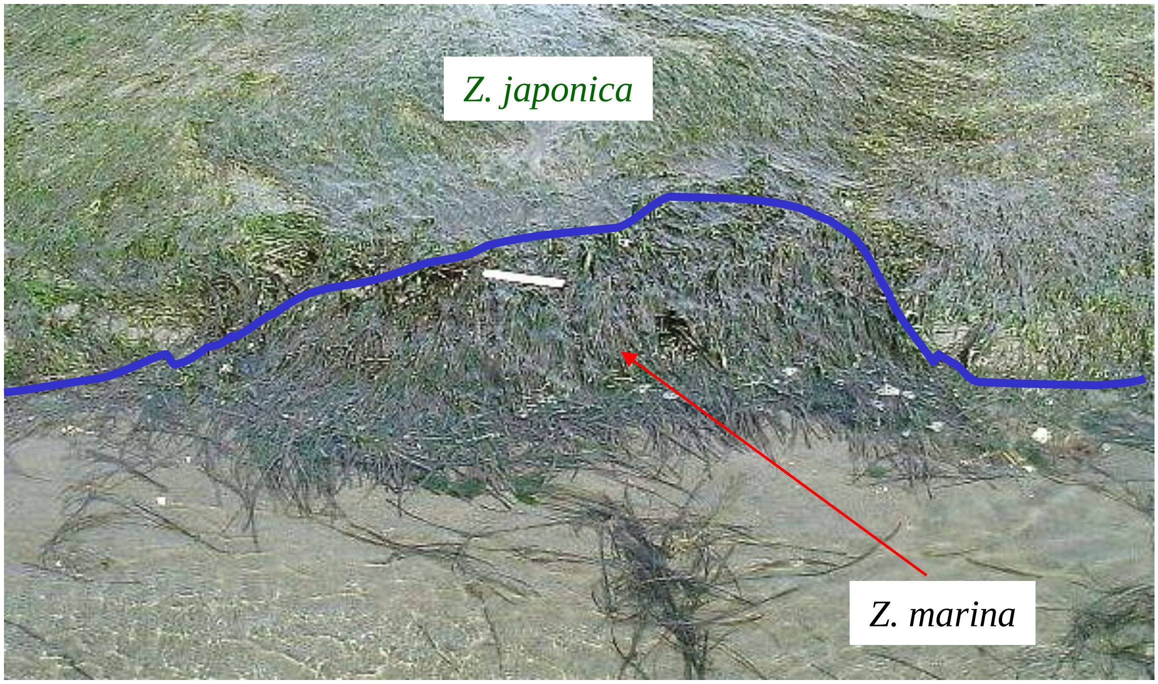


Figure 34. Photo of a seagrass patch on the tide flat at Maxwelton Shoreline Watershed with a mixed stand of *Z. marina* and *Z. japonica*.

Note: *Z. marina*, darker green in the foreground, grows in the entrapped water adjacent to *Z. japonica*, which is a lighter shade of green and more exposed. (Photo by T. Wyllie-Echeverria.)

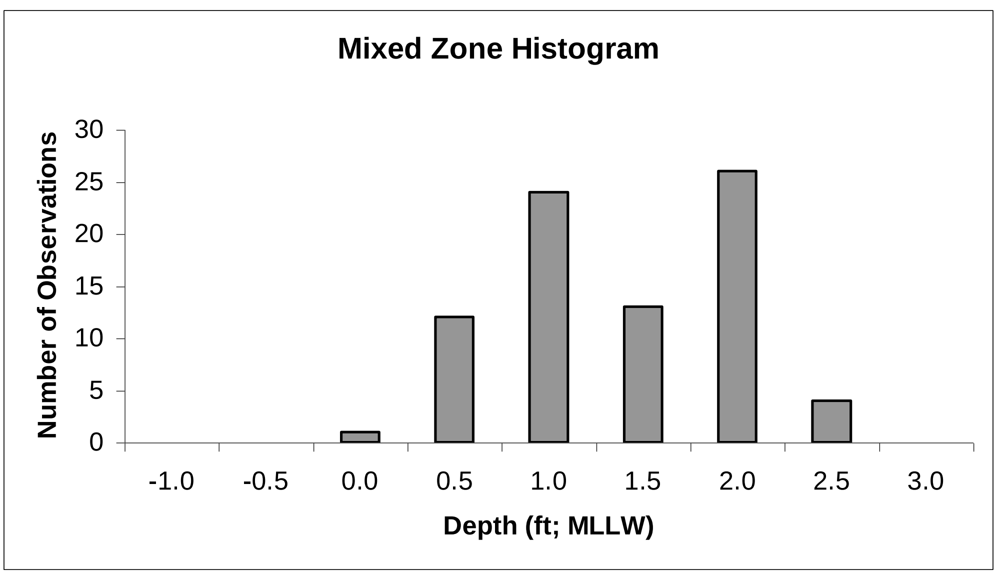


Figure 35. Histogram of depths where both *Z. marina* and *Z. japonica* were observed at the Maxwelton Watershed Shoreline site.

Figure 36. Photo of Black brant (*Branta bernicla*) grazing and resting on the tide flat at the north end the Maxwelton Watershed Shoreline site.

Note: This flock had approximately 2,500 individuals. (Photo taken on 14 April 2001 by T. Wyllie-Echeverria.)

Figure 37. Photo of Mallard ducks (*Anas platyrhynchos*) and black brant at the Maxwelton Watershed Shoreline site.

Note: The expansive intertidal seagrass habitat provides food for several species of waterfowl. (Photo taken on 14 April 2001 by T. Wyllie-Echeverria.)

Table 10. Parameter estimates and 95% confidence limits for Maxwelton.

Parameter	Estimate	Observed Range	Lower Limit	Upper Limit
Basal Area Coverage (m^2)				
Z. marina	65,635		37,852	93,418
Z. japonica	63,215		43,022	83,408
Total	128,850		80,874	176,826
Patchiness Index				
Z. marina	7.32			
Z. japonica	10.27			
Mean Minimum Eelgrass Depth (ft, MLLW)				
Z. marina	0.5	(-2.6, 2.1)	-1.1	2.1
Z. japonica	2.9	(1.5, 3.9)	1.3	4.5
Mean Maximum Eelgrass Depth (ft; MLLW)				
Z. marina	-11.3	(-14.2, -8.4)	-12.9	-9.6
Z. japonica	0.4	(-.7, 1.3)	-0.4	1.3
Mean Shoots/m^2				
Z. marina	260	(0, 780)	83	446
Mean Leaf Area (cm^2)				
Z. marina	49	(8, 236)	29	68
Mean Leaf Area Index (m/m)				
Z. marina	1.265		0.729	1.801

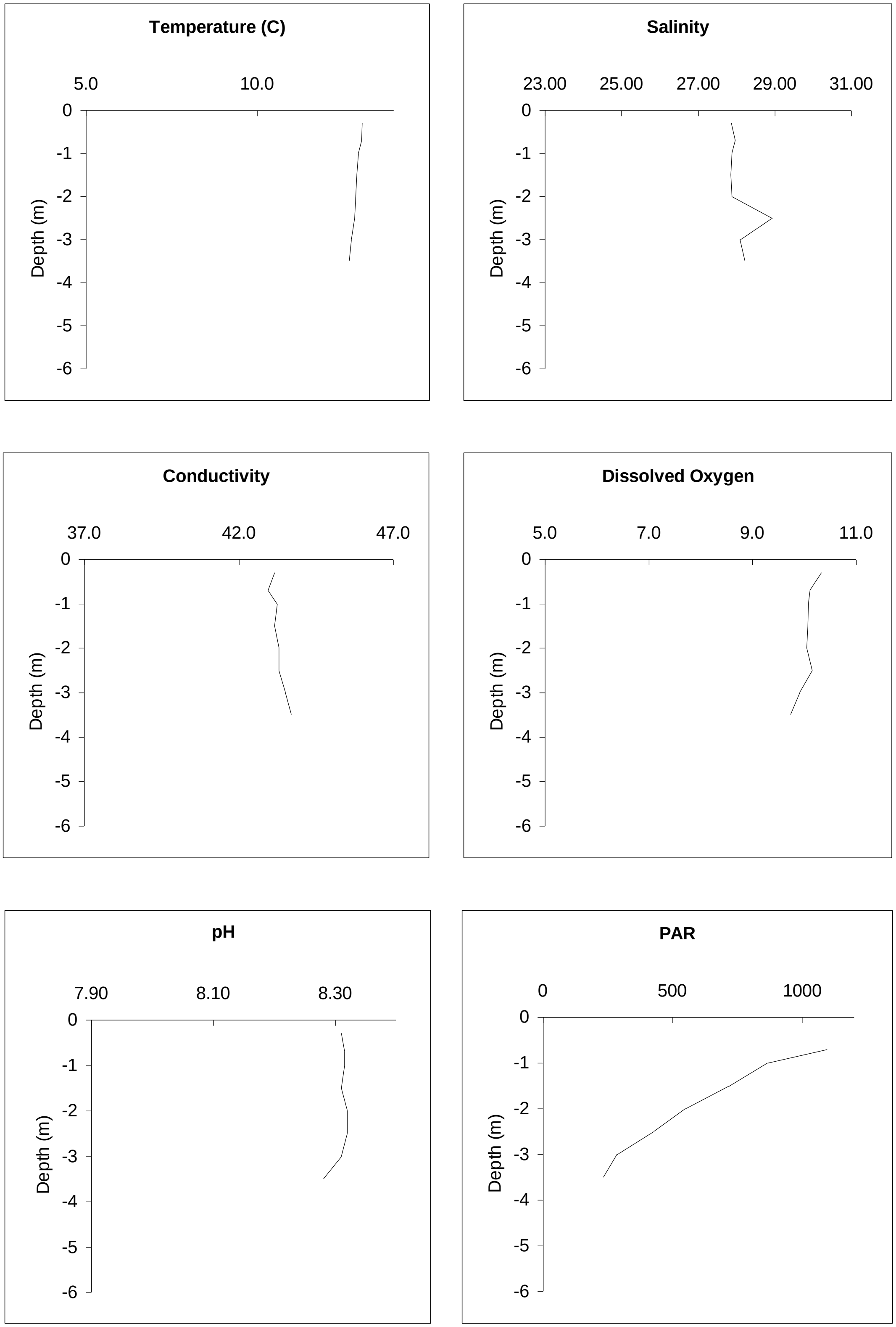


Figure 38. Water quality profiles for the Maxwelton Watershed Shoreline site.

Note: Data were collected at 122:26.786 and 47:56.597 on October 7, 2000 at 2:20 pm. Sky was bright sunshine. Sea state was a 1 ft swell with no chop. Wind was calm.

8 Summary

Tables 11, 12, and 13 summarize the parameter estimates from all sites. These parameter estimates, combined with confidence intervals presented in the previous five chapters, provide the baseline data needed to track critical eelgrass health indicators at each site over the next several years.

To place these site-specific data in a larger context and to help guide the Island County MRC in its mission to protect and enhance eelgrass habitats, we ranked each site in each parameter category and summed the ranks over all categories to get a combined "relative health score" for each site (Table 14). Rankings were based on the assumption that more basal area coverage, lower patchiness index, greater depth range (i.e., shallower minimum depth and deeper maximum depth), larger leaf area index, and lower light attenuation coefficient all improve eelgrass health. Thus, a rank of one is "better" than a rank of five, and a lower point total is "better" than a higher point total. We included leaf area index in the rankings, even though we did not estimate this parameter at all sites. From the video tape analysis it seemed obvious that the Holmes Harbor site had the highest leaf area index, and we assigned Penn Cove the same rank as nearby Oak Harbor. Other researchers have used similar ranking procedures to analyze eelgrass bed quality impacted by docks and floats (Burdick and Short 1999; Fresh et al. 2001).

Holmes Harbor and Maxwelton Watershed Shoreline eelgrass resources have lower (i.e., healthier) scores suggesting that they have more healthy eelgrass resources than Skagit Bay South, Oak Harbor, and Penn Cove (Table 14). Eelgrass at these two sites covers a greater depth range and is less patchy than the other sites. In terms of eelgrass area per shoreline length, Holmes Harbor and Maxwelton Watershed Shoreline have much more eelgrass per 1,000 m of shoreline than Penn Cove and Utsalady Bay. The inner portion of Penn Cove (sites swh0889 through swh0899) stands out because it has very sparse and patchy eelgrass that grows in a very narrow depth range: 0.9 ft down to only –1.0 ft.

Table 11. Summary of transect sampling parameter estimates for all sites.

Site	Basal Area (m^2)	Patchiness Index	Mean Min Depth (ft)	Mean Max Depth (ft)	Depth Range (ft)
Skagit Bay South					
Stratum I	48,399	12.58	-0.5	-4.3	3.8
Stratum II	39,933	17.40	-0.5	-5.7	5.2
Stratum III	7,636,491	7.15	-0.5	-7.8	7.3
Total	7,724,823				
Oak Harbor					
Small north bed	5,353	21.24	-3.1	-5.7	2.6
Large south bed	86,489	10.17	-2.0	-7.8	5.8
Total	91,842				
Penn Cove					
swh0887	15,579	15.80	-1.8	-9.7	7.9
swh0888	57,608	8.98	-0.1	-6.3	6.2
swh0889	12,018	12.29	1.0	-0.8	1.8
swh0891	0	N/A	N/A	N/A	
swh0893	2,619	9.21	0.3	-1.1	1.4
swh0895	0	N/A	N/A	N/A	
swh0897	1,900	10.93	1.3	-0.3	1.6
swh0898	10,953	10.68	1.4	-0.7	2.1
swh0899	5,246	10.11	0.4	-1.9	2.3
swh0901	21,507	16.37	0.8	-4.6	5.4
Holmes Harbor					
swh0924	30,464	0.97	-0.1	-6.9	6.8
swh0928	83,900	2.01	0.3	-12.3	12.6
swh0931	61,999	1.74	-1.2	-15.0	13.8
swh0932	96,710	6.79	-0.9	-11.2	10.3
swh0933	59,243	7.58	-1.1	-12.8	11.7
swh0935	81,285	2.57	0.6	-11.8	12.4
swh0937	82,289	2.72	-0.1	-12.2	12.1
Maxwelton					
Z. marina	65,635	7.32	0.5	-11.3	11.8
Z. japonica	63,215	10.27	2.9	0.4	3.3
Total	128,850				

Table 12. Summary of benthic grab sampling parameter estimates for the three sites sampled.

Site	Sample Date	Mean Shoot Density (per m^2)	Mean Leaf Area (cm^2)	Leaf Area Index (m/m)
Skagit Bay South	6-Dec	9	70.07	0.06
Oak Harbor	13-Dec	100	63.66	0.64
Maxwelton	7-Oct	260	48.64	1.26

Table 13. Summary of water quality parameters for all sites.

Site	Sample Date	Surface Temp	Bottom Temp	Bottom Sal	Bottom DO	Bottom pH	Bottom K_d	Bottom Depth (m)
Skagit Bay South	6-Dec	9.1	10.7	30.36	5.1	7.9	0.42	5.0
Oak Harbor	13-Dec	5.8	8.1	28.00	7.2	7.9	0.48	4.7
Penn Cove	8-Dec	6.2	7.3	24.86	9.3	8.1	0.44	4.0
Holmes Harbor	14-Dec	8.1	10.0	30.18	6.9	8.0	0.41	6.0
Maxwelton	7-Oct	13.1	12.7	28.21	9.7	8.3	0.28	3.5

Note: The bottom depth (last column) indicates the depth at which the “bottom” parameters were measured. This depth placed the instrument approximately 1 ft above the seabed and within the eelgrass canopy.

Table 14. Site rankings by parameter and total “Relative Health Score.”

Site	BAC	PI	Min Depth	Max Depth	Depth Range	LAI	K_d	Relative Health Score
Skagit Bay South	1	2	4	4	3	5	2	21
Oak Harbor	4	4	5	3	4	3.5	2	25
Penn Cove	3	5	1	5	5	3.5*	2	24
Holmes Harbor	2	1	3	1	2	1*	2	12
Maxwelton	5	2	2	2	1	2	1	15

Note: A rank of “1” means that the site had the “best,” or healthiest, value for that parameter. Conversely, a rank of “5” means that the site had the “worst,” or least healthy, value for that parameter. (* = subjective ranking.)

9 Discussion

Methods used to survey *Z. marina* in this study are consistent with guidelines specified by Washington Department of Fish and Wildlife (WDFW) for preliminary estimates of plant presence, with the exception of the requirement to space sampling transects at 40 ft intervals (Table 1). Nevertheless, we urge the Island County MRC to note that shoot densities reported here reflect winter biomass and are therefore lower than densities that would be found in summer (Phillips 1984; Kentula and McIntire 1986; Olesen and Sand-Jensen 1994b). As intended by a preliminary survey, our maps can be used to determine if eelgrass is present in the area of a prospective project. However, once a specific development site is chosen, a follow-up survey must occur in the June through September window. Sampling during this window will provide the shoot density data necessary to determine appropriate compensatory mitigation measures should a project be permitted.

There are some significant advantages to winter sampling. First, high tides generally occur during mid-day which allows vessel access to more of the inter-tidal zone. This advantage was particularly important when sampling the Skagit Bay South site. Second, macro algae, especially *Ulva lactuca* and *Laminaria saccharina,* are not present making it easier to see and identify smaller leaves and low densities associated with the biotic processes of eelgrass at particular sites. Third, water clarity can be better, provided sampling does not occur immediately after a heavy storm event. Fourth, at least one study documents that eelgrass extent (i.e., the eelgrass bed perimeter) can remain relatively constant throughout the season, despite the fact that shoot density, canopy height, and biomass increase throughout the growing season (Norris and Hutley 1998).

Even though *Z. marina* leaf metrics respond to changes in the submarine environment, emphasizing the ability of these plants to adapt to a range of environmental conditions (Phillips and Lewis 1983), five discrete varieties have been identified along the Pacific Coast of North America (Setchell 1927; Backman 1991). These varieties are distinguished by the width of their foliage leaves, the yearly percentage of flowering and the size of seeds (Setchell 1927; Phillips 1972; Backman 1991; Wyllie-Echeverria et al. in prep.). Three of these varieties grow in the Puget Sound and associated waters– *Z. marina* var. *typica*, *Z. marina* var. *phillipsii*, and *Z. marina* var. *latifolia*. They can be distinguished by their zone of growth along the tidal gradient and the width of their foliage leaves—var. *typica* is primarily found in the intertidal with leaf widths ranging from 1.5 to 4 mm; var. *phillipsii* grows primarily in subtidal regions and has leaves that range in width from 2 to 8 mm; and var. *latifolia* grows only in the subtidal region and has much wider leaves (6-20 mm) (Setchell 1927; Phillips 1972; Backman 1991). Based on an analysis of video images, field visits and plants sampled by benthic grab, we found at least two varieties at these five sites: *Z. marina* var. *typica* and *Z. marina* var. *phillipsii*. It is possible that variety *latifolia* may grow at Holmes Harbor where plants are growing more deeply, but additional sampling is needed to verify this conjecture.

In addition to these varieties of *Z. marina*, we also found the seagrass *Z. japonica* at the Maxwelton site. Since first reported in Washington State in 1957, these plants have spread north to British Columbia and south to Coos Bay, Oregon (Harrison and Bigley 1983; Wyllie-Echeverria and Phillips 1994) and are found at several sites in Puget Sound (Baldwin and Lovvorn 1994; Bulthuis 1995; Wyllie-Echeverria pers observation). However, when Dr. R. C. Phillips conducted his 1962-63, sound-wide, survey of *Z. marina*, which included the Maxwelton area, he did not find *Z. japonica* (R.C. Phillips pers com.). This could mean that either *Z. japonica* had not reached this site or plants were present in very low numbers and could not easily be found. *Z. japonica* was very abundant in 2000, covering over 63,000 m^2 of the tide flat and forming a mixed stand with *Z. marina* between 0.5 ft and 2.0 ft (Figs. 33 and 35).

Two seagrass genera are found in the waters of Washington State—*Phyllospadix* and *Zostera* (Dethier 1990; Wyllie-Echeverria and Phillips 1994) and both of these are found on Whidbey Island (Washington State Shorezone Inventory 2001; Norris 2000; Tom Mumford pers com). In fact the seagrass flora of Whidbey Island is relatively diverse because we can now confirm that within the genus *Zostera*, two varieties of *Z. marina* grow in Whidbey Island waters (Backman 1991). This diversity enhances coastal habitat complexity and biodiversity (e.g. Hemminga and Duarte 2000) and should be monitored and protected.

We also note that the presence of *Z. japonica* extends the seagrass zone from -11.3 ft to +2.9 ft across the gentle sloping tide flat at Maxwelton Watershed Shoreline (Table 11). This contributes to the high value of this site for shorebirds, wading birds, dabbling ducks and black brant (Phillips 1984; Baldwin and Lovvorn 1994; Matsunnaga 2000). When we visited the site on 14 April 2001, during a +0.3 low tide, flocks of sanderlings (*Calidris alba*) were feeding in the mud in and around the exposed seagrasses and approximately 2,500 black brant were feeding and resting at the waters edge. *Z. japonica* also increases the foraging territory available for invertebrate grazers such as the isopod *Idotea* spp., and the skeleton shrimp, *Caprella californica*, which are prey for shiner perch (*Cymatogaster aggregata*) (Phillips 1984; Thom et al. 1995). While *Z. japonica* is an introduced plant, the informal no net loss policy enforced by WDFW does extend to these plants (Pawlak and Olson 1995). Consequently, knowledge of *Z. japonica* distribution is vital for Island County MRC conservation planning.

The deep-water distribution of *Z. marina* (Figure 29; Table 11) at Holmes Harbor may explain why this location is an important herring spawning site on Whidbey Island (Pentilla 1999; Lemberg et al. 1997). The average maximum depth of plant growth at this site is approximately twice as deep as the average maximum depth at the other interior bays of Skagit Bay, Oak Harbor, and Penn Cove. This phenomenon may be linked to the quality of submarine light in the subtidal region, although our K_d estimates show no difference between these sites. (Given the overcast conditions when the PAR data were collected, the resulting K_d estimates should not be considered good indicators of overall light conditions at these sites.) Previous studies document that there is a strong relationship between the submarine light environment and the depth distribution of *Z. marina* (Zimmerman et al. 1991; Dennison et al. 1993; Koch and Beer 1996) and Short and Wyllie-Echeverria (1996) report that deteriorating water clarity is the single most important causative agent in seagrass loss globally.

We suspect that the variation in eelgrass depth distribution at Penn Cove (Table 7) may be linked to water quality issues. In the mouths of Penn Cove and nearby Oak Harbor, plants grow four times more deeply than at the head of this bay. Eelgrass in the main portion of Penn Cove is essentially an intertidal resource and, therefore, less desirable herring spawn habitat. In their review of historic changes in eelgrass meadows of Puget Sound, Thom and Hallum (1990) show sparse eelgrass observations in Penn Cove, but no surveys report maximum depth of occurrence (Fig. 39). The 1841 survey by the Wilkes Expedition provides depth soundings, but no mention of eelgrass (Fig. 40).

Variation in maximum depth at the Skagit Bay South site is also curious. The depth distribution for both nearshore strata is significantly shallower than the offshore strata even though, like Penn Cove, habitat appears to be available in deeper water (Figure 10; Table 4).

Thom and Hallum reported that the Shore Zone Atlas created in the 1970s shows many eelgrass observations in Utsalady Bay (Fig. 39). However, they caution that “the accuracy of the historical records for all habitat types is questionable.” For example, we note that the Shore Zone Atlas also shows numerous eelgrass observations along the shoreline in front of downtown Oak Harbor (Fig. 39) where we found no eelgrass (Fig. 18). Given the historic photos and information we reviewed in this report, we believe these Shore Zone Atlas observations for Oak Harbor are not correct and are most likely macro algae misinterpreted from an aerial photograph. The reported eelgrass observations in Utsalady Bay also may have been misinterpreted macro algae.

Defining the causative agent for this pattern of plant growth is beyond the scope of this report, however a possible explanation could be the reduction in water clarity linked to an increase of phytoplankton biomass fueled by watershed nutrient loading. Figure 6 shows that in 1993 residential houses were very prominent along this coastline. Accordingly, it may be important to determine if inputs from septic tanks and lawn fertilizers are increasing the inorganic nitrogen content of fresh water runoff in this region. Inputs of this kind have led to increases in nutrient loading at other sites where eelgrass grows (Lee and Olsen 1985; Valiela et al. 1992) and have enabled investigators to conclude that losses in eelgrass basal area cover over time are linked to an increase in residential housing which in turn increases the amount of inorganic nitrogen in groundwater seepage (Short et al. 1996; Short and Burdick 1996).

While sampling in the nearshore strata at Utsalady, we encountered a number of mooring buoys (occupied and unoccupied). Figure 6 (1993 aerial photograph) also shows buoys in this area. The swing of an anchor chain from a buoy or mooring has been known to scour the bottom and remove seagrass (Short et al. 1991; Walker et al. 1989). Based on the reported date and time of the 1993 aerial photograph, we estimate the tide height at the time the photograph was taken to be –1.5 ft. Thus, it appears that these buoys are located outside the potential eelgrass habitat. However, more accurate data regarding the location of buoys relative to the potential and existing eelgrass beds are required to better analyze this issue.

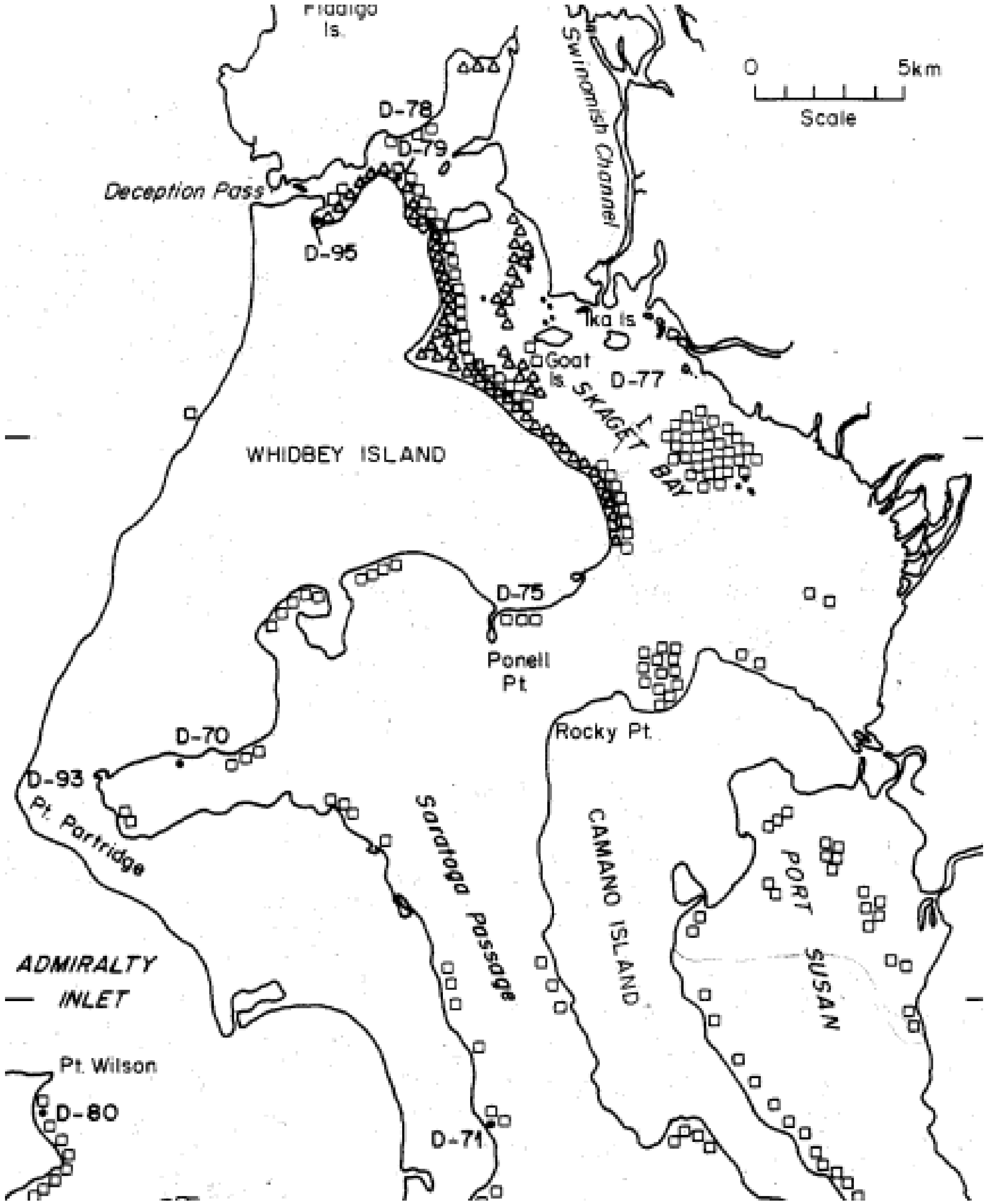


Figure 39. Historic eelgrass locations reported by Thom and Hallum (1990).

Note: The open squares are eelgrass observations reported by the Coastal Zone Atlas. The black dots are eelgrass observations reported by Ron Phillips (1962-63).

Figure 40. A 1841 map drawn during the Wilkes Expedition shows the depths in both Penn Cove and Oak Harbor, but does not report eelgrass.

Note: Map provided by Mrs. Janet Enzmann, Archivist, Island County Museum, Coupeville, WA.

10 Conclusions

Based on our findings we conclude the following:

- Of the five sites surveyed by this study, Penn Cove is the site of greatest concern. The fact that, on average, eelgrass does not grow deeper than –1.0 ft below MLLW in the main portion of the cove could be the natural state or a sign of environmental stress. A full evaluation of the historic and potential stressors, both natural and human induced, that may impact eelgrass is beyond the scope of this report. Nevertheless, it appears that Penn Cove is more likely a candidate for eelgrass restoration than for eelgrass protection.
- Another site of concern is Utsalady Bay, where maximum eelgrass depths were shallower than the surrounding areas and the patchiness indices were high. Describing a link between the causative agents and the state of eelgrass at this site is beyond the scope of this report. However, it is important to note that the eelgrass resources in adjacent Skagit Bay appear healthier, with a lower patchiness index and deeper maximum eelgrass depths. Surveying Skagit Bay provided important reference data to compare with Utsalady Bay. The most likely anthropogenic stressors for Skagit Bay lie outside of Island County and in the Skagit River watershed. Thus, as a practical matter, it is difficult to imagine what protective measures Island County can employ to protect the Skagit Bay eelgrass resource.
- We observed no eelgrass resources in the immediate vicinity of the town of Oak Harbor, including the small boat basin. Given the dredging history of this region, it seems unlikely that this region of Oak Harbor was historically occupied by a large bed of eelgrass, although we have no direct evidence to support this conjecture. We believe the eelgrass observations reported in the Coast Zone Atlas for this region are incorrect.
- Holmes Harbor appears to be the most healthy of the five sites. We observed eelgrass everywhere we surveyed, the patchiness indices were low, and the maximum eelgrass depths were about –12 ft—all signs of a healthy resource. Thus, Holmes Harbor is a good candidate for eelgrass protection, especially considering it is a known herring spawning site.
- Maxwelton Watershed Shoreline also appears to be a good candidate for eelgrass protection. The patchiness index was moderate and the maximum eelgrass depth was –11.3 ft. The main concern in this area is the lack of eelgrass in the plume at the mouth of Maxwelton Creek. This could be a sign of stress caused by land use activities in the watershed.

11 Recommendations

We strongly recommend that, at a minimum, the MRC monitor the maximum depth of *Z. marina* at all sites every three years. This single parameter is cost effective to measure and has been shown to be an effective tool to monitor the decline and improvement of estuarine water quality (Zimmerman et al 1991; Dennison et al. 1993). If funds are available, we recommend repeating this entire survey in three years. For the Utsalady site we advise that the Island County MRC include inorganic nitrogen within the suite of environmental parameters monitored.

We found *Z. japonica* at the Maxwelton Watershed Shoreline. Early observations by Miki (1933) in Japan suggested that these plants respond to estuarine pollution by not flowering. In two seminal texts describing seagrass phylogeny, taxonomy and ecology, authors repeat this account when discussing *Z. japonica* (Den Hartog 1970; Phillips and Menez 1988). Consequently, we propose that these plants could be potential biological indicators of coastal pollution and suggest the Island County MRC consider initiating a citizen-based monitoring program at the mouth of Maxwelton Creek in which *Z. japonica* flowering success is used as a potential early warning signal forecasting the decline of near-shore water quality. Prior to initiating such a program the MRC should sponsor a workshop designed to provide citizen volunteers with the knowledge to monitor the flowering processes of *Z. japonica*. We suggest that this program be started as soon as possible.

We recommend that future mapping programs be instructed to provide information relative to the presence of *Z. japonica* at other sites under the jurisdiction of the Island County MRC. Not only as a potential indicator of pollution, but also to document the spread of this plant on Whidbey Island.

We recommend that the Island County MRC continue the effort to locate historical information for these five sites as well as other future sites. This is especially true for Penn Cove. Our survey documents that the Penn Cove eelgrass resources do not extend to normal eelgrass depth limits. Without information about historic eelgrass depths, it is impossible to determine if this is a natural condition for this site or the result of environmental stress. And without that knowledge, it will be difficult to recommend appropriate management actions for this region.

We recommend that the Island County MRC enlarge the eelgrass monitoring effort to other sites in Island County. The survey methods should be capable of providing species identification, basal area coverage and minimum/maximum depth of seagrass growth.

Hemminga and Duarte (2000) state that “The detection of declines of seagrass meadows, although important because it gives information on the health status of the meadows, and has a signal function indicating environmental deterioration, is rather unsatisfactory for managers, for experience on seagrass losses shows that once losses become apparent it is probably too late to counteract the disturbance.” In addition to the “signal function” *Z. marina* plays in Puget Sound in terms of water quality conditions, these plants also provide valuable habitat for several key species. For these reasons we recommend that the Island County MRC consider techniques, not only designed to track basal area cover and maximum depth but also sufficient to assess the physiological health of *Z. marina* in a program to monitor this resource. We collected samples in a pilot study as part of this project to address this issue.

Our pilot study, in collaboration with colleagues at the Chemical Ecology Laboratory at Brigham Young University, was designed to measure the production of natural products such as phenolics and volatiles that are found in leaf tissues. This procedure as been used to evaluate short and long-term physiological stress, in terrestrial angiosperms because these compounds are energy sources, function as cofactors in metabolism, interact with plant hormones, defend against herbivores and pathogens, and regulate nutrient cycling (Cates 1996; Schimel et al. 1996). We advised that the pilot study be initiated because another pilot study in Puget Sound demonstrated that the technique was useful in characterizing the physiological health of *Z. marina* (Wyllie-Echeverria, Cates and Zou in prep). Accordingly and in consultation with Island County MRC we collected and archived samples for future analysis. We recommend that these samples be analyzed and the results discussed with the Island County MRC with the intent on refining the procedure for use in a seagrass management context.

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APPENDIX A

WASHINGTON STATE
DEPARTMENT OF NATURAL RESOURCES

SUBMERGED VEGETATION MONITORING PROJECT

PARAMETER ESTIMATION EQUATIONS

A-1. Patchiness Index

An eelgrass bed can be considered a two-phase mosaic (i.e., a surface partitioned into two types of polygons—eelgrass and no eelgrass). A straight-line transect through an eelgrass bed can have sections of eelgrass (patches) and no eelgrass (gaps). In terms of our post-processed videotape data, each transect will consist of sequences of 0s and 1s identifying eelgrass presence/absence. Each sequence of 0s represents a gap and each sequence of 1s represents a patch.

We define the patchiness index to be the number of eelgrass code transitions (i.e., 0 to 1 and 1 to 0) per 100 m of transect length through the eelgrass bed. Mathematically, we compute the patchiness index for each site as follows:

$$PatchinessIndex = d = \frac{\sum_i n_i}{\sum_i \sum_j l_{i,j}}$$

where

n_i = number of eelgrass code transitions between the first and last eelgrass observation on transect i;

l_{ij} = length of time/position record j on transect i (only for records lying between the first and last eelgrass observation of a transect).

A-2. Estimating Basal Area Coverage

The sampling in Puget Sound for a particular year can be conceptualized as a stratified sampling program. The four strata correspond to four mutually exclusive and exhaustive categories as follows:

Stratum 1. Core areas selected non-probabilistically;
Stratum 2: Randomly select flats sites;
Stratum 3: Randomly selected fringe sites with high eelgrass probability;

Stratum 4: Randomly selected fringe sites with low eelgrass probability.

Within flats and fringe strata, sampling will be conducted using simple random sampling (SRS). Over years, rotational sampling will be conducted independently within the three probabilistically sampled strata. The fractional rotation of sampling units in and out of strata will be 20%.

During the first year of the monitoring program, the sampling scheme is a stratified random sampling scheme. Define

x_{ij} = abundance of eelgrass in the jth sample $(j = 1,\ldots,m_i)$ for the ith strata $(i = 1,\ldots,4)$;

$\hat{x}_{ij}$ = estimated abundance of eelgrass in the jth sample $(j = 1,\ldots,m_i)$ in the ith stratum $(i = 1,\ldots,4)$;

N_i = number of sampling units in the ith stratum;

n_i = actual number of samples drawn in the ith stratum;

$Var(\hat{x}_{ij}|x_{ij})$ = sampling variance associated with estimating abundance x_i by $\hat{x}_{ij}$ at the jth sample $(j = 1,\ldots,m_i)$ for the ith stratum $(i = 1,\ldots,4)$.

It is worth noting that the within-site eelgrass abundance x_{ij} will be actually estimated by $\hat{x}_{ij}$ which will be assumed to be an unbiased estimator:

$$E(\hat{x}_{ij}) = x_{ij}$$

with an unbiased variance estimator

$$E\left[V\hat{a}r(\hat{x}_{ij}|x_{ij})\right] = Var(\hat{x}_{ij}|x_{ij}).$$

The overall abundance of eelgrass in Puget Sound will be expressed as

$$A_T = A_1 + A_2 + A_3 + A_4$$

where A_i is the eelgrass abundance in stratum i $(i = 1,\ldots,4)$ and estimated by

$$\hat{A}_T = \sum_{i=1}^{4} \hat{A}_i \qquad \text{(A1)}$$

with associated variance

$$Var(\hat{A}_T) = \sum_{i=1}^{4} Var(\hat{A}_i|A_i). \qquad \text{(A2)}$$

A-2.1. Estimation Within Core Stratum

In this stratum, all N_1 of N_1 sites will be sampled, in which case

$$\hat{A}_1 = \sum_{j=1}^{N_1} \hat{x}_{ij} \qquad \text{(A3)}$$

with associated variance estimator

$$V\hat{a}r(\hat{A}_1|A_1) = \sum_{j=1}^{N_1} V\hat{a}r(\hat{x}_{ij}|x_{ij}) \qquad \text{(A4)}$$

the sum of the within-site measurement errors.

A-2.2. Estimation Within Fringe Strata

The sampling units within each of these strata will be of constant shoreline length. Hence, there is simple random sampling of units of equal size within each stratum, in which case

$$\hat{A}_3 = \frac{N_3}{n_3}\sum_{j=1}^{n_3}\hat{x}_{ij} \qquad \text{(A5)}$$

with associated estimated sampling variance (Appendix D)

$$V\hat{a}r\left(\hat{A}_3 \middle| A_3\right) = \frac{N_3^2\left(1-\frac{n_3}{N_3}\right)s^2_{\hat{x}_i}}{n_3} + \frac{N_3}{n_3}\sum_{j=1}^{n_3}V\hat{a}r\left(\hat{x}_{ij} \middle| x_{ij}\right) \qquad \text{(A6)}$$

and where

$$s^2_{\hat{x}_{ij}} = \frac{\sum_{j=1}^{n_3}\left(\hat{x}_{ij}-\hat{\bar{x}}_i\right)^2}{\left(n_3-1\right)},$$

$$\hat{\bar{x}}_i = \frac{\sum_{j=1}^{n_3}\hat{x}_{ij}}{n_3}.$$

The estimates of $\hat{A}_4$ and $V\hat{a}r\left(\hat{A}_4 \middle| A_4\right)$ are analogous to Equations (A5) and (A6), respectively.

A-2.3. Estimation Within Flats Stratum

In this stratum, the sampling units are of dramatically different sizes. One could perform a simple random sample or sampling with probability proportional to size. In concert with rotational sampling, SRS would be the easiest to formulate and perform. Thus, in the case of SRS

$$\hat{A}_2 = \left(\frac{\sum_{j=1}^{n_2}\hat{x}_{2j}}{\sum_{j=1}^{n_2}a_{2j}}\right)\cdot\sum_{j=1}^{N_2}a_{2j} = \left(\frac{\sum_{j=1}^{n_2}\hat{x}_{2j}}{\sum_{j=1}^{n_2}a_{2j}}\right)\cdot a_2 \qquad \text{(A7)}$$

where

a_{2j} = area of the *j*th flats $\left(j = 1,\ldots,L_2\right)$ in the second stratum.

$a_2 = \sum_{j=1}^{N_2}a_{2j}$ = the total areal extent of flats sites within stratum 2.

The estimator and associated variance assume the areas a_{2j} $\left(j = 1,\ldots,L_2\right)$ are measured without error. The variance for $\hat{A}_2$ can be expressed (Appendix E) as

$$V\hat{a}r\left(\hat{A}_2 \middle| A_2\right) = a_j^2\left(1-\frac{n_2}{N_2}\right)\frac{\sum_{j=1}^{N_2}\left(x_{2j}-a_{2j}R\right)^2}{\left(N_2-1\right)} + \frac{N_2}{n_2}\sum_{j=1}^{N_2}V\hat{a}r\left(\hat{x}_{2j} \middle| x_{2j}\right)$$

and where

$$R = \frac{\sum_{j=1}^{N_2} x_{2j}}{\sum_{j=1}^{N_2} a_{2j}}.$$

In turn, this variance can be estimated by

$$\hat{Var}\left(\hat{A}_2 \middle| A_2\right) = a_2^2\left(1 - \frac{n_2}{N_2}\right)\frac{\sum_{j=1}^{n_2}\left(\hat{x}_{ij} - a_{2j}\hat{R}\right)^2}{\left(n_2 - 1\right)} + \left[\frac{N_2}{n_2} - \frac{a_2^2\left(1 - \frac{n_2}{N_2}\right)}{\left(n_2 - 1\right)}\right]\sum_{i=1}^{n_2}\hat{Var}\left(\hat{x}_{2j} \middle| x_{2j}\right) \tag{A8}$$

where

$$\hat{R} = \frac{\sum_{j=1}^{n_2} x_{2j}}{\sum_{j=1}^{n_2} a_{2j}}.$$

A-2.4. Within-Site Variance

Within a sampling unit, eelgrass abundance will be estimated in a two-step process of (1) delineating the area of the bed and (2) constructing line-intercept transects to estimate the percent cover (Norris et al. 1997). The estimator of eelgrass abundance can then be expressed as

$$\hat{x} = a \cdot \hat{\bar{p}} \tag{A9}$$

where

a = maximum outward size of the eelgrass bed based on a minimum convex polygon,

$\hat{\bar{p}}$ = estimated average percent cover along a line-intercept through the eelgrass bed.

The estimate of percent cover $\left(\hat{\bar{p}}\right)$ will be based on a ratio estimator of the form

$$\hat{\bar{p}} = \frac{\sum_{i=1}^{m} l_i}{\sum_{i=1}^{m} L_i} \tag{A10}$$

where

l_i = length of the ith transect $\left(i = 1, \ldots, m\right)$ that contains eelgrass,

L_i = actual total length of the ith transect $\left(i = 1, \ldots, m\right)$.

This ratio estimator has an approximate variance of

$$\hat{Var}\left(\hat{\bar{p}}\right) = \frac{\sum_{i=1}^{m}\left(l_i - \hat{\bar{p}}L_i\right)^2}{\left(m - 1\right)m\bar{L}^2} \tag{A11}$$

where

$$\bar{L} = \frac{\sum_{i=1}^{m} L_i}{m}.$$

It will be assumed that the maximal area of the eelgrass bed as characterized by the quantity a is known without error. In that case,

$$V\hat{a}r\left(\hat{A}\right) = a^2 Var\left(\hat{\bar{L}}\right). \tag{A12}$$

A-3. Plant Parameters

Two measures of eelgrass performance are described along with associated estimators and sampling variances. The measures to be estimated within a sampling site include:

- Shoot density;
- Leaf area index.

A-3.1. Mean Shoot Density

Average shoot density at a sampling location can be readily estimated from the simple random sample of 0.1 m^2 quadrates within a sampling location. Define

d_i = shoot density (i.e., number of shoots/0.1m^2) observed from the *i*th sample $\left(i = 1, \ldots, n\right)$ at a location.

The estimate of the mean number of shoots per 0.1m^2 area can be calculated as

$$\hat{D} = \frac{\sum_{i=1}^{n} d_i}{n} \tag{A13}$$

with a variance of

$$Var\left(\hat{D} \middle| D\right) = \frac{\left(1 - \frac{n}{N}\right) S_{d_i}^2}{n} \tag{A14}$$

and estimated variance of

$$V\hat{a}r\left(\hat{D} \middle| D\right) = \frac{\left(1 - \frac{n}{N}\right) s_{d_i}^2}{n} \tag{A15}$$

where

$$s_{d_i}^2 = \frac{\sum_{i=1}^{n} \left(d_i - \hat{D}\right)^2}{\left(n - 1\right)}.$$

A-3.2. Leaf Area Index

Leaf area index is a measure of the average area of eelgrass leaves per unit of substrate. This average is calculated over the population of eelgrass in a sampling area. Assume at a sampling location a random sample of n 0.1 m^2 quadrats are selected. From these samples, shoot density is measured. Define d_i = shoot density = number of shoots in the 0.1 m^2 area of the i^{th} sample $\left(i = 1, \ldots, n\right)$, and average shoot density $\left(\hat{D}\right)$ estimated by Equation (1).

From these samples and other random samples in the area, all eelgrass plants collected are accumulated. A simple random sample of *k* plants is then drawn and the leaf area of each shoot is measured. Define

l_j = leaf area of the *j*th shoot $(j = 1, \ldots, k)$ measured in the area.

Average leaf area per shoot is estimated as

$$\hat{\bar{l}} = \frac{\sum_{j=1}^{k} l_j}{k} \tag{A16}$$

with variance

$$Var\left(\hat{\bar{l}}\right) = \frac{\left(1 - \frac{k}{K}\right) S_{l_j}^2}{k} \tag{A17}$$

and with estimated variance

$$V\hat{a}r\left(\hat{\bar{l}}\right) = \frac{\left(1 - \frac{k}{K}\right) s_{l_j}^2}{k} \tag{A18}$$

and where

$$s_{l_j}^2 = \frac{\sum_{j=1}^{k}\left(l_j - \hat{\bar{l}}\right)^2}{(k-1)}$$

and where K is the total number of plants in the sampling area. Typically, the factor $\left(1 - \frac{k}{K}\right)$ in Equation (5) can be ignored.

Then the leaf area index (L) for a sampling location is estimated as

$$\hat{L} = \hat{D} \cdot \hat{\bar{l}} \tag{A19}$$

with exact variance of

$$Var\left(\hat{L}\right) = D^2 Var\left(\hat{\bar{l}}\right) + \hat{\bar{l}}^{\,2} Var\left(\hat{D}\right) + Var\left(\hat{D}\right) \cdot Var\left(\bar{l}\right) \tag{A20}$$

which can be estimated by

$$V\hat{a}r\left(\hat{L}\right) = \hat{D}^2 V\hat{a}r\left(\hat{\bar{l}}\right) + \hat{\bar{l}}^{\,2} V\hat{a}r\left(\hat{D}\right) + V\hat{a}r\left(\hat{D}\right) \cdot V\hat{a}r\left(\hat{\bar{l}}\right). \tag{A21}$$

APPENDIX B

ISLAND COUNTY EELGRASS SURVEY

UNDERWATER VIDEOGRAPHIC METHODS

Survey Equipment

Table B-1 lists the equipment used during the 2000 survey (see also Fig. 41). Sampling was conducted aboard the 36-ft *R/V Brendan D II*. The vessel was manned by a helmsman/scientist and a deckhand/winch operator.

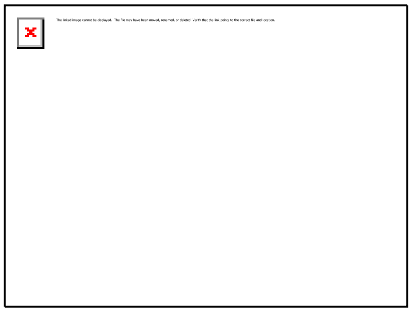
Eelgrass presence/absence was determined with an underwater video camera mounted in a “down-looking” orientation on a heavy towfish. Parallel lasers mounted 10 cm apart created two red dots in the video images as a scaling reference. A 250 watt underwater light provided illumination when needed. The towfish was deployed directly off the stern of the vessel using the cargo boom and boom winch. Time and position data were acquired using a differential global positioning system (DGPS) processor with the antenna located at the tip of the cargo boom used to deploy the camera. The weight of the towfish kept the camera positioned directly beneath the DGPS antenna, thus ensuring that the position data accurately reflect the geographic location of the camera. Differential corrections were received from the United States Coast Guard public DGPS network using the NAD 83 datum. Portable transducers mounted on the starboard side near the transom collected depth and bottom discrimination data.

A laptop computer equipped with a video overlay controller and data logger software integrated at 1 s intervals the DGPS data (date, time, latitude, longitude), user supplied transect information (transect number and site code), and the video signal. Video images with overlain DGPS data and transect information were stored onto VHS videotapes using two video cassette recorders (four head) and onto a digital videotape using a digital video camcorder. Date, time, position, and transect information also were stored on a floppy disk at 1 s intervals. Television monitors located in both the pilothouse and the work deck assisted the helmsman and winch operator control the speed and vertical position of the towfish.

A real-time plotting system used a multiplexer to integrate National Marine Electronic Association 0132 standard sentences produced by the DPGS, two depth sounders, a backscatter sensor, and a user-controlled toggle switch to indicate eelgrass presence/absence. These data streams were forwarded to a laptop personal computer running a spreadsheet program running proprietary plotting software. A red cursor plotted the current position of the vessel. When the underwater video camera was down and observing the seabed, a thin black line on the plotter traced the camera's position. As the vessel moved along the track line, the scientist/helmsman watched the television monitor and clicked the eelgrass toggle switch on or off each time eelgrass appeared or disappeared from view. When the eelgrass toggle was on, the track line pattern changed to a thick green line and the eelgrass positions were stored on a separate worksheet. The result was a real-time plot of the area sampled and where eelgrass was observed (Fig. 42).

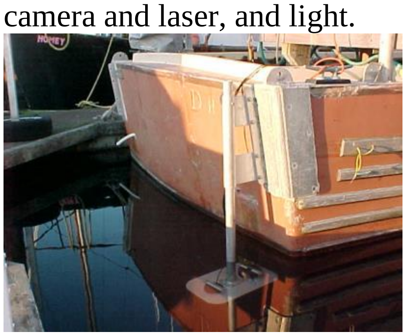
Table B-1. Equipment used to collect data during the Island County eelgrass survey.

Item	Manufacturer/Model
Differential GPS	Trimble AgGPS 132 Leica MX200 GPS Navigator
Depth Sounder	Garmin Fishfinder 240 (200 KHz transducer) American Pioneer Fishscope V (28, 160, 680 KHz transducers)
Water Quality Sensor	HydroLab DataSonde 4 (depth, temperature, salinity, conductivity, dissolved oxygen, pH, turbidity)
PAR Light Sensor	Licor LI-192 flat PAR sensor
Sea Surface Temperature	Garmin Fishfinder 240 (200 KHz transducer w/temperature sensor)
Backscatter	HOBI Labs HydroScat-2 Spectral Backscattering Sensor (470 nm & 676 nm)
Benthic Grab	Kohl Scientific Stainless Steel 0.1 m^2 van Veen Grab
Underwater Camera	Deep Sea Power & Light SeaCam 2000
Lasers	Deep Sea Power & Light
Underwater Light	Deep Sea Power & Light RiteLite (250 watt)
Plotting Computer	MarsPal, Mars Technology
Backup System	Iomega USB Zip Drive (250 MB)
Color Printer	Hewlett-Packard HP DeskJet 840C
Video Overlay Computer	Toshiba 1200 Laptop
Video Overlay Controller	Discovery Bay Software
VCR#1 (master tapes)	General Electric VG4043 VHS 4-Head
VCR#2 (backup tapes)	Zenith TV/VCR Combo 4-Head Emerson TV/VCR Combo VT 1321 2-Head Panasonic TV/VCR Combo PV-M 939 2-Head
Digital Tape Recorder	Sony 930 Digital8 Camcorder
Generators	Honda EX 650 Honda EU 1000i
Ambient Water Pump	Jabsco PAR – MAX 4 30700 washdown pump
Fresh Water Rinse System	GreenThumb non-corrosive, polyethylene compressed air sprayer (2.5 gal)



R/V Brendan D II. Note DGPS antenna at tip of cargo boom.

Towfish with HydroScat-2 (near hand), camera and laser, and light.



Echosounder transducers.

Figure 41. Photographs of sampling equipment used during the Island County eelgrass survey.

American Pioneer echosounder monitor; Garmin in background.

HydroLab DataSonde IV. Note PAR sensor to the right.

0.1 m^2 van Veen benthic grab.

Overlay laptop computer and eelgrass toggle switch.

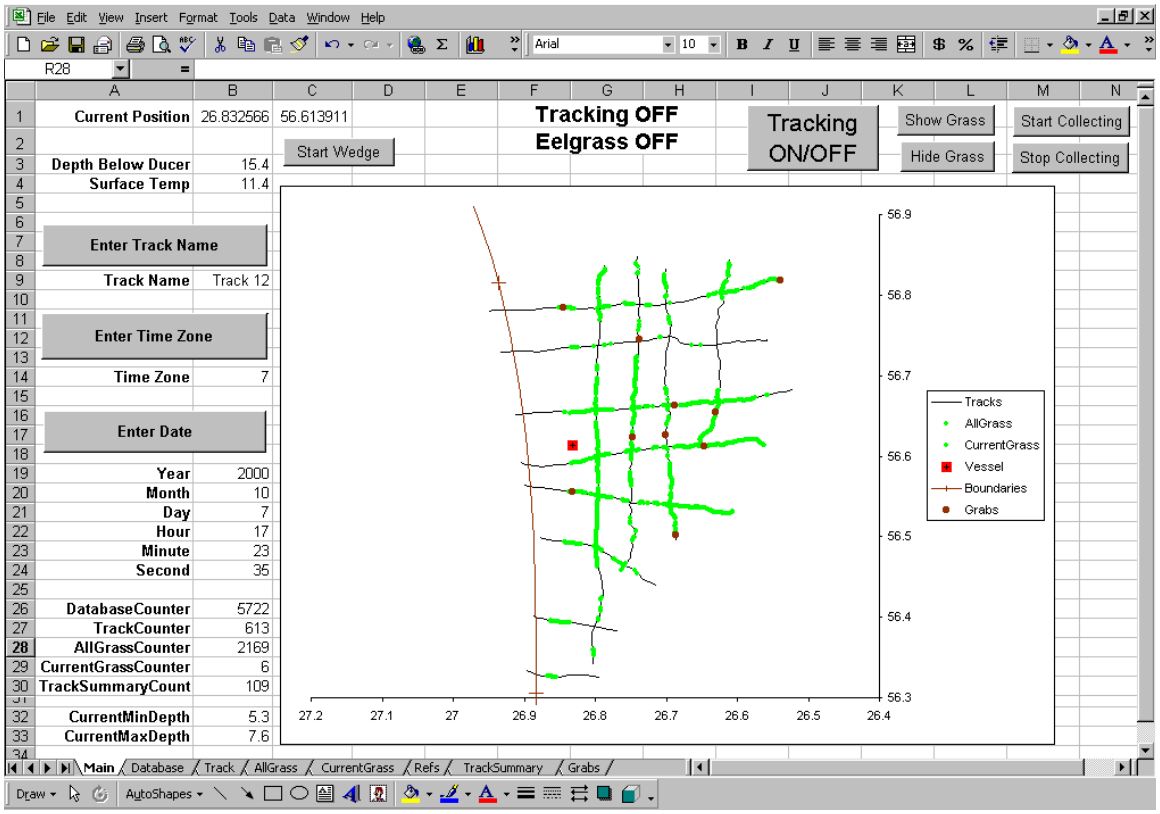


Figure 42. Sample screen from the real-time plotting system.

APPENDIX C

WASHINGTON STATE
DEPARTMENT OF NATURAL RESOURCES

SUBMERGED VEGETATION MONITORING PROJECT

BENTHIC GRAB SAMPLING METHODS

At each site, the objective of benthic grab sampling is to estimate the mean shoot density, mean leaf area, and leaf area index. Plant specimens will be harvested using a 0.1 m^2 van Veen benthic grab.

A critical aspect of the benthic grab sampling plan is defining the sample populations for each parameter. For the mean shoot density at a site, the sample population is the collection of 1 m^2 sections of the seabed that have eelgrass (i.e., the area for which basal area coverage is estimated). Thus, the grab must be dropped on a section of seabed that has at least one eelgrass shoot per square meter. Note that since the grab only samples 0.1 m^2 of the seabed, it is still possible to have a sample with no eelgrass. For the mean leaf area the sample population is the collection of all eelgrass shoots at a site.

With the above populations in mind, the benthic grab sampling plan is as follows:

- grab sampling must occur after transect sampling has identified eelgrass locations;
- randomly select 10 grab stations from the positions where eelgrass was observed;
- at each grab station take grab samples until a sample is acceptable (discussed below);
- for each sample (acceptable and unacceptable) record the date, time, position, depth below transducer, and sediment type; for acceptable samples also record the number of vegetative and generative shoots collected;
- store all vegetative shoots in labeled bags;
- when all 10 grab samples have been completed, randomly select 30 acceptable shoots from all the plants collected at all 10 stations for leaf area measurements (if less than 30 plants are collected at all 10 stations, measure all of them).

We randomly select 10 grab stations from the eelgrass positions observed during the underwater video survey. There are two critical issues regarding the underwater video survey. First, eelgrass positions must be correctly identified during transect sampling. If a falsely identified eelgrass position is selected for grab sampling, the density count for that station will be recorded incorrectly as a zero. Second, the vessel towing the underwater video camera must proceed along each transect at a constant speed. Failure to maintain a constant speed will create relatively more eelgrass locations where the vessel is slow and the opposite when the vessel is fast (i.e., some sections of the seabed will have greater probability of being selected than others).

A grab sample is acceptable if it meets two criteria: (1) the jaws close; and (2) it was taken directly over a position at which eelgrass was observed. The first criteria is easy to determine. The second is more difficult whenever the grab sample has no plants. There are four reasons why a grab may have no plants:

- During transect sampling, eelgrass may be misidentified during data collection. If a misidentified position (i.e., eelgrass is identified when none was present) is randomly selected for grab sampling, an incorrect zero density will be recorded.
- The DGPS errors at observation time and the grab sample time are sufficient in combination to misplace the vessel relative to the eelgrass (i.e., the vessel will appear to be on-station and over eelgrass when in fact it is located slightly off the true eelgrass position).
- The eelgrass patch is so small it is difficult to hit with the grab. Given the usual wind and current conditions, it is virtually impossible to hold the vessel dead still over a point and drop the grab. Also, the grab often meanders a little from side to side during descent.
- The eelgrass is so sparse that the individual plants are one or more feet apart, and the grab simply misses hitting any plants.

Our criteria for accepting an empty grab sample is as follows. If the vessel appears to be on-station as indicated by the real-time plotting screen and there is eelgrass sign on the echo sounder exactly when the grab is dropped, accept the grab sample regardless of the contents. That is, we assume that the density is so low that it is possible to miss the eelgrass with a grab of only 0.1 m^2. In cases where the water is clear enough to see the seabed, we will use direct observation to determine that the vessel was directly over the eelgrass observation.

Each acceptable grab will be emptied into a sieve for processing. We will wash the mud and sand from the plants and count the vegetative and generative shoots. The key issue is which shoots to count. The general requirement is to count only those shoots that emerged from the seabed within the 0.1 m^2 sampled by the grab. When current causes the leaves to bend over, some plants will have their leaves in the jaws of the grab, but their sheath and root system will lie outside the grab by several inches. When the grab is retrieved, the sheath and root system are left dangling below the jaws. These plants will be rejected under the assumption that the plants did not originate from within the seabed area directly within the jaws of the grab (i.e., the jaws pulled the plant out by the leaves). The main judgment call is how much of the sheath and root system must hang below the jaws before a shoot is rejected.

Diver observations of the van Veen grab indicate that the jaws first penetrate the seabed at a nearly vertical orientation, but then cut horizontally through the seabed until the jaws close. The penetration depth is a function of the grab weight, speed of descent, and type of sediment. If the penetration depth is less than the depth at which the root system is located, the jaws will contact the sheath just above the root system. If the roots are secure in the seabed, the sheath will be pulled from the root system, usually near the root primordia. When this occurs, the shoots will not have any root material and a small portion of each sheath (usually less than 2 in) will stick out below the jaws. Without further study, we have no specific length criteria for determining when a shoot has too much sheath and root material hanging below the jaws to be acceptable.

Some grabs have shoots containing all of the root system, but the sheath or leaves are cut off by the jaws. These shoots are counted because it is clear that they originated from within the seabed area sampled by the grab. However, shoots with missing or cut leaves are not measured for leaf length.

Once the shoots are counted, the vegetative specimens will be bagged, labeled, and stored on ice—one bag per grab station. Note that for statistical purposes it is not necessary to store shoots by grab, because the plant parameters are to be estimated from a random sample of 30 shoots from all the shoots collected at a site. Thus, one could simply put the shoots from all grabs into a single bag. However, it would not be possible to know the location and depth at which each shoot was collected. These location and depth data will be useful for examining the relationship between parameters and depth and/or location within a site.