Puget Sound

Submerged Vegetation Monitoring Project

2005 Monitoring Report

February 2007

Jeffrey Gaeckle, Pete Dowty, Blain Reeves, Helen Berry,
Sandy Wyllie-Echeverria, Thomas Mumford

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

PSAMP
Puget Sound Assessment and Monitoring Program

The Submerged Vegetation Monitoring Project is implemented by the Nearshore Habitat Program. It is a component of the Puget Sound Assessment and Monitoring Program.

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

Nearshore Habitat Program
Aquatic Resources Division
Washington State Department of Natural Resources
1111 Washington St SE, 1st floor
P.O. Box 47027
Olympia, WA 98504-7027
U.S.A.

(tel) 360.902.1100
http://www.dnr.wa.gov/htdocs/aqr/nshr/index.html

February 2007

Puget Sound

Submerged Vegetation Monitoring Project

2005 Monitoring Report

Jeffrey Gaeckle[1], Pete Dowty[1], Blain Reeves[1], Helen Berry[1],
Sandy Wyllie-Echeverria[2], Thomas Mumford[1]

[1] Nearshore Habitat Program, Aquatic Resources Division, Washington State Department of Natural Resources, P.O. Box 47027, Olympia, WA 98504-7027

[2] UW Botanic Gardens, College of Forest Resources, University of Washington, Box 354115, Seattle, WA 98195-4115

Acknowledgements

The authors would like to give special recognition to Jim Norris and Ian Fraser of Marine Resources Consultants (MRC) who continue to play a significant role in the ongoing monitoring and success of the project. Marine Resources Consultants showed great dedication and logged many hours of ship time collecting data for the project.

Betty Bookheim assisted with site delineation, advised on sampling procedures and program direction, and contributed to the field sampling effort.

John Skalski provided valuable statistical consultation and guidance.

Michael Hannam and Patricia Milos assisted with data preparation, field sampling effort and video processing and Jennifer McKim and Trisha Towanda made valuable comments to improve this document.

The Nearshore Habitat Program, part of the Puget Sound Assessment and Monitoring Program, is under the auspices of the Washington State Department of Natural Resources' Aquatic Resources Division, the steward for state-owned aquatic lands. Program funding is provided through the Aquatic Lands Enhancement Act.

The following document fulfills, in part, Action DNR-01 of the 2003-2005 Puget Sound Water Quality Work Plan and the 2005-2007 Puget Sound Conservation and Recovery Plan.

Contents

EXECUTIVE SUMMARY

The primary purpose of this report is to present the 2005 monitoring results and analysis from the Submerged Vegetation Monitoring Project (SVMP) on the abundance and distribution of eelgrass, *Zostera marina* L., in greater Puget Sound. The SVMP monitors *Z. marina* because it provides valuable nearshore habitat to economically important species and species currently under federal and state protection.

In 2005, the SVMP continued to assess, in greater detail, the ecological integrity of a focus area within one of the five regions of the greater Puget Sound. The *Hood Canal Region* was selected for intensive focus area sampling to address concerns about *Z. marina* decline in the region and to contribute to efforts to quantify the oxygen budget.

Underwater videography continued to be the primary method of data collection. However, adjustments were made to the sampling equipment and analysis methods based on recommendations from earlier reports (Berry et al. 2003, Dowty et al. 2005) as well as those from a project review (Sewell et al. In prep.) and a detailed statistical study (Dowty 2005a). Some important changes for the 2005 sampling season included the retrofit of the research vessel, implementation of video post-processing quality assurance/quality control (QA/QC), and modifications to the underwater video camera array.

KEY FINDINGS

1. The 2005 *Z. marina* area estimate (20,400 ± 3,300 hectares, 50,409 ± 8,200 acres) was consistent with the previous estimates of approximately 20,000 ha in 2000 – 2004. Although the sound-wide *Z. marina* area results suggest stability, there is substantial evidence of *Z. marina* decline at the site-level throughout greater Puget Sound.
2. A multiple parameter assessment identified 18 sites, dispersed among all five regions of Puget Sound, with strong evidence of declining *Z. marina*.
3. A multiple parameter assessment of significant results at the regional scale identified Hood Canal as a region of major concern due to high overall variation and high proportion of significant negative results. Declines of lower magnitude also occurred in the *San Juan-Straits* and *Central Puget Sound Regions.* Trends appear to be either stable or positive in the *Saratoga-Whidbey* and *North Puget Sound Regions*.
4. Focus study data provides more detailed information on the status of *Z. marina* in the *Hood Canal Region*. *Zostera marina* in the *Hood Canal Region* accounts for approximately 7.5% of the total amount of *Z. marina* area in the greater Puget Sound study area. Approximately half of the *Z. marina* habitat in the *Hood Canal Region* occurs in narrow fringing beds, while the remainder is found in wide fringe and embayments.
5. The 2002-2004 sampling data was analyzed to determine the depth distribution of *Z. marina* by region and habitat type (flats, narrow fringe and wide fringe). During the 2002-2004 sampling interval, the maximum depth of *Z. marina* in greater Puget Sound was observed to be near 10 m. Depth distribution and maximum depth varied among regions.

6. Video post-processing observer agreement was evaluated to quantify processing precision, and help minimize observer variability. It was found that video processing was not a statistically significant portion of sampling variability.

Based on previous findings and further supported by the results of the multiple parameter assessment, the entire *Hood Canal Region* continues to be an area of concern for *Z. marina* status. Given the current interest in identifying factors that contribute to low dissolved oxygen conditions, it is important not only to examine the stressors that cause *Z. marina* decline but also to characterize the role of *Z. marina* in the Hood Canal oxygen budget.

Five embayments in the San Juan Islands continue, through a collaborative effort, to be closely monitored to investigate *Z. marina* status and trends. In addition, the SVMP continued to monitor sites that were identified as areas of localized concern in 2004. Four sites have rotated out of the sample pool in 2005 and it is important to develop a mechanism to ensure some level of continued monitoring at these sites.

The sound-wide *Z. marina* area estimate appears stable with previous results but the prevalence of decline at the site-level suggests otherwise. The observed site-level *Z. marina* losses are not sufficiently widespread or large enough to cause overall declines in the sound-wide area estimates. The results indicate that declines are of a localized nature, as observed in the shallow embayments of the San Juan Islands and at sites throughout the *Hood Canal Region*. In the case of the *Hood Canal Region*, declines were observed at numerous sites and the multiple parameter assessment indicated a greater proportion of significant negative changes in this region compared to the other regions.

FUTURE PRIORITIES

The SVMP has identified several priorities to guide future efforts based on the project findings and the overall assessment to date.

1. In 2006, complete sound-wide sampling and focus area sampling in *Saratoga-Whidbey Basin Region*. Examine results for *Z. marina* status and trends at the site, region and sound-wide scales.
2. Maintain partnerships with local groups to continue to assess the status of *Z. marina* in Hood Canal.
3. Maintain current collaboration with the University of Washington and the FRIENDS of the San Juans to study trends in *Z. marina* area and maximum depth within embayments of the San Juan Islands.
4. Further develop the multiple parameter assessment of change at sites with significant declines in the 5-year trend analyses.
5. Enhance web-based data dissemination for the SVMP.
6. Provide technical support and data to collaborators researching harmful algal blooms and invasive species.
7. Provide status and trends data to the newly established WA DNR Eelgrass Stressor-Response Project.

1 Introduction

1.1 The Submerged Vegetation Monitoring Project

The overall goal of the Submerged Vegetation Monitoring Program (SVMP) is to monitor the status and trends of *Z. marina* in greater Puget Sound. *Zostera marina* is the focus species because it is distributed throughout the study area and it is an important nearshore resource that is an indicator of estuarine health and provides a suite of ecological functions. As a primary producer, it generates oxygen to support marine organisms, provides habitat for numerous flora and fauna and sustains complex food webs. In Puget Sound, *Z. marina* provides spawning grounds for Pacific herring (*Clupea harengus pallasi*), out migrating corridors for juvenile salmon (*Oncorhynchus* spp.) (Phillips 1984; Simenstad 1994), and important feeding and foraging habitats for waterbirds such as the black brant (*Branta bernicla*) (Wilson and Atkinson 1995) and great blue heron (*Ardea herodias*) (Butler 1995).

Zostera marina has been extensively studied throughout its range generating an abundance of peer-reviewed literature and significant scientific and political attention (for example, Phillips 1984; Orth and Moore 1988; Krause-Jensen et al. 2003; Kemp et al. 1983, 2004). Previous work has demonstrated its usefulness as an indicator of habitat condition and impacts from anthropogenic stressors (Dennison et al. 1993; Short and Burdick 1996; Lee et al. 2004; Kenworthy et al. 2006). *Zostera marina* also has strong cultural significance for both Native Americans and First Nation People in the Pacific Northwest as both a valued hunting ground and important ceremonial food (Suttles 1951; Felger and Moser 1973; Kuhnlein and Turner 1991; Wyllie-Echeverria and Ackerman 2003).

The SVMP is one component of the Puget Sound Assessment and Monitoring Program (PSAMP), a program coordinated by the Puget Sound Action Team (2002a). PSAMP is a multi-agency effort mandated by the state legislature (RCW 90.71.060) to monitor diverse physical and biotic aspects of the Puget Sound system. The legislature further intended that PSAMP data be used to

> "*track quantifiable performance measures that can be used by the governor and the legislature to assess the effectiveness over time of programs and actions initiated under the [Puget Sound management] plan to improve and protect Puget Sound water quality and biological resources*" RCW 90.71.060.

Currently, the SVMP *Z. marina* status and trend data provide the basis for a key ecosystem indicator that is used for integrated assessments of Puget Sound (Puget Sound Action Team 2005, 2002b).

The SVMP is implemented by the Washington State Department of Natural Resources (DNR) and represents a key component of the agency's contribution to PSAMP. DNR initiated *Z. marina* monitoring as a natural complement to its role as manager of state-owned aquatic lands, including all subtidal areas and a substantial amount of the state's intertidal lands. The legislature has stipulated management guidelines for these lands that balance various uses of state aquatic resources with "ensuring environmental protection" (RCW 79.105.030). Given the key ecological functions of *Z. marina* and subsequently its value as a resource under DNR's management, the tracking of seagrass resources by SVMP serves DNR's direct mandate as well as that of the broader PSAMP.

The actions of other state agencies also reflect the recognized value of *Z. marina* as an aquatic resource. The Washington Department of Fish and Wildlife has designated areas of *Z. marina* as habitats of special concern (WAC 220-110-250) under its statutory authority over hydraulic projects (RCW 77.55.021). Similarly, the Washington Department of Ecology has designated *Z. marina* areas as critical habitat (WAC 173-26-221) under its statutory authority in implementing the state Shoreline Management Act (RCW 90.58).

In order to satisfy a broad range of data needs, the SVMP produces results at a range of spatial scales (site, region and sound-wide scales; see Figure 1-1) based on sampling at randomly selected sites. The SVMP was also designed to produce results at annual and long-term (5- and 10-year) temporal scales although the data record is not yet sufficient to support the 10-year trend analyses.

The SVMP primary programmatic performance measure is the ability to detect a decline in *Z. marina* abundance over 10 years at the sound-wide scale, which coincides with the entire study area and includes 4115 km (2557 miles) of shoreline. The ability to detect a 20% decline in *Z. marina* over 10 years will be achieved with suitable levels of statistical power (Dowty 2005a). At present there is not enough data to test for a 10-year decline, therefore, yearly performance is measured through the evaluation of the change detected in the existing data.

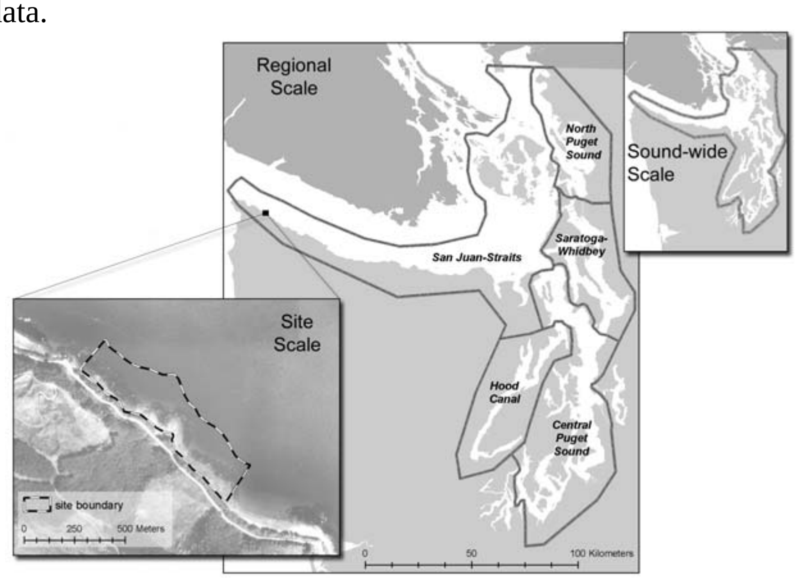


Figure 1-1. The SVMP produces estimates of *Z. marina* abundance and distribution at sound-wide, regional and site scales throughout greater Puget Sound, WA.

1.2 Climatic Conditions from 2000-2005 and its Relationship to *Zostera marina*

It is important to consider general climatic conditions when interpreting ecological monitoring data. Oviatt (2004) argues that two periods of twentieth century *Z. marina* decline in an east coast estuary were not associated with anthropogenic effects but were related to periods of elevated marine water temperature and broad climatic patterns as captured by a North Atlantic climate index. Climate change can also affect seagrass through alterations in sea level, tidal cycles, salinity, storm events, carbon dioxide levels and solar radiation (Spaulding et al. 2003). The lack of long-term seagrass monitoring data limits the ability to relate the loss of the seagrass resource to climate change (Hemminga and Duarte 2000). Further complicating the study of climatic effects, changes in *Z. marina* at any given site may be dominated by local factors that overwhelm broad climatic signals.

The El Niño-Southern Oscillation has been found to influence regional climate and ecosystems, including seagrass communities (Ward et al. 2005; Johnson et al. 2003; Thom et al. 2003; Nelson 1997). More specifically, the Pacific Decadal Oscillation (PDO) may be strongly related to conditions in the Pacific Northwest (Hare and Mantua 2000). In addition, the magnitude and timing of freshwater inputs to greater Puget Sound may directly affect *Z. marina* abundance through modification of water clarity (Zimmerman et al. 1995; Zimmerman 2003) and salinity (Biebl and McRoy 1971). Prior to the 2005 field season, mild El Niño conditions prevailed (late 2004 and early 2005) but these gave way to neutral conditions during the summer field season. To date, correlations between *Z. marina* status and regional or local climatic conditions in greater Puget Sound have not been identified (Berry et al. 2003; Dowty et al. 2005).

1.3 Developments in 2005

The results from academic, private and public research are considered each year to assist in directing the SVMP monitoring effort. The SVMP collaborates with and supports research efforts to increase the visibility and application of the SVMP assessment and to influence strategic initiatives that are relevant to monitoring and managing *Z. marina*.

In 2005, there was continued scientific and political attention focused on the reoccurring low dissolved oxygen conditions in Hood Canal (http://www.hoodcanal.washington.edu/). There is evidence that low dissolved oxygen impacts seagrass (Lapointe et al. 1994), thereby increasing the concern regarding the effects low oxygen may have on *Z. marina* populations throughout Hood Canal. In January 2006, DNR staff presented preliminary 2005 results to the Select Committee on Hood Canal (Dowty et al. 2005). The overall effect of *Z. marina* on the Hood Canal oxygen budget is not well understood but *Z. marina* plays a role directly through oxygen generation and indirectly through nutrient uptake and detritus decomposition (Borum et al. 2006).

In December 2005, Governor Gregoire introduced the Puget Sound Initiative to bring new resources and focus to Puget Sound protection and restoration. A new body, the Puget Sound Partnership, was formed with 14 members to play a central role in this initiative. The Puget Sound Partnership formed a scientific working group that included a representative from the SVMP team. In addition, the SVMP made several specific program developments during 2005. The key developments are discussed briefly in the following sections.

1.3.1 Video Sampling Assessment

The SVMP assessed sources of sampling variation associated with classifying the underwater video for *Z. marina* presence (Reeves et al. 2007) and implemented a formal quality assurance program on the video classification component (Milos et al. 2005).

1.3.2 Depth Distribution

The objectives of the depth distribution study were to provide depth profiles of *Z. marina* by region and geomorphic category, to test for significant differences among these variables, and to display spatial patterns in *Z. marina* maximum depth (Selleck et al. 2005).

1.3.3 Patchiness Index

A study was performed to assess spatial patterns in patchiness and to assess whether the Patchiness Index was a useful indicator of *Z. marina* change (Hannam In prep.).

1.3.4 Intensive Site Study

In the 2005-2007 biennial state budget the legislature directed funds to the Nearshore Habitat Program to initiate an Eelgrass Stressor-Response Project. The funds for the Eelgrass Stressor-Response Project were requested based on the feedback received from the SVMP review (Dowty et al. 2005, Sewell et al. In prep.). The objective of the project is to characterize key factors that affect *Z. marina* in Puget Sound and the nature of its response to these impacts.

2 Methods

2.1 The SVMP Study Area and Sampling Design

The SVMP study area includes all of greater Puget Sound: the Strait of Juan de Fuca, southern Georgia Strait, the San Juan Islands, Saratoga Passage – Whidbey Basin, Hood Canal as well as Puget Sound proper. The extreme reaches of southern Puget Sound are excluded from the study area because the sparse distribution of *Z. marina* in the area did not justify the SVMP sampling effort (Figure 1-1; Berry et al. 2003).

The SVMP sampling design and statistical analyses have been thoroughly described in earlier reports (Berry et al. 2003; Skalski 2003; Dowty 2005a; Dowty et al. 2005). A review of the sound-wide and focus area sampling designs including specific changes for the 2005 sampling effort is outlined below.

2.2 Sound-Wide Sampling Design

2.2.1 Stratification and Sampling Frames

Sound-Wide

All potential *Z. marina* habitat within the study area was delineated into either the flats or fringe geomorphic category (Berry et al. 2003). The fringe sampling frame was further divided into narrow fringe and wide fringe (Table 2-1; Berry et al. 2003). The distribution of the frames and strata throughout the study area is summarized in Table 2-1.

Table 2-1. Summary of SVMP sampling frames, strata and numbers of sites in 2005. Distribution includes 2005 sampling frame corrections and updates (see Section 2.6.4) (Dowty 2006a).

Geomorphic Category	Sampling Frame	No. Sites in Frame	Stratum	No. Sites in Stratum
fringe	fringe	2396	core	2
			narrow fringe	2035
			wide fringe	359
flats	flats frame	73	core	4
			persistent flats	3
			rotational flats	66

Regional

The regional analysis of *Z. marina* area uses a post-hoc stratification of the sound-wide data based on the fringe and flats sampling frames. The regional analysis collapsed the sound-wide sites into only two strata, regional flats and regional fringe, in order to increase sample size within each stratum to support estimates of regional *Z. marina* change (Berry et al. 2003; Dowty 2005a). The regional flats stratum consisted of the sound-wide rotational flats, persistent flats and core flats strata and the regional fringe stratum consisted of the sound-wide narrow and wide fringe strata (Dowty et al. 2005).

For all fringe sites, except two in the core stratum, a prefix was used to identify the associated region (Table 2-2.). The regions associated with 2005 core sites and flats sites are not indicated with a prefix (Table 2-3).

Table 2-2. Prefixes used in the site codes to identify the SVMP region for the fringe sites.

Prefix	Region
cps	Central Puget Sound
hdc	Hood Canal
nps	North Puget Sound
sjs	San Juan Islands – Strait of Juan de Fuca*
swh	Saratoga Passage – Whidbey Basin*

* Note: the San Juan Islands – Strait of Juan de Fuca Region is referred to as the *San Juan-Straits Region* and the Saratoga Passage – Whidbey Basin Region is referred to as the *Saratoga – Whidbey Basin Region* throughout the report.

Table 2-3. The regions associated with core sites and flats sites sampled in 2005. Note: *core005-Dumas Bay* and *core006-Burley Spit* are wide and narrow fringe sites respectively. An asterisk (*) indicates persistent flats, a stratum established in 2004, which is surveyed each year.

Site Code	Site Name	Region
core001	Padilla Bay	nps
core002	Picnic Cove	sjs
core003	Jamestown	sjs
core004	Lynch Cove	hdc
core005	Dumas Bay	cps
core006	Burley Spit	cps
flats08	Portage Bay North	nps
flats10	Nooksack Delta East	nps
flats11*	Samish Bay North*	nps
flats12*	Samish Bay South*	nps
flats18	Similk Bay	swh
flats19	Pull and Be Damned Point	swh
flats20*	Skagit Bay North*	swh
flats35	Nisqually Delta East	cps
flats37	Wing Point	cps
flats41	Dosewallips	hdc
flats67	Fossil Bay	sjs
flats70	S. Fork Skagit River	swh

2.2.2 Rotational Design and Site Selection

Yearly site selection follows a rotational design in the narrow fringe, wide fringe and rotational flats strata as performed in previous years (Berry et al. 2003; Dowty 2005a). The core stratum and the persistent flats stratum are completely surveyed each year and are therefore not subject to rotation (Table 2-3; Dowty et al. 2005). The rotational design and site selection is described in more detail in Appendix G.

2.2.3 Sound-wide and Regional Sites

In 2005, a total of 78 sites were selected as part of the sound-wide rotational design and site selection process. The sites were distributed in the core, flats and fringe strata throughout the five regions of greater Puget Sound (Figure 2-1). There were 62 sites selected for sampling in 2005 that were sampled in 2004 and used to calculate the sound-wide and regional change estimates which rely on matching sites between years (Table 2-4).

Table 2-4. Distribution of 2005 sample sites by region. The regional estimates are calculated from the number of 2004 – 2005 matching sites.

	CPS	HDC	SJS	SWH	NPS	Total
SOUND-WIDE						
core	2	1	2	0	1	6
flats – persistent	0	0	0	1	2	3
flats – rotational	2	1	1	4	2	10
narrow fringe	17	6	11	6	5	45
wide fringe	1	3	4	3	3	14
						78
2004 – 2005 Matching Sites						
flats	2	2	2	3	3	12
fringe	17	8	12	6	7	50
						62

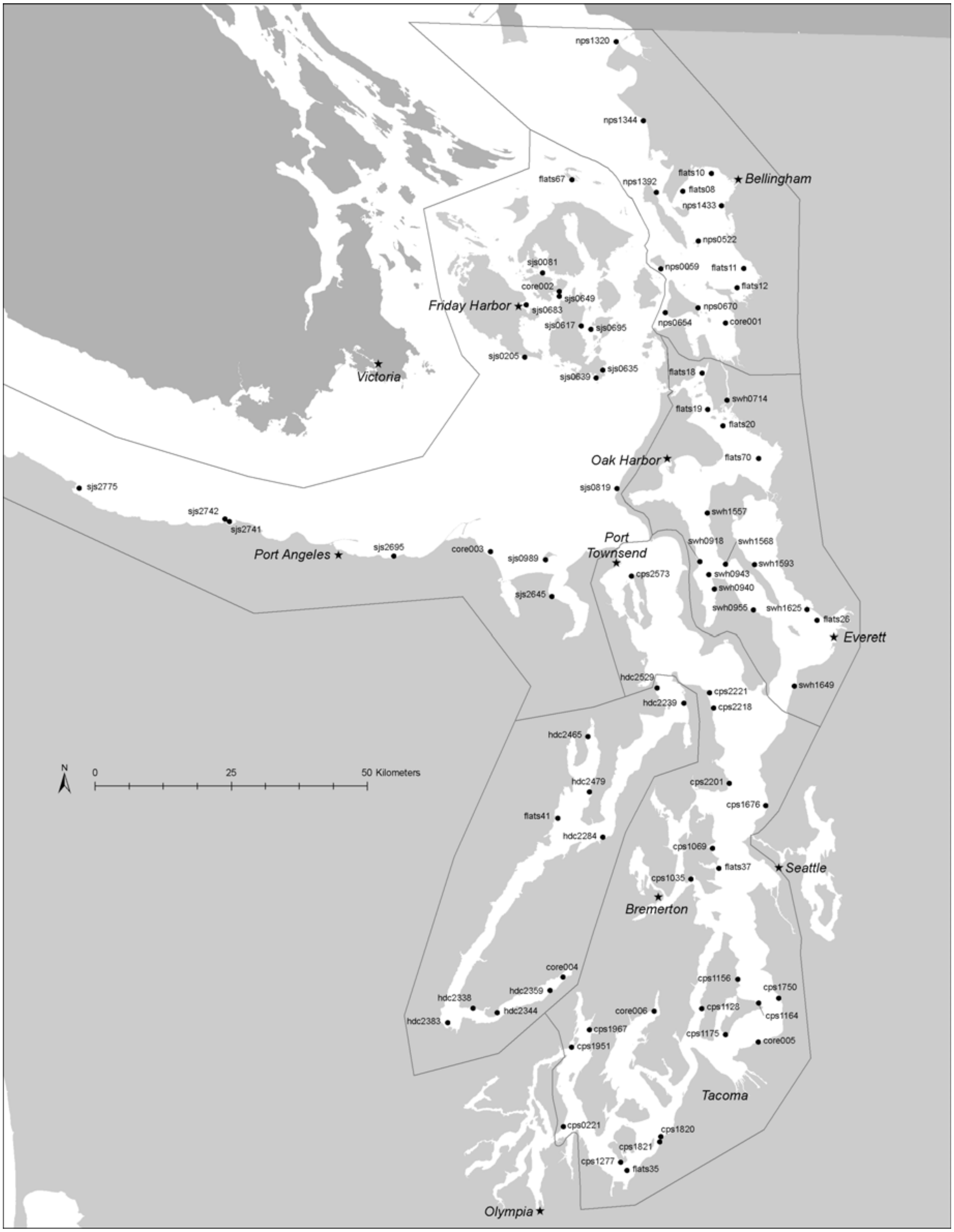


Figure 2-1. Sites sampled in 2005 as part of the SVMP sound-wide study.

2.3 Focus Area Sampling Design and Site Selection: 2005 Hood Canal Focus Area

The *Hood Canal Region* was selected as the SVMP focus area in 2005 (Figure 1-1). The *Hood Canal Region* focus area sampling effort was based on the 2004 focus area sampling in the *San Juan-Straits Region* (Dowty et al. 2005). The sampling effort goal of 28 sites was set for the 2005 *Hood Canal Region* focus area based on the effort from the previous year. A more detailed description of the site selection for the 2005 focus area is outlined in Appendix I.

2.3.1 Stratification and Site Selection

Five flats sites were selected in the *Hood Canal Region* focus area based on the focus area site selection procedure (Appendix I). The difference in the flats sampling effort between the 2004 and 2005 focus areas was accounted for with the addition of fringe sites (fringe equivalents) at a 2:1 (fringe:flats) effort ratio. The 2:1 (fringe:flats) effort ratio was established to account for the greater effort generally required at flat sites. Eight additional fringe sites (based on the 2:1 effort ratio, fringe:flats) were selected to make the *Hood Canal Region* focus area sampling effort consistent with the 2004 focus area effort (Table I-1). The final allocation of flats sites for the *Hood Canal Region* focus area is outlined in Table 2-5, Figure 2-1 and Appendix J.

Twenty-six fringe sites were selected to match the total effort between 2004 and 2005 based on calculations in Appendix I. The final allocation of fringe sites for the *Hood Canal Region* focus area is outlined in Table 2-5 and Appendix J.

Table 2-5. Total number of sites sampled in Hood Canal and used to calculate the *Z. marina* area in the region. The total numbers of sites were calculated as the combination of the final allocation of the sampling effort by stratum for the 2005 Hood Canal focus area sampling (Focus *n*) as well as sites sampled as part of the sound-wide study (Other *n*).

	2005 Hood Canal Focus Area			
	Stratum	**Focus *n***	**Other *n***	**Total *n***
flats strata	flats	5	1	6
fringe strata	narrow	16	6	22
	wide	10	3	13
total		31	10	41

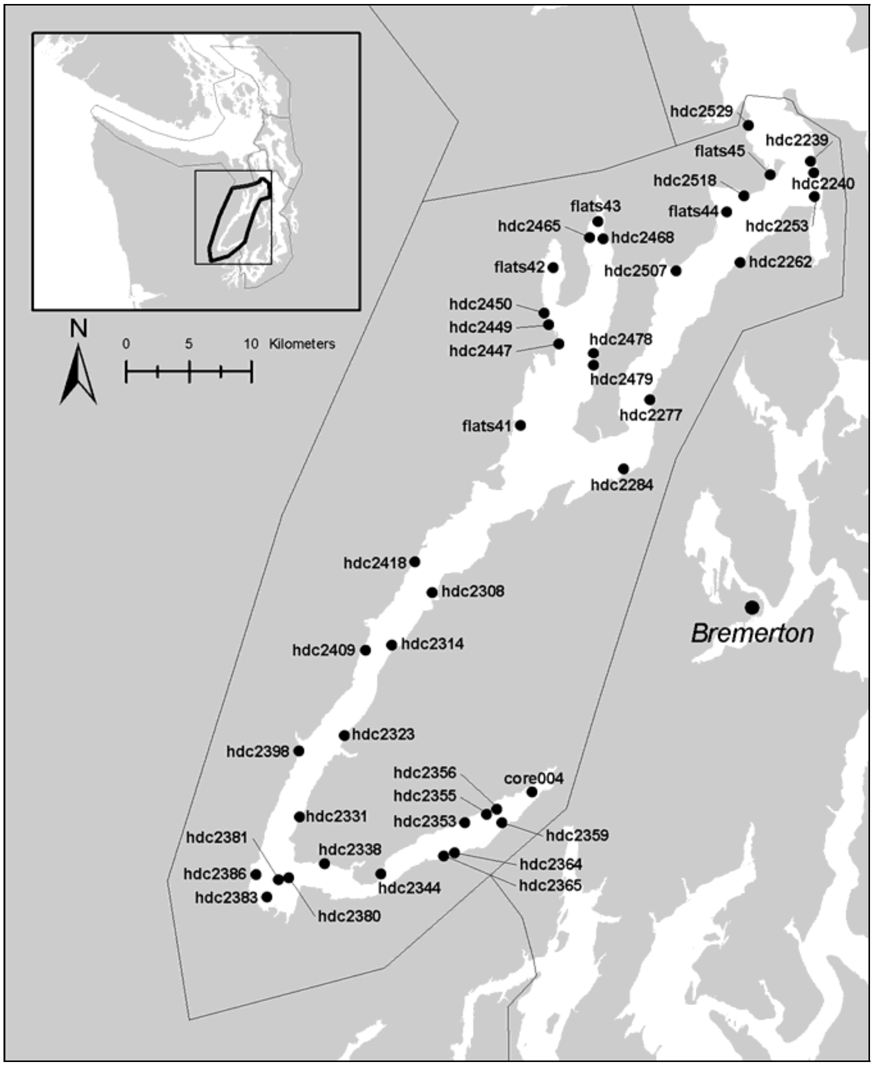


Figure 2-1. Sites sampled in the SVMP 2005 Hood Canal focus area and used for the focus area *Z. marina* estimate (n = 41).

2.4 Site Sampling

At each site, random transects are sampled using underwater videography (Norris et al. 1997) in a modified line-intercept technique between June and September 2005. Specific details of site sampling methods are provided in earlier reports (Berry et al. 2003; Dowty et al. 2005).

Random transect sampling is restricted to a sample area, referred to as the sampling polygon. The sampling polygon which represents the area of *Z. marina* presence within a site is delineated based on reconnaissance and any available data from previous years and other sources (e.g. Puget Sound Environmental Atlas 1987; ShoreZone Inventory 2001). The random transects oriented perpendicular to shore extend beyond the shallow and deep edges of the sampling polygon.

The video sampling resolution is nominally one square meter and *Z. marina* is categorized as being present or absent based on the observation of rooted shoots within the video field of view. The minimum number of 11 random transects varies in practice and depends on the precision of previous estimates sampled at the site. The fractional cover of *Z. marina* along transects is used to calculate site *Z. marina* area. The depth at which *Z. marina* grows along each transect is used to estimate mean maximum and minimum depth of *Z. marina* relative to Mean Low Low Water (MLLW) at each site and within each region.

A 17' aluminum work skiff is used to sample sites where obstructions prevent the primary research vessel safe access. Although the data collection method at these sites varies from normal protocols, *Z. marina* presence/absence is determined from interpretation of the BioSonics echosounder echogram in concert with the drop-camera observations (Sabol et al. 2002).

2.5 Video Data Processing and Analysis

The video from the random transects at each site is reviewed by technicians and classified as to *Z. marina* presence or absence. The fundamental procedures are described in greater detail in earlier reports (Berry et al. 2003; Dowty et al. 2005).

2.5.1 Data Processing

Inter- and intra – observer agreement were evaluated to determine if processing precision significantly affected *Z. marina* area estimates (Reeves et al. 2007). It was demonstrated that variation from video processors was not a significant contribution to overall sampling variation. A formal video processing training and QA/QC process was initiated to maintain consistency among years.

2.5.2 Data Analysis

Zostera marina Area Estimation

Zostera marina area estimation at the site-level follows procedures described in Appendix L of the first SVMP report (Berry et al. 2003; Skalski 2003). The fraction of *Z. marina* along each video transect and associated variance is calculated using a modified line-intercept transect method (Norris et al. 1997). The fraction of *Z. marina* along the sampling transects is extrapolated to estimate the overall *Z. marina* area in the sampling polygon.

The probabilistic sampling design allows for statistical extrapolation methods to calculate the status of *Z. marina* area within each stratum, and on a site and sound-wide basis. Status estimates are produced annually for each stratum and on a sound-wide basis. Status estimates are not produced annually for regions because the number of sites sampled annually in each region is not adequate to produce a reliable status estimate. Instead, status estimates in each region are produced every five years as part of the rotating focus area study. In focus areas, the *Z. marina* area estimate is calculated from the sites selected in the focus area sampling plus any sites selected in the sound-wide sampling that are located in the focus area (Dowty et al. 2005).

Zostera marina Change Analysis

The sampling design allows for change analysis at varying temporal and spatial scales (Berry et al. 2003; Skalski 2003). The SVMP is designed to detect five and 10-year trends in *Z. marina* area at the site- and sound-wide scales. Furthermore, documentation of the shallow and deep edge of the seagrass bed provides a basis to detect change in *Z. marina* depth distribution at the site-level. At all scales, long-term trend calculations rely on regression analysis of status estimates. Year-to-year change analysis methods vary depending on the scale of the site- and sound-wide data.

At the site-level, year-to-year change was assessed and tested for significance based on the calculation of relative change in three parameters (area, mean minimum depth and mean maximum depth) for consecutive years. Confidence intervals, measures of estimate precision, were calculated using analytical statistics.

At the sound-wide level, we assess year-to-year change through comparing paired sites sampled in consecutive years. Confidence intervals are derived through Monte Carlo simulations. The Monte Carlo method is designed to obtain a measure of the precision based on construction of the actual sampling distribution through repeated numerical sampling. Confidence intervals derived from the Monte Carlo technique provide a more conservative measure of precision (Dowty 2005a, 2006b).

Multiple Parameter Assessment of Region-Level Change

At the regional level, change analysis does not employ the paired site approach because precision associated with these estimates is very low due to small sample sizes (Dowty 2006b). Instead, multiple parameters were combined to assess the condition of *Z. marina* in each region relative to the other regions. The multiple parameter analysis assessed the number of significant changes (positive or negative), measured at the 95% confidence level, relative to the cumulative number of significant changes in each region from 2000 to 2005. The five parameters used to determine the status of *Z. marina* at the regional level include:

- Region-level *Z. marina* change: the proportion of significant regional *Z. marina* estimate changes. The region-level extrapolation is calculated from randomly selected sites sampled over two consecutive years. The method for the region-level *Z. marina* estimate is thoroughly defined in the Statistical Framework section of the first report (Berry et al. 2003).
- Site-level *Z. marina* change: the proportion of sites with significant a change in *Z. marina* area from one year to the next.
- Deep edge depth change: the proportion of sites with a significant change in the deep edge depth of *Z. marina* from one year to the next.
- Shallow edge depth change: the proportion of sites with a significant change in the shallow edge depth of *Z. marina* from one year to the next.
- Five-year trends: the proportion of sites with significant five-year trends.

The primary goal of the multiple parameter assessment was to identify the status of *Z. marina* in the regions based on the proportion of significant positive or negative indicators of *Z. marina* change. Another goal of the multiple parameter assessment was to identify region(s) with the greatest frequency of change (variability), identified as the region(s) with the greatest proportion of positive or negative change.

Multiple Parameter Assessment of Site-Level Change

The ability to detect change at individual sites was improved by evaluating multiple parameters in concert. There is data for estimates of changes in *Z. marina* area, mean maximum and minimum depth, and five-year trends at the site-level, although estimates for all these parameters is not complete for all sites. Also, several of the 2004-2005 monitoring sites were sampled during the 2002-2004 time period. The 2002-04 sites were previously evaluated and classified into three categories; no evidence of decline, strong evidence of decline, and very strong evidence of decline (Dowty et al. 2005).

Sites with a history of *Z. marina* decline were of greatest concern and have the most applicable management relevance. The analyses of all five parameters increased the complexity, therefore, the multiple parameter assessment classified the available data for all sampled sites in two categories. The *Z. marina* decline from 2002 to 2004, changes in *Z. marina* area from 2004 to 2005, mean maximum and mean minimum depth were classified into one category while the five-year trends in a separate category.

Three or more of the parameters that indicated *Z. marina* decline were classified as strong evidence of decline and additional weight was given to statistically significant results. In addition, a significant five-year declining trend was classified as strong evidence of decline except when other data was conflicting or equivocal. For those exceptions, the temporal pattern of the data points used in the five-year trend analysis (Appendix L) was assessed for completeness of the data (number of values available for consideration). All data were initially summarized in a format to facilitate the site-level multiple parameter assessment (Appendix L).

2.6 Equipment and Methodological Changes in 2005

Each year the SVMP refines the monitoring design, equipment and analysis techniques when appropriate, in order to increase efficiency or upgrade technology. An overview of the methods and the changes employed in 2005 are outlined in the following section.

2.6.1 Research Vessel

The 11 m research vessel Brendan D II, owned and contracted through Marine Resources Consultants for the SVMP in 2000 to 2003, was retrofitted prior to the 2005 sampling season (Figure 2-2). Mechanical alterations included the installation of a bow thruster and more sensitive throttle controls that improved vessel maneuverability and boat speed during sampling. A complete description of the survey equipment used aboard the *R/V* Brendan D II in addition to new equipment installed for the 2005 SVMP field sampling is presented in Table 2-6.

Figure 2-2. The *R/V Brendan D II, Marine Resources Consultants*.

Table 2-6. Survey equipment provided by Marine Resources Consultants onboard the *R/V Brendan D II* during 2005 SVMP field sampling. Equipment updated in 2005 is indicated in bold.

Equipment	Manufacturer/Model
Differential GPS	Trimble AgGPS 132 (sub-meter accuracy)
Depth Sounders	BioSonics DE 4000 system (including Dell laptop computer with Submerged Aquatic Vegetation software)
	Garmin FishFinder 250
Underwater Cameras (2)	SplashCam Deep Blue Pro Color (Ocean Systems, Inc.)
Lasers	Deep Sea Power & Light
Underwater Light	Deep Sea Power & Light RiteLite (500 watt)
Navigation Software	Hypack Max
Video Overlay Controller	Intuitive Circuits TimeFrame
DVD Recorder	Sony RDR-GX7
Digital Video Recorder	Sony DVR-TRV310 Digital8 Camcorder

2.6.2 Hypack Max

A new navigation tool, Hypack Max hydrographic survey software, was implemented to enable on-board creation and editing of GIS shape files based on real-time position, depth and user-supplied transect data.

2.6.3 Additional video camera to improve the view for the winch operator

In previous years, a single underwater camera was used to acquire *Z. marina* images and to provide the winch operator a view of the seabed. In 2005, a second underwater video camera (Table 2-6) was mounted on the towfish in a forward-looking position to provide the winch operator an improved view of impending changes in the seabed.

2.6.4 Sampling Frame Corrections and Updates

GIS Base Layers

The GIS base layers are important because they provide the basis for the site selection and the extrapolation parameters for *Z. marina* area estimates. Several corrections and improvements were made to the SVMP GIS base layers (Dowty 2006a). All results presented in this report are based on the updated sampling frames and strata.

1. Errors in the fringe base layer at the margin of flats and core sites were corrected. The changes included re-classifying fringe segments that bordered flats and core sites. In some cases fringe segments were split and the remaining portion was classified as an orphan. Orphans are stretches of shoreline that are too short to meet the minimum site length threshold of 1000 m.

2. The SVMP region boundaries at intersections with the shoreline were adjusted. Previously, fringe segments were split by the region boundary creating two orphans and thereby removing a site from the fringe sample frame. The region boundaries were shifted to adjacent fringe site endpoints and the existing orphans were reconnected and added as a fringe site back into the sampling frame.

The changes to the GIS base layer created more fringe sites and will improve the accuracy of the extrapolated *Z. marina* estimates on a regional and sound-wide scale.

Region Boundaries

Since the start of the SVMP, Pt. Roberts has been located in the *San Juan-Straits Region,* but it has a greater similarity to the *North Puget Sound Region* coastline in terms of general oceanographic characteristics. Furthermore, reassignment of Pt. Roberts as part of the *North Puget Sound Region* is consistent with the oceanographic basins adopted by the PSAMP Steering Committee (Puget Sound Action Team 2002a). The change to the region boundaries does not affect previously reported SVMP regional results because Pt. Roberts was not included in the sampling frames as noted below.

Addition of Pt. Roberts, Salmon Bank and Wyckoff Shoal to the Study Area

As part of the effort to improve the GIS layers, it was observed that the nearshore area around Pt. Roberts (*North Puget Sound Region*), Salmon Bank (*San Juan-Straits Region*) and Wyckoff Shoal (*Central Puget Sound Region*) was not previously included in the SVMP sampling frames and was not considered in the delineation of potential habitat (Dowty 2006a). The addition of these sites represents a small relative change to the amount of potential habitat in the study area used to extrapolate sample results. All extrapolated results for the sound-wide estimates and the each of the three regional estimates are based on the revised sampling frames that include the additional sites at Pt. Roberts, Salmon Bank and Wyckoff Shoal. The addition of Pt. Roberts, Salmon Bank and Wyckoff Shoal were made following random site selection for 2005 and did not affect the site selection process.

The unintentional absence of the Pt. Roberts, Salmon Bank and Wyckoff Shoal sites also has implications for the random site selection performed in previous years. For example, the inclusion of Pt. Roberts sites would have changed the size of the site selection pool in previous years. The change in the site selection pool, however, is small (< 0.5%) and the probability of any particular site being selected would have been virtually the same under either scenario.

The inclusion of Pt. Roberts (13 sites) added the majority of the new sites (15 sites). Of the 13 sites from Pt. Roberts there were 12 fringe (3 narrow and 9 wide) and one flats site (Figure 2-3). Wyckoff Shoal and Salmon Bank added one flats site each to the sampling frames.

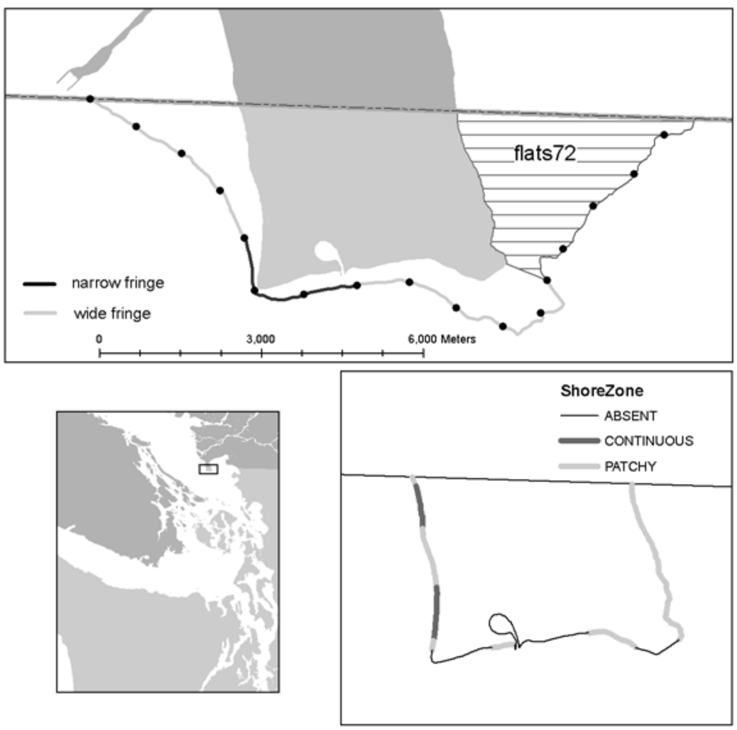


Figure 2-3. Pt. Roberts sites and ShoreZone eelgrass presence.

2.6.5 Regional Distribution of Sampling Frames, Strata and Potential Habitat

The updated regional distribution of sampling frames, strata and orphans used for the 2005 data analysis and areal estimates includes 73 flats sites, 2396 fringe sites and 68 km of orphans distributed throughout the five SVMP sampling regions (Figure 2-4).

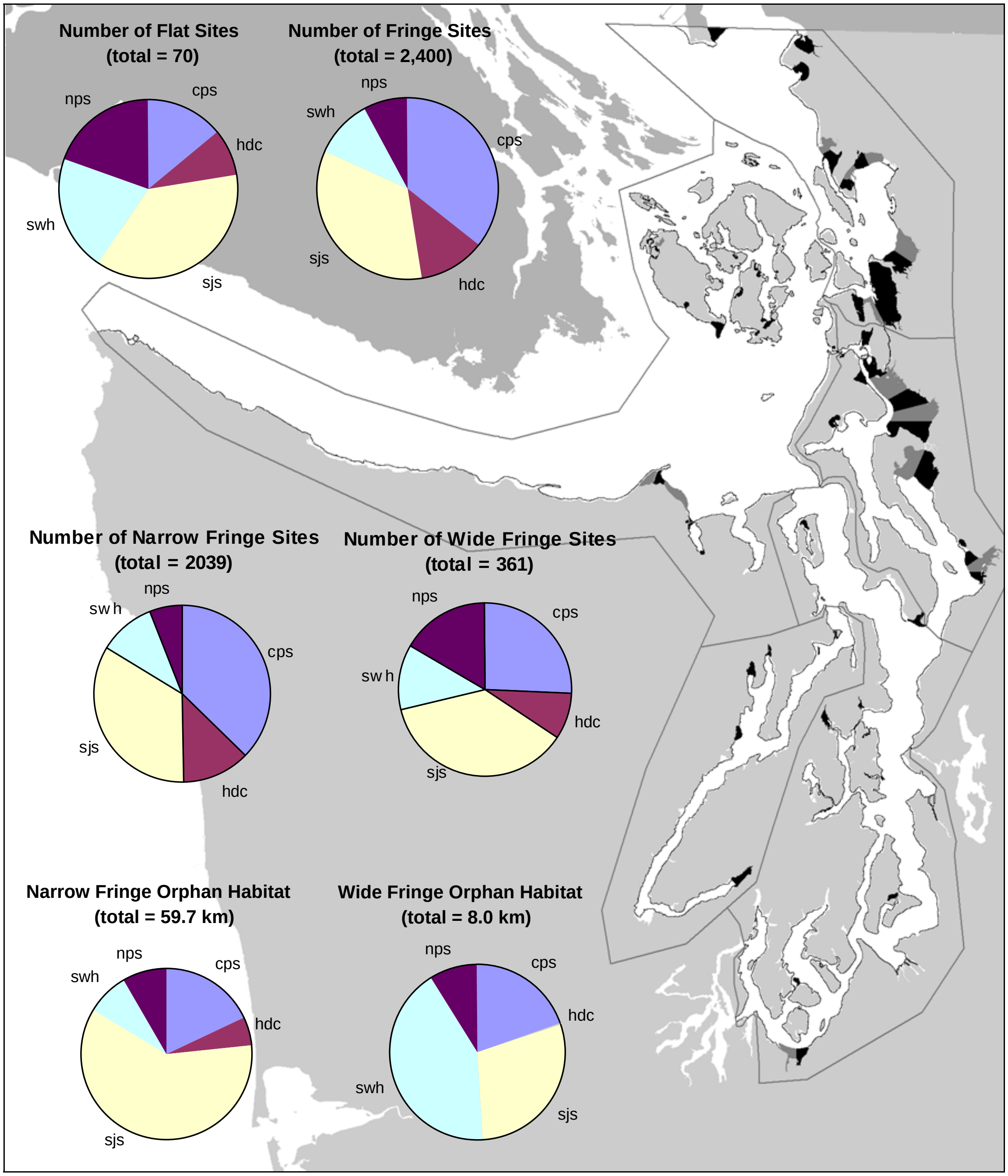


Figure 2-4. The 2005 SVMP regional distribution of the flats and fringe sampling frames and fringe orphans based on the updated GIS base layers. Sites at Pt. Roberts are included. The site prefix abbreviations are: cps, Central Puget Sound; hdc, Hood Canal; nps, North Puget Sound; sjs, San Juan Islands – Strait of Juan de Fuca; and swh, Saratoga Passage – Whidbey Basin (Table 2-2). Grey and black polygons indicate adjacent flats sites.

The potential *Z. marina* habitat was added to the flats and fringe sampling frames resulting in the additional sites shown in Table 2-7.

Table 2-7. Sites added to the flats and fringe sampling frames as a result of including Pt. Roberts, Salmon Bank and Wyckoff Shoal into the SVMP.

category	stratum	additional sites
flats	rotational flats	3
fringe	narrow fringe	3
	wide fringe	9

The summary of changes in 2005 were as follows:

- 63 new orphans were created and added 29.9 km of potential orphans habitat. While orphans are not part of the sampling pool, the area is included in the total estimate of *Z. marina* area in Puget Sound by including the length of shoreline in the *Z. marina* area extrapolation.
- 1 narrow fringe site was removed and 20 fringe sites (19 narrow; 1 wide) were added as a result of the GIS corrections
- the addition of Wyckoff Shoal (flats site) in the *Central Puget Sound Region*
- the addition of Salmon Bank (flats site) in the *San Juan-Straits Region*.

All results presented in this report reflect extrapolations that include the modifications described in Section 2.6.4.

3 Results

3.1 Field Effort Summary

The SVMP sampled 108 sites from July through September 2005 (Table 3-1). The level of effort devoted to sound-wide *Z. marina* monitoring in 2005 remained consistent with the previous year. In 2004 and 2005, the total number of sites sampled increased by approximately 30 due to the addition of focus area study sites (Table 3-1, Dowty et al. 2005). In 2005, a total of 78 sites were selected for sampling as part of the sound-wide and regional effort while an additional 30 sites were selected in the *Hood Canal Region* for the focus area effort.

Table 3-1. Summary of the SVMP sampling effort for 2000-2005. The value in the parentheses ( ) indicates the number of sites sampled in the focus area for that year.

Year	Field season months	Number of sites visited	Number sampled	Sites not sampled due to obstructions	Average transects per site	Sites without eelgrass	Number of sampling days
2000	July – October	66	61 (0)	5	12	13	46
2001	July – October	77	74 (0)	3	13	15	54
2002	June - September	76	73 (0)	3	12	14	54
2003	July and August	76	76 (0)	0	15	12	50
2004	June – September	110	110 (28)	0	14	12	72
2005	June – September	109	108 (30)	1	14	6	67

Three sites were sampled in 2005 from a 17' aluminum work skiff with the Biosonics echosounder due to extensive shoaling (*flats08-Portage Bay*), moored boats (*flats67-Fossil Bay*) and large rocks (*nps0522-Eliza Island NE*). The average number of random videography transects per sites was 14 and ranged from 5 – 27 (*sjs0649-Canoe Island* and *flats19-Pull and Be Damned*, respectively) (Table 3-1). Previously, an average of 12 to 15 random transects were surveyed from 2000 to 2004 (Table 3-1). One site (*swh0714-Across from LaConner*) selected for sampling in 2005 was not sampled because of obstructions that occupied greater than 25% of the site and the site was discarded as per the SVMP sampling plan protocols (Reeves 2005).

3.2 Status of *Zostera marina*

3.2.1 Sound-wide *Zostera marina* Area

The data collected at the 78 sound-wide sample sites were used to extrapolate sound-wide *Z. marina* area estimates (Table 3-1, Appendix A, Appendix E). The 2005 greater Puget Sound *Z. marina* estimate with 95% confidence interval is 20,400 ha ± 3,300 (Figure 3-1, Appendix A, Appendix E).

The re-calculated 2000 eelgrass area estimate value and confidence intervals (Figure 3-1), although not significantly different from the previously stated values (Berry et al. 2003; Dowty et al. 2005), are a result of updated estimates for the flats stratum in 2000 (Dowty 2006c). The new estimate better represents the design in place when the data were collected and provides a more reliable flats and overall *Z. marina* estimate. The effect of including Pt. Roberts, Salmon Bank and Wyckoff Shoal into the SVMP sampling was similar across all years (Appendix K).

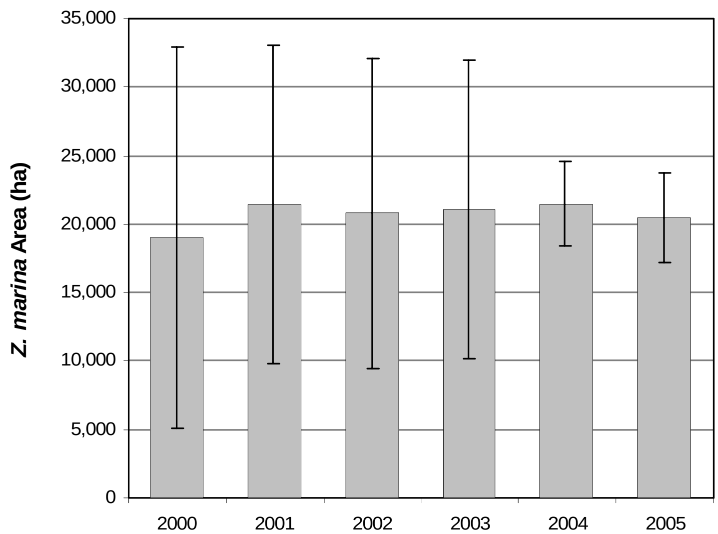


Figure 3-1. Estimates of total *Z. marina* area in the study area, 2000-2005. Error bars are 95% confidence intervals.

The total estimated *Z. marina* area is approximately evenly divided between the flats and fringe geomorphic categories. The distribution of *Z. marina* area within the sites sampled and within the study area as a whole is disproportionate and aggregated in a few large flats sites (Figure 3-2). Three sites in the *North Puget Sound Region*, *core001-Padilla Bay*, *flats11-Samish Bay N.* and *flats12-Samish Bay S.* in two different embayments, represent 27% of *Z. marina* area in the study area (Figure 3-2). In the *Saratoga – Whidbey Basin Region* the flats sites sampled contain 862 ha (4%) of the *Z. marina* in the study area.

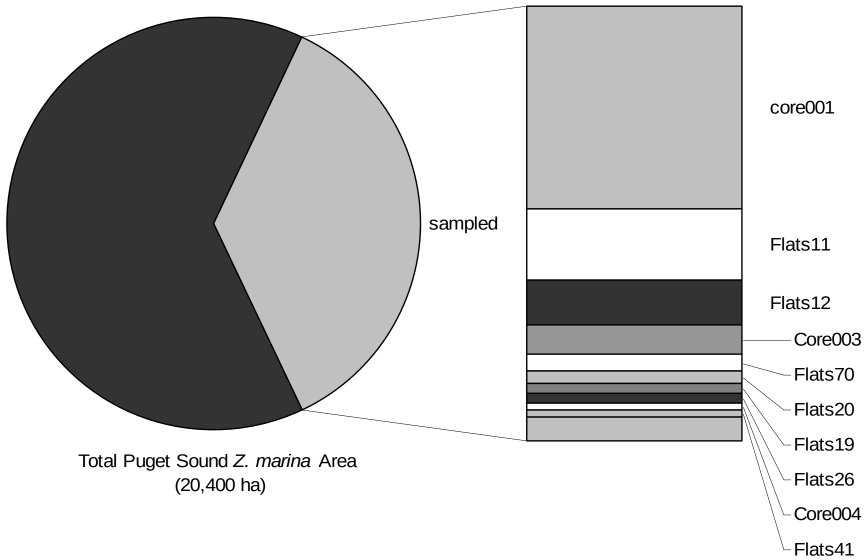


Figure 3-2. Approximately 36% of the estimated *Z. marina* area is sampled in the greater Puget Sound study area as represented in the pie chart. The bar chart shows the distribution of *Z. marina* area among sampled sites. *Core001-Padilla Bay* contains approximately 17% of the total *Z. marina* area in the study area. Data in the graphic are based on 2005 site results and a total of 20,400 ha in the Puget Sound study area.

In 2005, the average *Z. marina* fraction at a site was 0.46 and ranged from 0.00 (several sites) to 0.91 (e.g. *swh0943-Hackney Island Whidbey*) (Appendix A). The average Coefficient of Variation (CV) for all sample sites in 2005 was 0.14 and ranged from 0.02 (*swh0943-Hackney Island Whidbey*) to 1.00 (*cps1035-NE of Point White*).

3.2.2 *Zostera marina* Area – Hood Canal Focus Area

Nine fringe sites (6 narrow and 3 wide) that were sampled as part of the sound-wide study fell within the Hood Canal focus area and were used in the *Z. marina* area estimates for this region (Appendix A). In addition, one flats sites (*core004-Lynch Cove*) was included in the 2005 focus area analysis. As a result, a total of 41 sites (11 from the yearly sound-wide rotation, Appendix A; 30 for the focus area site selection, Appendix B) were sampled in the *Hood Canal Region* focus area and used to calculate *Z. marina* area.

The Hood Canal focus area *Z. marina* estimate of 1,500 ha (3,800 acres) represents 7.5% of the total sound-wide estimate (20,400 ha). Nearly 75% of the *Z. marina* area in the *Hood Canal Region* falls within the fringe strata, whereas the flats strata (core and flats) comprise only 25% of the total *Z. marina* area estimate (Table 3-2, Figure 3-3, Appendix B).

Table 3-2. Estimates of *Z. marina* area and uncertainty by stratum for the Hood Canal focus area. *Core004-Lynch Cove* is shown separately under the core stratum. The number of sites used in each estimate (*n*) and the total number of sites in the stratum (*N*) are also shown.

Strata	*n*/*N*	*Z. marina* Area (ha)	Variance	s.e.	c.v.	95% CI	Proportion of Hood Canal *Z. marina* area
Flats	6/6	376	234	15	0.04	30	24%
Narrow Fringe	22/255	824	30,795	175	0.21	344	54%
Wide Fringe	13/31	327	3,828	62	0.19	121	21%
Total		1,527	34,857	187	0.12	366	

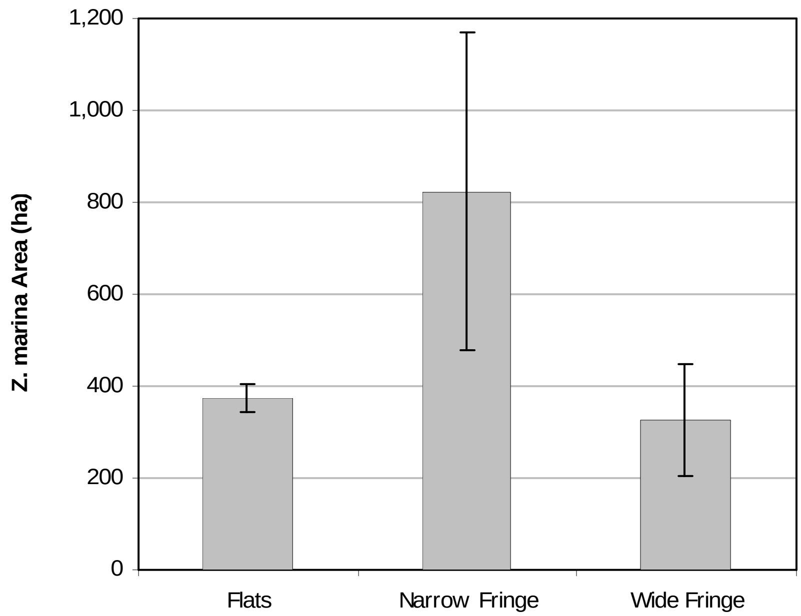


Figure 3-3. Estimates of *Z. marina* area by stratum for the Hood Canal focus area. Error bars are 95% confidence intervals.

3.3 Change in *Zostera marina*

3.3.1 Sound-Wide Change in *Zostera marina* Area

The *Z. marina* area change estimate between 2004 and 2005 was not statistically significant (Figure 3-4, Monte Carlo 95% confidence intervals).

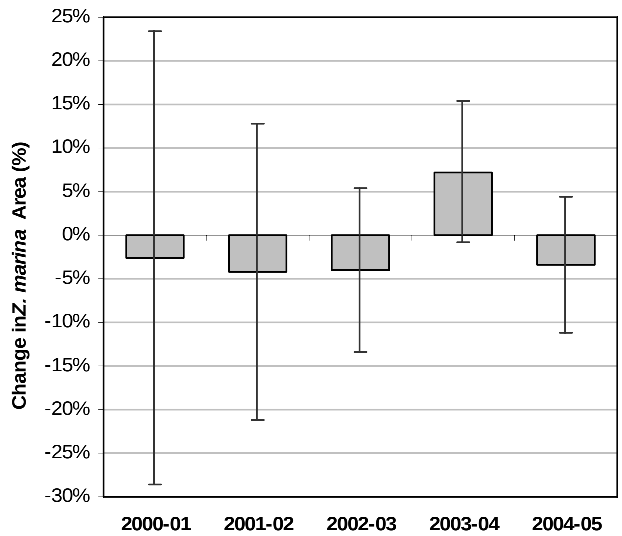


Figure 3-4. Overall sound-wide annual change in *Z. marina* area from 2000 - 2005. Error bars are Monte Carlo 95% confidence intervals.

3.3.2 <u>Site-Level Change in *Zostera marina* Area</u>

<u>Year-to-Year Change in Zostera marina Area</u>

An alternate measure of sound-wide change was to quantify the number of significant observations of *Z. marina* area increase and decrease at the site-level. There were 62 sites that were sampled in 2004 and 2005 that were tested for year-to-year change in *Z. marina* area (Figure 3-5). The complete 2004 to 2005 *Z. marina* area change results at the site-level are presented in (Appendix C).

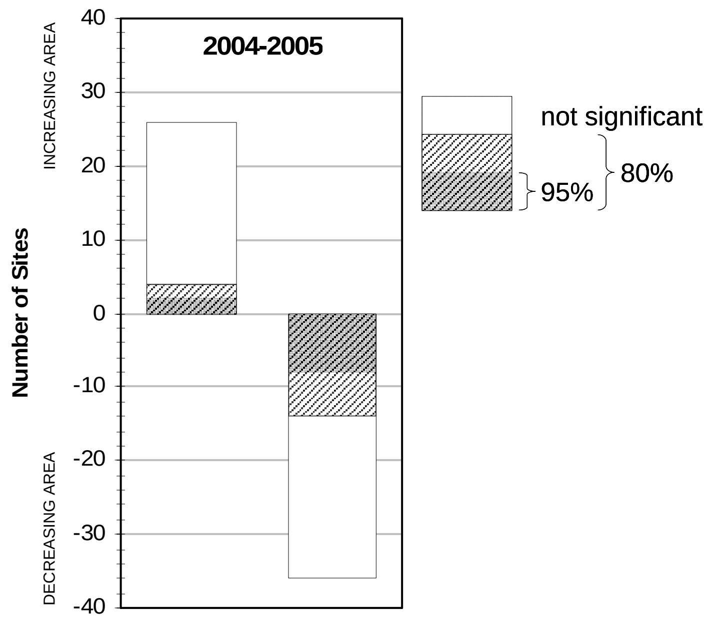


Figure 3-5. Numbers of sites sampled with observed increases and decreases in *Z. marina* area over the 2004-2005 interval. Shading is used to distinguish sites with statistically significant change at 95%, additional sites with significant change at 80% and sites where change was not significant.

The majority of the observed site-level changes were not statistically significant from 2004 - 2005. *Zostera marina* area increased at two sites while it decreased at eight sites at the 95% confidence level (Figure 3-5, Figure 3-6). Half of the sites that showed *Z. marina* decline at the 95% confidence level were less than 2.0 ha in size (Figure 3-7). When tested at the 80% confidence level, the *Z. marina* area increased at three additional sites and decreased at six more sites (Figure 3-5). With the exception of one significant increase in the *North Puget Sound Region* (*nps1320-Semiamo Spit*), all other increases at the two confidence levels took place at sites located within the *Saratoga-Whidbey Basin Region* (*swh0940-Holmes Harbor E. Whidbey Island, swh1593-Camano Island Cornell, swh1625-S. of Tulalip Bay*) (Figure 3-6).

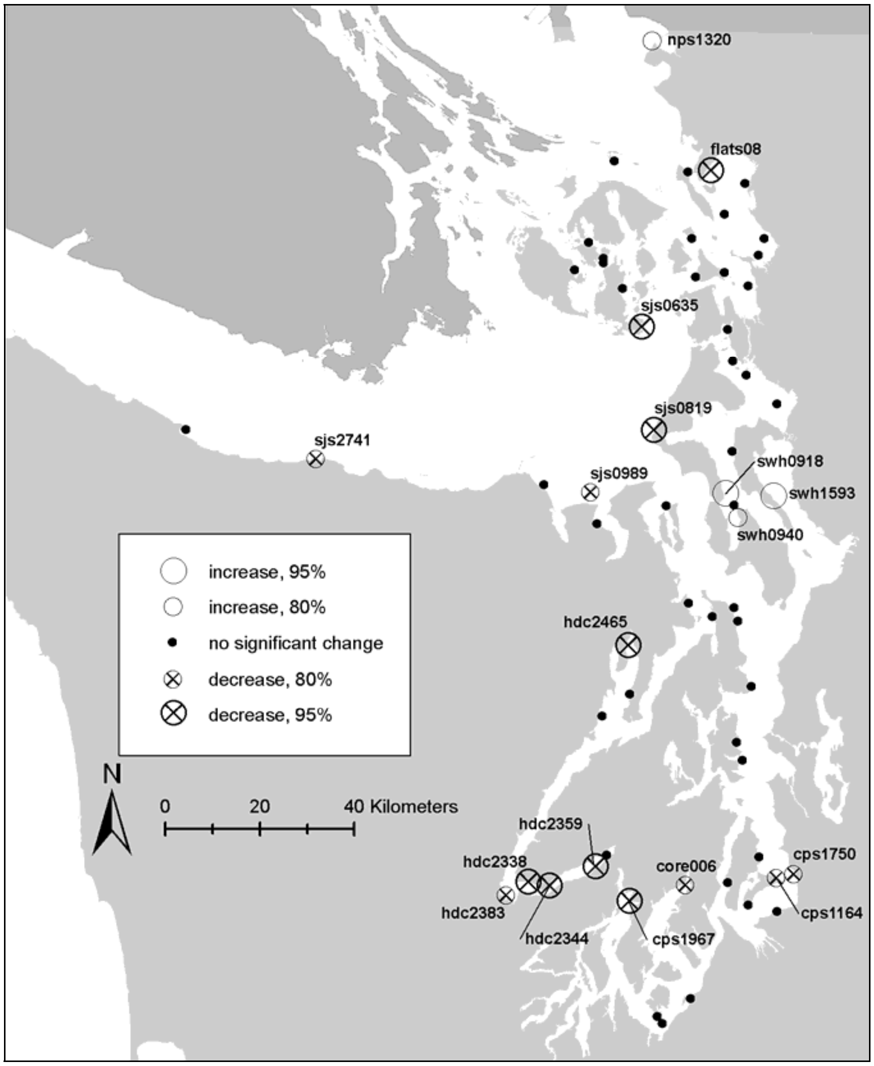


Figure 3-6. Sites with significant relative change in *Z. marina* area from 2004 to 2005 when tested at 80% and 95%. A total of 62 sites were sampled in 2004 and 2005; four sites exhibited a significant increase in *Z. marina* area, 14 sites exhibited a significant decrease in area and 44 sites exhibited no significant change.

There were five sites in the *Hood Canal Region*, four at the most southern extent, where a significant decrease in *Z. marina* area was observed. A similar pattern was observed in the southern reaches of the *Central Puget Sound Region* (Figure 3-6).

The estimated relative change in *Z. marina* area varied in magnitude between sites from 2004 to 2005. The greatest significant estimates of relative decrease from 2004 to 2005, were observed at *hdc2344-Great Peninsula* and *sjs0819-N. of Partridge Point* (–67.1% and –71.0 respectively, 95% confidence level, Appendix C). The greatest significant estimates of relative increase were observed at *swh0918-N. of Partridge Point* and *swh1593-Camano Island, Cornell* (+15.8% and +52.8% respectively, 95% confidence level) during the same time period (Figure 3-7, Appendix C).

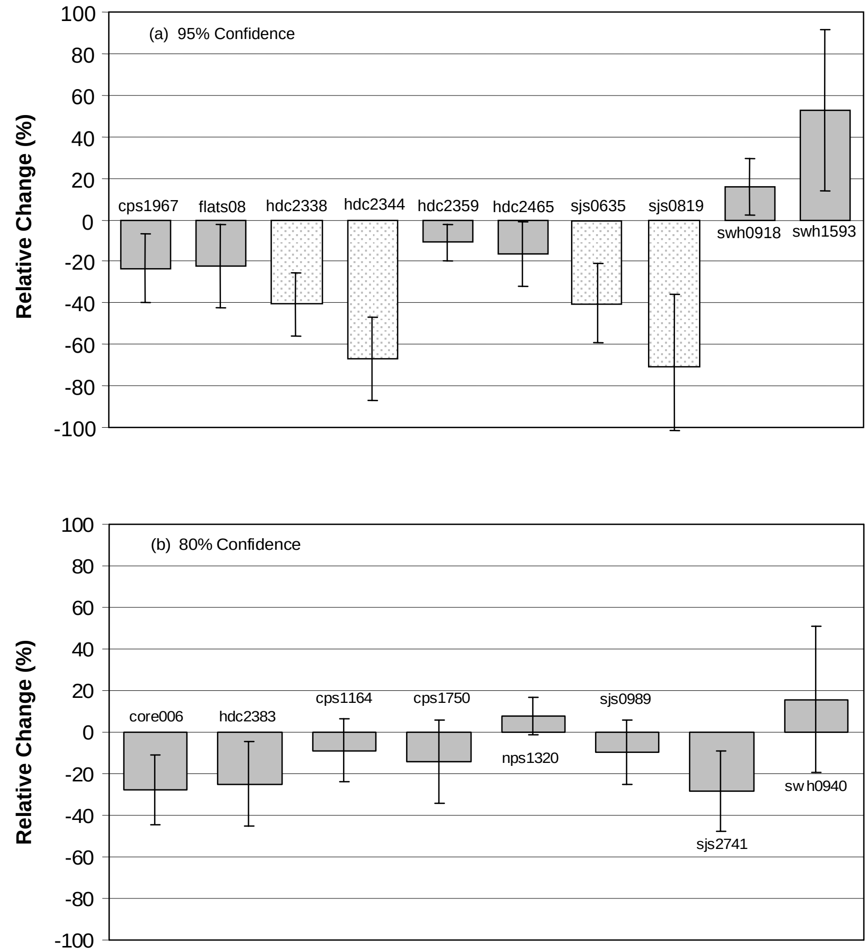


Figure 3-7. Estimated relative change in *Z. marina* area from 2004 to 2005 at the (a) 95% and (b) 80% confidence levels (error bars are associated 95% or 80% confidence intervals respectively). Stippled pattern indicates sites that are less than 2.0 ha.

Five-Year Trends in Site-Level Zostera marina Area

Through 2005, 20 sites have been sampled for five or more consecutive years (Figure 3-8, Table 3-3). Three of the 20 sites had significant declining trends at the 95% confidence level while two sites showed a significant increase in *Z. marina* area (Figure 3-8, Table 3-3). An additional five sites had significant trends at the 80% confidence level; one site showed an increasing trend and the *Z. marina* area at the other four sites had a decreasing trend. There were 10 sites that have been sampled for five or more consecutive years through 2005 that showed no significant change in *Z. marina* area.

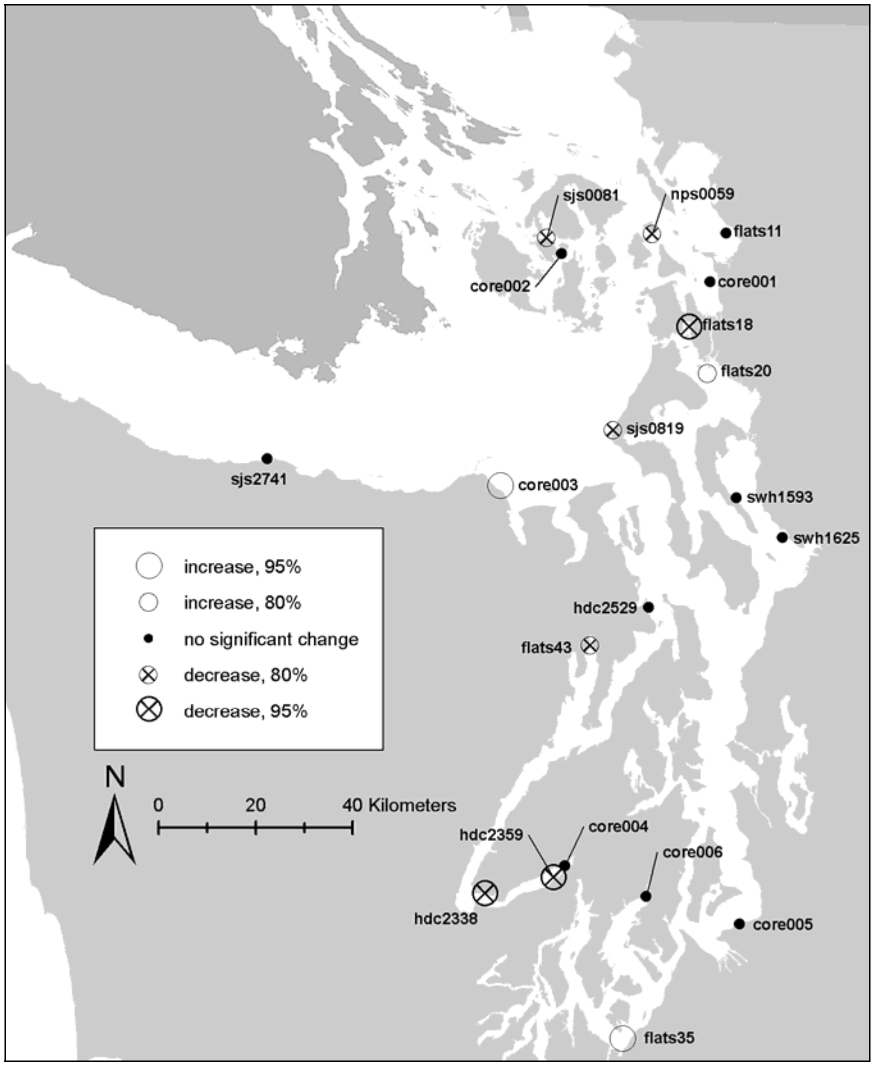


Figure 3-8. Sites with significant trends in *Z. marina* area estimates for five or more years when tested at 80% and 95% confidence levels. Sites that exhibited no significant trend are also shown.

Over the last five to six years, there have been no spatial patterns to the significant site-level trends (Figure 3-8, Table 3-3). On an absolute areal basis, two sites (*core003-Jamestown*, +25.8 ha yr^{-1}; *flats20-Skagit Bay N.*, +11.9 ha yr^{-1}) had far greater increasing trends than other sites (Table 3-3). On a relative basis, the highest relative annual increasing trend (+29.2 % yr^{-1}) in *Z. marina* area was observed at *flats35-Nisqually Delta E*.

Table 3-3. *Zostera marina* area trends observed for five years or more through 2005 at two levels of significance. The estimated trends are based on the regression slope and the percentage change values are relative to the estimated *Z. marina* area at each site in 2000.

Direction of Trend	Site code	Site name	Years of trend	Confidence of test result	Estimated trend (ha yr^{-1})	Equivalent annual relative change (% yr^{-1})
increasing area	core003	Jamestown	6	95%	+25.8	+6.9
	flats35	Nisqually Delta E.	6	95%	+2.7	+29.2
	flats20	Skagit Bay N.	6	80%	+11.9	+6.1
decreasing area	flats18	Similk Bay	6	95%	-1.9	-4.3
	hdc2338	Across from Union	6	95%	-0.2	-8.6
	hdc2359	Lynch Cove Fringe	6	95%	-0.5	-4.4
	flats43	Dabob Bay	6	80%	-0.6	-4.3
	nps0059	Sinclair Island	6	80%	-0.04	-5.1
	sjs0081	Broken Pt. (Shaw Island)	6	80%	-0.1	-8.0
	sjs0819	N. of Partridge Point	5	80%	-0.09	-22.0
no trend	core001	Padilla Bay	5	no trend	no trend	no trend
	core002	Picnic Cove	6			
	core004	Lynch Cove	6			
	core005	Dumas Bay	6			
	core006	Burley Spit	6			
	flats11	Samish Bay N.	5			
	hdc2529	S. of Tala Point	6			
	sjs2741	West of Crescent Bay	6			
	swh1593	Cornell (Camano Island)	6			
	swh1625	S. of Tulalip Bay	6			

An additional site, *hdc2239-Hood Canal NE* in the *Hood Canal Region* had a significant decrease in *Z. marina* area but over a period of four years, 2002 to 2005. The observed decrease (-14.2 % yr^{-1}) in *Z. marina* area at *hdc2239-Hood Canal NE* was the second greatest relative annual decrease recorded compared to sites sampled over five or six years (Table 3-3).

3.4 *Zostera marina* Depth Distribution

3.4.1 2005 *Zostera marina* Depth Distribution

The minimum and maximum depths (MLLW) of *Z. marina* were recorded at all sites sampled in 2005 (greater Puget Sound study area, Appendix F; Hood Canal Focus Area, Appendix G). In the five SVMP sample regions the range of minimum and maximum mean depths showed slight changes from the depths recorded in the previous year (Table 3-4, Dowty et al. 2005). In 2005, the deepest *Z. marina* was observed in the *San-Juan Straits Region* (-10.7 m, *sjs0205-E. of Eagle Point*) and in the *Central Puget Sound Region* (-11.9 m, *cps2573-Ft. Flagler*) regions. The mean maximum *Z. marina* depth occurred in the *San Juan-Straits Region* followed by *North Puget Sound* and *Central Puget Sound Regions*. Although the shallow depths were similar across regions, the deep depth limit in the *Hood Canal Region* and *Saratoga-Whidbey Basin Region* were comparable to each other but noticeably less than the other three regions (Table 3-4).

Table 3-4. Range of maximum and minimum *Z. marina* depth (MLLW) for all strata by region in 2000-2005. The 2005 depths that differed from 2004 values are in bold with the 2004 value in parentheses.

Region	Minimum Depth (m)		Maximum Depth (m)	
	Absolute	Range in Site Means	Absolute	Range in Site Means
North Puget Sound	+1.4	+0.6 to -3.3	-8.4	**-2.0** (-2.3) to -6.6
San Juan-Straits	+1.5	+0.4 to -5.4	**-10.7** (-10.5)	-0.4 to **-10.3** (-8.3)
Saratoga-Whidbey Basin	+1.3	+0.5 to **-1.7** (-1.2)	-8.0	-0.3 to **-4.5** (-4.4)
Hood Canal	+1.8	+1.1 to **-1.7** (-1.4)	-7.3	**-1.6** (-2.3) to -4.4
Central Puget Sound	+1.6	+1.1 to -1.3	**-11.9** (-10.1)	-0.5 to -6.3

3.4.2 2002 – 2004 Regional *Zostera marina* Depth Profiles

An analysis was performed on the 2002-2004 depth data to create depth profiles for each stratum and region (Figure 3-9; Selleck et al. 2005). The depth profiles, from 2002 to 2004, varied greatly between regions, geomorphic categories and individual sites (Figure 3-9). Based on the 2002-2004 analyses, a large proportion of the sound-wide *Z. marina* occurred shallower than –1.5 m (-5 ft) (MLLW) and fringe sites displayed deeper absolute maximum depths than flats sites. In the *San Juan-Straits Region*, fringe sites displayed the deepest absolute maximum depths with a distribution peak at approximately –5.5 m (MLLW). An ANOVA found differences in absolute maximum depth to be significant for region ($p < 0.001$), but no differences were observed for geomorphic categories ($p < 0.125$) (Selleck et al. 2005).

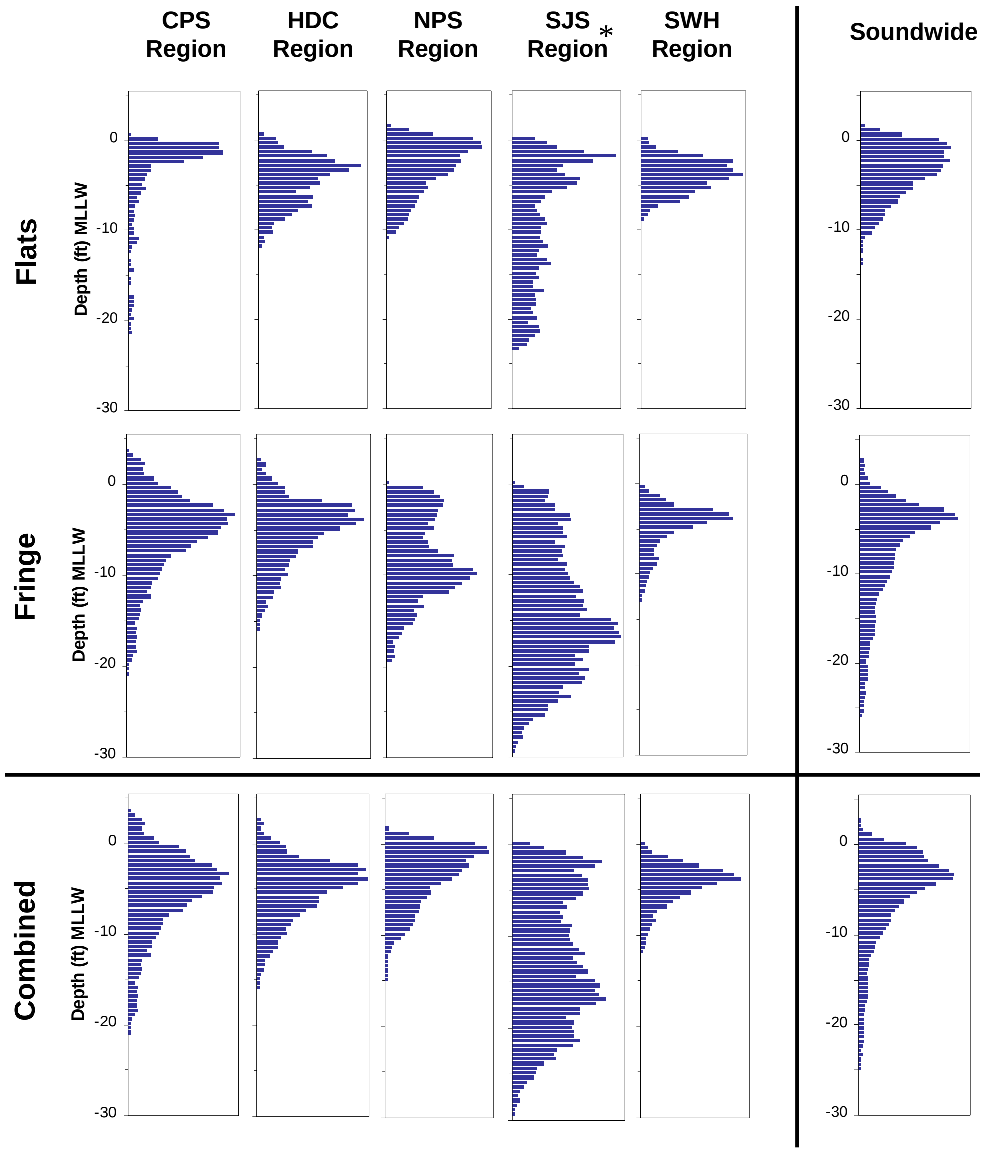


Figure 3-9. Depth profiles of *Z. marina* from 2002-2004 aggregated by the SVMP regions, flats and fringe habitat and combined (adapted from Selleck et al. 2005). Note: The asterisk (*) indicates that *Z. marina* was observed at depths greater than 30 ft (9 m) in the *San Juan-Straits Region* but these data do not appear in the depth profiles due to the small quantity of observations and therefore are not included in the figure.

3.4.3 Site-Level Change in *Zostera marina* Depth from 2004 to 2005

Mean maximum depth

There were 25 sites, from a pool of 62 paired sites, with significant changes in mean maximum *Z. marina* bed depth from 2004 to 2005 (Figure 3-10, Table 3-5). The maximum *Z. marina* depth at two sites was deeper when tested at the 95% confidence level. At the same level of precision, the maximum *Z. marina* depth was shallower than the maximum deep edge recorded in 2004 at seven other sites. At the 80% confidence interval, the maximum *Z. marina* deep edge changed from 2004 to 2005 at 16 additional sites. The deep edge of *Z. marina* was observed deeper at nine sites and shallower at seven sites. There were no strong spatial patterns across greater Puget Sound, although the *Central Puget Sound Region* had the most sites where the *Z. marina* deep edge depth changed at the 80% and 95% confidence interval (Figure 3-10). The *San Juan-Straits Region* had the fewest sites where the *Z. marina* deep edge depth changed.

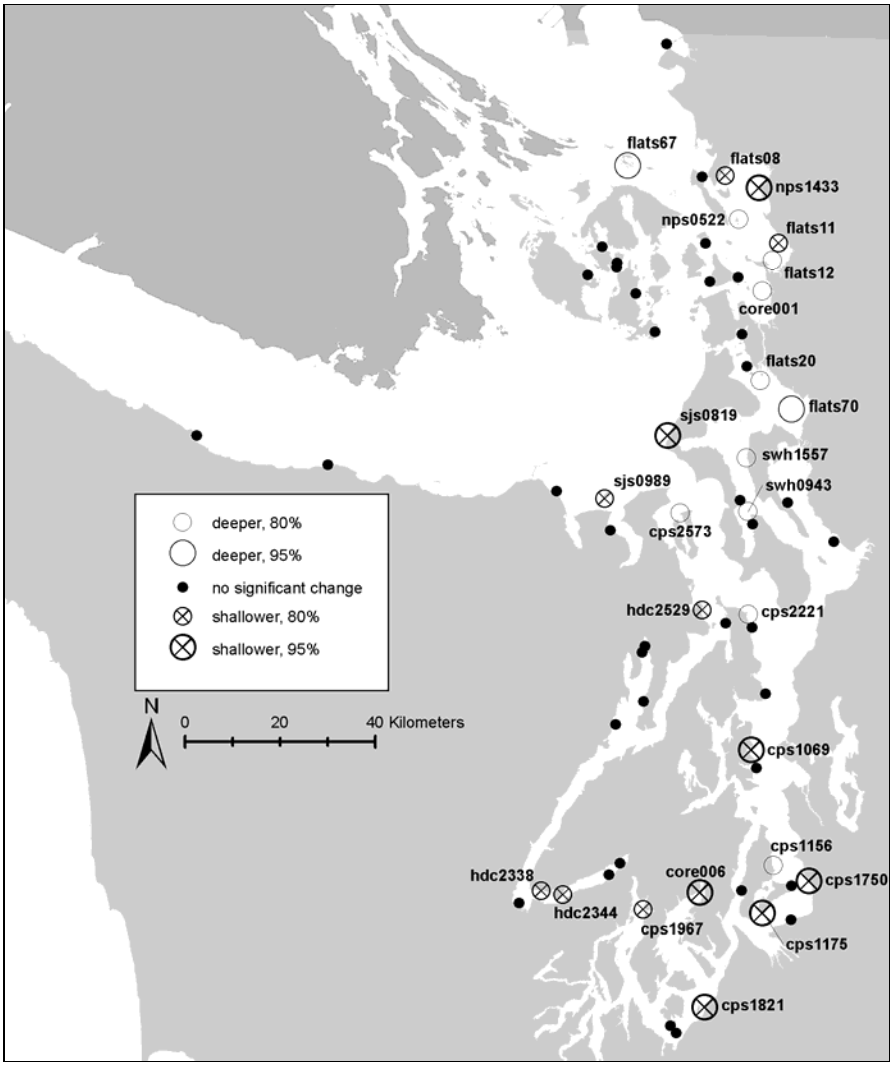


Figure 3-10. Sites with significant change in mean maximum *Z. marina* depth from 2004 to 2005 when tested at α = 0.2 and α = 0.05. Thirty-seven (37) sites exhibited no significant change in maximum depth.

Table 3-5. Significant changes in mean maximum *Z. marina* depth from 2004 to 2005 tested at two different levels of significance (α = 0.2 and α = 0.05).

Deep edge direction of change	Site	α	Mean maximum depth (m)		
			2004	2005	Change
deeper	flats67	0.05	-3.0	-5.4	-2.4
	flats70	0.05	-2.7	-3.4	-0.7
	core001	0.2	-3.8	-4.3	-0.5
	flats12	0.2	-3.0	-3.1	-0.1
	flats20	0.2	-1.4	-1.7	-0.3
	cps1156	0.2	-2.5	-3.2	-0.7
	cps2573	0.2	-3.7	-5.9	-2.2
	cps2221	0.2	-4.5	-5.1	-0.6
	nps0522	0.2	-3.7	-4.1	-0.4
	swh0943	0.2	-3.8	-4.5	-0.7
	swh1557	0.2	-3.0	-3.9	-0.9
shallower	core006	0.05	-2.5	-2.2	0.3
	cps1069	0.05	-4.3	-3.7	0.6
	cps1175	0.05	-3.1	-2.3	0.8
	cps1750	0.05	-5.4	-3.5	1.9
	cps1821	0.05	-4.0	-2.8	1.2
	nps1433	0.05	-3.5	-3.0	0.5
	sjs0819	0.05	-6.2	-5.2	1.0
	flats08	0.2	-2.6	-2.3	0.3
	flats11	0.2	-3.4	-3.2	0.2
	cps1967	0.2	-3.0	-2.6	0.4
	hdc2338	0.2	-3.2	-2.8	0.4
	hdc2344	0.2	-3.2	-2.7	0.5
	hdc2529	0.2	-3.7	-3.5	0.2
	sjs0989	0.2	-7.1	-5.6	1.5

Mean minimum depth

The mean minimum depth at 24 of the 62 paired sites showed significant change from 2004 to 2005 (Figure 3-11, Table 3-6). The mean minimum depth was shallower at six sites in 2005 compared to 2004 when calculated at the 95% confidence level. Five additional sites observed a similar direction of change at the 80% confidence level. The mean minimum depth was deeper at four sites calculated at the 95% confidence level. Another nine sites had a similar direction of change in the mean minimum depth but at the 80% confidence level.

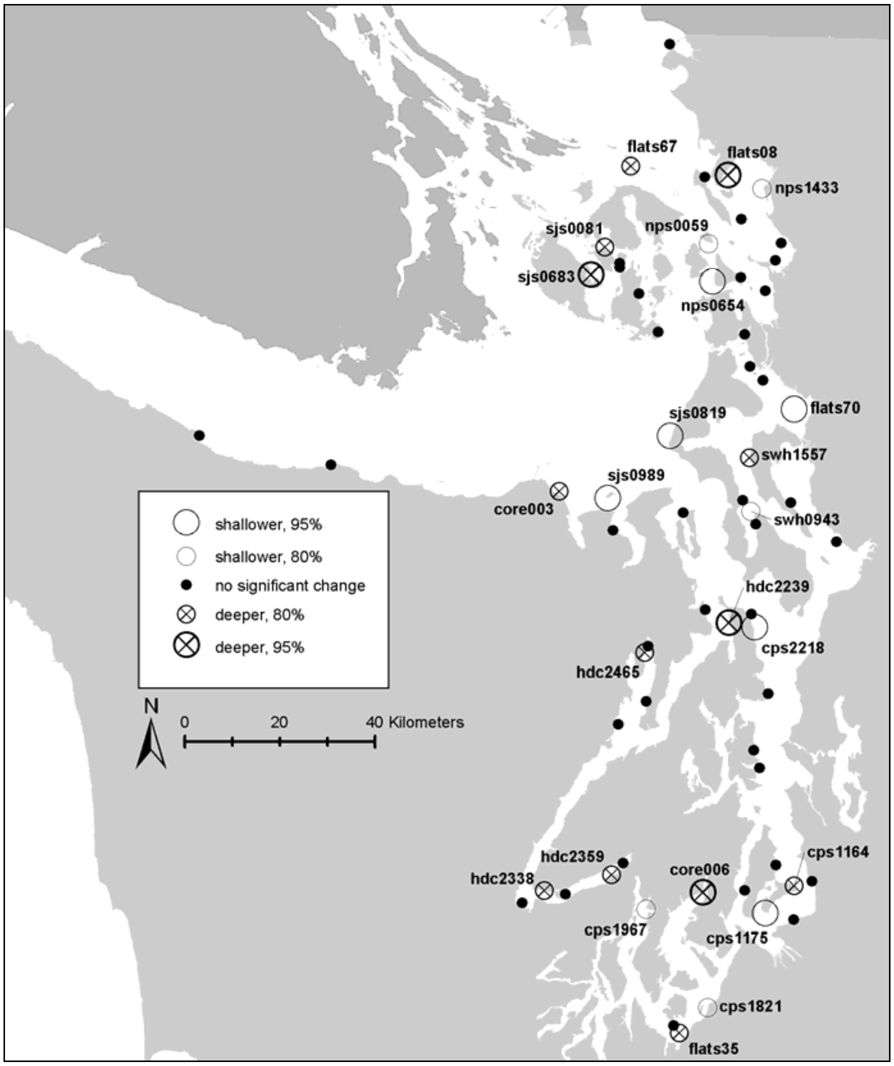


Figure 3-11. Sites with significant change in mean minimum *Z. marina* depth from 2004 to 2005 when tested at α = 0.2 and α = 0.05. Thirty-eight (38) sites exhibited no significant change in depth.

Table 3-6. Significant changes in mean minimum *Z. marina* depth from 2004 to 2005 when tested at two different levels of significance (α = 0.2 and α = 0.05).

Shallow edge direction of change	Site	α	Mean minimum depth (m) 2004	2005	Change
shallower	flats70	0.05	-0.5	-0.3	0.2
	cps1175	0.05	-0.2	0.0	0.2
	sjs0819	0.05	-5.3	-4.1	1.3
	sjs0989	0.05	-0.5	-0.2	0.3
	cps2218	0.05	0.5	0.9	0.4
	nps0654	0.05	-1.9	-1.3	0.6
	cps1821	0.2	-0.9	-1.3	0.2
	cps1967	0.2	-1.0	-0.8	0.2
	nps0059	0.2	-2.3	-1.9	0.6
	nps1433	0.2	-0.9	-0.4	0.5
	swh0943	0.2	-0.6	-0.4	0.2
deeper	core006	0.05	-0.9	-1.1	-0.2
	flats08	0.05	-0.5	-0.7	-0.2
	sjs0683	0.05	-2.5	-3.6	-1.1
	hdc2239	0.05	0.4	0.2	-0.2
	core003	0.2	0.0	-0.4	-0.4
	flats35	0.2	0.0	-0.2	-0.2
	flats67	0.2	-2.0	-2.6	-0.6
	cps1164	0.2	-0.6	-0.9	-0.3
	hdc2338	0.2	-1.2	-1.5	-0.3
	hdc2359	0.2	-0.4	-0.5	-0.1
	hdc2465	0.2	-0.7	-0.9	-0.2
	sjs0081	0.2	-1.0	-1.4	-0.4
	swh1557	0.2	-0.5	-0.8	-0.3

3.5 Multiple Parameter Assessment

3.5.1 Assessment of Region-Level *Zostera marina* Change

The multiple parameter assessment evaluated regional trends by quantifying the proportion of significant changes for all *Z. marina* parameters within each region from 2000 to 2005 (Table 3-7). The proportion of significant *Z. marina* parameter assessments indicates variability, or overall change, within a region, while the proportion of negative or positive changes indicates the status of the seagrass in the region (Table 3-7, Figure 3-12).

Every region exhibited both positive and negative changes in four of the five measured parameters from 2000-2005 (Table 3-7). The region-level *Z. marina* area estimate was calculated in all of the regions for most of the years but none of the results showed a significant change from one year to the next. Overall, the shallow edge depth of *Z. marina* had the greatest relative number of significant changes and more than half of these were negative changes. In addition, more than half of the significant deep edge depth changes and the site-level area changes in all the regions were negative.

Table 3-7. Results of multiple parameter assessment of regional *Z. marina* trends based on data collected from 2000 – 2005. The number of measurable changes within a region was quantified and compared to the number of significant positive or negative changes. The *Hood Canal Region* has been identified as the region of highest concern for *Z. marina* losses due to the high proportion of significant negative results.

	CPS				HDC				NPS				SJS				SWH			
	No. Change Tests	Significant change	Positive change	Negative change	No. Change Tests	Significant change	Positive change	Negative change	No. Change Tests	Significant change	Positive change	Negative change	No. Change Tests	Significant change	Positive change	Negative change	No. Change Tests	Significant change	Positive change	Negative change
Region-level area	3	0	0	0	5	0	0	0	4	0	0	0	5	0	0	0	5	0	0	0
Site-level area	69	6	0	6	41	11	1	10	31	4	3	1	72	12	1	11	49	8	4	4
Deep edge depth	69	12	4	8	41	8	0	8	31	6	4	2	72	10	2	8	43	8	5	3
Shallow edge depth	69	15	6	9	40	12	5	7	30	4	1	3	71	12	6	6	42	13	5	8
5-year area trends	3	1	1	0	6	3	0	3	3	0	0	0	5	1	1	0	4	1	0	1
Proportion of significant results	0.16				0.26				0.14				0.16				0.21			
Proportion of significant positive results	0.32				0.18				0.57				0.29				0.47			
Proportion of significant negative results	**0.68**				**0.82**				**0.43**				**0.71**				**0.53**			

The results of the multiple parameter assessment show substantial evidence of significant negative changes in *Z. marina* in the *Hood Canal Region*. The *Hood Canal Region* had the largest proportion of significant and negative changes in the *Z. marina* parameter compared to the other four regions in the study area (Table 3-7, Figure 3-12). Two other regions, the *San Juan-Straits* and *Central Puget Sound* also had a greater number of significant negative changes to *Z. marina* than positive changes, however the magnitude was lower (Table 3-7, Figure 3-12). In contrast, the *Saratoga-Whidbey* and *North Puget Sound Regions* did not show a greater proportion of declines relative to increases. The *North Puget Sound Region* was the region with the greatest proportion of significant positive changes and the lowest frequency of change (Figure 3-12).

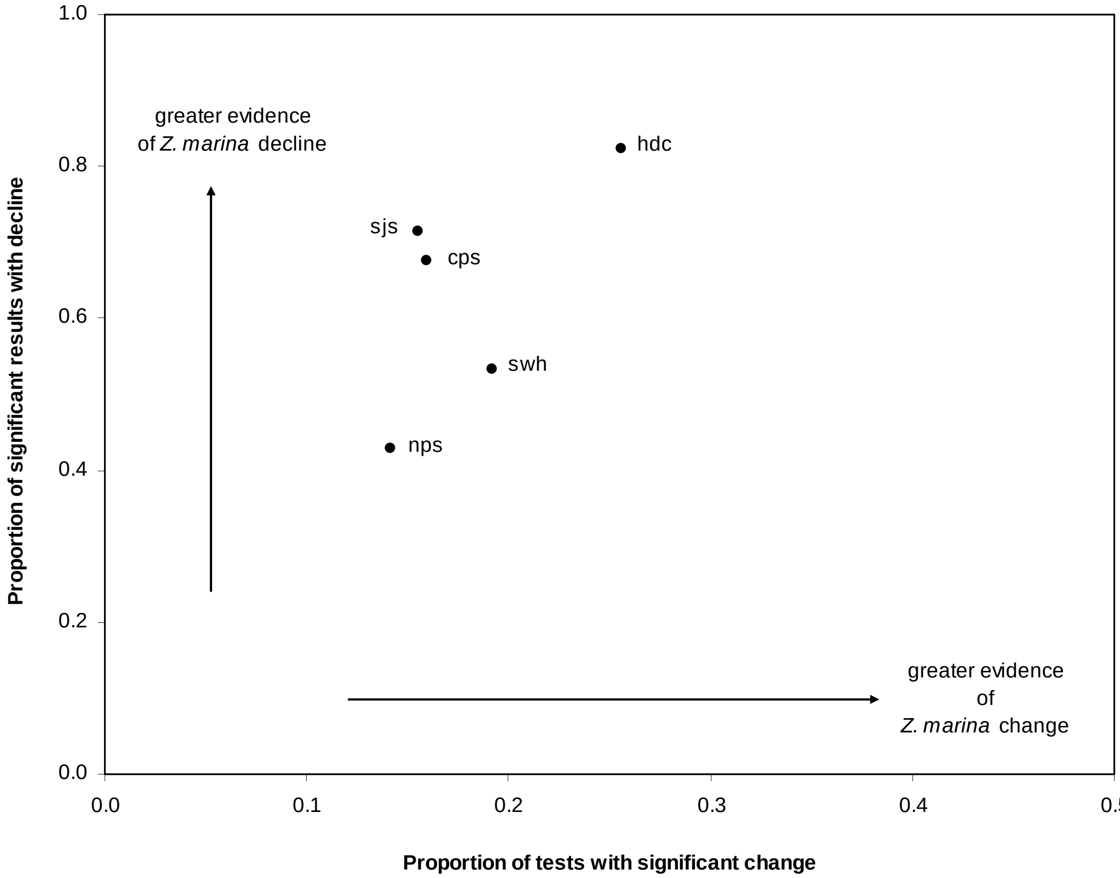


Figure 3-12. Proportion of significant declining results in the multiple parameter *Z. marina* assessment relative to the proportion of significant *Z. marina* parameter changes in each region from 2000 - 2005.

3.5.2 Assessment of Site-Level *Zostera marina* Change

Eighteen sites were identified through the multiple parameter assessment as strong or very strong evidence of declining *Z. marina* (Table 3-8, Figure 3-13). There are six new sites that were not identified in the previous assessment (Dowty et al. 2005) and two sites previously identified that were removed adding four sites in the two categories. Four of the six new sites identified in this assessment are in the *Hood Canal Region*.

Five sites, *cps1686-Fort Lawton*, *flats53-Westcott Bay*, *flats62-Swifts Bay*, *nps1363-Village Point*, and *swh1556-NW Camano Island*, were identified as having strong evidence of decline previously but due to site rotation were not sampled in 2005 (Dowty et al. 2005). Two sites previously identified as having strong evidence of decline (Dowty et al. 2005) were sampled in 2005 and removed from this list due to recent stability (*flats37-Wing Point* and *nps0654-Yellow Reef*). Seven additional sites on this list rotated out of the sampling pool following the 2005 sample season; *hdc2338-Across from Union*, *sjs0081-*

Broken Point, *sjs0819-N. of Partridge Point*, *flats43-Dabob Bay*, *hdc2529-S. of Tala Point*, *nps0059-Sinclair Island* and *swh1625-S. of Tulalip Bay*.

Table 3-8. Sites identified by the multiple parameter assessment as having a strong evidence of *Z. marina* decline. The last column indicates sites that will be sampled in 2006 and sites that have rotated out of the SVMP sampling after the year listed in the parentheses ( ).

category	site code	site name	region	remains in sample in 2006?
very strong evidence of decline	core006	Burley Spit	Central Puget Sound	yes
	flats18	Similk Bay	Saratoga – Whidbey	yes
	flats53	Westcott Bay	San Juan – Straits	no (2001)
	hdc2239	Hood Canal NE	Hood Canal	yes
	hdc2338	Across from Union	Hood Canal	no (2005)
	hdc2359	Lynch Cove Fringe	Hood Canal	no (2005)
	sjs0081	Broken Point	San Juan – Straits	no (2005)
	sjs0819	N. of Partridge Point	San Juan – Straits	no (2005)
strong evidence of decline	cps1686	Fort Lawton	Central Puget Sound	no (2004)
	flats43	Dabob Bay	Hood Canal	no (2004)
	flats62	Swifts Bay	San Juan – Straits	no (2004)
	hdc2344	Great Peninsula	Hood Canal	yes
	hdc2465	SE of Dabob Bay	Hood Canal	yes
	hdc2529	S. of Tala Point	Hood Canal	no (2005)
	nps0059	Sinclair Island	North Puget Sound	no (2005)
	nps1363	Village Point (Lummi Is.)	North Puget Sound	no (2004)
	swh1556	NW Camano Island	Saratoga – Whidbey	no (2004)
	swh1625	South of Tulalip Bay	Saratoga – Whidbey	no (2005)

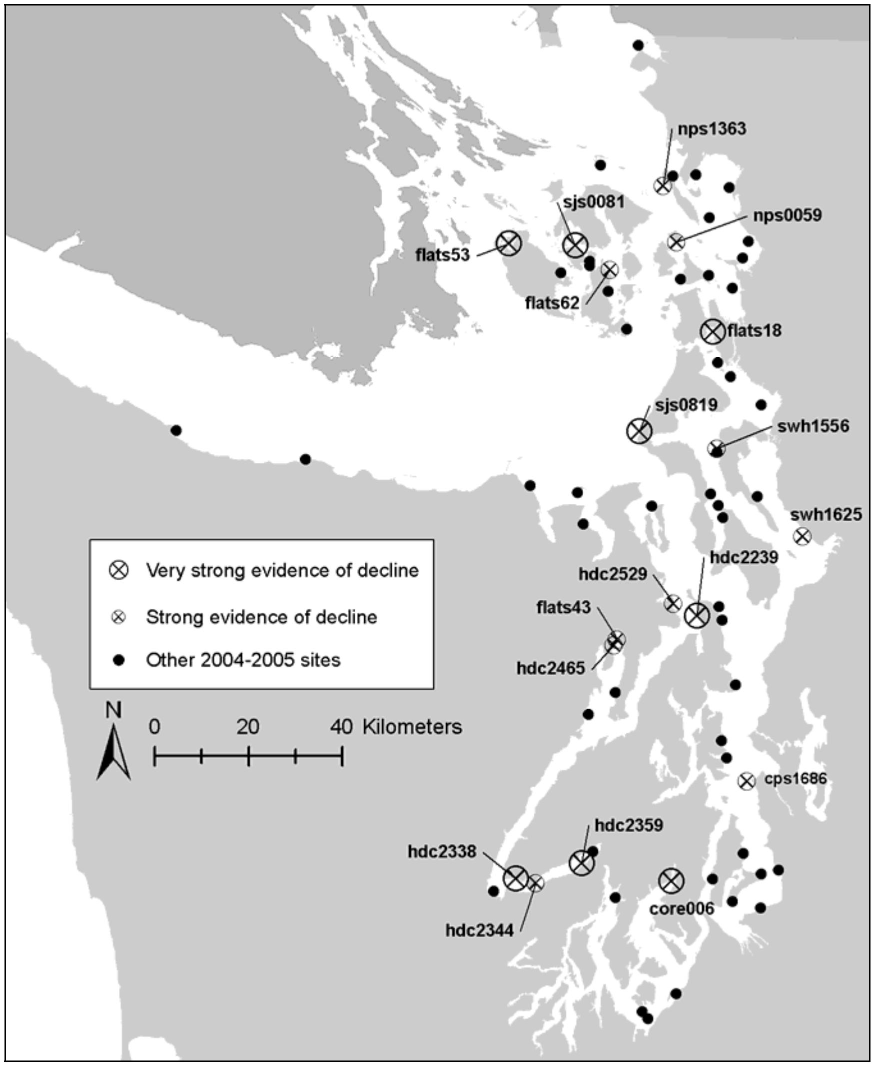


Figure 3-13. Sites with strong evidence of decline as identified by the multiple parameter site-level assessment. Sites were placed in one of two categories depending on the strength of the evidence in the available data.

3.6 Observations of *Zostera japonica*, *Phyllospadix* spp. and *Chorda filum*

The SVMP continued to maintain records of sites where seagrass species other than *Z. marina* have been observed. The most common congener was *Z. japonica*. *Zostera japonica* was often found in higher intertidal areas compared to *Z. marina*, but in some cases there were areas where the range of these two species overlapped. In addition, *Phyllospadix* spp. surfgrass was observed in the video images.

In 2005, *Z. japonica* was observed at 30 sites throughout Puget Sound (Figure 3-14). The highest concentration of sites with *Z. japonica* present was in *Hood Canal Region*, but it was also found in the *North Puget Sound*, *Saratoga-Whidbey Basin* and the *Central Puget Sound Regions*. *Zostera japonica* was not observed in the *San Juan-Straits Region* in

2005. *Phyllospadix* spp. were observed at three sites in the *San Juan-Straits Region*; two along the northern shore of the Olympic Peninsula and one on the western shore of Whidbey Island (Figure 3-14).

In 2005, large amounts of *Chorda filum*, a non-native brown algae, was observed at two sites (*hdc2356-NE of Stimsom Creek* and *hdc2365-W. of Forest Beach*) in the southern extent of the *Hood Canal Region* during the 2005 sampling (Figure 3-14).

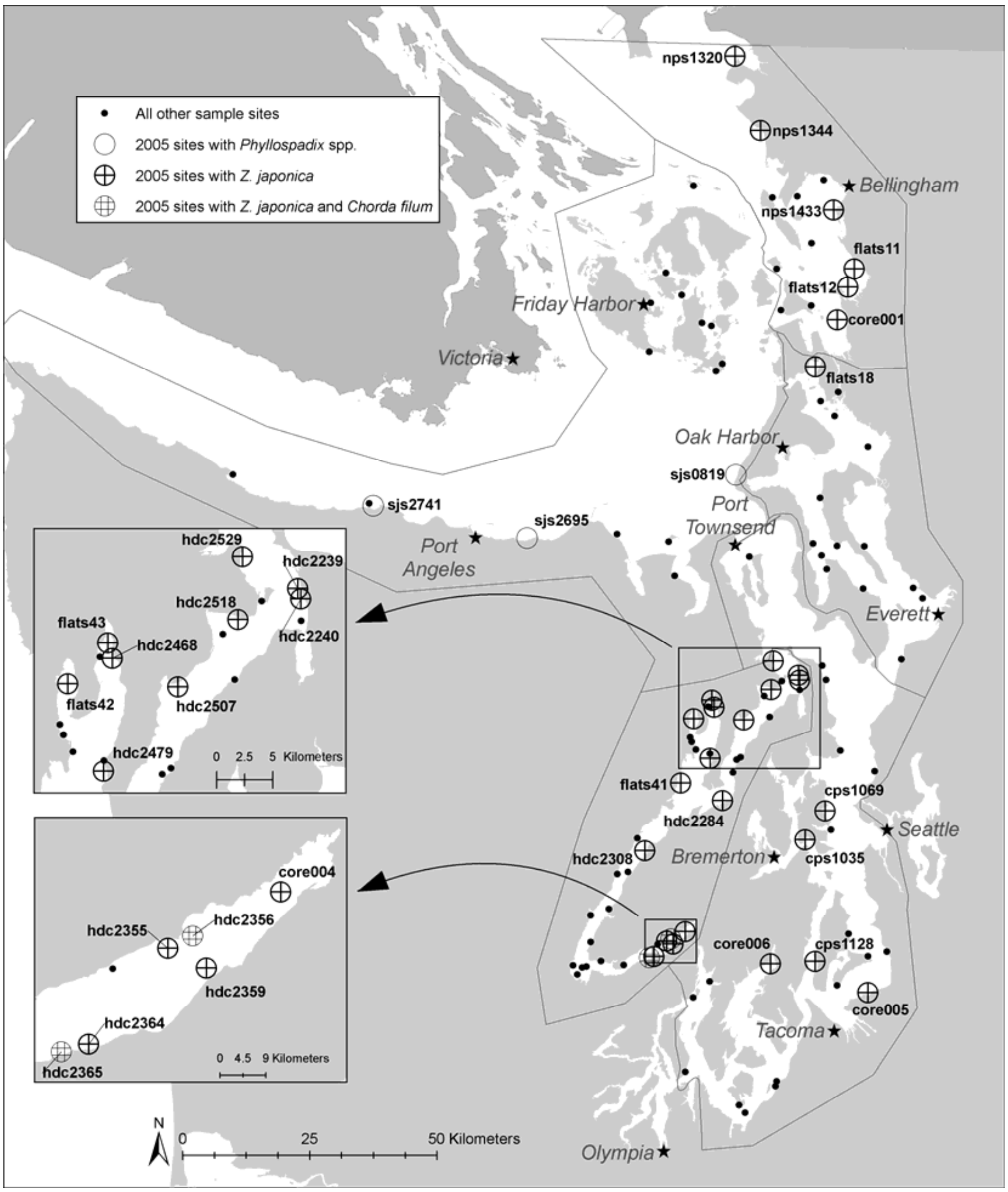


Figure 3-14. The distribution of the seagrass species *Z. japonica* and *Phyllospadix spp*. and the brown algae, *Chorda filum* determined by the 2005 SVMP sampling.

4 Discussion

4.1 Status of *Zostera marina*

Over the last few decades, science has demonstrated the ecological importance of seagrass in nearshore systems (Hemminga and Duarte 2000; Larkum et al. 2006, Orth et al. 2006). Seagrass systems are essential components to marine biodiversity (Hemminga and Duarte 2000), and the ecosystem services that seagrass systems provide are critical to human welfare and often irreplaceable (Costanza et al. 1997). However, the lack of information on the extent of seagrass area makes detection of decline difficult and often seagrass systems collapse before stressors are identified and remediation plans are implemented (Short and Burdick 1996, Short and Wyllie-Echeverria 1996). Large-scale seagrass loss can lead to significant changes in bottom habitat, particularly sediment composition. Changes at this magnitude can impact seagrass systems for years and potentially inhibit natural recolonization and even restoration efforts of the area. The SVMP was designed to determine the distribution and area of *Z. marina* throughout Puget Sound and to report on the status of seagrass in the study area in anticipation of decline from impending natural and human-induced stressors.

4.1.1 Sound-wide *Zostera marina* Area

The 2005 sound-wide *Z. marina* area estimate was consistent with the seagrass area estimated in previous years (Figure 3-1). There is strong evidence of *Z. marina* decline at numerous sites throughout the study area (Section 3.3.2), but the cumulative change in area at these sites was not significant enough to be detected in the sound-wide estimate. The only site greater than 10 ha that had a significant decrease in *Z. marina* area at the 95% confidence level was *swh0918-Pratts Bluff* and at the 80% confidence level was *sjs2741-West of Cresent Bay* (Figure 3-8). Many of the larger seagrass sites (*Core001-Padilla Bay, flats11-Samish Bay N. and flat12-Samish Bay S.*) sampled have remained stable since 2000. These sites contain 27% of the seagrass sampled (5,400 ha) in greater Puget Sound and will continue to be sampled each year because of their status as core and persistent sites in the SVMP protocol and because of their importance to the region (Thom 1990, Wyllie-Echeverria and Ackerman 2003).

Shoreline development and nutrient loading directly affect water quality and available light and have impacted *Z. marina* throughout its range (Kemp et al. 1983; Orth and Moore 1983; De Jonge and De Jong 1992; Short and Burdick 1996; Tamaki et al. 2002). The *Z. marina* population within Puget Sound remains susceptible to decline from increased shoreline development and urbanization that could disrupt natural estuarine processes, change nutrient loads and alter light availability. Although the current sound-wide status of *Z. marina* area, to within ± 10% accuracy, shows no indication of decline or change (Figure 3-1), findings at smaller spatial scales, such as the region and site-level (Sections 4.2.2, 4.4.1 and 4.4.2) raise cause for concern.

4.1.2 Hood Canal *Zostera marina* Area Estimates

The *Z. marina* area in the *Hood Canal Region* is a small fraction (1500 ha, ± 400, 7.5%, Appendix B) of the overall estimated seagrass area in Puget Sound (20,400 ha, ± 3300, Appendix E). Over half (54%) of the *Z. marina* area in the *Hood Canal Region* is distributed in the narrow fringe stratum (Table 3-2, Figure 3-3), which is indicative of the bathymetry of a fjord-like estuary (http://www.hoodcanal.washington.edu/aboutHC/brochure.html). There are only six flats sites in the *Hood Canal Region* and *core001-Lynch Cove* is the largest with 131 ha of *Z. marina*, nearly 53% of the combined *Z. marina* area at the other five flats sites within the region.

The current status of *Z. marina* in the *Hood Canal Region*, from the results of the multiple parameter assessment, suggests there are factors causing negative impacts to the seagrass in this region (Figure 3-12). The SVMP and other interest groups have not successfully identified the cause for the poor *Z. marina* status in the *Hood Canal Region*, but there has been recent attention focused on the low levels of dissolved oxygen (DO) in the area (Newton & Hannafious 2006). There is significant evidence that low DO is linked to seagrass loss (Lapointe et al. 1994) and specifically *Z. marina* declines (Holmer and Bondgaard 2001; Koch 2001; Greve et al. 2003; Kemp et al. 2004). *Zostera marina* can survive exposure to short-term anoxic conditions, however, repeated anoxic events will cause depletion of rhizome and root carbon reserves (Kraemer and Alberte 1995), an increase in sediment sulfide production (Koch 2001) and eventual plant die-off (Terrados et al. 1999; Greve et al. 2003). Recurring low light levels will decrease photosynthesis rates and increase anoxic sediment conditions. Although research has demonstrated persistent low DO conditions in Hood Canal (Newton & Hannafious 2006), it remains uncertain whether it is the primary factor to cause *Z. marina* decline in the region.

The *Z. marina* decline in the *Hood Canal Region* could be related to seagrass bed size, in addition to other factors (eutrophication and disease). The *Hood Canal Region* has a high percentage of narrow fringe sites (89%) relative to all fringe sites when compared to other regions (*Central Puget Sound Region*, 89%; *San Juan-Straits Region*, 84%; *Saratoga-Whidbey Basin Region*, 84%; and *North Puget Sound Region*, 68%) and approximately 54% of the estimated *Z. marina* in the *Hood Canal Region* is in the narrow fringe stratum (Table 3-2). In *Z. marina* meadows, research has found that narrow seagrass beds (narrow fringe sites) are more prone to disturbance from hydrodynamic forces than wide seagrass sites (wide fringe and flats sites) (Koch 2001; Greve and Krause-Jensen 2005). The concept that ‘self-protection’ or ‘mutual protection’ increases as patch size or bed size increases provides wide seagrass sites a mechanism to withstand disturbance (Duarte and Sand-Jensen 1990a,b; Olesen and Sand-Jensen 1994; Vidondo et al. 1997; Olesen et al. 2004; Kendrick et al. 2005). In addition, wide fringe and flats sites have a greater ability to recruit new shoots through sexual and asexual reproduction (Greve and Krause-Jensen 2005).

4.2 Change in *Zostera marina*

4.2.1 Sound-wide Change in *Zostera marina* Area

The sound-wide *Z. marina* estimates of relative change in area and Monte Carlo confidence intervals (Figure 3-4) were not significant during the first six years (2000-2005) of the SVMP sampling.

Variation in seagrass habitat occurs on a wide range of spatial and temporal scales. Seagrass decline can be attributed to anthropogenic activities (Cambridge et al. 1986; Orth and Moore 1983; Short and Burdick 1996), however, there are documented cases that show natural year-to-year variation (Kentula and McIntire 1986; Morris and Virnstein 2004; Evans and Short 2005) in seagrass cover and biomass. An assessment of change at a smaller scale, such as regional and site-level, demonstrates the dynamic nature of the system compared to sound-wide estimates of *Z. marina* area. Although results indicate that the overall sound-wide area is stable, there are a number of sites with evidence of decline in *Z. marina*. The ability to identify a significant *Z. marina* change in the sound-wide estimate is masked by the stability of the large sites (*Core001-Padilla Bay, flats11-Samish Bay N. and flat12-Samish Bay S.*), even though results show significant declines in *Z. marina* area at many smaller sites throughout the study area.

4.2.2 Site-Level Assessment of *Zostera marina* Change

Year-to-Year Change in Zostera marina Area

The measure of site-level *Z. marina* relative change is important to identify specific areas within Puget Sound where significant seagrass change is observed from one year to the next. The paired site estimate of *Z. marina* change provides an indication of the *Z. marina* change and a measure of reliability for the yearly calculations. Sites that show a persistent and significant decline in *Z. marina* area can be considered strong candidates for additional, more intensive analysis to determine the source of stressors. From 2004 – 2005, most of the sites with a significant decline at the 95% confidence interval were located in the *Hood Canal* and *San Juan-Straits Regions* (Figure 3-6, Figure 3-7). In 2005, there was evidence of seagrass loss in two *San Juan-Straits Region* embayments at the 80% and two at the 95% confidence levels compared to four sites in decline at the 95% confidence level and one site at the 80% in the *Hood Canal Region*. Since *Z. marina* decline has been documented in these areas it is imperative that additional research investigate causative factors to help formulate management alternatives that will minimize cumulative effects of long-term *Z. marina* decline and restore habitat functions (Orth et al. 2006).

The year-to-year video analysis also provides an opportunity to assess other changes at the site level. In 2005, *Chorda filum*, an exotic algae, was present at two sites in the *Hood Canal Region* (*hdc2356-NE of Stimson Creek* and *hdc2365-W of Forest Beach*). These sites were not sampled in previous years and therefore, no comparison is possible, but it is important to document the presence of exotic species to monitor its distribution and to determine its interaction or impact on *Z. marina* populations. In 2010, the SVMP focus area effort will return to the *Hood Canal Region* and assess the changes in *Chorda filum* distribution.

Five-Year Trends in Zostera marina Area

The five-year trends in *Z. marina* area provide a more reliable indication that seagrass area at certain sites throughout Puget Sound is increasing or decreasing compared to the year-to-year change (Table 3-3, Appendix D). It is common to observe seasonal (Sand-Jensen 1975; Guidetti et al. 2002) and yearly variation in seagrass parameters, such as biomass, shoot density and cover (Frederiksen et al. 2004), but significant trends over long intervals can increase certainty in observed changes in seagrass and distinguish trends meaningful in a management context from natural variability.

The 2005 sites with significant long-term trend results showed increasing or decreasing trends in *Z. marina* area at the 80% or 95% confidence level (Table 3-3, Appendix D). Significant change in *Z. marina* area at the site level will have ecological impacts, but the individual changes at the site level are not necessarily reflected in the sound-wide estimate (Figure 3-4). The seven sites that showed a significant five-year decline in *Z. marina* area were small in area compared to the three sites that showed a significant increase in seagrass (Table 3-3).

4.3 Regional *Zostera marina* Depth

The regional variation in *Z. marina* depth distribution is critical to determine the stability of *Z. marina* beds. Areas with large tidal ranges and shallow seagrass beds are susceptible to losses associated with water quality (Koch and Beer 1996). The deep depth limit of *Z. marina* is dependent on the nutrient concentration, water clarity (indication of available light) and dissolved oxygen (Greve and Krause-Jensen 2005). At the shallow edge of *Z. marina* distribution, research has found that environmental factors other than light, such as disturbance, tend to control productivity (Dennison and Alberte 1985, 1986). It has been demonstrated that *Z. marina* requires a minimum of 21% ambient light at its maximum depth (Dennison et al. 1993; Kemp et al. 2004). The available light in estuaries is subject to spatial and temporal variability and any reduction in available light will have detrimental effects on seagrass populations emphasizing the need for rigorous water quality regulations (Koch and Beer 1996).

4.3.1 2002 – 2004 Regional *Zostera marina* Depth Distribution

The analysis of the 2002 – 2004 depth data demonstrated that the shallow depth is consistent throughout the five SVMP regions (Figure 3-9; Selleck et al. 2005). In areas with a large tidal range seagrass can tolerate a small change in water quality at shallow depths but not at the deep depth limit (Koch and Beer 1996).

The maximum *Z. marina* depth observed in the *San Juan-Straits Region* from 2002 – 2004 was probably a result of the proximity to oceanic waters and limited coastal development in the region (Figure 3-9). Nearshore habitat with extensive ocean flushing and limited nutrient inputs tend to have greater water quality and lower nutrient concentrations than developed embayments distant from oceanic waters (Dennison et al. 1993; Greve and Krause-Jensen 2005).

4.3.2 2005 Regional *Zostera marina* Depth Distribution

The shallow depth distributions from 2004 to 2005 were consistent across regions similar to the results found in the depth profiles from the 2002 to 2004 analyses (Section 4.3.1). The maximum depth distribution in the *Hood Canal Region* (-4.5 m) was comparable to the *Saratoga-Whidbey Basin Region* (-4.5 m) but both regions were markedly shallower than the other three regions (Table 3-4). The combination of a shallower deep depth limit and a deeper shallow depth leads to a decrease in seagrass area. *Zostera marina* is typically not light limited in the shallow depths of its range (Dennison and Alberte 1985, 1986), and a decrease in water quality will most likely result in a loss of seagrass habitat in the deeper depth range.

The narrow range of the cumulative *Z. marina* mean depth distribution in the *Hood Canal Region* from 2000 to 2005 (Table 3-4) makes the seagrass susceptible to disturbances because it is less protected and more vulnerable to waves and currents (Greve and Krause-Jensen 2005). Furthermore, narrow fringe seagrass sites have less reproductive potential than seagrass that grows in wide fringe or flats type stratum. Wide fringe and flats stratum sites will be more likely to expand by vegetative and sexual reproductive strategies (Greve and Krause-Jensen 2005).

It is generally understood that that poor water quality and other factors cause decreases in the maximum depth limit of seagrass populations (Boström et al. 2003; Nielsen et al. 2003; Krause-Jensen et al. 2005). The slightly deeper *Z. marina* depth limits in the *San Juan-Straits* and *Saratoga-Whidbey Basin Regions* could indicate enhanced water clarity in these regions (Table 3-4), while the shallower *Z. marina* depth limit in the *Hood Canal Region* likely suggests poor water clarity.

4.3.3 Site Level Change in *Zostera marina* Depth from 2004-2005

A Danish study found that deep *Z. marina* populations were more stable compared to populations in shallow waters (Greve and Krause-Jensen 2005). The high variability in *Z. marina* depth limits within many sites may initially suggest a permanent change in bed area, but tend to only be temporal variation.

Site-Level

Site-level analysis differs from the regional and sound-wide scales. There are several parameters estimated at the site-level (area, maximum and minimum depth) and it is possible to look at a combination of parameters for corroborating evidence of change. An assessment of *Z. marina* area estimate data and the depth data can more reliably detect change at the site level. If *Z. marina* area estimate decreases from one year to the next and the deep edge becomes shallower during the same time period while the shallow edge depth is constant, it is likely that *Z. marina* area is decreasing at a particular site. However, an equal but similar direction change in depth at the shallow and deep edge might not always indicate a change in *Z. marina* area.

There were 64% of the sites sampled in 2004 and 2005 that showed no relationship between a change in depth and a change in *Z. marina* area. The correspondence of depth and *Z. marina* area results at the remaining 36% of the sites were consistent – i.e. both indicate decline or improvement.

4.4 Multiple Parameter Assessment

4.4.1 Assessment of Region-Level *Zostera marina* Change

The goal of the multiple parameter assessment was to identify region(s) in which the results of several independent tests indicated significant changes in *Z. marina*. Although each of the regions showed evidence of significant change, the *Hood Canal Region* had the greatest proportion of significant and negative changes compared to the other regions (Table 3-7, Figure 3-12). The collective evidence of negative changes to measured seagrass parameters in the *Hood Canal Region* suggests this region is experiencing significant declines in *Z. marina*. Furthermore, the high occurrence of significant changes in the *Hood Canal Region* could be interpreted as instability in the region and subsequently lead to additional *Z. marina* loss. It is recommended that additional sampling and investigations explore the causal factors for seagrass decline in the *Hood Canal Region*.

The *San Juan-Straits* and *Central Puget Sound Regions* also had evidence of negative change suggesting seagrass decline but not to the magnitude observed in the *Hood Canal Region*. The change in measured *Z. marina* parameters in the *San Juan-Straits* and *Central Puget Sound Regions* was larger than in the *Saratoga-Whidbey Region* and validates the need for additional sampling effort in these regions to identify causal factors.

Our regional results support other scientific findings that have identified the *Hood Canal* and *San Juan-Straits Regions* as areas of concern. In Hood Canal, low dissolved oxygen levels and fish kills have stimulated greater scientific and management focus on understanding environmental health throughout the fjord (HCDOP 2006). In the San Juan Archipelago, complete loss of eelgrass in Westcott Bay and hypothesized losses in other embayments has fueled interest in status and trends of *Z. marina* in shallow embayments (FRIENDS of the San Juans 2004, Wyllie-Echeverria et al. 2005b). Documented seagrass loss in other locations throughout the world has been linked to shoreline development and industrialization (Ibarra-Obando and Escofet 1987), nutrient and sediment loading (Orth and Moore 1983; Short and Burdick 1996), contaminants (Ralph and Burchett 1998a,b) and direct impacts such as dock construction (Burdick and Short 1999).

While the multiple parameter results suggest evidence of differing magnitudes of decline in three of the SVMP regions (*Hood Canal*, *San Juan-Straits*, and *Central Puget Sound*), the results suggest either stable conditions or positive changes in the *Saratoga-Whidbey* and *North Puget Sound Regions*.

4.4.2 Assessment of Site-Level *Zostera marina* Change

There was a preponderance of evidence from the site-level multiple parameter assessment that indicated *Z. marina* decline in the *Hood Canal Region*. Although the objectives of the

SVMP were not designed to investigate factors that cause seagrass decline, it is evident from outside data sources that poor water quality could be attributed to the loss of seagrass in the region (HCDOP 2006, Newton & Hannafious 2006).

In another region, the *San Juan-Straits*, the decline of *Z. marina* is further supported by the results of the site-level multiple parameter assessment. Again, the cause of decline at the sites in the *San Juan-Straits Region* has not been determined but future research collaborations will test a number of hypotheses.

There is a clear need to continue monitoring sites in the *Hood Canal* and *San Juan-Straits Regions* that have *Z. marina* decline. The need to continue to monitor sites with declining *Z. marina* will likely rely on partnerships with other agencies and local entities when possible. The Eelgrass Stressor-Response Project will consider these sites when selecting sites for more intensive monitoring.

<u>*Continued monitoring for sites removed from sampling pool*</u>
A number of sites that showed a significant change in *Z. marina* area or a significant change in depth from year-to-year and over a five-year period have rotated out of the sampling pool. In 2005, the sites that rotated out included: *sjs0351-NW Waldron Island*, *cps1686-Fort Lawton*, *cps1118-Neill Point (Vashon Island)*, *cps2545-Olele Point*, *swh1647-Mukilteo*, *nps1363-Village Point (Lummi Island)*, *swh0848-Ala Spit*, and *swh1556-NW Camano Island*. Although the current SVMP protocols are not designed to identify causative factors for significant seagrass decline, there is value to local governments, interest groups and the state Department of Natural Resources to continue to monitor these sites and identify causative factors for *Z. marina* decline and restoration priorities. Detection of *Z. marina* change at the site-level on a year-to-year and five-year time scale provides valuable information for managers prior to irreversible seagrass loss (Kirkman 1996).

4.5 Observations of *Zostera japonica*, *Phyllospadix* spp. and *Chorda filum*

<u>*Zostera japonica*</u>
The most common congener in Puget Sound is *Z. japonica*, a native to the western Pacific and first observed on the Pacific Coast of North America in 1957 (Harrison 1976). *Zostera japonica* was most likely introduced to Washington as early as the turn of the 20th century with the introduction of Japanese oysters to Samish Bay (Harrison and Bigley 1982; Bulthuis 1995). The SVMP video data confirms previous findings that *Z. japonica* tends to colonize shallower areas in the upper intertidal compared to *Z. marina* and that the depth range of these two species overlaps (Thom 1990; Bulthuis 1995). In some cases, the video data has found unvegetated areas separating the beds of *Z. japonica* and *Z. marina* while in other cases there have been extensive zones where the two species intermix.

Zostera japonica tends to have a shorter growth form and different leaf morphology than *Z. marina*. *Zostera japonica* leaf length is approximately 20 cm and leaf width is often between 0.8 – 1.2 mm (Moore and Short 2006) and its distribution has been shown to be highly variable on spatial and temporal scales (Bulthuis and Shull 2003).

It is not clear if the ecological services provided by *Z. japonica* differ from the services provided by *Z. marina*. Studies have demonstrated that the presence of *Z. japonica* baffles hydrodynamic energy and reduces sediment grain size (Posey 1988), provides habitat for benthic infauna (Posey 1988) and is a source of food for waterfowl (Baldwin and Lovvorn 1994). However, the documented ecological services provided by *Z. japonica* remains limited and the detrimental effects *Z. japonica* may have on native flora and fauna associated with *Z. marina* beds has not been thoroughly studied (Posey 1988).

The SVMP will continue to record observations of *Z. japonica* within and among sites to identify spatial and temporal trends. In addition, it is important to assess the ecological functions and values that *Z. japonica* provides and the competitive interactions it has on its native counterpart, *Z. marina*, to determine the long-term implications *Z. japonica* may have in Puget Sound.

Phyllospadix spp.

There are three species of *Phyllospadix* spp. that grow in Puget Sound. *Phyllospadix serrulatus* grows in the upper intertidal zone (+1.5 m MLLW), *P. scouleri* inhabits the lower intertidal zone and shallow subtidal zone and *P. torreyi* grows at greater depths and is generally more abundant on the exposed parts of the coast (Wyllie-Echeverria and Ackerman 2003).

Again little research has been done on the ecological importance of these species. The SVMP will continue to record observations of *Phyllospadix* spp. within and among sites to identify spatial and temporal trends and to accurately differentiate it from *Z. marina* presence.

Chorda filum

Algae are present throughout Puget Sound but the assessment of algae at the monitoring sites is not the primary focus of the SVMP sampling. *Chorda filum*, sea lace or dead man's rope, is a brown algae and it has not been documented by the SVMP in the *Hood Canal Region* prior to 2005, where it was observed at two sites (*hdc2356-NE of Stimsom Creek*, and *hdc2365-W. of Forest Beach*). The occurrence of *C. filum* in the *Hood Canal Region* is unexpected as the species is typically found in cold water and high salinity environments, whereas the seawater in the far reaches of Hood Canal is often warmer and less saline than other parts of Puget Sound (Newton & Hannafious 2006).

It is unclear what impact *C. filum* has on seagrass, but its presence alone suggests it could be competing for resources with *Z. marina*. Numerous studies have identified the mechanisms by which algae compete with seagrass and *Z. marina* specifically (den Hartog 1994, Short and Burdick 1996). Near Blakely Island, WA, the presence of an ulvoid alga, *Ulvaria obscura*, caused significant declines to *Z. marina* shoot density compared to experimental plots where the alga was removed (Nelson and Lee 2001). In another study, direct competition between *Z. marina* and a brown alga, *Sargasum muticum*, was not evident but it was observed that *S. muticum* colonized open spaces within the seagrass bed faster than *Z. marina* (den Hartog 1997).

4.6 Areas of Concern

There are a number of sites in Puget Sound with significant *Z. marina* decline that the SVMP considers areas of concern. The *Z. marina* loss at these sites has led to the initiation of more intensive research. Continued monitoring at sites throughout the greater Puget Sound study area, and in particular the *Hood Canal* and *San Juan-Straits Regions,* could provide insight on the causal factors for seagrass loss.

Hood Canal

Regional multiple parameter results suggest that *Z. marina* losses may be occurring in the *Hood Canal Region*. At the site-level, the multiple parameter results identified seven sites that indicated *Z. marina* decline in the *Hood Canal Region*. It has been hypothesized that site specific *Z. marina* declines and the reduction in the observed *Z. marina* depth range were a result of low dissolved oxygen (Section 4.1.2). Additional research has to be conducted to isolate the impact low dissolved oxygen has on *Z. marina* in the *Hood Canal Region*.

In the long-term, as climate change affects sea level it is possible that *Z. marina* loss will continue. The narrow band of suitable habitat in the *Hood Canal Region* already restricts the distribution of *Z. marina* in the region. *Zostera marina* expansion at the deep edge is limited by water quality and light conditions while *Z. marina* movement upslope is restricted by armored and developed shorelines (Orth et al. 2006). In addition to climate change (Short and Neckles 1999), it is possible that numerous other factors will affect seagrass.

The SVMP will continue to monitor *Z. marina* in the *Hood Canal Region* through the yearly rotational sound-wide sampling, and the next focus area effort in the region in 2010 will provide a five-year change estimate at the region-level. The yearly sound-wide sampling will provide site specific year-to-year *Z. marina* changes in the *Hood Canal Region* and an opportunity to compare the condition of *Z. marina* in the region relative to the other four regions. Future sampling efforts and collaborations with other interest groups could focus on observed change at the site and regional level to determine the effect of low dissolved oxygen and the trend of seagrass decline.

San Juan Archipelago

The results of the site- and region-level multiple parameter assessments on *Z. marina* change in the *San-Juan Straits Region* further supports the site-level seagrass decline observed in this region (Figure 3-12, Figure 3-13). It appears that the significant decrease in the seagrass area at specific sites is driving the status of *Z. marina* in the *San-Juan Straits Region* further supporting the need to investigate causative factors for seagrass decline in this region too.

The total loss of *Z. marina* within three to four years at *flats53-Westcott Bay* in the San Juan Islands is a clear example of the dramatic loss of seagrass habitat in this region. In another embayment, two sites, *sjs0285-Echo Bay N.* and *sjs0286- Echo Bay S.,* have been identified as potential impact areas from recreational boat moorings. The two narrow fringe sites in Echo Bay will be sampled in 2006 prior to relocating state regulated mooring buoys and then sampled again at a later date to determine the change in *Z. marina* area following the removal of the moorings. The SVMP observed a significant declining trend in *Z. marina* area over the last six years at *sjs0081-Broken Point, Shaw Island*. It appeared that the southeast side of the *sjs0081-Broken Point, Shaw Island* site has seen a significant decline in *Z. marina*, while there has been no observed change in seagrass in the west side of the site. Again, additional higher resolution monitoring in conjunction with other environmental parameters is necessary to determine the causal factors of decline at this site.

The total loss or sharp decline of *Z. marina* abundance in a few embayments in the San Juan archipelago has been documented (Dowty et al. 2005; Reeves et al. 2005; Wyllie-Echeverria et al. 2005a, b) and requires additional research to identify causal factors. The development of an early warning system to identify sites that are susceptible to future losses has been suggested since it is difficult, but not impossible (Kendrick et al. 1999, 2002), to reverse decline after it has been detected (Short and Burdick 1996, Hemminga and Duarte 2000).

Shellfish practices

Currently, intertidal shellfish aquaculture occurs throughout Puget Sound. Numerous studies have demonstrated the impacts of commercial or recreational harvest of clams (Boese 2002), scallops (Fonseca et al. 1984), mussels (Neckles et al. 2005) and cockles (De Jonge and De Jong 1992) to *Z. marina.* However, there is also evidence that shellfish aquaculture improves water quality (Rice et al. 1999; Newell 2005; Lindahl et al. 2004) and therefore, would increase available light to seagrass. To date, there is no evidence of an increase or decrease in *Z. marina* area at sites because of active shellfish aquaculture practices (*flats11-Samish Bay N. and flats12-Samish Bay S.).*

4.7 Assessment of Current Methods

Video classification consistency is an important factor to consider when processing SVMP field data because the variability in the data set generated by observer bias (Scott 2002; Kercher 2003).

Video processing assessment

In 2005, a study was designed to investigate the importance of intra- and inter-observer classification variation in the estimates of *Z. marina* cover from underwater video images (Reeves et al. 2007). The intra- and inter-observer variation ranged from 0.4% to 8.9% and 1.4% to 22.2% respectively. The greatest variability between video processing observers was found in areas with patchy or sparse *Z. marina* habitat. It was found that video processing varies across transects and sites, but the variability makes up a negligible component of overall error in site level *Z. marina* area estimates (Reeves et al. 2007).

A second study was performed to quantify classification consistency between video processors on the 2004 field data. The study determined the level of consistency between processors, habitat characteristics (habitat type transitions) and video quality (water clarity) that scored low processor agreement (consistency). Approximately 3-5% of all video were processed by multiple people and tested for discrepancies in video processing. The study found that *Z. marina* classification inconsistency was related to transition points, species identification and uncertainty about whether seagrass was rooted in the video frame (Milos et al. 2005). It was recommended that formal training and development of quality assurance standards be employed to minimize potential variability in video processing. The recommendations from the study will be implemented during the 2006 video post-processing procedures.

4.8 Current Priorities

Although *Z. marina* area has remained relatively constant in the study area throughout the last six years (Figure 3-1), the region- and site-level results have identified areas of *Z. marina* decline. While Phase I was only designed to monitor *Z. marina* status and trends, the SVMP was ultimately developed to investigate and identify the causal factors for seagrass decline. While the current seagrass status and trend assessment will continue, Phase III of the SVMP, the Eelgrass Stressor-Response Project, will develop experiments to identify the cause for seagrass decline and to assess seagrass functionality and habitat quality in parts of greater Puget Sound.

There are a number of sites that are no longer sampled where a significant change was observed in *Z. marina* area or depth. Sites that were not sampled in 2005 that showed a significant decline in *Z. marina* area or maximum depth in the period between 2003 – 2004 include *sjs0351-NW Waldron Island* (area @ 95%), *cps1118-Neill Point (Vashon Island)* (max depth @ 80%), *cps2545-Olele Point* (max depth @ 80%), *swh1647-Mukilteo* (max depth @ 80%). Sites with a significant five-year declining *Z. marina* area trend that were removed from rotation in 2005 include *nps1363-Village Pt (Lummi Island)* (95%), *cps1686-Fort Lawton* (80%), *swh0848-Ala Spit* (80%) and *swh1556-NW Camano Island* (80%).

The results from the monitoring program thus far have provided information on sites and regions of particular concern. Continued monitoring will provide a baseline inventory of *Z. marina* throughout greater Puget Sound. The monitoring also identifies new sites in Puget Sound where seagrass presence has not been confirmed. The additional data collected each year provides more statistical power to determine trends at various scales through trend analysis techniques (Skalski 2003).

The *Z. marina* area results are used by the SVMP to improve the reliability of the experimental design and overall project efficiency. In addition, the results are used to monitor more closely sites where significant changes have occurred and to improve management objectives and strategies to minimize seagrass loss in Puget Sound.

The priority issues identified by the SVMP for future sampling seasons include:

1. Complete the 2006 focus area sampling in the *Saratoga-Whidbey Basin Region*.
2. Initiate process studies and pursue partnerships and external funding to identify causal relationships between *Z. marina* decline and environmental stressors in the *Hood Canal Region*.

3. Increase effort in current collaboration with the University of Washington and the FRIENDS of the San Juans to identify factors causing *Z. marina* decline in shallow embayments of the San Juan Islands.
4. Develop plan to build partnerships that ensures sites with strong evidence of *Z. marina* decline are monitored when these sites rotate out of the SVMP sample.
5. Explore means of improving precision in the regional change estimates.
6. Further develop the multiple parameter assessment of change at sites with significant declines in the 5-year trend analyses.
7. Improve web data dissemination including site-level data.
8. Complete comparative analysis of options for change analysis in the focus areas.
9. Explore utility of epiphyte growth on seagrass as an indicator of nutrient loading.
10. Explore utility of seagrass cover class as a proxy for shoot density during video processing (as suggested by Berry et. al. 2003).

5 Summary

The SVMP has completed its sixth year of sampling *Z. marina* throughout Puget Sound. The project has addressed the Phase I goals of the project which were to assess seagrass vegetation distribution and abundance, to identify sound-wide, regional and site-level trends, monitor seagrass parameters and to consider stressors that may impact seagrass in Puget Sound (Berry et al. 2003; Dowty et al. 2005).

The SVMP has initiated Phase II through the assessment of other seagrass and algal species that exist in Puget Sound. Video sampling documents the presence of submerged vegetation, including *Zostera japonica*, *Phyllospadix* spp. and algae such as *Chorda filum* that grow in Puget Sound. In addition, long-term seagrass trends at the sound-wide, region- and site-level have been analyzed since program initiation in 2000.

The following points summarize the main findings from this report.

1. The 2005 estimate of *Z. marina* area (approximately 20,000 ha, 49,000 ac) in greater Puget Sound is consistent with previous years.
2. Although, the sound-wide estimate suggests stability, there is a preponderance of evidence that shows significant declines in *Z. marina* area at smaller spatial scales (region- and site-level) which were not detected in the sound-wide area estimates.
3. The results from the multiple parameter region assessment show greater evidence of negative changes to measured seagrass parameters in the *Hood Canal Region* compared to the other four regions.
4. The site-level results identified 14 sites with strong evidence of declining *Z. marina* from 2004 – 2005 dispersed among four of the regions.
5. Long-term trend analysis found seven sites with significant declines in *Z. marina* area over five years.

The current SVMP monitors the status of seagrass throughout Puget Sound, but does not address the specific stressors that cause decline. Elsewhere in the range of *Z. marina* there have been studies that have investigated the cumulative effects of the direct impact of dredging (Davis and Short 2003), dock construction (Burdick and Short 1999) and anchoring (Francour et al. 1999).

It is evident that specific stressors need to be addressed at a higher resolution to identify factors that cause seagrass decline in Puget Sound. The direct impacts of dredging, boat anchors, and dock and marina construction can be identified, but challenges arise when seagrass systems are affected by multiple indirect factors. Indirect nutrient loading can cause a combination of factors such as algal blooms and increased epiphytic growth, both directly reducing available light. It has been demonstrated that contamination from oil spills (Juday and Foster 1999) and herbicides (Scarlett et al. 1999) can impact *Z. marina* and associated organisms. Furthermore, increased sedimentation has affected seagrass populations (Kemp et al. 1983; Orth and Moore 1983, 1984).

Based on the findings in this report and supplemental evidence (Newton & Hannafious 2006), the entire *Hood Canal Region* has been considered an area of concern for *Z. marina* decline. The relationship between low oxygen conditions in Hood Canal and seagrass loss needs to be investigated further to characterize the role *Z. marina* has in the Hood Canal oxygen budget.

The SVMP data and other data sources identified *Z. marina* decline in shallow embayments in the San Juan Islands. The embayments of the San Juan Islands are considered areas of concern and will continue to be sampled to document declines and to identify causal factors.

In addition, there were 14 sites with evidence of *Z. marina* declines from 2004 – 2005 and seven sites showed significant decline over a five-year period representing localized areas of concern. In 2006 we will continue to monitor most of these sites but for the few that have rotated out of the sample pool it is important to develop a mechanism to ensure some level of continued monitoring.

The variable results across spatial scales indicate that the observed declines are not sufficient to cause significant decrease in the sound-wide *Z. marina* area estimate. There are localized results of decline and the collective evidence of the multiple parameter analysis suggests these declines are persistent throughout the *Hood Canal*, *San Juan-Straits* and *Central Puget Sound Regions*. The continued loss of *Z. marina* at small spatial scales (region- and site-level) will have significant impacts on ecological functions and could affect the overall health of Puget Sound.

The SVMP has identified several research priorities, in addition to the annual effort to monitor seagrass distribution and trends within Puget Sound, which will improve the overall understanding of seagrass distribution and investigate factors that cause decline at sites in the study area. The SVMP has developed methods to effectively monitor *Z. marina* distribution and trends (Phase I) and is exploring methods to monitor the distribution and abundance of additional seagrass species and algae species (Phase II). The next step is to focus resources that will develop programs to monitor submerged habitat at higher spatial and temporal resolutions. The goals of Phase III, the Eelgrass Stressor-Response Project, are to investigate causal factors that stress seagrass systems in greater Puget Sound and to build models that address seagrass functionality, habitat quality, and wildlife usage.

To meet these goals and objectives, the current SVMP priorities include:

1. Complete the 2006 focus area sampling in the *Saratoga-Whidbey Basin Region*.

2. Initiate process studies and pursue partnerships and external funding to identify causal relationships between *Z. marina* decline and environmental stressors in the *Hood Canal Region*.
3. Increase effort in current collaboration with the University of Washington and the FRIENDS of the San Juans to identify factors causing *Z. marina* decline in shallow embayments of the San Juan Islands.
4. Develop a plan to build partnerships that ensures sites with strong evidence of *Z. marina* decline are monitored when these sites rotate out of the SVMP sample.
5. Explore means of improving precision in the regional change estimates.
6. Further develop the multiple parameter assessment of change at sites with significant declines in the five-year trend analyses.
7. Improve web data dissemination including site-level data.
8. Complete comparative analysis of options for site rotation and change analysis in the focus areas.
9. Explore utility of epiphyte growth on seagrass as an indicator of nutrient loading.
10. Explore utility of seagrass cover class as a proxy for shoot density during video processing (as suggested by Berry et. al. 2003).

6 References

Baldwin, J.R. and J.R. Lovvorn. 1994. Expansion of seagrass habitat by the exotic *Zostera japonica*, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. *Marine Ecology Progress Series* 103:119-127.

Berry, H.D., A.T. Sewell, S. Wyllie-Echeverria, B.R. Reeves, T.F. Mumford, Jr., J.R., Skalski, R.C. Zimmerman and J. Archer. 2003. *Puget Sound Submerged Vegetation Monitoring Project: 2000-2002 Monitoring Report*. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 60pp. plus appendices. Available online: http://www2.wadnr.gov/nearshore.

Biebl, R. and C.P. McRoy. 1971. Plasmatic resistance and rate of respiration and photosynthesis of *Zostera marina* at different salinities and temperatures. *Marine Biology* 8:48-56.

Boese B.L. 2002. Effects of recreational clam harvesting on eelgrass (*Zostera marina*) and associated infaunal invertebrates: *in situ* manipulative experiments. *Aquatic Botany* 73:63-74.

Borum, J., K. Sand-Jensen, T. Binzer and O. Pedersen. 2006. Oxygen movement in seagrasses. pp. 255-270 *In:* Larkum, A.W.D., R.J. Orth, R.J. and C.M. Duarte (eds.). 2006. *Seagrasses: Biology, Ecology and Conservation*. Springer, Dordrecht, 691 pp.

Boström, C., S.P. Baden, and D. Krause-Jensen. 2003. The seagrasses of Scandinavia and the Baltic Sea. pp. 27-37. In: Green, E.P. and F.T. Short (eds). 2003. *World Atlas of Seagrasses*. University of California Press, Berkeley. 298 pp.

Bulthuis, D.A. 1995. Distribution of seagrasses in a North Puget Sound estuary: Padilla Bay, Washington, USA. *Aquatic Botany* 50:99-105.

Bulthuis, D.A. and S. Shull. 2003. *Eelgrass Distribution in Padilla Bay, Washington in 2000: Gains and Losses over a Decade*. Presentation at the Pacific Estuarine Research Society, April 3-4, 2003, Vancouver, Canada.

Burdick, D.M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management* 23:231-240.

Butler, R.W. 1995. The patient predator: Foraging and population ecology of the great blue heron, *Ardea herodias*, in British Columbia. *Occasional Papers for Canadian Wildlife Service* No. 86.

Cambridge, M.L., A.W. Chiffins, C. Brittan, L. Moore and A.J. McComb. 1986. The loss of seagrass in Cockburn Sound, Western Australia. II. Possible causes of seagrass decline. *Aquatic Botany* 24:269-285.

Costanza R, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton P and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:252-260

Davis R.C. and F.T. Short. 2003. Assessment of eelgrass plantings at Little Harbor, New Hampshire, Pierces Island, New Hampshire, Kittery Point, Maine. Monitoring report – year 1 to the US Army Corps of Engineers. Rummel, Klepper and Kahl, LLP., p 27.

De Jonge, V.N. de and D.J. De Jong. 1992. Role of tide, light, and fisheries in the decline of *Zostera marina* in the Dutch Wadden Sea. *Netherlands Institute for Sea Research Publication Series* 20:161-176.

den Hartog, C. 1994. Suffication of a littoral *Zostera* bed by *Enteromorpha radiate*. Aquatic Botany, 47:21-28.

den Hartog, C. 1997. Is *Sargassum muticum* a threat to eelgrass bed? *Aquatic Botany* 58:37-41.

Dennison, W.C. and R.S. Alberte. 1985. Role of daily light period in the depth distribution of *Zostera marina* (eelgrass). *Marine Ecology Progress Series* 25:51-61.

Dennison, W.C. and R.S. Alberte. 1986. Photoadaptation and growth of *Zostera marina* L. (eelgrass) transplants along a depth gradient. *Journal of Experimental Marine Biology and Ecology* 98:265-282.

Dennison, W.C., R.J. Orth, K.A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation: habitat requirements as barometers of Chesapeake Bay health. *BioScience* 43(2):86-94.

Dowty, P. 2005a. *A Study of Sampling and Analysis Methods: Submerged Vegetation Monitoring Project at Year 4*. Nearshore Habitat Program, Washington Department of Natural Resources, Olympia, Washington. 133 pp. Available online: http://www2.wadnr.gov/nearshore.

Dowty, P. 2005b. *Assessment of Sound-Wide Change Estimates From Paired-Site Analysis*. Unpublished report. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 8 pp.

Dowty, P., R. Reeves, H. Berry, S. Wyllie-Echeverria, T. Mumford, A. Sewell, P. Milos and R. Wright. 2005. *Puget Sound Submerged vegetation Monitoring Project: 2003-2004 Monitoring Report*. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 95 pp.

Dowty, P. 2006a. *SVMP Sampling Frames and Strata*. Unpublished report. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 20 pp.

Dowty, P. 2006b. *SVMP Annual Change Estimates: Assessment of Uncertainty at Soundwide and Region Scales*. Unpublished report. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 24 pp.

Dowty, P. 2006c. *Reconstruction of Original 2000 SVMP Results, Revised 2000-2005 Results and New Bonus Material*. Unpublished report. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 36 pp.

Duarte, C.M. and K. Sand-Jensen. 1990a. Seagrass colonization: patch formation and patch growth in *Cymodocea nodosa* patches. *Marine Ecology Progress Series* 65:193-200.

Duarte, C.M. and K. Sand-Jensen. 1990b. Seagrass colonization: biomass development and shoot demography in *Cymodocea nodosa* patches. *Marine Ecology Progress Series* 67:97-103.

Evans, N.T. and F.T. Short. 2005. Functional Trajectory Models for Assessment of Transplant Development of Seagrass, *Zostera marina* L., Beds in the Great Bay Estuary, NH, USA. *Estuaries* 28:936-947.

Felger, R. and M.B. Moser. 1973. Eelgrass (*Zostera marina* L.) in the Gulf of California: discovery of its nutritional value by the Seri Indians. *Science* 181:355-356.

Fonseca M.S., G.W. Thayer, A.J. Chester and C. Foltz. 1984. Impact of scallop harvesting on eelgrass (*Zostera marina*) meadows: implications for management. *North American Journal of Fish Management* 4:286-293.

FRIENDS of the San Juans, J. Slocomb, S. Buffum-Field, S. Wyllie-Echeverria, J. Norris, I. Fraser and J. Cordell. 2004. San Juan County Eelgrass (*Z. marina*) Survey Mapping Project Final Report, Friends of the San Juans, Friday Harbor, Washington. 40 pp.

Francour P., A. Ganteaume and M. Poulain. 1999. Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea). *Aquatic Conservation: Marine Freshwater Ecosystem* 9:391-400.

Frederiksen, M., D. Krause-Jensen, M. Holmer and J.S. Laursen. 2004. Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. *Aquatic Botany* 78:167-181.

Greve, T.M., J. Borum and O. Pedersen. 2003. Meristematic oxygen variability in eelgrass (*Zostera marina*). *Limnology and Oceanography* 48:210-216.

Greve, T.M. and D. Krause-Jensen. 2005. Stability of eelgrass (*Zostera marina* L.) depth limits: influence of habitat type. *Marine Biology* 147:803-812.

Guidette, P., M. Lorenti, M.C. Buia and L. Mazzella. 2002. Temporal dynamics and biomass partitioning in three Adriatic seagrass species: *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina*. *Marine Biology* 23:51-67.

Harrison, P.G. 1976. *Zostera japonica* Aschers. and Braebn. in British Columbia, Canada. *Syesis* 9:359-360.

Harrison, P.G. and R.E. Bigley. 1982. The recent introduction of the seagrass *Zostera japonica* Aschers. & Graebn. to the Pacific Coast of the North America. *Canadian Journal of Fisheries and Aquatic Sciences*. 39:1642-1648.

Hannam, M. Quantifying Spatial Patterns in *Zostera marina*: An Examination of SVMP Patchiness Index. In prep. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington.

Hare, S.R. and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography* 47:103-145.

Hemminga, M.A. and C.A. Duarte. 2000. *Seagrass Ecology*. Cambridge University Press, Cambridge, UK. 310 pp.

Holmer, M. and E.J. Bondgaard. 2001. Photosynthetic and growth response of eelgrass to low oxygen and high sulfide concentrations during hypoxic events. *Aquatic Botany* 70:29-38.

HCDOP 2006. http://www.hoodcanal.washington.edu/.

Ibarra-Obando, S.E. and A. Escofet. 1987. Industrial development effects on the ecology of a Pacific Mexican estuary. *Environmental Conservation* 14:135-141.

Johnson, M.R., S.L. Williams, C.H. Liberman and A. Solbak. 2003. Changes in the abundance of the seagrasses *Zostera marina* L. (eelgrass) and *Ruppia maritima* L. (widgeon grass) in San Diego, California, following an El Nino event. *Estuaries* 26(1):106-115.

Juday, G.P. and N.R. Foster. 1999. A preliminary look at effects of the Exxon Valdez oil spill on Green Island Research natural area. *Agroborealis* 22:10-17.

Kemp W.M, W.R. Boynton, R.R Twilley, J.C. Stevenson and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesepeake Bay: summary of results concerning possible causes. *Marine Technology Society Journal* 17:78-89.

Kemp W.M, R. Batiuk , R. Bartleson , P. Bergstrom, V. Carter, C.L. Gallegos, W. Hunley, L. Karrh, E.W. Koch , J.M. Landwehr, K.A. Moore, L. Murray, M. Naylor, N.B. Rybicki, J.C. Stevenson and D.J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality, light regime, and physical-chemical factors. *Estuaries* 27(3):363-377.

Kendrick, G.A., J. Eckersley and D.I. Walker. 1999. Landscape scale changes in seagrass distribution over time: a case study from Success Bank, Western Australia. *Aquatic Botany* 65:293-309.

Kendrick, G.A., C.M. Duarte and N. Marbà. 2005. Clonality in seagrasses, emergent properties and seagrass landscapes. *Journal: Marine Ecology Progress Series* 290:291-296

Kentula M.E. and C.D. McIntire. 1986. The autecology and production dynamics of eelgrass (*Zostera marina* L.) in Netarts Bay, Oregon. *Estuaries* 9:188-199

Kenworthy W.J., S. Wyllie-Echeverria, R.G. Coles, G. Pergent and C. Pergent-Martini. 2006. Seagrass conservation biology: an interdisciplinary science for protection of the seagrass biome. pp. 595-623. *In*: Larkum AWD, Orth RJ, Duarte CM (eds). 2006. *Seagrasses: Biology, Ecology and Conservation*. Springer, Dordrecht, 691 pp.

Kercher, S.M., C.B. Frieswyk and Z.B. Zedler. 2003. Effects of sampling teams and estimation methods on the assessment of plant cover. *Journal of Vegetation Science* 14:899-906.

Kirkman, H. 1996. Baseline and monitoring methods for seagrass meadows. *Journal of Environmental Management* 47:191-201.

Koch, E.W. 2001. Beyond light: physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. *Estuaries* 24:1-17.

Koch E.W. and S. Beer. 1996. Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. *Aquatic Botany* 53:97-107.

Kraemer, G.P. and R.S. Alberte. 1995. Impact of daily photosynthetic period on protein synthesis and carbohydrate stores in *Zostera marina* L. (eelgrass) roots:

implications for survival in light-limited environments. *Journal of Experimental Marine Biology and Ecology* 185:191-202.

Krause-Jensen D., T.M. Greve and K. Nielsen. 2005. Eelgrass as a bioindicator under the European Water Framework Directive. *Water Resources Management* 19(1):63-75.

Krause-Jensen D., M.F., Pedersen and C. Jensen. 2003. Regulation of eelgrass (*Zostera marina*) cover along depth gradients in Danish coastal waters *Estuaries* 26(4A):866-877.

Kuhnlein, H.V. and N.J. Turner. 1991. *Traditional plant foods of Canadian Indigenous Peoples: Nutrition, Botany and Use*. Gordon and Breach Science Publishers, Philadelphia. 633 pp.

Larkum, A.W.D., Orth, R.J. and Duarte, C.M. 2006. *Seagrasses: Biology, Ecology and Conservation.* Springer, Dordrecht, 691 pp.

Lapointe, B.E., D.A. Tomasko and W.R. Matzie. 1994. Eutrophication and trophic state classification of seagrass communities in the Florida Keys. *Bulletin of Marine Science* 54(3):696-717.

Lee, K-S., F.T. Short and D.M. Burdick. 2004. Development of a nutrient pollution indicator using the seagrass, *Zostera marina*, along nutrient gradients in three New England estuaries. *Aquatic Botany* 78:197-216.

Lindahl, O., R. Hart, B. Hernroth, S. Kollberg, L-O. Loo, L. Olrog, A-S. Rehnstam-Holm, J. Svensson, S. Svensson and U. Syversen. 2004. Improving marine water quality by mussel farming: a profitable solution for Swedish society. *Ambio* 34:131-138.

Milos, P., H. Berry and B. Reeves. 2005. An assessment of the classification consistency of 2004 monitoring data for the submerged vegetation monitoring project. Unpublished report. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 6 pp.

Moore K.A. and F.T. Short. 2006. Biology of Zostera. pp. 361-386. *In*: Larkum A.W.D., R.J. Orth, C.M. Duarte (eds) *Seagrasses: Biology, Ecology and Conservation*. Springer, Dordrecht. 691 pp.

Morris, L.J. and R.W. Virnstein. 2004. The demise and recovery of seagrass in Northern Indian River Lagoon, FL. *Estuaries* 27:915-922.

Neckles H.A., F.T. Short, S. Barker and B.S. Kopp. 2005. Disturbance of eelgrass *Zostera marina* by commercial mussel *Mylitus edulis* harvesting in Maine: dragging impacts and habitat recovery. *Marine Ecology Progress Series* 285:57-73.

Nielsen, K., B. Sømod, C. Ellegaard and D. Krause-Jensen. 2003. Assessing reference conditions according to the European water framework directive using modelling and analysis of historical data: an example from the Randers Fjord, Denmark. *Ambio* 32:287-294.

Nelson, T.A. 1997. Interannual variance in a subtidal eelgrass community. *Aquatic Botany* 56:245-252.

Nelson, T.A. and A. Lee. 2001. A manipulative experiment demonstrates that blooms of the macroalga *Ulvaria obscura* can reduce eelgrass shoot density. *Aquatic Botany* 71:149-154.

Newell, R.I.E. 2004. Ecosystem influences of natural and cultivated populations of suspension feeding bivalve mollusks: a review. *Journal of Shellfish Research* 23:51-61.

Newton, J.A. and D. Hannafious. 2006. Hood Canal Dissolved Oxygen Program – Integrated Assessment and Modeling Fourth Quarterly Report: 2/1/2006-4/25/2006. 16 pp.

Norris, J.G., S. Wyllie-Echeverria, T. Mumford, A. Bailey and T. Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. *Aquatic Botany* 58:269-287.

Olesen, B. and K. Sand-Jensen. 1994. Patch dynamics of eelgrass *Zostera marina*. *Marine Ecology Progress Series* 106:147-156.

Olesen, B., N. Marbà, C.M. Duarte, R.S. Savela and M.D. Fortes. 2004. Recolonization dynamics in a mixed seagrass meadow: the role of clonal versus sexual processes. *Estuaries* 27:770-780.

Orth, R.J. and K.A. Moore. 1988. Distribution of *Zostera marina* L. and *Ruppia maritima* L. *sensu lato* along depth gradients in the lower Chesapeake Bay, U.S.A. *Aquatic Botany* 32:291-305.

Orth, R.J. and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. *Science* 222:51-53.

Orth, R.J. and K.A. Moore. 1984. Distribution and abundance of submerged aquatic vegetation in Chesapeake Bay: an historical perspective. *Estuaries* 7:531-540.

Orth, R.J., T.J.B. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendricks, W.J. Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A global crisis for seagrass ecosystems. Bioscience 56:987-996.

Oviatt, C.A. 2004. The Changing Ecology of Temperate Coastal Waters During a Warming Trend. *Estuaries* 27(6):895-904.

Phillips, R.C. 1984. *The ecology of eelgrass meadows in the Pacific Northwest: a community profile*. U. S. Fish and Wildlife Service FSW/OBS-84/24. 85pp. Available online: http://www.nwrc.gov/library.html.

Posey, M.H. 1988. Community changes associated with the spread of an introduced seagrass, *Zostera japonica*. *Ecology* 69:974-983.

Puget Sound Action Team. 2005. *State of the Sound*. Puget Sound Action Team Pub. No. PSAT 05-01, Olympia, Washington. 64pp. Available online: http://www.psat.wa.gov.

Puget Sound Action Team. 2002a. 2002 *Puget Sound Update: Eighth Report of the Puget Sound Ambient Monitoring Program*. Puget Sound Action Team, Olympia, Washington, 144 pp. Available online: http://www.psat.wa.gov.

Puget Sound Action Team. 2002b. *Puget Sound's Health 2002*. Puget Sound Action Team, Olympia, Washington. 16 pp. Available online: http://www.psat.wa.gov.

Puget Sound Environmental Atlas. 1987. Prepared by Evans-Hamilton, Inc. US EPA.

Ralph, P.J. and M.D. Burchett. 1998a. Photosynthetic response of *Halophila ovalis* to heavy metal stress. *Environmental Pollution* 103:91-101.

Ralph, P.J. and M.D. Burchett. 1998b. Impact of petrochemicals on the photosynthesis of *Halophila ovalis* using chlorophyll fluorescence. *Marine Pollution Bulletin* 36:429-436.

Reeves, B. 2005. Submerged vegetation monitoring project sampling plan. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 25 pp.

Reeves, B., P. Dowty, H. Berry, T. Mumford, S. Wyllie-Echeverria, J. Norris and I. Fraser. 2005. *Spatial Patterns and Trends of Eelgrass (Zostera marina) at Multiple Scales in Puget Sound: Key Findings from the First Five Years of Long-Term Monitoring*. 2005. Presented at the 2005 Puget Sound Georgia Basin Research Conference, March 29-31, Seattle, Washington.

Reeves, B.R., P.R. Dowty, H.D. Berry, and S. Wyllie-Echeverria. (2007) Classifying the seagrass *Zostera marina* L. from underwater video: an assessment of sampling variation. *Journal of Marine Environmental Engineering*.

Rice, M.A., A. Valliere, M. Gibson and A. Ganz. 1999. Eutrophication control by bivalves: population filtration, sedimentation and nutrient removal through secondary production. *Journal of Shellfish Research* 18:333.

Sabol, B.M., R.E. Melton Jr., R. Chamberlain, P. Doering and K. Haunert. 2002. Evaluation of a digital echo sounder system for detection of submersed vegetation. *Estuaries* 25(1):133-141.

Sand-Jensen, K. 1975. Biomass, net production and growth dynamics in an eelgrass (*Zostera marina* L.) population in Vellerup Vig, Denmark. *Ophelia* 14:185-201.

Scarlett, A., P. Donkin, T.W. Fileman, S.V. and M.E. Donkin. 1999. Risk posed by the antifouling paint Irgarol 1051 to the seagrass, *Zostera marina*. *Aquatic Toxicology* 45:159-170.

Scott, A. and C.J. Hallam. 2002. Assessing species misidentification rates through quality assurance of vegetation monitoring. *Plant Ecology* 165:101-115.

Selleck, J.R., H.D. Berry, and P. Dowty. 2005. Depth profiles of *Zostera marina* throughout the Greater Puget Sound: results from 2002-2004 monitoring data. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. 14 pp.

Sewell, A.T., S. Wyllie-Echeverria, H.D. Berry, T.F. Mumford, B.R. Reeves and P.R. Dowty. (In prep.) *Submerged Vegetation Monitoring Project: 2003 External Project Review*. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, WA.

ShoreZone Inventory. 2001. The Washington State ShoreZone Inventory. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, WA.

Short, F.T. and D.M. Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. *Estuaries* 19(3):730-739.

Short, F.T. and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23(1):17-27.

Short , F.T. and H.A. Neckles. 1999. The effects of global climate change on seagrasses. *Aquatic Botany* 63:169-196.

Simenstad, C.A. 1994. Faunal associations and ecological interactions in seagrass communities of the Pacific Northwest coast, pp.11-17. *In*: Wyllie-Echeverria, S., A.M. Olson and M.J. Hershman (eds). 1994. *Seagrass Science and Policy in the*

Pacific Northwest: Proceedings of a Seminar Series. U.S. Environmental Protection Agency, Seattle, WA. (SMA 94-1). EPA 910/R-94 004. 63 pp.

Skalski, J.R. 2003. Statistical Framework for Monitoring *Zostera marina* (Eelgrass) Area in Puget Sound. *In*: Berry et al. 2003. *Puget Sound Submerged Vegetation Monitoring Project: 2000-2002 Monitoring Report*. Appendix L. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. Available online: http://www2.wadnr.gov/nearshore.

Spaulding, M., M. Taylor, C. Ravilious, F. Short and E. Green. 2003. *In*: Green, E.P. and F.T. Short (eds). 2003. *World Atlas of Seagrasses*. UNEP World Conservation Monitoring Centre. University of California Press, Berkeley, USA.

Suttles, W.P. 1951. *Economic Life of the Coast Salish of Haro and Rosario Straits*. Ph.D. dissertation. University of Washington, Seattle, WA.

Tamaki, H., M. Tokuoka, W. Nishijima, T. Terawaki and M. Okada. 2002. Deterioration of eelgrass, *Zostera marina* L., meadow by water pollution in Seto Inland Sea, Japan. *Marine Pollution Bulletin* 44:1253-1258.

Terrados, J., C.M. Duarte, L. Kamp-Nielsen, N.S.R. Agawin, E. Gacia, D. Lacap, M.D. Fortes, J. Borum, M. Lubanski and T. Greve. 1999. Are seagrass growth and survival constrained by the reducing conditions of the sediment? *Aquatic Botany* 65:175-197.

Thom, R.M. 1990. Spatial and temporal patterns in plants standing stock and primary production in a temperate seagrass system. *Botanica Marina* 33:497-510.

Thom, R.M., A.B. Borde, S. Rumrill, D.L. Woodruff, G.D. Williams, J.A. Southard and S. L. Sargeant. 2003. Factors influencing spatial and annual variability in eelgrass (*Zostera marina* L.) meadows in Willapa Bay, Washington and Coos Bay, Oregon, Estuaries. *Estuaries* 26(4B):1117-1129.

Vidondo, B., C.M. Duarte, A.L. Middleboe, K. Stefansen, T. Lützen and S.L. Nielsen. 1997. Dynamics of a landscape mosaic: size and age distributions, growth and demography of seagrass *Cymodocea nodosa* patches. *Marine Ecology Progress Series* 158:131-138.

Ward, D.H., A. Reed, J.S. Sedinger, J.M. Black, D.V. Derksen and P.M. Castelli. 2005. North American Brant: effects of changes in habitat and climate on population dynamics. *Global Change Biology* 11:1-12.

Wilson, U.W. and J.B. Atkinson. 1995. Black brant winter and spring-stages use at two Washington coastal areas in relation to eelgrass abundance. *The Condor* 97:91-98.

Wyllie-Echeverria, S., T. Mumford, B. Reeves, H. Berry, P. Dowty, N. Hu and B. Bookheim. 2005a. *Analysis of Seagrass (Zostera marina) Declines in the San Juan Archipelago: Using Historical Aerial Photography to Describe Fragmentation and Reduction patterns*. Presentation at the 2005 Annual Meeting of the Pacific Estuarine Research Society, March 19-20, Coos Bay, Oregon.

Wyllie-Echeverria, S., T. Mumford and N. Hu. 2005b. *Retrospective analysis of eelgrass (Zostera marina L.) abundance in small embayments within the San Juan Archipelago, Washington*. Presentation at the 2005 Puget Sound Georgia Basin Research Conference, March 29-31, Seattle, Washington.

Wyllie-Echeverria, S. and J.D. Ackerman. 2003. The seagrasses of the Pacific Coast of North America, pp.199-206. *In*: Green, E.P. and F.T. Short (eds) *The World Atlas of Seagrasses*. Prepared by the UNEP World Conservation Monitoring Centre. University of California Press, Berkeley, California. 298 pp.

Zimmerman, R.C. 2003. A Bio-Physical Model Evaluation of Eelgrass Distribution and Habitat Potential in Dumas Bay, WA. *In*: Berry et al. 2003. *Puget Sound Submerged Vegetation Monitoring Project: 2000-2002 Monitoring Report*. Appendix M. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, Washington. Available online: http://www2.wadnr.gov/nearshore.

Zimmerman, R.C., J.L. Reguzzoni, and R.S. Alberte. 1995. Eelgrass (*Zostera marina* L.) transplants in San Francisco Bay: role of light availability on metabolism, growth and survival. *Aquatic Botany* 51:67-86.

7 APPENDICES

Appendix A *Z. marina* area estimates at 2005 SVMP sample sites

Site	Location	Approximate Latitude (decimal degrees)	Approximate Longitude (decimal degrees)	Date Sampled	Number of Transects	*Z. marina* Fraction Along Transects	*Z. marina* Area at Site (hectares)	Variance	Coefficient of Variation	Estimated *Z. marina* Area Confidence Interval (hectares): 80% Lower Limit	80% Upper Limit
Core											
Core001	Padilla Bay	48.52086	-122.50592	8-Jul	10	0.7835	3,459.14	43718.658	0.06	3,191.51	3,726.78
Core002	Picnic Cove	48.56229	-122.92167	20-Jun	14	0.7239	3.32	0.038	0.06	3.07	3.57
Core003	Jamestown	48.13078	-123.07213	16-Sep	11	0.5825	493.39	2327.419	0.10	431.64	555.14
Core004	Lynch Cove	47.43036	-122.86130	31-Aug	10	0.5704	130.79	155.539	0.10	114.82	146.75
Core005	Dumas Bay	47.33286	-122.37606	2-Aug	11	0.3337	1.39	0.071	0.19	1.05	1.73
Core006	Burley Spit	47.37774	-122.63707	9-Aug	15	0.2724	3.60	0.296	0.15	2.90	4.29
Persistent Flats											
Flats11	Samish Bay N.	48.55837	-122.52759	5-Jul	8	0.7979	1,186.48	3209.715	0.05	1,113.96	1,259.00
Flats12	Samish Bay S.	48.57917	-122.48041	7-Jul	11	0.6834	772.48	2452.415	0.06	709.09	835.86
Flats20	Skagit Bay N.	48.38564	-122.57115	21-Jul	20	0.3332	230.48	668.823	0.11	197.38	263.59
Rotational Flats											
Flats08	Portage Bay S.	48.73727	-122.62043	29-Jun	17	0.5286	47.34	29.786	0.12	40.36	54.33
Flats10	Nooksack Delta E.	48.76776	-122.55054	27-Jun	N/A	N/A	0	N/A	N/A	N/A	N/A
Flats18	Similk Bay	48.43667	-122.56061	18-Jul	25	0.4334	35.92	8.008	0.08	32.30	39.54
Flats19	Pull and Be Damned	48.37637	-122.54388	20-Jul	27	0.3471	162.59	405.317	0.12	136.82	188.36
Flats26	Snohomish Delta N	48.03343	-122.26322	17-Jun	11	0.3023	150.68	1342.458	0.24	103.78	197.58
Flats35	Nisqually Delta E.	47.11264	-122.69174	4-Aug	11	0.2894	20.97	29.354	0.26	14.04	27.91
Flats37	Wing Point	47.61775	-122.48772	28-Jul	11	0.3544	14.96	7.584	0.18	11.44	18.49
Flats41	Dosewallips	47.69311	-122.88664	12-Aug	12	0.8244	108.85	40.226	0.06	100.73	116.97
Flats67	Fossil Bay	48.75037	-122.90005	30-Jun	17	0.3708	5.16	1.647	0.25	3.52	6.80
Flats70	South Fork Skagit River	48.29729	-122.41593	25-Jul	11	0.3166	282.36	1600.939	0.14	231.15	333.58
Narrow Fringe											
cps0221	SE Harstene Island	47.18247	-122.84974	5-Aug	N/A	N/A	0	N/A	N/A	N/A	N/A
cps1035	NE of Point White	47.35918	-122.45125	29-Jul	13	0.0036	0.01	0.000	1.00	0.00	0.01
cps1069	Murden Cove (Bainbridge Island)	47.65080	-122.50460	28-Jul	11	0.4043	9.40	0.669	0.09	8.36	10.45
cps1128	Paradise Cove (Vashon Island)	47.38423	-122.52060	1-Aug	18	0.4207	2.68	0.095	0.12	2.28	3.07
cps1156	Klahanic Beach (Vashon Island)	47.43463	-122.43504	3-Aug	11	0.6547	6.52	0.430	0.10	5.68	7.36

Site	Location	Approximate Latitude (decimal degrees)	Approximate Longitude (decimal degrees)	Date Sampled	Number of Transects	*Z. marina* Fraction Along Transects	*Z. marina* Area at Site (hectares)	Variance	Coefficient of Variation	Estimated *Z. marina* Area Confidence Interval (hectares) 80% Lower Limit	80% Upper Limit
cps1164	N. of Pt. Robinson (Maury Island)	47.39574	-122.38260	3-Aug	17	0.6486	5.92	0.076	0.05	5.57	6.27
cps1175	Piner Point (Maury Island)	47.34251	-122.46132	2-Aug	16	0.5152	3.93	0.023	0.04	3.74	4.13
cps1277	Thompson Cove (Anderson Island)	47.12628	-122.70791	4-Aug	15	0.3892	1.98	0.161	0.20	1.46	2.49
cps1676	Broadview	47.43400	-122.22610	27-Jul	11	0.4071	4.88	0.202	0.09	4.30	5.45
cps1750	Des Moines Beach	47.40448	-122.33522	3-Aug	11	0.4341	3.99	0.099	0.08	3.59	4.39
cps1820	Gordon Point	47.16997	-122.61359	5-Aug	12	0.0921	0.045	0.000	0.30	0.03	0.06
cps1821	Cormorant Passage	47.16177	-122.61504	5-Aug	15	0.2560	0.92	0.031	0.19	0.69	1.14
cps1951	S. of Stretch Island	47.31581	-122.83490	8-Aug	N/A	N/A	0	N/A	N/A	N/A	N/A
cps1967	Vaughn Bay (Case Inlet)	47.34373	-122.79453	8-Aug	11	0.5035	2.51	0.042	0.08	2.24	2.77
cps2201	South of President Point	47.75883	-122.46804	27-Jul	10	0.5403	8.37	0.466	0.08	7.50	9.25
cps2218	Pilot Pt.	47.88290	-122.51054	26-Jul	11	0.1563	3.42	0.217	0.14	2.82	4.02
cps2573	Ft. Flagler	48.09745	-122.72160	9-Sep	15	0.4565	5.32	1.334	0.22	3.84	6.80
hdc2338	Across from Union	47.37391	-123.07831	1-Sep	18	0.3626	0.98	0.015	0.13	0.82	1.14
hdc2344	Great Peninsula	47.36785	-123.01834	2-Sep	19	0.1547	0.48	0.021	0.30	0.30	0.67
hdc2359	Lynch Cove Fringe	47.40760	-122.89194	31-Aug	11	0.6139	8.96	0.102	0.04	8.55	9.36
hdc2465	SE of Dabob Bay	47.83015	-122.81914	11-Aug	14	0.5618	5.76	0.148	0.07	5.27	6.25
hdc2479	Toanados Peninsula, West Side	47.73832	-122.81109	12-Aug	10	0.5790	7.42	0.227	0.06	6.81	8.03
hdc2529	S. of Tala Point	47.91407	-122.65129	11-Jul	12	0.5089	5.39	0.160	0.07	4.88	5.90
nps0059	Sinclair Island	48.60780	-122.67027	24-Jun	16	0.3942	0.56	0.007	0.15	0.45	0.67
nps0522	Eliza Island NE	48.65539	-122.57840	29-Jun	11	0.4439	3.27	0.064	0.08	2.95	3.59
nps0670	Boat Harbor (Guemes Island)	48.54435	-122.57668	24-Jun	11	0.4811	0.13	0.000	0.16	0.10	0.16
nps1344	E. of Ferndale	48.51148	-122.43443	4-Jul	19	0.0491	0.29	0.004	0.22	0.20	0.37
nps1392	Lummi Point (Lummi Island)	48.73358	-122.68769	28-Jun	18	0.6766	15.03	0.808	0.04	13.88	16.18
sjs0081	Broken Point (Shaw Island)	48.59528	-122.96486	22-Jun	19	0.4688	1.20	0.040	0.17	0.95	1.45
sjs0205	E. of Eagle Point	48.27320	-123.02075	21-Jun	13	0.4130	12.65	0.584	0.06	11.68	13.63
sjs0617	Lopez Sound Road	48.50891	-122.86472	23-Jun	20	0.2578	2.07	0.067	0.13	1.74	2.40
sjs0635	Watmough Bay (Lopez Island)	48.42688	-122.80167	9-Jun	14	0.3384	1.72	0.054	0.13	1.42	2.02
sjs0639	Blind Island	48.42355	-122.82234	23-Jun	N/A	N/A	0	N/A	N/A	N/A	N/A
sjs0649	Canoe Island (Shaw Island)	48.55695	-122.92123	20-Jun	5	0.4074	0.03	0.000	0.19	0.02	0.04
sjs0683	Brown Island N.	48.54114	-123.00301	22-Jun	16	0.4969	0.92	0.017	0.14	0.75	1.09
sjs0695	Trump Island (near Decatur Island)	48.50396	-122.83958	9-Jun	N/A	N/A	0.00	N/A	N/A	N/A	N/A
sjs0819	N of Partridge Point	48.24140	-122.76352	21-Sep	11	0.0398	0.10	0.003	0.55	0.03	0.16
sjs0989	Protection Island SW	48.12010	-122.93553	14-Sep	12	0.6714	7.08	0.209	0.06	6.49	7.66
sjs2645	Gardiner, Discovery Bay	48.05943	-122.91812	14-Sep	15	0.3900	0.43	0.008	0.21	0.31	0.54
swh0940	Holmes Harbor E. (Whidbey Island)	48.07925	-122.51623	14-Jun	12	0.8027	8.14	0.103	0.04	7.73	8.55
swh1557	Rockaway Beach	48.20463	-122.53993	13-Jun	15	0.5648	3.62	0.221	0.13	3.02	4.22
swh1568	Lowell Point	48.72693	-122.29535	15-Jun	11	0.4723	0.17	0.001	0.17	0.14	0.21
swh1593	Camano Island, Cornell	48.12136	-122.41851	16-Jun	16	0.4387	4.35	0.132	0.08	3.88	4.81

Site	Location	Approximate Latitude (decimal degrees)	Approximate Longitude (decimal degrees)	Date Sampled	Number of Transects	*Z. marina* Fraction Along Transects	*Z. marina* Area at Site (hectares)	Variance	Coefficient of Variation	Estimated *Z. marina* Area Confidence Interval (hectares) 80% Lower Limit	80% Upper Limit
swh1625	So of Tulalip Bay	48.04926	-122.28672	16-Jun	17	0.1583	0.31	0.008	0.30	0.19	0.43
swh1649	Nelson's Corner	47.55312	122.18864	25-Jul	11	0.7404	5.26	0.065	0.05	4.93	5.58
<u>Wide Fringe</u>											
cps2221	Point no Point	47.90831	-122.52171	26-Jul	11	0.3378	9.31	0.528	0.08	8.38	10.24
hdc2239	Hood Canal NE	47.88957	-122.58418	12-Jul	12	0.3007	6.20	0.321	0.09	5.47	6.92
hdc2284	Warrenville	47.66278	-122.77334	10-Aug	14	0.5193	7.86	0.608	0.10	6.87	8.86
hdc2383	Anna's Bay	47.34856	-123.13948	6-Sep	15	0.1798	2.84	0.249	0.18	2.20	3.47
nps0654	Yellow Reef (Guemes Island)	48.53537	-122.65604	10-Jun	11	0.8487	9.94	0.142	0.04	9.46	10.43
nps1320	Semiamo Spit	48.98181	-122.79820	1-Jul	10	0.5938	16.31	0.303	0.03	15.61	17.02
nps1433	Post Point, Fairhaven	48.71454	-122.52422	27-Jun	17	0.6201	2.70	0.054	0.09	2.40	3.00
sjs2695	W. Green Point	48.11803	-123.31007	13-Sep	N/A	N/A	0	N/A	N/A	N/A	N/A
sjs2741	West of Crescent Bay	48.16444	-123.71955	13-Sep	15	0.3497	13.05	9.173	0.23	9.17	16.92
sjs2742	Between Agate & Crescent Bays	48.16697	-123.73143	13-Sep	N/A	N/A	0	N/A	N/A	N/A	N/A
sjs2775	Pysht River	48.20922	-124.09449	12-Sep	15	0.4111	5.93	0.173	0.07	5.39	6.46
swh0918	Pratts Bluff (Whidbey Island)	48.12393	-122.55524	14-Jun	13	0.8070	16.07	0.310	0.03	15.35	16.78
swh0943	Hackney Island (Whidbey)	48.10306	-122.53057	14-Jun	15	0.9144	18.50	0.165	0.02	17.98	19.02
swh0955	West of Langley	48.04484	-122.41940	15-Jun	12	0.6571	6.13	0.072	0.04	5.79	6.48

Appendix B *Z. marina* area estimates at the 2005 Focus Area sample sites

Site	Location	Approximate Latitude (decimal degrees)	Approximate Longitude (decimal degrees)	Date Sampled	Number of Transects	*Z. marina* Fraction Along Transects	*Z. marina* Area at Site (hectares)	Variance	Coefficient of Variation	Estimated *Z. marina* Area Confidence Interval (hectares) 80% Lower Limit	80% Upper Limit
Flats											
Flats42	Quilcene Bay	47.80326	-122.85656	15-Aug	11	0.6425	98.57	25.563	0.05	92.10	105.04
Flats43	Dabob Bay	47.83891	-122.81747	11-Aug	20	0.5330	11.68	2.4949	0.14	9.66	13.70
Flats44	Case Shoal	47.85167	-122.67326	14-Jul	11	0.3388	18.64	8.579	0.16	14.90	22.39
Flats45	Hood Head	47.88092	-122.62733	15-Jul	20	0.2955	7.00	1.152	0.15	5.63	8.37
Narrow Fringe											
hdc2262	Lofall	47.81475	-122.65649	12-Jul	12	0.2422	1.66	0.161	0.24	1.15	2.18
hdc2277	S of King Spit	47.71472	-122.74897	18-Aug	10	0.2406	1.23	0.098	0.25	0.83	1.64
hdc2308	Anderson Cove	47.57111	-122.97215	17-Aug	11	0.6291	13.29	1.922	0.10	11.51	15.06
hdc2323	N of Dewatto Bay	47.46556	-123.06342	29-Aug	15	0.0353	0.07	0.003	0.83	0.00	0.14
hdc2331	Cougar Spit	47.40617	-123.10788	8-Sep	15	0.2497	0.60	0.035	0.31	0.36	0.84
hdc2353	E of Sisters Point	47.40700	-122.93353	7-Sep	11	0.2959	1.53	0.127	0.23	1.08	1.99
hdc2364	Forest Beach	47.38374	-122.94204	7-Sep	11	0.2654	1.25	0.096	0.25	0.85	1.64
hdc2365	W of Forest Beach	47.38154	-122.95333	7-Sep	15	0.3405	1.86	0.192	0.24	1.30	2.43
hdc2398	S of Lilliwaup Bay	47.45426	-123.11050	8-Sep	15	0.4376	1.99	0.097	0.16	1.59	2.38
hdc2418	Becon Pt Loop	47.59251	-122.99499	17-Aug	11	0.5185	1.83	0.028	0.09	1.62	2.05
hdc2447	S of Whitney Pt	47.75273	-122.84882	16-Aug	12	0.3916	3.09	0.285	0.17	2.41	3.78
hdc2449	N of Whitney Pt	47.76632	-122.86048	16-Aug	15	0.2946	1.18	0.023	0.13	0.98	1.38
hdc2450	S of Frenchmans Pt	47.77455	-122.86506	16-Aug	13	0.1057	0.28	0.026	0.58	0.07	0.48
hdc2468	S of Long Spit	47.82913	-122.80317	11-Aug	11	0.4771	5.06	0.338	0.12	4.31	5.80
hdc2478	Tabook Pt	47.74682	-122.81035	16-Aug	12	0.2737	1.36	0.136	0.27	0.89	1.83
hdc2518	E of Squamish Harbor	47.86443	-122.65565	13-Jul	11	0.3907	4.95	1.325	0.23	3.48	6.43
hdc2240	N. of Port Gamble	47.88205	-122.57898	19-Aug	11	0.4141	9.69	0.419	0.07	8.86	10.52
hdc2253	Entrance to Port Gamble	47.85862	-122.58129	11-Jul	11	0.8001	17.61	0.251	0.03	16.97	18.25
hdc2314	Chinom Point	47.53162	-123.01435	17-Aug	11	0.1926	0.22	0.006	0.36	0.12	0.32
hdc2355	Stimson Creek	47.41430	-122.90987	1-Sep	16	0.4446	2.87	0.312	0.19	2.15	3.58
hdc2356	NE of Stimson Creek	47.41528	-122.90362	1-Sep	16	0.4307	7.30	0.695	0.11	6.23	8.37
Wide Fringe											
hdc2380	Skokomish Flats	47.35996	-123.11676	30-Aug	11	0.5227	32.22	5.722	0.07	29.16	35.28
hdc2381	Skokomish Flats West	47.35935	-123.12612	30-Aug	10	0.6110	25.55	0.739	0.03	24.45	26.65
hdc2386	Potlatch State Park	47.36302	-123.15441	6-Sep	11	0.7350	9.62	0.176	0.04	9.09	10.16
hdc2409	Jorsted Creek	47.52882	-123.04612	29-Aug	13	0.4340	3.35	0.393	0.19	2.55	4.15
hdc2507	N of Thorndyke Bay	47.80850	-122.73067	18-Aug	11	0.4883	11.93	1.683	0.11	10.27	13.59

Appendix C Relative change in *Z. marina* area for sites sampled in 2004 and 2005

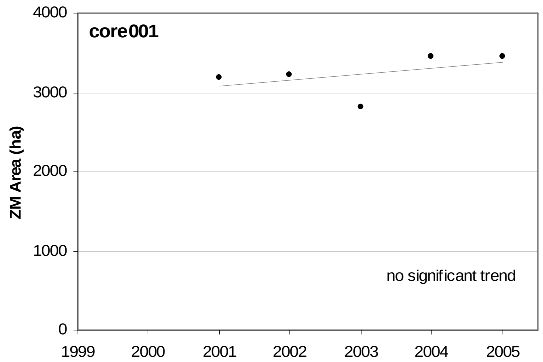
Site	2004 *Z. marina* area (m^2)	2004 variance	2005 *Z. marina* area (m^2)	2005 variance	Relative Change (%)	Variance of Change	SE of Change	80% CI (half width)	95% CI (half width)	Confidence in Detected Change
core001	34,589,845	3,900,657,802,997	34,591,411	4,371,865,751,298	0.0	69.14	8.32	10.7	16.3	ns
core002	32,980	6,509,834	33,178	3,839,209	0.6	95.87	9.79	12.6	19.2	ns
core003	5,428,615	30,077,796,316	4,933,871	232,741,890,907	-9.1	87.41	9.35	12.0	18.3	ns
core004	1,266,029	19,362,931,169	1,307,853	15,553,912,903	3.3	225.96	15.03	19.3	29.5	ns
core005	12,206	9,121,863	13,897	7,093,193	13.9	1,269.75	35.63	45.7	69.8	ns
core006	49,822	65,638,155	35,967	29,564,863	-27.8	256.92	16.03	20.5	31.4	(80%) decrease
cps1069	102,861	81,054,685	94,036	66,887,158	-8.6	127.25	11.28	14.5	22.1	ns
cps1128	30,666	5,951,677	26,754	9,512,101	-12.8	149.32	12.22	15.7	24.0	ns
cps1156	64,555	14,085,106	65,156	43,002,548	0.9	137.62	11.73	15.0	23.0	ns
cps1164	64,952	4,361,182	59,189	7,558,444	-8.9	26.50	5.15	6.6	10.1	(80%) decrease
cps1175	41,169	2,781,262	39,346	2,285,582	-4.4	28.47	5.34	6.8	10.5	ns
cps1277	14,893	11,122,274	19,758	16,107,345	32.7	1,608.78	40.11	51.4	78.6	ns
cps1750	46,480	6,754,231	39,909	9,879,524	-14.1	68.78	8.29	10.6	16.3	(80%) decrease
cps1820	20	392	447	17,892	2135.0	5,344,870.50	2,311.90	2963.9	4531.3	n/a
cps1821	9,072	3,687,658	9,162	3,086,955	1.0	832.08	28.85	37.0	56.5	ns
cps1967	32,742	6,003,695	25,069	4,239,526	-23.4	72.38	8.51	10.9	16.7	(95%) decrease
cps2201	80,731	23,557,710	83,722	46,630,349	3.7	110.42	10.51	13.5	20.6	ns
cps2218	38,790	8,998,744	34,202	21,734,204	-11.8	190.9	13.82	17.7	27.1	ns
cps2221	88,993	34,677,853	93,095	52,840,694	4.6	114.6	10.71	13.7	21.0	ns
cps2573	47,118	69,732,424	53,174	133,383,421	12.9	1,000.82	31.64	40.6	62.0	ns
flats08	609,629	1,624,871,545	473,424	2,978,554,250	-22.3	106.51	10.32	13.2	20.2	(95%) decrease
flats11	12,028,483	244,666,338,124	11,864,803	320,971,546,899	-1.4	38.64	6.22	8.0	12.2	ns
flats12	7,463,692	353,847,540,298	7,724,758	245,241,501,616	3.5	112.06	10.59	13.6	20.7	ns
flats18	324,739	744,830,595	359,197	800,802,582	10.6	162.35	12.74	16.3	25.0	ns
flats19	1,751,041	19,835,749,878	1,625,885	40,531,698,708	-7.1	187.97	13.71	17.6	26.9	ns
flats20	2,355,140	45,289,749,341	2,304,826	66,882,326,823	-2.1	198.78	14.10	18.1	27.6	ns
flats35	247,638	1,854,801,614	209,744	2,935,440,405	-15.3	695.65	26.38	33.8	51.7	ns
flats37	128,844	798,257,093	149,608	758,365,720	16.1	1,105.15	33.24	42.6	65.2	ns
flats41	1,066,643	2,179,832,221	1,088,506	4,022,621,634	2.0	55.31	7.44	9.5	14.6	ns
flats43	108,763	222,197,226	116,801	249,494,717	7.4	427.54	20.68	26.5	40.5	ns
flats67	47,273	90,961,985	51,611	164,710,209	9.2	1,222.21	34.96	44.8	68.5	ns
flats70	3,197,554	107,306,714,923	2,823,638	160,093,852,587	-11.7	238.42	15.44	19.8	30.3	ns
hdc2239	70,247	18,831,998	61,959	32,137,986	-11.8	94.82	9.74	12.5	19.1	ns
hdc2338	16,497	396,102	9,790	1,500,829	-40.7	60.27	7.76	10.0	15.2	(95%) decrease
hdc2344	14,745	2,318,810	4,846	2,064,703	-67.1	106.49	10.32	13.2	20.2	(95%) decrease
hdc2359	100,598	13,169,475	89,559	10,188,696	-11.0	20.38	4.51	5.8	8.8	(95%) decrease
hdc2383	37,826	9,706,194	28,357	24,861,254	-25.0	211.88	14.56	18.7	28.5	(80%) decrease
hdc2465	68,754	21,106,878	57,586	14,785,845	-16.2	62.60	7.91	10.1	15.5	(95%) decrease

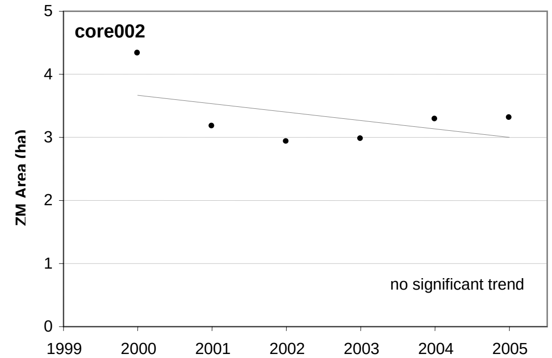
Site	2004 *Z. marina* area (m²)	2004 variance	2005 *Z. marina* area (m²)	2005 variance	Relative Change (%)	Variance of Change	SE of Change	80% CI (half width)	95% CI (half width)	Confidence in Detected Change
hdc2479	78,657	14,452,800	74,210	22,665,331	-5.7	57.43	7.58	9.7	14.9	ns
hdc2529	55,767	20,324,061	53,871	15,969,859	-3.4	112.33	10.60	13.6	20.8	ns
nps0059	6,547	227,631	5,594	691,637	-14.6	200.13	14.15	18.1	27.7	ns
nps0522	29,168	20,124,113	32,700	6,425,549	12.1	372.82	19.31	24.8	37.8	ns
nps0654	92,677	25,570,453	99,437	14,193,102	7.3	50.80	7.13	9.1	14.0	ns
nps0670	1,260	23,607	1,299	45,249	3.1	443.06	21.05	27.0	41.3	ns
nps1320	151,458	30,111,569	163,144	30,250,429	7.7	28.42	5.33	6.8	10.4	(80%) increase
nps1392	149,239	97,966,495	150,328	80,764,047	0.7	80.89	8.99	11.5	17.6	ns
nps1433	30,624	4,164,258	26,966	5,439,288	-11.9	92.43	9.61	12.3	18.8	ns
sjs0081	10,443	506,308	11,999	3,967,017	14.9	425.05	20.62	26.4	40.4	ns
sjs0617	20,996	8,305,707	20,721	6,740,440	-1.3	336.41	18.34	23.5	35.9	ns
sjs0635	28,771	7,410,664	17,205	5,390,936	-40.2	97.14	9.86	12.6	19.3	(95%) decrease
sjs0649	220	3,255	292	3,055	32.7	1,815.9	42.61	54.6	83.5	ns
sjs0683	8,458	1,841,205	9,204	1,700,419	8.8	542.47	23.29	29.9	45.7	ns
sjs0819	3,278	860,071	951	274,923	-71.0	323.2	17.98	23.0	35.2	(95%) decrease
sjs0989	78,270	7,581,178	70,751	20,887,031	-9.6	44.2	6.65	8.5	13.0	(80%) decrease
sjs2645	5,271	575,005	4,253	766,521	-19.3	410.6	20.26	26.0	39.7	ns
sjs2741	182,488	643,248,444	130,471	917,301,964	-28.5	374.2	19.34	24.8	37.9	(80%) decrease
sjs2775	57,071	28,191,306	59,265	17,295,156	3.8	146.4	12.10	15.5	23.7	ns
swh0918	138,728	43,675,558	160,651	30,996,661	15.8	46.5	6.82	8.7	13.4	(95%) increase
swh0940	70,429	16,733,930	81,433	10,296,670	15.6	65.9	8.12	10.4	15.9	(80%) increase
swh0943	179,364	23,786,162	184,979	16,466,568	3.1	13.0	3.60	4.6	7.1	ns
swh1557	30,484	22,737,244	36,176	22,110,463	18.7	582.5	24.14	30.9	47.3	ns
swh1593	28,437	8,087,465	43,459	13,219,596	52.8	397.1	19.93	25.5	39.1	(95%) increase
swh1625	1,773	238,819	3,097	839,248	74.7	4,987.8	70.62	90.5	138.4	ns

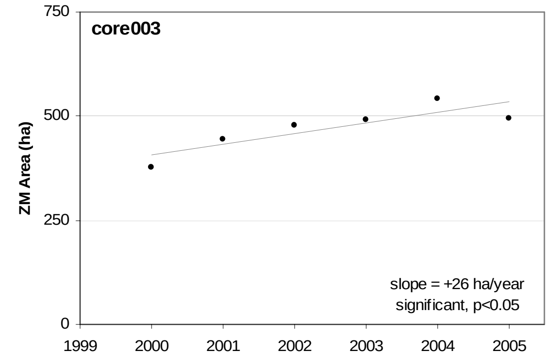
ns = change is not significant

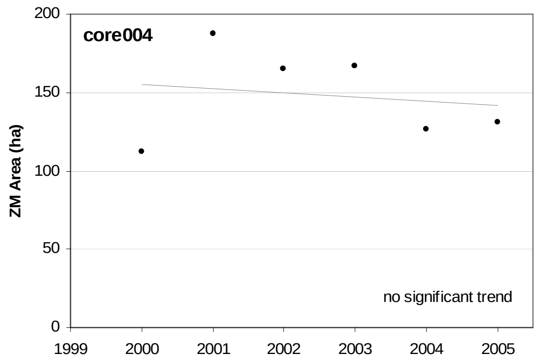
n/a = estimate of change is not valid

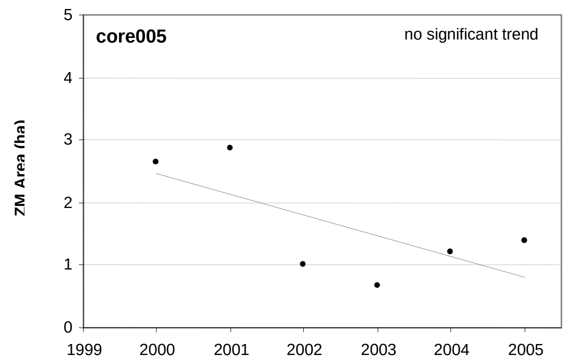
Appendix D Site-level trend analysis

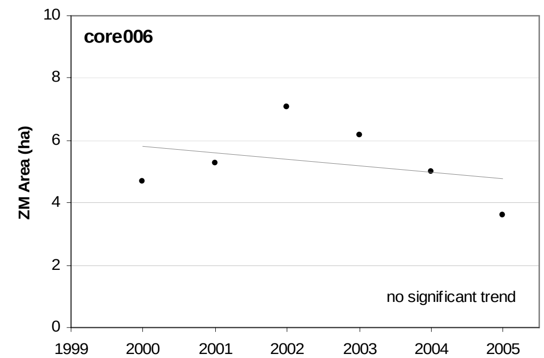


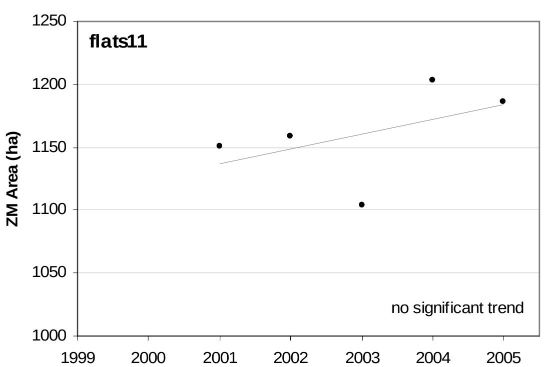


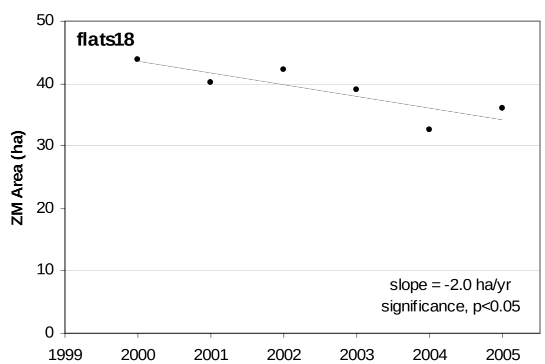


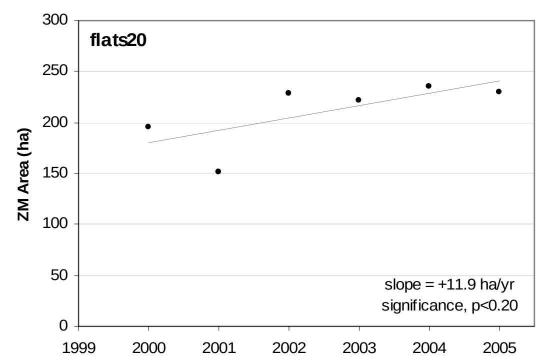


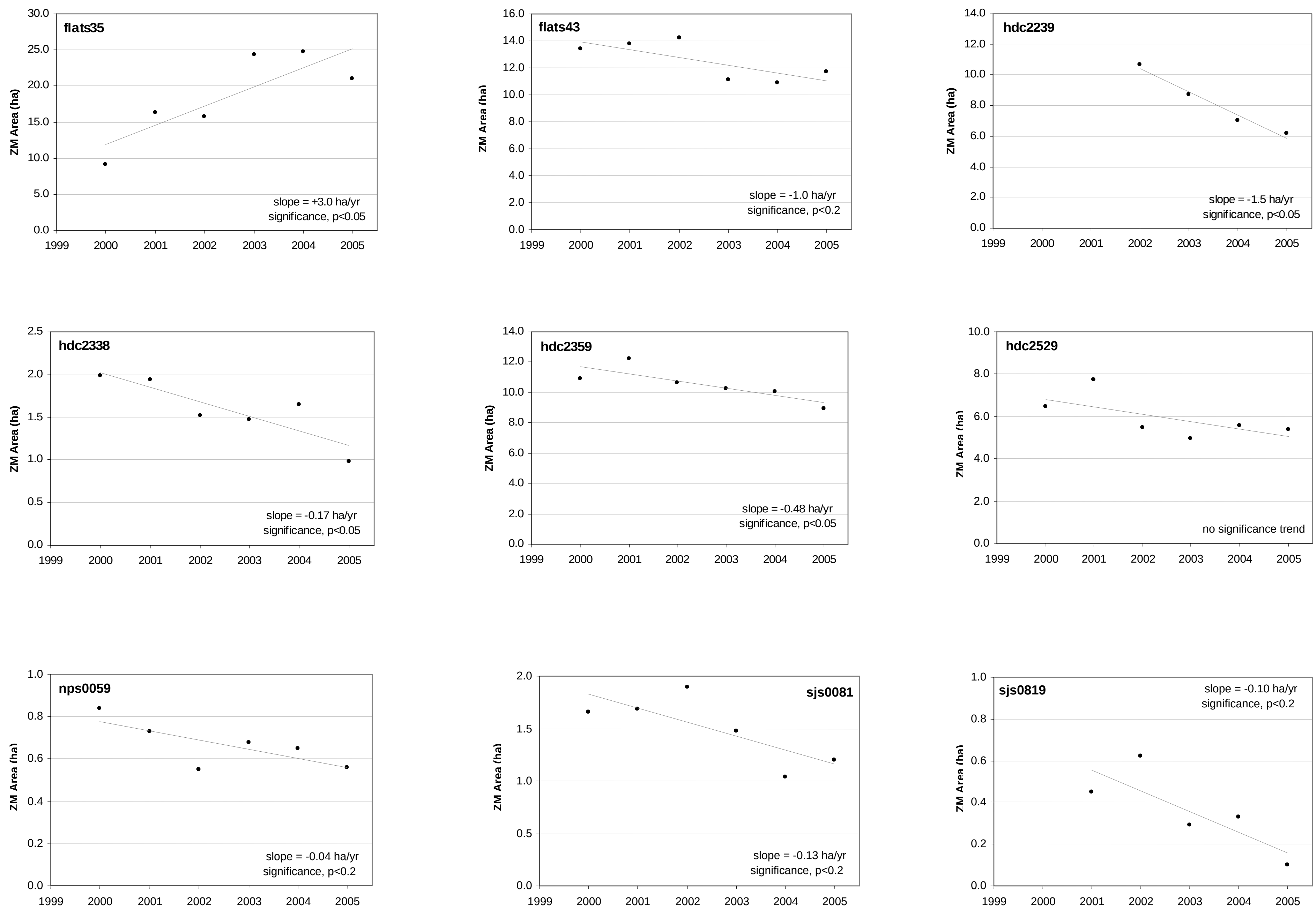


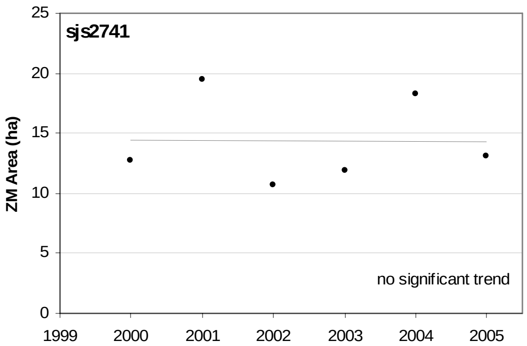


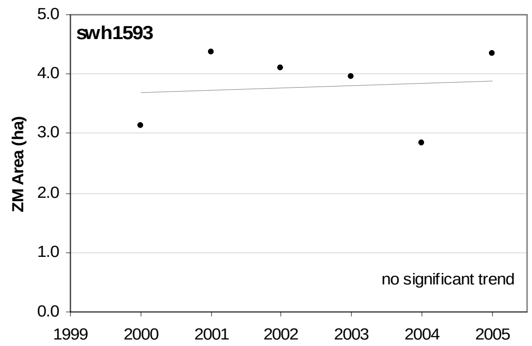


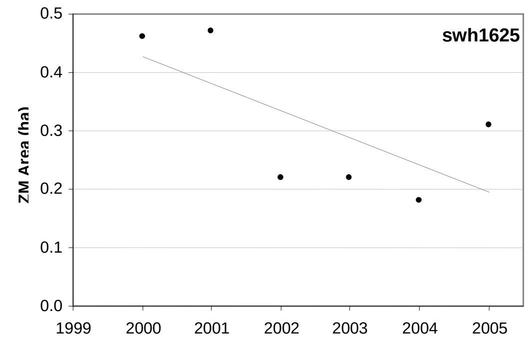





flats35
ZM Area (ha)
slope = +3.0 ha/yr
significance, p<0.05
flats43
ZM Area (ha)
slope = -1.0 ha/yr
significance, p<0.2
hdc2239
ZM Area (ha)
slope = -1.5 ha/yr
significance, p<0.05
hdc2338
ZM Area (ha)
slope = -0.17 ha/yr
significance, p<0.05
hdc2359
ZM Area (ha)
slope = -0.48 ha/yr
significance, p<0.05
hdc2529
ZM Area (ha)
no significance trend
nps0059
ZM Area (ha)
slope = -0.04 ha/yr
significance, p<0.2
sjs0081
ZM Area (ha)
slope = -0.13 ha/yr
significance, p<0.2
sjs0819
ZM Area (ha)
slope = -0.10 ha/yr
significance, p<0.2
1999
2000
2001
2002
2003
2004
2005


sjs2741
ZM Area (ha)
25
20
15
10
5
0
1999
2000
2001
2002
2003
2004
2005
no significant trend


swh1593
ZM Area (ha)
5.0
4.0
3.0
2.0
1.0
0.0
1999
2000
2001
2002
2003
2004
2005
no significant trend


swh1625
ZM Area (ha)
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
2002
2003
2004
2005

Appendix E Total *Z. marina* area estimates from 2000-2005

	2000	2001	2002	2003	2004	2005
Initial Estimate (ha)	19,000	21,400	20,800	21,000	21,500	20,400
Standard Error (ha)	7,100	5,900	5,800	5,600	1,600	1,700
CV	0.17	0.27	0.27	0.26	0.07	0.08
Conf. Interval (95%)	±13,970	±11,570	±11,330	±10,880	±3,090	±3,300

Note: Values listed for 2000 to 2004 reflect the inclusion of Pt. Roberts, Salmon Bank and Wyckoff Shoal and therefore differ slightly from values published in previous reports (Berry et al. 2003, Dowty et al. 2005).

Appendix F *Z. marina* depth estimates at 2005 SVMP sample sites

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site	Location	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)
Core													
Core001	Padilla Bay	10	0.6	0.4	0.4	0.1	0.6	10	-6.8	-4.3	1.1	-5.0	-3.5
Core002	Picnic Cove	14	-0.4	-2.0	1.5	-3.0	-1.0	14	-6.2	-5.4	0.5	-5.7	-5.0
Core003	Jamestown	11	0.2	-0.4	0.8	-0.9	0.2	11	-7.7	-6.0	1.4	-7.0	-5.1
Core004	Lynch Cove	10	0.2	-0.5	0.7	-1.0	0.0	10	-3.7	-3.0	0.6	-3.4	-2.6
Core005	Dumas Bay	8	-0.1	-0.6	0.4	-0.9	-0.4	9	-2.0	-1.6	0.2	-1.7	-1.4
Core006	Burley Spit	15	-0.8	-1.1	0.1	-1.1	-1.0	15	-3.0	-2.2	0.3	-2.4	-2.0
Persistent Flats													
Flats11	Samish Bay N.	8	0.6	0.1	0.5	-0.2	0.5	8	-3.3	-3.2	0.1	-3.3	-3.1
Flats12	Samish Bay S.	9	0.9	0.4	0.3	0.2	0.6	11	-3.3	-3.1	0.1	-3.2	-3.0
Flats20	Skagit Bay N.	17	-0.1	-0.5	0.3	-0.6	-0.3	18	-3.0	-1.7	0.5	-2.0	-1.4

Site	Location	Minimum *Z. marina* Depth n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)	Maximum *Z. marina* Depth n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)
Rotational Flats													
Flats08	Portage Bay S.	17	-0.5	-0.7	0.2	-0.8	-0.6	17	-2.9	-2.3	0.3	-2.5	-2.2
Flats18	Similk Bay	24	0.2	-0.4	0.2	-0.5	-0.3	25	-4.1	-2.2	0.5	-2.5	-1.9
Flats19	Pull and Be Damned	21	0.7	-0.2	0.5	-0.5	0.2	21	-2.4	-1.6	0.3	-1.9	-1.4
Flats26	Snohomish Delta N	11	0.7	-0.2	0.4	-0.4	0.1	11	-2.8	-2.2	0.3	-2.4	-2.0
Flats35	Nisqually Delta E.	9	0.2	-0.2	0.3	-0.4	0.1	9	-1.3	-1.0	0.2	-1.2	-0.9
Flats37	Wing Point	11	-0.5	-1.2	0.6	-1.6	-0.9	11	-7.8	-4.9	1.2	-5.8	-4.1
Flats41	Dosewallips	12	0.3	-0.3	0.5	-0.7	0.0	12	-7.8	-4.1	1.2	-4.9	-3.4
Flats67	Fossil Bay	14	-0.4	-2.6	1.0	-3.2	-1.9	9	-5.6	-5.4	0.2	-5.5	-5.2
Flats70	South Fork Skagit River	11	0.0	-0.3	0.2	-0.4	-0.1	11	-4.4	-3.4	0.7	-3.8	-2.9
Narrow Fringe													
cps1069	Murden Cove (Bainbridge Island)	11	0.2	-0.4	0.3	-0.6	-0.2	11	-4.3	-3.7	0.6	-4.1	-3.3
cps1035	NE of Point White	1	-1.2	N/A	N/A	N/A	N/A	1	-1.3	N/A	N/A	N/A	N/A
cps1128	Paradise Cove (Vashon Island)	17	1.0	-0.8	1.2	-1.5	0.0	17	-5.9	-4.5	0.9	-5.0	-3.9
cps1156	Klahanic Beach (Vashon Island)	11	1.1	0.0	0.7	-0.5	0.5	11	-4.6	-3.2	1.1	-3.9	-2.5
cps1164	N. of Pt. Robinson (Maury Island)	17	-0.3	-0.9	0.4	-1.2	-0.6	17	-3.1	-2.5	0.3	-2.7	-2.3
cps1175	Piner Point (Maury Island)	16	0.4	0.0	0.2	-0.1	0.2	16	-2.9	-1.9	0.5	-3.9	-2.5
cps1277	Thompson Cove (Anderson Island)	10	0.0	-0.5	0.5	-0.8	0.2	11	-3.6	-2.2	0.7	-2.7	-1.7
cps1676	Broadview	11	0.2	-0.8	0.5	-1.1	-0.4	11	-5.9	-4.4	1.1	-5.1	-3.6
cps1750	Des Moines Beach	11	-0.1	-0.4	0.4	-0.7	-0.1	11	-7.9	-3.5	1.5	-4.5	-2.5
cps1820	Gordon Point	4	-0.6	-0.9	0.6	-1.5	-0.4	4	-2.3	-1.7	1.2	-2.9	-0.5
cps1821	Cormorant Passage	12	-0.1	-0.7	0.4	-1.0	-0.4	12	-4.3	-2.7	1.2	-3.6	-1.9
cps1967	Vaughn Bay (Case Inlet)	11	-0.5	-0.8	0.2	-1.0	-0.6	11	-3.4	-2.6	0.6	-3.0	-2.2
cps2201	South of President Point	10	0.3	-0.5	0.6	-0.9	0.0	10	-7.6	-5.5	1.4	-6.4	-4.5
cps2218	Pilot Pt.	11	1.4	0.9	0.2	0.8	1.1	11	-4.5	-1.4	1.5	-2.5	-0.4
cps2573	Ft. Flagler	9	-0.6	-1.0	0.4	-1.3	-0.7	12	-11.9	-5.9	3.6	-8.3	-3.5
hdc2338	Across from Union	18	-0.5	-1.5	0.4	-1.7	-1.2	18	-4.3	-2.8	0.5	-3.1	-2.4
hdc2344	Great Peninsula	13	-0.8	-1.7	0.6	-2.1	-1.3	13	-4.5	-2.7	0.7	-3.1	-2.2
hdc2359	Lynch Cove Fringe	11	-0.3	-0.5	0.2	-0.7	-0.4	11	-4.3	-3.6	0.4	-3.9	-3.4

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site	Location	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)
hdc2465	SE of Dabob Bay	14	-0.6	-0.9	0.2	-1.1	-0.8	14	-4.4	-3.4	0.5	-3.7	-3.0
hdc2479	Toanados Peninsula, West Side	10	-0.6	-0.7	0.1	-0.8	-0.7	10	-4.7	-4.0	0.4	-4.3	-3.7
hdc2529	S. of Tala Point	11	0.9	0.4	0.4	0.2	0.7	12	-8.2	-3.4	0.6	-3.7	-3.0
nps0059	Sinclair Island	13	-0.9	-1.9	0.7	-2.3	-1.4	15	-6.6	-5.4	0.7	-4.0	-5.0
nps0522	Eliza Island NE	11	-1.2	-2.1	0.6	-2.5	-1.7	11	-4.8	-4.1	0.4	-4.4	-3.8
nps0670	Boat Harbor (Guemes Island)	11	-0.7	-0.9	0.1	-1.0	-0.9	11	-3.0	-2.5	0.5	-2.8	-2.2
nps1344	E. of Ferndale	10	-0.3	-1.4	0.8	-1.9	-0.9	10	-3.4	-2.0	0.9	-2.7	-1.4
nps1392	Lummi Point (Lummi Island)	18	0.2	-0.5	0.4	-0.7	-0.2	18	-4.1	-3.4	0.6	-3.8	-3.0
sjs0081	Broken Point (Shaw Island)	16	-0.6	-1.4	0.6	-1.8	-0.9	16	-7.0	-4.3	1.4	-5.2	-3.4
sjs0205	E. of Eagle Point	13	-3.6	-4.9	0.5	-5.3	-4.5	13	-10.7	-10.3	0.3	-10.5	-10.1
sjs0617	Lopez Sound Road	20	-0.1	-0.5	0.4	-0.7	-0.2	20	-6.8	-3.5	1.7	-4.6	-2.5
sjs0635	Watmough Bay (Lopez Island)	12	-3.9	-4.8	0.8	-5.3	-4.3	12	-8.0	-6.2	0.8	-6.7	-5.7
sjs0649	Canoe Island (Shaw Island)	5	-2.9	-3.5	0.6	-4.0	-3.0	5	-6.7	-5.8	0.8	-6.5	-5.2
sjs0683	Brown Island N.	20	-0.9	-3.6	1.1	-4.3	-2.9	20	-7.8	-6.0	1.1	-6.7	-5.3
sjs0819	N of Partridge Point	4	-3.6	-4.1	0.7	-4.7	-3.4	4	-5.8	-5.2	0.7	-5.9	-4.5
sjs0989	Protection Island SW	12	0.3	-0.2	0.2	-0.4	-0.1	13	-9.4	-5.6	2.6	-7.4	-3.9
sjs2645	Gardiner, Discovery Bay	10	-0.7	-1.2	0.6	-1.6	-0.7	10	-5.3	-4.3	0.6	-4.8	-3.9
swh0940	Holmes Harbor E. (Whidbey Island)	12	0.2	-0.1	0.1	-0.2	0.0	12	-6.1	-4.0	0.8	-4.5	-3.5
swh1557	Rockaway Beach	13	-0.1	-0.8	0.4	-1.0	-0.5	13	-7.3	-3.9	1.8	-5.1	-2.6
swh1568	Lowell Point	10	-1.1	-1.7	0.5	-2.1	-1.4	10	-6.1	-3.6	1.0	-4.3	-3.0
swh1593	Camano Island, Cornell	15	0.1	-0.7	0.4	-0.9	-0.4	15	-1.8	-1.6	0.2	-1.7	-1.5
swh1625	So of Tulalip Bay	10	0.1	-0.5	0.3	-0.7	-0.2	10	-1.1	-0.6	0.4	-0.9	-0.4
swh1649	Nelson's Corner	11	0.4	-0.1	0.4	-0.4	0.2	11	-6.3	-3.4	1.0	-4.1	-2.7
Wide Fringe													
cps2221	Point no Point	11	0.9	0.1	0.9	-0.5	0.7	11	-6.4	-5.1	0.9	-5.8	-4.5
hdc2239	Hood Canal NE	12	0.4	0.2	0.2	0.1	0.3	12	-4.7	-4.0	0.7	-4.5	-3.5
hdc2284	Warrenville	14	0.5	0.1	0.4	-0.2	0.3	14	-3.5	-3.1	0.3	-3.3	-2.9
hdc2383	Anna's Bay	12	-0.1	-0.5	0.2	-0.6	-0.3	12	-3.2	-1.6	0.7	-2.1	-1.1
nps0654	Yellow Reef (Guemes Island)	10	-0.6	-1.3	0.4	-2.3	-1.4	10	-6.0	-5.4	0.3	-5.6	-5.2
nps1320	Semiamo Spit	8	0.2	-0.1	0.2	-0.2	0.1	10	-3.9	-3.6	0.2	-3.7	-3.5

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site	Location	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)
nps1433	Post Pt. (Fairhaven)	14	0.0	-0.4	0.3	-0.5	-0.2	17	-3.4	-3.0	0.2	-3.1	-2.8
sjs2741	West of Crescent Bay	13	-0.1	-4.3	2.2	-5.7	-2.8	13	-9.2	-8.0	1.0	-8.7	-7.3
sjs2775	Pysht River	13	-1.8	-3.2	0.9	-3.8	-2.6	13	-7.5	-6.2	0.9	-6.8	-5.6
swh0918	Pratts Bluff	11	-0.2	-0.5	0.2	-0.6	-0.3	13	-4.2	-3.5	0.2	-3.7	-3.4
swh0943	Hackney Island (Whidbey)	14	0.1	-0.4	0.3	-0.6	-0.2	10	-6.6	-4.5	0.9	-5.1	-3.8
swh0955	West of Langley	12	0.2	0.0	0.1	-0.1	0.1	12	-4.5	-3.9	0.3	-4.1	-3.7

Appendix G *Z. marina* depth estimates at the 2005 Focus Area sample sites

Site	Location	Minimum *Z. marina* Depth: n	Minimum *Z. marina* Depth: Absolute Depth (m)	Minimum *Z. marina* Depth: Mean Depth (m)	Minimum *Z. marina* Depth: Standard Error	Minimum *Z. marina* Depth: 95% Lower Limit (m)	Minimum *Z. marina* Depth: 95% Upper Limit (m)	Maximum *Z. marina* Depth: n	Maximum *Z. marina* Depth: Absolute Depth (m)	Maximum *Z. marina* Depth: Mean Depth (m)	Maximum *Z. marina* Depth: Standard Error	Maximum *Z. marina* Depth: 95% Lower Limit (m)	Maximum *Z. marina* Depth: 95% Upper Limit (m)
Flats													
Flats42	Quilcene Bay	9	0.4	0.1	0.4	-0.2	0.4	10	-4.2	-2.7	1.0	-3.4	-2.0
Flats43	Dabob Bay	19	0.0	-0.4	0.2	-0.5	-0.3	19	-7.4	-3.7	1.5	-4.6	-2.7
Flats44	Case Shoal	N/A	N/A	N/A	N/A	N/A	N/A	11	-7.7	-4.8	1.3	-5.6	-3.9
Flats45	Hood Head	17	-0.2	-0.6	0.4	-0.9	-0.4	17	-3.5	-2.0	0.7	-2.5	-1.6
Narrow Fringe													
hdc2262	Lofall	11	0.3	-0.2	0.3	-0.4	0.0	11	-6.6	-3.4	1.7	-4.5	-2.2
hdc2277	S of King Spit	9	-0.5	-1.0	0.5	-1.4	-0.6	9	-4.4	-2.7	1.1	-3.4	-1.9
hdc2308	Anderson Cove	11	0.6	-0.4	0.6	-0.8	0.0	11	-5.5	-4.4	0.7	-4.8	-3.9
hdc2323	N of Dewatto Bay	3	-1.3	-1.6	0.8	-2.7	-0.5	3	-2.7	-2.3	1.4	-4.1	-0.4
hdc2331	Cougar Spit	6	-1.0	-1.3	0.3	-1.6	-1.1	6	-3.5	-2.8	1.1	-3.7	-2.0
hdc2353	E of Sisters Point	10	-0.5	-1.0	0.5	-1.4	-0.7	10	-3.5	-2.7	0.7	-3.2	-2.3
hdc2364	Forest Beach	7	-0.5	-1.1	0.6	-1.6	-0.6	7	-3.0	-2.6	0.5	-3.0	-2.2
hdc2365	W of Forest Beach	8	-1.0	-1.9	0.5	-2.3	-1.5	8	-3.6	-3.2	0.3	-3.4	-3.0
hdc2398	S of Lilliwaup Bay	13	-0.1	-1.2	0.6	-1.6	-0.8	14	-4.9	-3.9	0.4	-4.1	-3.7
hdc2418	Becon Pt Loop	11	-0.8	-1.2	0.3	-1.4	-0.9	11	-6.1	-4.5	1.2	-5.3	-3.7
hdc2447	S of Whitney Pt	12	-0.5	-1.3	0.6	-1.7	-0.9	12	-6.1	-4.2	1.2	-5.0	-3.4
hdc2449	N of Whitney Pt	11	-0.9	-1.5	0.5	-1.9	-1.1	13	-6.5	-4.3	1.1	-5.0	-3.6
hdc2450	S of Frenchmans Pt	5	-0.9	-2.2	1.4	-3.4	-1.0	5	-4.5	-3.2	1.5	-4.5	-1.9
hdc2468	S of Long Spit	11	-0.3	-0.6	0.2	-0.8	-0.5	11	-4.8	-3.7	0.9	-4.2	-3.1
hdc2478	Tabook Pt	9	-0.2	-0.9	0.6	-1.3	-0.4	9	-5.9	-4.0	1.0	-4.7	-3.3
hdc2518	E of Squamish Harbor	11	-0.1	-1.2	1.1	-2.0	-0.5	11	-5.2	-3.8	1.4	-4.7	-2.8
Wide Fringe													
hdc2240	N. of Port Gamble	11	0.6	-0.1	0.5	-0.5	0.3	11	-4.9	-4.1	0.4	-4.4	-3.8
hdc2253	Entrance of Port Gamble	11	-0.3	-2.1	1.0	-2.7	-1.4	11	-5.9	-5.2	0.4	-5.5	-5.0

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site	Location	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)	n	Absolute Depth (m)	Mean Depth (m)	Standard Error	95% Lower Limit (m)	95% Upper Limit (m)
hdc2314	Chinom Point	6	-0.9	-1.2	0.3	-1.4	-0.9	6	-4.9	-3.0	1.8	-4.4	-1.6
hdc2355	Stimson Creek	14	-0.1	-1.1	0.4	-1.3	-0.8	14	-4.4	-3.2	0.7	-3.7	-2.8
hdc2356	NE of Stimson Creek	15	0.2	-0.5	0.3	-0.7	-0.3	15	-4.3	-3.4	0.7	-3.9	-3.0
hdc2380	Skokomish Flats	11	-0.2	-0.5	0.2	-0.6	-0.4	11	-3.0	-2.4	0.3	-2.7	-2.2
hdc2381	Skokomish Flats West	10	0.1	-0.1	0.2	-0.2	0.0	10	-2.4	-1.9	0.3	-2.1	-1.7
hdc2386	Potlatch State Park	10	-0.6	-1.4	0.8	-1.9	-0.8	11	-4.6	-3.6	0.5	-3.9	-3.2
hdc2409	Jorsted Creek	12	0.0	-0.8	0.4	-1.0	-0.5	11	-6.8	-5.0	0.9	-5.6	-4.4
hdc2507	N of Thorndyke Bay	11	0.4	0.1	0.3	-0.1	0.2	11	-4.6	-3.7	0.7	-4.1	-3.2

Appendix H 2005 SVMP rotational sample design and site selection

The narrow fringe, wide fringe and rotational flats strata are selected based on a yearly rotational sample design. For these strata, 80% of the randomly selected sites from the previous year are retained and 20% are replaced with new randomly selected sites (Berry et al. 2003). The rate of site rotation to determine status estimates and change estimates has been thoroughly reviewed (Dowty 2005a).

In general, for each field season the sample of sites within each stratum subject to rotation is determined in two steps. First, 20% of sites from the previous year that have been sampled for at least five years are randomly selected for removal. Second, an equal number of sites are randomly selected from eligible sites in the stratum for addition to the pool of sites. Eligible sites are those that (a) are not currently in the sample and (b) have not been in the sample pool within the previous five years.

Appendix I 2005 Hood Canal Focus Area site selection

For the purposes of matching the overall 2005 focus area sampling effort with that in 2004, the initial task of the Hood Canal site selection process was to match the eight flats sampled in the 2004 San Juan – Straits focus area. A complete survey of the five eligible flats sites plus an additional core site, *Core001-Lynch Cove*, would not reach this level of effort, therefore all eligible flats sites were sampled and the remaining effort was redirected to fringe sites. The difference in flats sampling effort between the 2004 and 2005 focus areas will be accounted for with the addition of fringe sites (fringe equivalents) at a 2:1 effort ratio (fringe:flats) to account for the greater effort generally required at flat sites. Eight additional fringe sites (based on the 2:1 effort ratio, fringe:flats) were selected to make the *Hood Canal Region* focus area sampling effort consistent with the 2004 focus area effort (Table I-1).

Fringe Stratification

The precision of the SVMP estimates is important to detect and reliably report *Z. marina* change and status estimates. The precision for the fringe stratum *Z. marina* area can potentially be improved by pooling these data from the two strata but this depends upon the similarity of the narrow and wide fringe strata. Statistically similar area estimates between the narrow and wide fringe strata would suggest pooling data to increase sample size whereas different area estimates would suggest stratifying the fringe sites to create more homogeneous groups. *Zostera marina* area estimates for the narrow and wide fringe sites from 2000 to 2004 were compared prior to site selection in the Hood Canal focus area to determine whether the fringe strata should be stratified or pooled (Figure I-1).

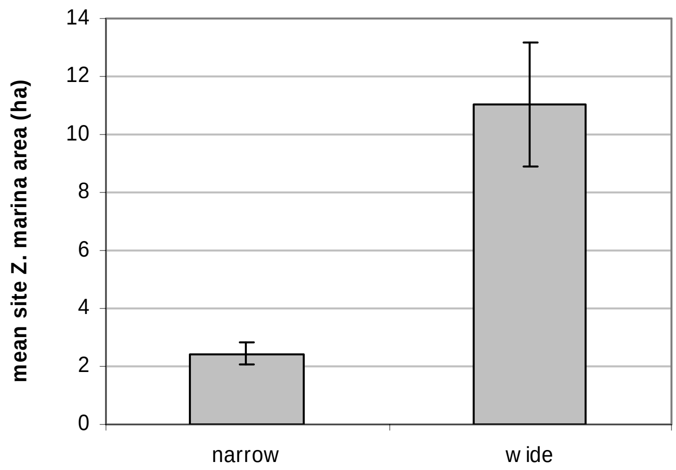


Figure I-1. Mean *Z. marina* area in narrow and wide fringe sites sampled from 2000 - 2004. Error bars indicate 95% confidence intervals on the mean based on an assumption of normality. Results support the separation of the narrow and wide fringe strata in the 2005 Hood Canal focus area.

The difference in the mean *Z. marina* area between the narrow and wide fringe strata (Figure I-1) justified maintaining the stratification of the fringe sites. The optimal sample size per fringe stratum for 2005, calculated from (Equation I-1), can be determined given the constraints that 1) the overall focus area effort in 2005 will be the same as in 2004, and 2) the effort to sample a typical flats site is twice that of a fringe site.

The standard deviations from sound-wide sampling and the total number of fringe sites to be sampled in the 2005 Hood Canal focus area were used to calculate the optimal allocation of sites sampled between the narrow and wide fringe strata (Equation I-1).

The optimal allocation of sampling effort minimizes variance of *Z. marina* estimates for these strata in Hood Canal. Based on Cochran (1977, equation 5.26, p. 98), the variance is minimized for a fixed total sample size n if

(Equation I-1)

$$n_i = n \frac{N_i s_i}{\sum N_i s_i}$$

where

n_i = sample size for stratum i
N_i = total number of sample units (sites) in stratum i
s_i = standard deviation for samples from stratum i

Site selection

The allocation of effort between the strata was determined and the respective numbers of sites were randomly selected from the pool of eligible sites in each stratum. Since sites for the sound-wide sampling were randomly selected, data from sites that fell within the focus area could be used in the focus area *Z. marina* analysis and estimates.

The optimal site allocation (Equation I-1) produced a small sample size in the wide fringe stratum (*n*=7), therefore effort was reallocated from the narrow fringe stratum to reach a sample size equal of 10 in the wide fringe stratum. The fringe sites were distributed as 16 in the narrow fringe and 10 in the wide fringe (Table I-1). The final allocation of sites selected in the 2005 Hood Canal focus area (31 sites of 286 total fringe sites) was only slightly more than the number of sites sampled in the 2004 focus area (28 sites) (Table I-1, Dowty et al. 2004). To improve the 2005 focus area estimate, additional sites from the sound-wide rotational sampling were used to calculate the *Z. marina* area in Hood Canal (Table I-1).

Table I-1. Allocation of sampling effort among the flats and fringe frames in 2004 and 2005. Sites were selected on the basis that 1) overall focus area effort in 2005 will be the same as in 2004, and 2) the effort to sample a typical flats site is twice that of a fringe site (fringe equivalency was 2 fringe sites equals 1 flats site, 2:1). Number in parentheses in flats stratum is the fringe equivalents. A fringe equivalent is the amount of effort required to sample a fringe site.

	San Juan Focus Area	Hood Canal Focus Area
flats	8 (16)	5 (10)
fringe	20	26
total effort (fringe equivalents)	36	36

Appendix J Sites used in Focus Area analysis

Table J-1. Complete list of sites used to calculate the Hood Canal focus area status estimate. The list includes sites sampled explicitly as part of the focus area study and sites sampled as part of the Puget Sound study.

geomorphic category	study	Site	sound-wide stratum	focus area stratum
fringe	focus area study	hdc2240	wide fringe	fringe-other
		hdc2253	wide fringe	fringe-other
		hdc2262	narrow fringe	fringe-other
		hdc2277	narrow fringe	fringe-other
		hdc2308	narrow fringe	fringe-other
		hdc2314	wide fringe	fringe-other
		hdc2323	narrow fringe	fringe-other
		hdc2331	narrow fringe	fringe-other
		hdc2353	narrow fringe	fringe-other
		hdc2355	wide fringe	fringe-other
		hdc2356	wide fringe	fringe-other
		hdc2364	narrow fringe	fringe-other
		hdc2365	narrow fringe	fringe-other
		hdc2380	wide fringe	fringe-other
		hdc2381	wide fringe	fringe-other
		hdc2386	wide fringe	fringe-other
		hdc2398	narrow fringe	fringe-other
		hdc2409	wide fringe	fringe-other
		hdc2418	narrow fringe	fringe-other
		hdc2447	narrow fringe	fringe-other
		hdc2449	narrow fringe	fringe-other
		hdc2450	narrow fringe	fringe-other
		hdc2468	narrow fringe	fringe-other
		hdc2478	narrow fringe	fringe-other
		hdc2507	wide fringe	fringe-other
		hdc2518	narrow fringe	fringe-other
	sound-wide study	hdc2338	narrow fringe	fringe-other
		hdc2344	narrow fringe	fringe-other
		hdc2239	wide fringe	fringe-other
		hdc2284	wide fringe	fringe-other
		hdc2359	narrow fringe	fringe-other
		hdc2383	wide fringe	fringe-other
		hdc2465	narrow fringe	fringe-other
		hdc2479	narrow fringe	fringe-other
		hdc2529	narrow fringe	fringe-other
flats	focus area study	flats41	rotational flats	flats-other
		flats42	rotational flats	flats-other
		flats43	rotational flats	flats-other
		flats44	rotational flats	flats-other
		flats45	rotational flats	flats-other
	sound-wide study	core004	core	flats-other

Appendix K Detailed assessment of the methodological changes in 2005

Sampling frames and strata corrections
Numerous updates were made to the GIS base layers and sampling strata to streamline the data and provide better representation of the sampling area.

Changes to region boundaries
The SVMP region boundaries were changed to improve the project GIS base layers (Figure K-1). Since the start of the SVMP, Point Roberts was located in the *San Juan-Straits Region*, but it has a greater similarity to the *North Puget Sound Region* coastline in terms of general oceanographic characteristics. Furthermore, reassignment of Point Roberts as part of *North Puget Sound Region* is consistent with the oceanographic basins adopted by the PSAMP Steering Committee. The change to the region boundaries does not affect previously reported SVMP results as discussed in the next section.

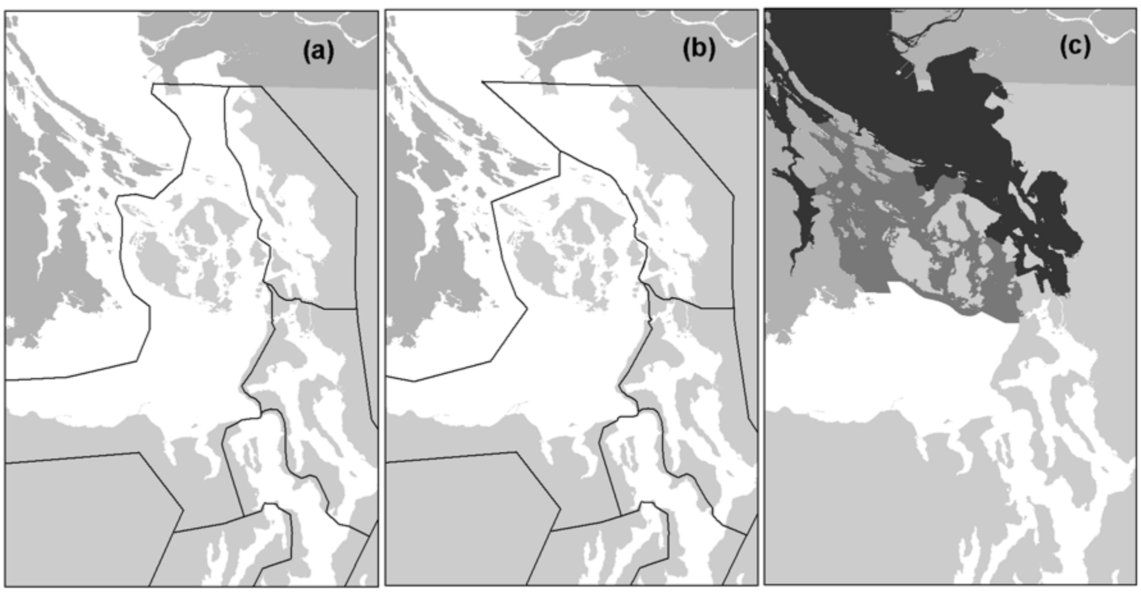


Figure K-1. Change to SVMP region boundaries: (a) the original region boundaries; (b) the new region boundaries implemented in Janauary 2006; (c) the delineation of the Strait of Georgia and San Juan Archipelago basins adopted by the PSAMP Steering Committee as a basis for reporting PSAMP results.

Adjustment to the North Puget Sound and San Juan-Straits Regions boundaries
The *North Puget Sound* and *San Juan-Straits Regions* boundaries facing Canadian were snapped, in the SVMP GIS layer, to the international boundary (Figure K-1). The change was for map display purposes and had no affect on the amount of potential habitat in the study area or the allocation among the regions.

Addition of Point Roberts to study area

To assess the implications of incorporating the Point Roberts seagrass habitat into the sampling framework, the -20ft bathymetric contour was used to add a line to the fringe GIS base layer. The –20ft bathymetric line was divided into 1000m segments and a flats site was created on the eastern side of the peninsula. The flats site does not meet the normal criteria for designating flats (embayment with -20ft contour much shorter than mean high water line or river delta) but it was included based on the rationale that it is part of Boundary Bay that meets the criteria although the majority of the bay is in Canadian waters.

Some results were calculated with and without the Point Roberts addition to assess the magnitude of this change to the sampling design, but in general, the results throughout the report include Pt. Roberts. Future reports will present data with the inclusion of Point Roberts as part of the SVMP sampling.

GIS maintenance – frames and strata

Several corrections and improvements were made to the SVMP GIS base layers (Dowty 2006). These layers are important because they are the basis for the sampling frames and the extrapolation parameters.

Known errors in the fringe base layer at flats and core sites were corrected. These errors included incorrectly classified segments and segments that needed to be split where a portion bounded a flats site and the remainder needed to be classified as an orphan.

Region boundaries at intersections with the shoreline were adjusted. Previously fringe segments were split by the boundary creating two orphans and thereby removing a site from the fringe sampling frame. The region boundaries were shifted to adjacent fringe site endpoints and the existing orphans were reconnected to add sites back to the sampling frame.

The fringe-marina category (frm, fringe – marina) was eliminated and the three fringe segments were returned to the narrow fringe stratum (Shilshole marina, Des Moines marina and Edmonds marina). Previously these were removed from the sampling frame and not included in the extrapolations because they were considered permanently obstructed (see Procedure for Obstructed Sites below).

The six separate flats GIS layers were merged into a single layer named "flats.shp" and extraneous fields were deleted. The previous six layers were based on the five SVMP regions with *San-Juan Straits Region* divided into the Straits ("fuc") and San Juan Islands ("sji") portions.

The areas of the flats sites were updated upon completion of the edits. There were only a few changes associated with minor snapping of boundaries to fringe site endpoints. All fringe segment lengths were also updated.

Summary
Sixty-three (63) new orphans were created adding 29.9 km of potential habitat as orphans. One (1) narrow fringe site was removed and 20 fringe sites (19 narrow; 1 wide) were added as a result of the GIS corrections

Procedure for obstructed sites
In 2000, three sites (*cps1685-Edmond's marina*; *cps1682-Shilshole marina*; *cps1751-Des Moines marina*) were placed in the fringe-marina group (frm, fringe – marina) and considered permanently obstructed – sites that contain navigational obstructions that inhibit safe maneuverability of the research vessel for effective and representative videography. The three sites have not been included in fringe extrapolations and presumably not in the pool of sites available for random draws.

As noted in the *GIS-maintenance – frames and strata* section, the fringe-marina category has been eliminated and these three sites have been returned to the fringe sampling frame and will, hence forth, be included in the region and sound wide *Z. marina* extrapolations.

Some sites found to be obstructed in the field were left in the sample pool the next year and revisited. Some sites found to be obstructed in the field may have been intentionally removed from the sample pool at some point (nps1342/2002, swh0718/2003, sjs2764/2001, sjs2815/2002, sjs2692/2002). Listing obstructed sites in the GIS layer (if visited) is problematic. While it correctly represents sampling effort (it was visited), it does not accurately represent sites used in the final *Z. marina* estimates since data was not collected. The 2003-2004 report (Dowty et al. 2005) lists the number of obstructed sites in 2000 as five, but it should state 3 (Table K-1 below).

Table K-1. Record of all sites that have been considered obstructed, 2000-2005, and whether the site was actually visited or whether it was replaced at the time of the random draw. The "in GIS" label indicates that the site is represented in the GIS point layer used to create maps that show yearly and overall site locations.

	2000	2001	2002	2003	2004	2005
nps1342	visited obstructed in GIS	visited obstructed in GIS	visited obstructed in GIS			
sjs0819	visited obstructed in GIS	visited sampled in GIS	visited sampled in GIS	visited sampled in GIS	visited sampled in GIS	visited sampled in GIS
swh0718	visited obstructed in GIS	visited sampled in GIS	visited sampled in GIS	visited sampled in GIS		
sjs2764		visited obstructed in GIS				
sjs2815		visited obstructed in GIS	visited obstructed in GIS			
sjs2692			visited obstructed in GIS			

swh0714		visited obstructed in GIS
hdc2276		drawn/repl. obstructed not in GIS
hdc2274		drawn/repl. obstructed not in GIS

Proposal for dealing with obstructed sites in the future

When a site in the random draw is found to be obstructed by inspection of ortho photos, it is discarded and replaced with a new randomly chosen site. The original obstructed site will remain in the site selection pool to allow for changes in the causes of obstruction and to eliminate the complexity of tracking these sites over years. When any site is found to be obstructed in the field, it does not supply data for *Z. marina* estimates and therefore reduces the effective sample size. Again, sites found to be obstructed in the field remain in the selection pool to draw sites from for the following year. If subsequently drawn, a decision must be made as to whether the site can be considered still obstructed without another field visit.

The three fringe-marina sites have been returned to the sampling pool that forms the basis of *Z. marina* extrapolations. Although the effect should be negligible, the calculations from 2000-2005 should be repeated with new extrapolation parameters. Although the effect should be negligible the 2005 results will incorporate the changes.

Appendix L Multiple parameter assessment of site-level change

All site level results that were used for the multiple parameter assessment of change are shown in Table L-1. The results of the assessment are summarized in Section 3.5.2.

Table L-1. Summary of measures of site-level change in Z. marina for all sites sampled in 2004-2005. The four measures of change are shown. Many sites do not have values for all four measures. Results of the five-plus-year trend tests are also included. Statistical significance of individual measures of change is indicated for p<0.2 (*) and p<0.05 (**). Sites considered to have sufficient evidence for heightened concern are bolded.

site	2002-04 *Z. marina* decline evidence	2004-05 *Z. marina* area change	2004-05 mean maximum depth change	2004-05 mean minimum depth change	number of indications of decline	5 plus-year *Z. marina* area trend
core001	no	no change	expanded*	receded	1	no trend
core002	no	increase	expanded	expanded	0	decreasing*
core003	no	decrease	no change	receded	2	expanding**
core004	no	increase	no change	no change	0	no trend
core005	no	increase	no change	no change	0	decreasing**
core006	strong	decrease*	receded*	receded*	4	no trend
cps1069	no	decrease	receded**	expanded	2	
cps1128	no	decrease	expanded	receded*	2	
cps1156	no	increase	expanded**	receded	1	
cps1164	no	decrease*	no change	receded*	2	

site	2002-04 *Z. marina* decline evidence	2004-05 *Z. marina* area change	2004-05 mean maximum depth change	2004-05 mean minimum depth change	number of indications of decline	5 plus-year *Z. marina* area trend
cps1175	no	decrease	receded**	expanded*	2	
cps1277	no	increase	expanded	expanded	0	
cps1750	no	decrease*	receded**	receded	3	
cps1821	no	increase	receded**	expanded	1	
cps1967		decrease**	receded	expanded	2	
cps2201	no	increase	receded*	receded	2	
cps2218	no	decrease	receded	expanded*	2	
cps2221	no	increase	expanded*	receded	1	
cps2573	no	increase	expanded**	receded	1	
flats08	no	decrease	receded*	receded	3	
flats11	no	decrease	receded	no change	2	no trend
flats12	no	increase	expanded	receded	1	
flats18	very strong	increase	no change	no change	1	decreasing**
flats19	no	decrease	expanded	no change	1	
flats20	no	decrease	expanded*	no change	1	expanding**
flats35	no	decrease	expanded	receded	2	expanding**
flats37	strong	increase	expanded	receded	2	
flats41		increase	expanded	receded	1	
flats43	strong	increase	expanded	expanded	1	decreasing**
flats67		increase	no change	receded*	1	
flats70		decrease	expanded**	expanded	1	
hdc2239	very strong	decrease	expanded	expanded	2	
hdc2338	no	decrease**	receded*	receded*	3	decreasing**
hdc2344	no	decrease**	receded*	receded	3	
hdc2359	strong	decrease**	expanded	receded	3	decreasing**
hdc2383		decrease*	expanded	no change	1	
hdc2465		decrease**	receded	receded	3	
hdc2479		decrease	receded	no change	2	
hdc2529	no	decrease	receded	expanded	2	decreasing*
nps0059	no	decrease	receded*	expanded	2	decreasing**
nps0522	no	increase	expanded*	receded	1	
nps0654	strong	increase	expanded	no change	1	
nps0670		increase	receded	receded*	2	
nps1320	no	increase	receded	no change	1	
nps1392		increase	receded	no change	1	
nps1433		decrease	receded*	expanded	2	
sjs0081	very strong	increase	expanded	receded*	2	decreasing**
sjs0617	no	decrease	receded	no change	2	
sjs0635	no	decrease**	expanded**	receded	2	
sjs0649	no	increase	expanded	no change	0	
sjs0683	no	increase	expanded	receded**	1	
sjs0819	no	decrease**	receded**	receded*	3	decreasing**
sjs0989	no	decrease*	receded**	expanded*	2	
sjs2645		decrease	expanded	no change	1	
sjs2741	no	decrease*	receded	receded	3	no trend
sjs2775	no	increase	receded	receded*	2	
swh0918		increase**	no change	receded	1	
swh0940	no	increase*	receded	no change	1	
swh0943	no	increase	receded**	expanded	1	
swh1557		increase	receded**	receded	2	
swh1593	no	increase**	no change	receded	1	no trend
swh1625	very strong	increase	receded	receded	3	decreasing*

In general, the focus was to identify sites with decline in *Z. marina*. The number of the parameters indicating decline was first compared to the results of the five-year trend analysis. Agreement in the evidence clearly identified a site of concern. When the evidence was conflicting, other factors were considered. Some examples are given below of how conflicting evidence was weighed.

core002: While the long-term trend at this site is significant, it is interpreted with caution because of methodological differences related to the 2000 estimate which drives the long-term trend. Specifically, the site boundaries changed at this site following 2000 sampling. In addition, 2004-05 represents the third time interval in a row with increase in *Z. marina* area and there were no additional indications of decline. Therefore, this site was not identified as a site of concern.

core005: While the long-term trend at this site is significant, it is interpreted with caution because of methodological differences related to the 2000-01 estimates which drive the long-term trend. Specifically, this site has extensive *Z. japonica* throughout and this non-native species was first classified in 2002. In addition, the temporal pattern of data used in the five-year trend analysis shows stability following the 2001 season (Appendix D) and there are no additional indications of decline. Therefore, this site was not identified as a site of concern.

core006: The temporal pattern of data used in the five-year trend analysis shows persistent decline from 2002-05 (Appendix D). There were also three statistically significant indications of decline from 2004-05. Therefore, this site was identified as a site of concern.

cps1750: This site was sampled in 2004-05 only. Therefore, this site will be watched closely but not identified as a site of concern at this time.

flats08: There is not enough statistically significant evidence of decline in the three year record (2003-05) to support identifying this as a site of concern at this time.