NATURAL RESOURCES

Eelgrass (*Zostera marina* L.) Abundance and Depth Distribution Along Selected San Juan Archipelago Shallow Embayments

May 2010

WASHINGTON STATE DEPARTMENT OF
Natural Resources

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Acknowledgements

The Nearshore Habitat Program (NHP) is part of the Washington State Department of Natural Resources' (DNR) Aquatic Resources Division, the steward for 2.6 million acres of state-owned aquatic lands. Program funding is provided through the Aquatic Lands Enhancement Act. The NHP monitors and evaluates the status and trends of submerged aquatic vegetation for DNR and the Puget Sound Partnership.

We especially want to the recognize Jim Norris and Ian Fraser of Marine Resources Consultants who continue to be major participants in the ongoing success of our monitoring efforts. Marine Resources Consultants demonstrate great dedication to project goals and has logged many hours of fieldwork collecting underwater video data for the project.

We want to recognize two important collaborators that contributed to this work: Sandy Wyllie-Echeverria, University of Washington, has provided extremely valuable observations, data and assessments. The Friends of the San Juans has worked closely with us in adapting our protocol for local monitoring projects, and also provided eelgrass monitoring data that they collected (their data are included in this report).

Anja Schanz initiated this project and provided essential input and support in the collection and analysis of data in this report.

Jeff Gaeckle and Pete Dowty provided valuable comments in earlier versions of the report.

Hannah Julich and Dolores Sare contributed greatly to the data collection efforts and interpreted video data for this report.

We also would like to thank Tonya Rogers (UW Friday Harbor Labs) who volunteered several hours of her time collecting data for the project.

All contributors are staff of the Washington State Department of Natural Resources (DNR) unless otherwise noted.

Contents

EXECUTIVE SUMMARY

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic lands within the Puget Sound region. As part of its management responsibilities, DNR monitors the status and trends of eelgrass (*Zostera marina*) through the Submerged Vegetation Monitoring Project (SVMP). In an effort to better understand stressors that drive *Z. marina* declines, DNR also investigates causes of decline through the Eelgrass-Stressor Response Project (ES-RP). These efforts help to better understand nearshore dynamics and, ultimately, work to protect and improve the health of Puget Sound, as mandated by the DNR and the Puget Sound Partnerships' Action Agenda.

The San Juan Archipelago (SJA) has been identified as a region of concern following substantial losses of *Z. marina*, predominantly occurring at the head of several shallow embayments. The most renowned decline of *Z. marina* in the SJA was the sudden, and extensive, loss at the head of Westcott Bay on San Juan Island between 2001 and 2003.

This report summarizes the findings of collaborative work between the SVMP and ES-RP to document current abundance and depth distribution of *Z. marina* in the Westcott Bay Complex (inclusive of Westcott Bay proper and five other sites) as well as several other shallow embayments in the SJA. Westcott Bay was surveyed in 2008 and 2009 using SVMP methodologies to assess the current status of *Z. marina* within the bay and determine what, if any, changes have occurred since the die-off. Additionally, four other embayments were sampled to provide regional comparisons.

Key findings:

1. There has been no recovery of *Z. marina* in the head of Westcott Bay since the population crash documented in 2003.
    a. There is a distinct gradient of decreasing *Z. marina* abundance and depth distribution from the mouth to the head of the Westcott Bay Complex.
2. In Picnic Cove, *Z. marina* has significantly declined since 2000 (α=0.05). However, the population did not crash as it did in Westcott Bay.
    a. *Z. marina* area significantly decreased at an estimated rate of 0.2 ha yr^{-1} since 2000.
    b. The depth range of *Z. marina* is contracting, with the shallow edge of the bed receding to greater depths each year since 2000.
3. In Mitchell Bay, changes in *Z. marina* area and depth distribution are occurring with significant changes detected over the data record.
    a. Between 2003 and 2008, *Z. marina* abundance declined at an estimated rate of 0.1 ha yr^{-1}.
    b. From 2008 to 2009, *Z. marina* area increased significantly (+1.6 ha).
    c. *Z. marina* depth range is expanding, with the deep edge of the bed increasing in the depth from 2008 to 2009.
4. Shallow and Shoal Bays show no change in *Z. marina* abundance or depth distribution since initial surveys in 2003.

These results provide insight into the status and trends of a recognized indicator of environmental condition in a region of concern. They also provide a powerful baseline that will allow us to better understand future changes and trends of *Z. marina* in the region.

1 Introduction

Zostera marina (eelgrass) is an aquatic flowering plant that grows primarily within the shallow subtidal zone of Puget Sound. *Z. marina* is widely recognized as an indicator of ecosystem health and stability, sensitive to changes in its physical environment. It provides a suite of critical habitat functions to many aquatic and terrestrial animals (Mumford 2007, Eissinger 2007), reduces current flow and stabilizes sediment (Gambi et al. 1990, Fonseca et al. 1982) and improves water quality (Dennison et al. 1993).

The Submerged Vegetation Monitoring Project (SVMP) within the Washington State Department of Natural Resources' (DNR) Nearshore Habitat Program monitors the status and trends of *Z. marina* within Puget Sound. In 2005, the Nearshore Habitat Program established the Eelgrass Stressor – Response Project (ES-RP) in an effort to identify and understand environmental stressors leading to declines of *Z. marina* in areas of concern as identified by the SVMP and scientifically sound evidence from other researchers (Wyllie-Echeverria 2003, Dowty et al. 2007). These efforts help to better understand the dynamics of nearshore ecological functions and, ultimately, work to protect and improve the health of Puget Sound, as mandated by the DNR and the Puget Sound Partnerships' Action Agenda.

Since monitoring began in 2000, the SVMP has identified two geographic "areas of concern", where *Z. marina* declines have been documented and concern over further loss creates a need to investigate causal factors:

1. Shallow embayments of the San Juan Straits Region (Dowty et al. 2007)
2. Hood Canal Region (Gaeckle et al. 2007)

Known *Z. marina* losses in the San Juan Archipelago (SJA) have been noted in the head of some shallow embayments. The most widely known and studied is the sudden loss of *Z. marina* in Westcott Bay on San Juan Island, first identified in 2003 (Dowty et al. 2007, Wyllie-Echeverria et al. 2005).

The main focus of ES-RP research has been in shallow embayments within the SJA, with a special emphasis of work in Westcott Bay (Schanz et al. 2010). *Z. marina* transplant experiments and water quality monitoring stations were established in 2007 and data collected from 2007 – 2008 suggest light is not limiting *Z. marina* growth or recovery (Dowty & Ferrier 2009) but may play a role in the presence of other environmental stressors (Schanz et al. 2010).

In 2008 and 2009, the SVMP surveyed the Westcott Bay Complex to determine current abundance and distribution of *Z. marina* and to document the extent of *Z. marina* losses in Westcott Bay. Several sites located throughout the SJA, with similar geomorphology were also sampled to document current *Z. marina* status across the SJA and provide regional comparisons.

This report summarizes the collaborative work between the SVMP and ES-RP to document abundance and depth distribution of *Z. marina* in Westcott Bay, and other shallow embayments in the SJA, in an effort to better understand findings at individual sites and across the region.

Objectives:

1. Determine current abundance and distribution of *Z. marina* in the Westcott Bay Complex
2. Evaluate *Z. marina* trends over time in Westcott Bay using quantitative comparisons from surveys with similar methodologies and qualitative considerations of additional existing historical datasets.
3. Assess status and trends of *Z. marina* in other shallow embayments in the SJA and compare results from individual sites.

2 Methods

2.1 *Study Area Description*

The areas surveyed in this project were confined to shallow embayments within the marine water of the San Juan Archipelago (SJA). In total, 10 sites were surveyed for the project and data from all sites will be presented in this report. The SVMP sampling methods are described in detail in SVMP reports (Berry et al. 2003, Dowty et al. 2005, Gaeckle et al. 2009 and are summarized briefly in the following sections to provide context for the objectives of this project.

2.1.1 *Westcott Bay Complex*

The Westcott Bay Complex is located in the northwest corner of San Juan Island and includes waters east of Mosquito Pass to the heads of Westcott and Garrison Bays proper. The comprised of six discrete SVMP sites (Figure 2-1).

The sampling diverged from the standard SVMP protocols in one respect. Two sites in the Westcott Bay Complex are "orphans" – habitat segments that are too short to meet criteria for SVMP sites (<984m of shoreline) – and therefore will never be selected for SVMP sound-wide sampling. However, in an effort to understand the extent of all *Z. marina* in the Westcott Bay Complex, these two orphan sites were sampled as part of this project.

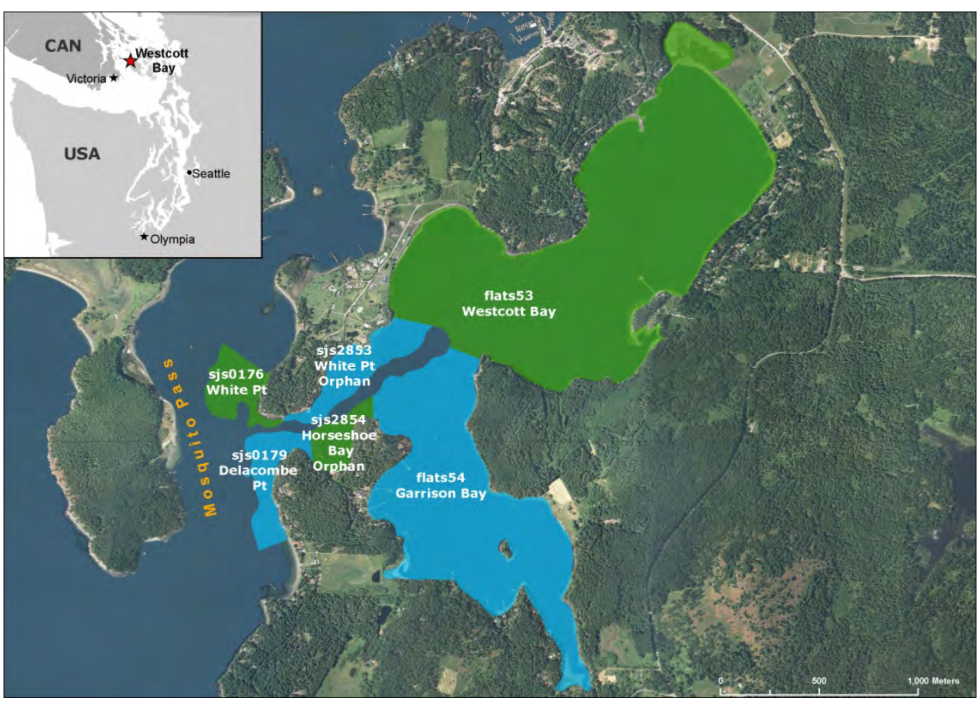

Figure 2-1. Map of *Z. marina* monitoring area within the Westcott Bay Complex. Blue and green polygons represent the spatial extents of each SVMP site.

2.1.2 San Juan Archipelago Shallow Embayments

Embayments selected for sampling were located on Sucia, Lopez, Shaw and San Juan Island and were surveyed as discrete sites to maintain methodological continuity with SVMP sampling frames (Figure 2-2). Three sites surveyed were in the 2008 and 2009 SVMP sample pool (1 as an annual core site, 2 as flats sites subject to 5-year rotation out of the sample pool) and the remaining site was sampled expressly for the ES-RP (Table 2-1).

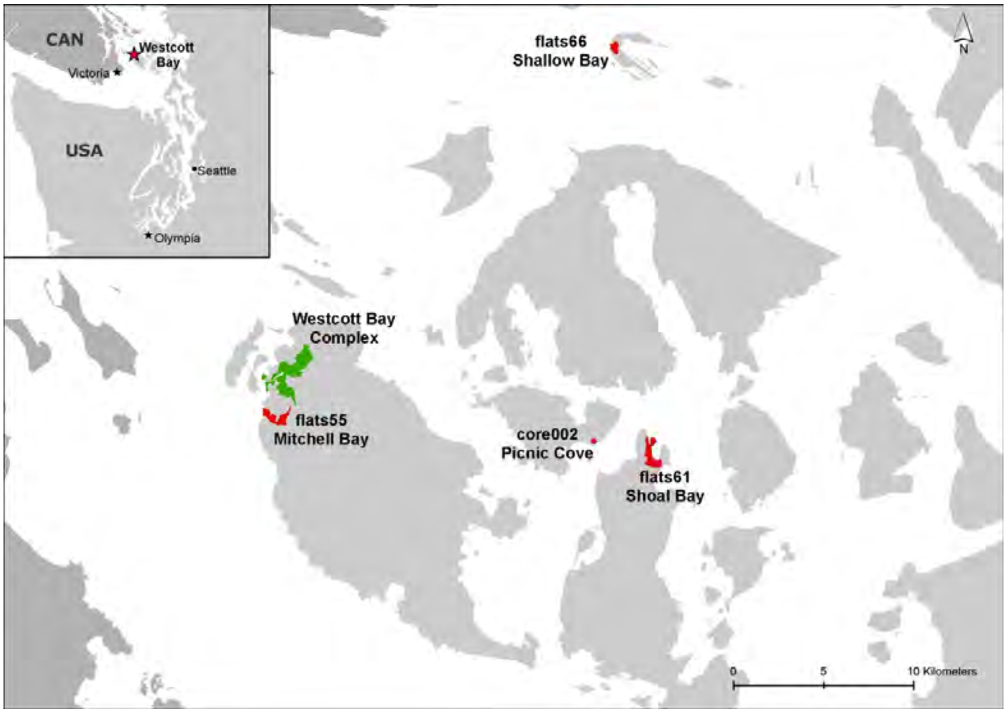

Figure 2-2. Map of monitoring area for the ES-RP. The Westcott Bay Complex is shown in green and the additional embayments surveyed in the region are represented as red polygons.

Table 2-1. Sites in the SJA surveyed for *Z. marina* abundance and depth distribution in 2008 and 2009. SITE CODE is a unique identifier for each site. SITE NAME refers to an adjacent, corresponding geographical location. The STRATA column indicates whether the site is a narrow fringe (fr), wide-fringe (frw), flats (fl) site, or narrow fringe orphan (fr-orp). The PROJECT column lists the sites monitored for this project (ES-RP) and sites monitored as part of the annual, SVMP sound-wide sampling (SVMP-SW).

SITE CODE		SITE NAME	STRATA	PROJECT
flats53	**Westcott Bay Complex**	Westcott Bay	fl	ES-RP
flats54		Garrison Bay	fl	ES-RP
sjs0176		White Point	frw	ES-RP
sjs0179		Delacombe Point	fr	ES-RP
sjs2853		White Point – Orphan	fr-orp	ES-RP
sjs2854		Horseshoe Bay – Orphan	fr-orp	ES-RP
core002		Picnic Cove	fl	SVMP – SW
flats55		Mitchell Bay	fl	SVMP – SW
flats61		Shoal Bay	fl	ES-RP
flats66		Shallow Bay	fl	SVMP – SW

2.2 ***Field Sampling***

Field sampling was conducted from mid-June to mid-July in both years from a 36-ft research vessel, *R/V Brendan D II* (Figure 2-3).

Figure 2-3. The *R/V Brendan D II* owned and operated by the Marine Resources Consultants. *Z. marina* presence and depth distribution data was collected from the *R/V Brendan D II* using underwater videography and depth sounding instrumentation.

2.2.1 Equipment

The *R/V Brendan D II* was equipped with an underwater video camera mounted in a "downward-looking" orientation on a weighted towfish (Figure 2-4a). Parallel lasers mounted 10 cm apart provide scaling reference in video images. The towfish was deployed directly off the stern of the vessel using an A-frame cargo boom and hydraulic winch. The weight of the towfish positioned the camera directly beneath a DGPS antenna, ensuring that the data accurately reflected the geographic location of the camera (Figure 2-4b). Time, differential global positioning system (DGPS) data, Garmin and Biosonics depth data were acquired simultaneously during sampling. Differential corrections were received from the United States Coast Guard public DGPS network using the WGS 84 datum. Table 2-2 lists the equipment used to conduct the video sampling and acquisition of *Z. marina* depth data.

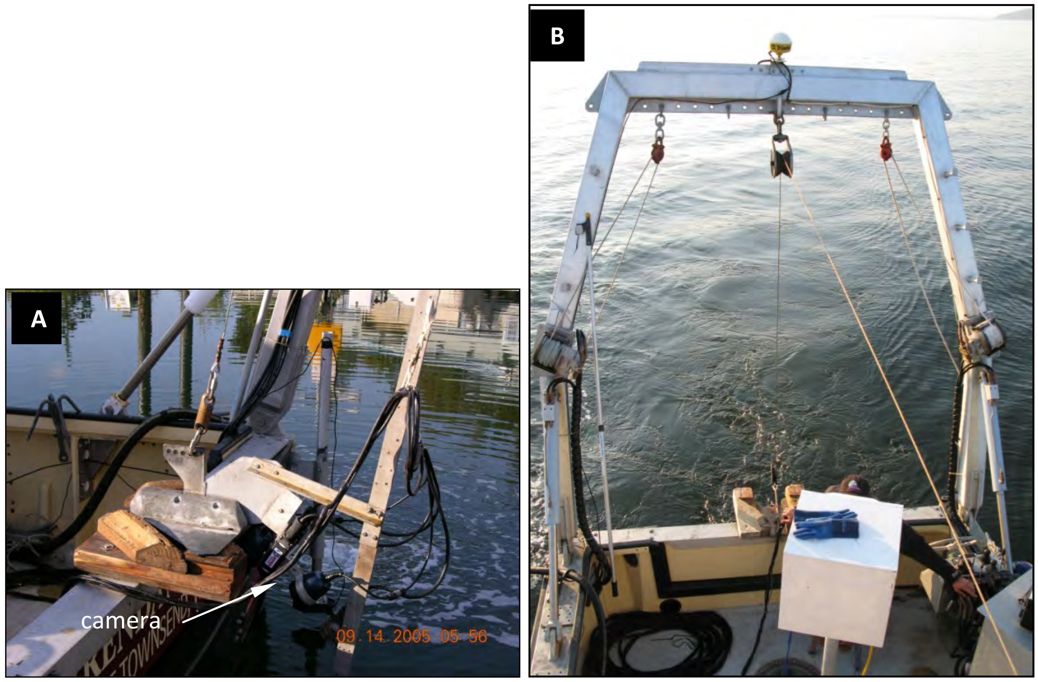

Figure 2-4. The *R/V Brendan D II* is equipped with a weighted towfish that contains an underwater video camera mounted in a 'downward looking' orientation, dual lasers for scaling reference, and underwater lights for night work (A). The towfish is deployed directly beneath the DGPS antenna attached to the A-frame cargo boom, ensuring accurate geographic location of the camera (B)

Table 2-2. Equipment and software used to collect underwater video and depth data.

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

2.2.2 Site and Sample Polygons

Prior to field sampling, a site polygon was defined for each site, bounded by the -20 ft bathymetry contour and the ordinary high water mark as described in the SVMP methods (Berry et al. 2003, Figure 2-5A). Fringe sites are 1000 m along the -20 ft contour on the deep edge, while the segment lengths vary for flats sites (e.g., depending on embayment size). A series of reconnaissance transects were completed throughout the site to delineate the sample polygon (Figure 2-5B). Sample polygons include all observed eelgrass and any potential habitat where eelgrass presence could not be ruled out with a high degree of certainty (Berry et al. 2003). Random transects were selected from within the sample polygon for each site using ArcGIS software (Figure 2-5c).

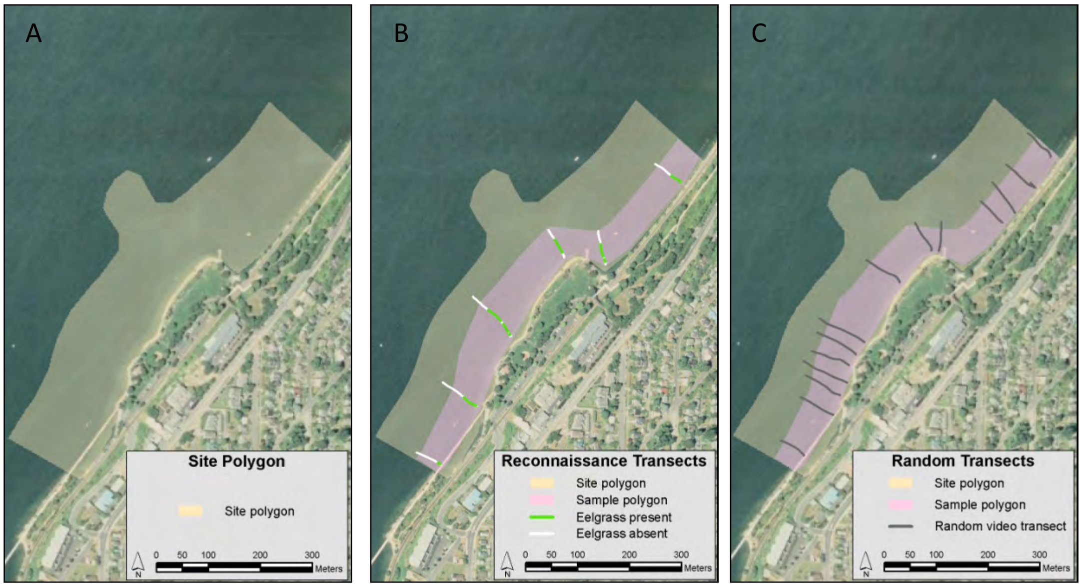

Figure 2-5. Prior to field work, a site polygon is delineated as the area between the -6 m (-20 ft) bathymetry contour and the ordinary high water mark using ArcGIS (A). Several underwater videography reconnaissance transects are performed throughout the site to provide data necessary to identify a sample polygon (B). The site is then surveyed with random underwater videography transects (C).

2.2.3 Z. marina video data collection

At each site, underwater videography was used to sample the presence of eelgrass along random transects in a modified line-intercept technique (Norris et al. 1997). Random transects are restricted to a sample polygon (delineated from reconnaissance transects) that represents the general location of eelgrass presence within a site. Random video transects, oriented perpendicular to shore, extend beyond the shallow and deep edges of the sample area.

In an effort to get a higher resolution of eelgrass distribution patterns (e.g., deep and shallow extent of beds), extra reconnaissance transects were performed at all sites when large gaps in random transects occurred.

2.2.4 Video data processing and analysis

The video sampling resolution is nominally one square meter and eelgrass is categorized as present or absent based on the observation of rooted shoots within the video field of view. All *Z. marina* presence and absence classification results were recorded with corresponding spatial information. The fractional cover of eelgrass along transects is used to calculate site eelgrass area. The depth at which eelgrass grows along each transect is used to estimate mean maximum and minimum depth of eelgrass relative to Mean Lower Low Water (MLLW) within each sample polygon at each site.

All measured depths were corrected to the MLLW datum by adding the transducer offset, subtracting the predicted tidal height for the site and adding the tide prediction error (calculated using measured tide data from the National Oceanic and Atmospheric Administration website http://co-ops.nos.noaa.gov/data_res.html). These final corrected depth data were merged with eelgrass data and spatial information into a site database so the eelgrass observations had associated date/time, position and depth measurements corrected to MLLW datum.

Eelgrass area at each site was calculated using ARC GIS software and the site database file in the following sequential steps:

1. Calculated the area within the sample polygon;
2. Calculated the fraction of eelgrass along each random line transect;
3. Calculated the mean fraction and associated variance;
4. Estimated the overall eelgrass area and variance at the site by extrapolating the mean fraction along random transects over the sample polygon area.

Each random video transect that intersected *Z. marina* had a minimum and maximum depth observation. Minimum and maximum *Z. marina* depth characteristics for each site are described using descriptive statistics (i.e., means and ranges). Findings of sites sampled prior to 2008 for *Z. marina* abundance and depth distribution are presented to better understand trends and changes observed since 2000.

Sites with *Z. marina* area estimates from 2003 were sampled using modified SVMP methods (FRIENDS of the San Juans et al. 2004), did not produce reliable depth data for comparison with SVMP surveys and, therefore, are excluded from the analyses.

3 Results

3.1 Z. marina abundance in the Westcott Bay Complex

The six sites in the Westcott Bay Complex were surveyed in mid-June in 2008 and mid-July in 2009. The estimate of total *Z. marina* area in the Westcott Bay Complex for 2008 was 13.1 ± 2.7 ha and 13.6 ± 2.5 ha in 2009 (Table 3-1, Appendix A1, Appendix A2).

Table 3-1. 2008 and 2009 *Z. marina* monitoring summary statistics from the Westcott Bay Complex.

Year	Total eelgrass area (ha)	95% Confidence Interval	Number of sites sampled	Number of sites with eelgrass	Number of sites without eelgrass	Average number of transects	Average Fraction	Total variance (ha)
2008	13.1	2.7	6	6	0	15	0.3246	0.44
2009	13.6	2.5	6	5	1*	19	0.3875	0.44

***Z. marina was absent in all random videography transects used to calculate area but was present at the site in trace amounts. Refer to Figure 2-1 for site locations.**

Z. marina is not evenly distributed across the Westcott Bay Complex study sites. Sites at the entrance of the Complex (*sjs0179 – Delacombe Point, sjs0176 – White* Point) had the greatest amount of *Z. marina* present while sites at the head of Garrison and Westcott Bay proper (*flats54* and *flats53*, respectively) contained the smallest amount (less than 0.5 ha) of *Z. marina* observed in 2008 and 2009 (Figure 3-1). Similarly, the overall proportion of the site vegetated with *Z. marina* differed substantially from the entrance (88-90%) to the head (5-6%) of Garrison and Westcott Bay proper (Figure 3-3, Appendix F).

In 2009, *Z. marina* was observed in reconnaissance transects at *Flats53 – Westcott Bay* but the amount was too small to survey following SVMP methodologies.

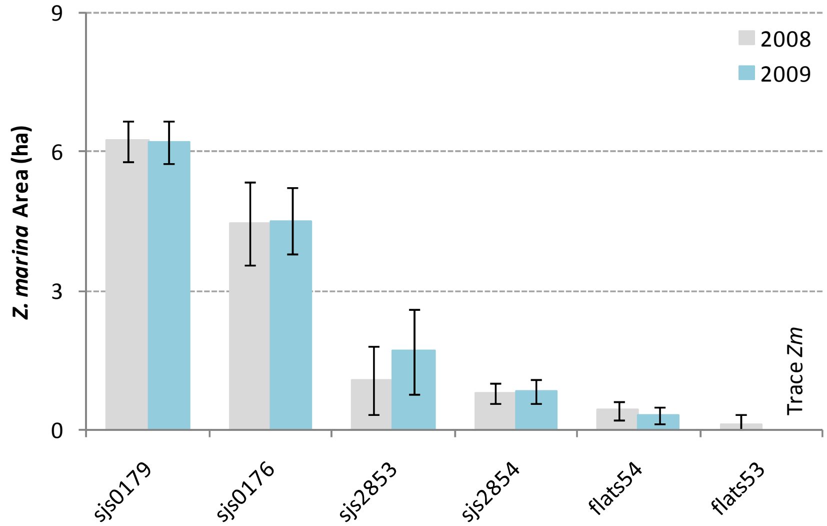

Figure 3-1. ***Z. marina*** **area in 2008 (grey bars) and 2009 (blue bars) at the six discrete Westcott Bay Complex sites. Error bars are 95% confidence intervals. Refer to Figure 2-1 for site locations. See Figure 3-3 for general spatial location where** ***Z. marina*** **was observed. Detailed maps of** ***Z. marina*** **transects are presented in Appendix G.**

3.2 Z. marina abundance in SJA shallow embayments

In total, four embayments were surveyed in 2008 and 2009. The areal extent of *Z. marina* in the four embayments ranged from 2.3 to 5.2 ha in 2008 and 2.3 to 6.5 ha in 2009 (Appendix B1&2). The proportion of *Z. marina* vegetation relative to site area was distinctly different at each site, ranging from 14% at *flats61 – Shoal Bay* to 62% at *flats66 – Shallow Bay* (Appendix F).

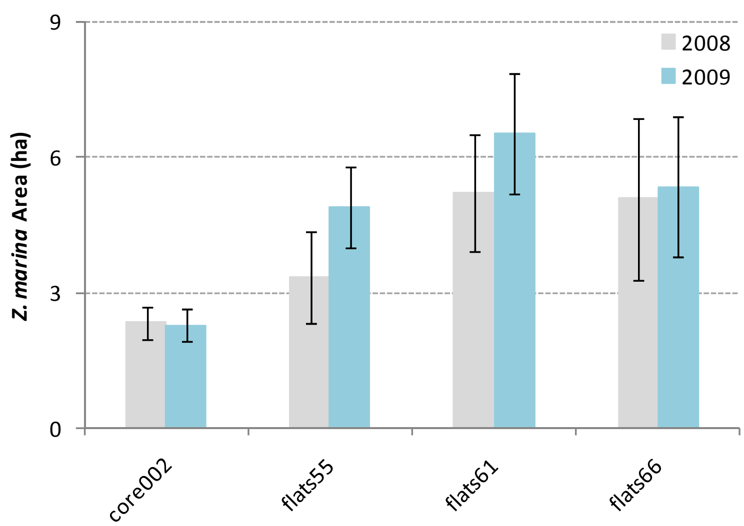

Figure 3-2. ***Z. marina*** **area in 2008 (grey bars) and 2009 (blue bars) at four SJA shallow embayments. Errors bars are 95% confidence intervals. Refer to Figure 2-1 for site locations. See Figure 3-3 for general spatial locations where** ***Z. marina*** **was observed. Detailed maps of** ***Z. marina*** **transects are presented in Appendix G.**

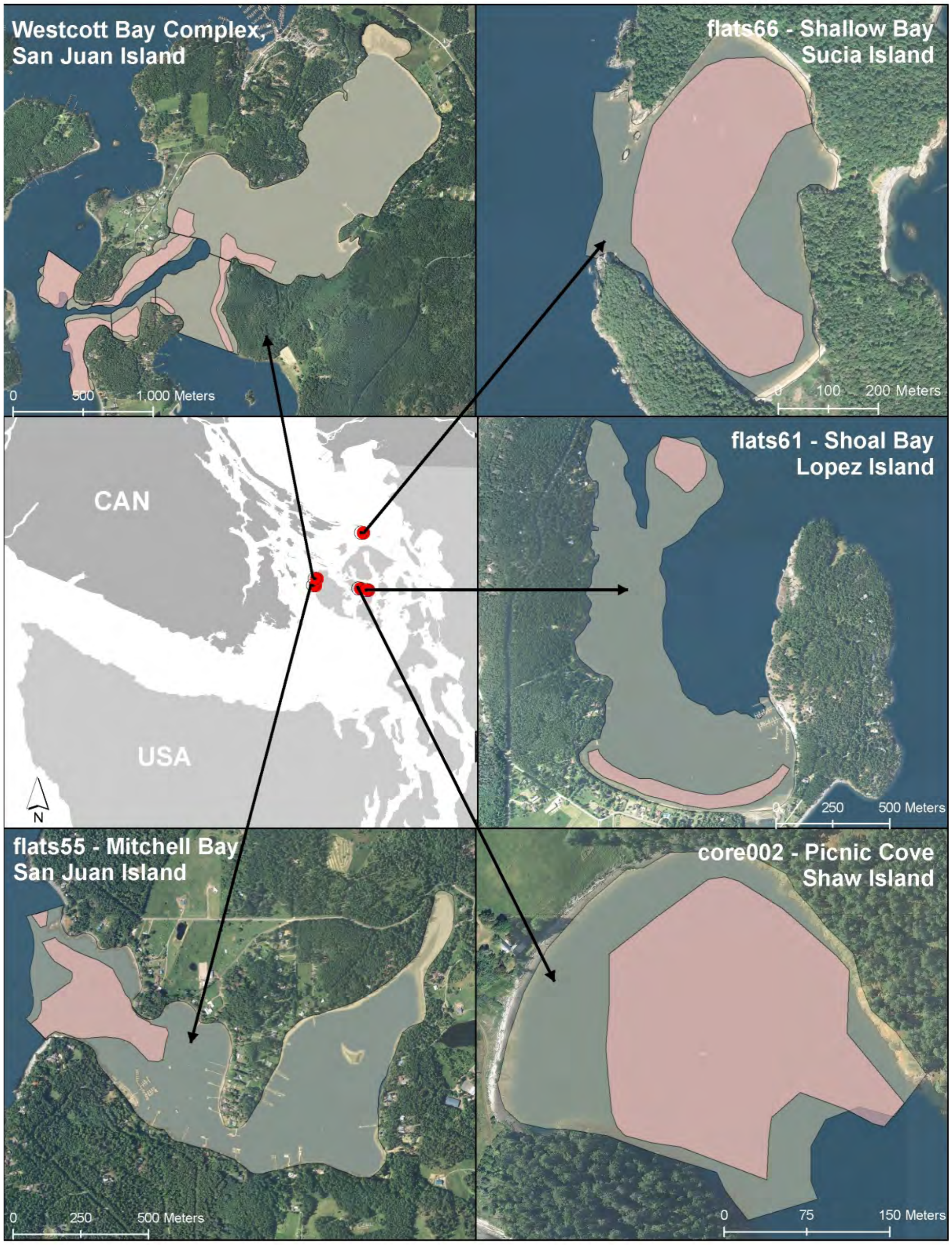

Figure 3-3. Generalized areas where *Z. marina* was observed (pink polygons) at each site during sampling.

3.3 *Z. marina* depth distribution in the Westcott Bay Complex

In the Westcott Bay Complex, *Z. marina* depth distribution is best characterized at the site level. *Z. marina* grows in the greatest depth range at the mouth of the bay and decreases in range approaching the head (Figure 3-4, Figure 3-6). In 2008, *Z. marina* in the Westcott Bay Complex ranged from the absolute minimum and maximum depths of -0.33 m to -7.06 m, had a mean minimum depth of -0.89 m to -2.04 m and a mean maximum depth of -2.30 m to -5.71 m (Appendix C1). In 2009, *Z. marina* ranged from the absolute minimum and maximum depths of -0.37 m to -7.28 m, had a mean minimum depth of -0.93 m to -2.06 m and a mean maximum depth of -2.40 m to -6.43 m (Appendix C2).

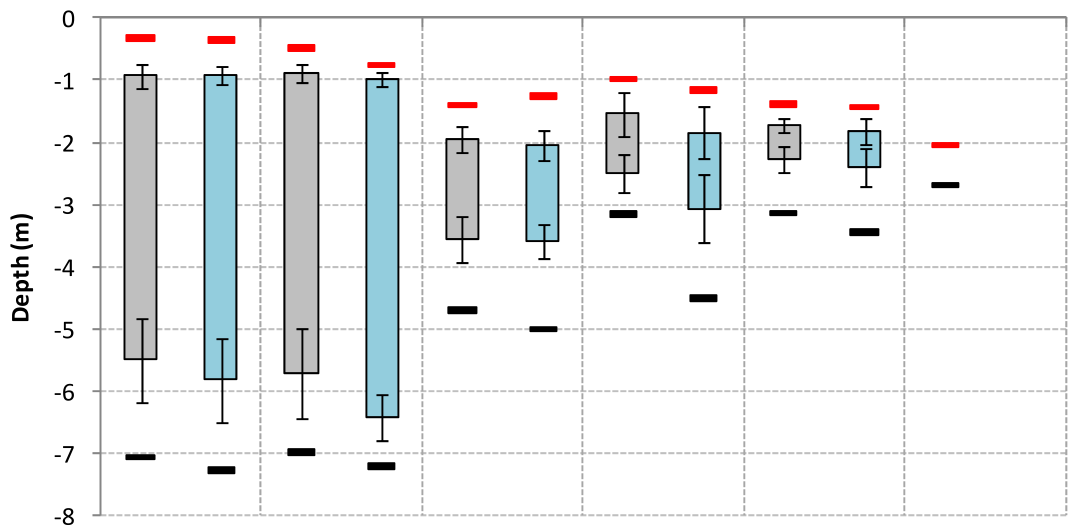

Figure 3-4. ***Z. marina*** **mean minimum, mean maximum and absolute minimum and maximum depth (meters) observed in 2008 (grey bars) and 2009 (blue bars). Error bars are associated 95% confidence intervals. Red lines indicate the absolute minimum depth where** ***Z. marina*** **was observed while black lines indicate the absolute maximum depth where** ***Z. marina*** **was observed at each site.**

3.4 *Z. marina* depth distribution in SJA embayments

In 2008, *Z. marina* in the four SJA embayments surveyed ranged from a depth of +0.01 m to -6.84 m, had a mean minimum depth of -0.40 m to -2.79 m and a mean maximum depth of -2.40 to -4.79 (Figure 3-5, Figure 3-6, Appendix D1). In 2009, *Z. marina* ranged from a depth of +0.20 m to -6.24 m, had a mean minimum depth of -0.33 m to -3.53 m and a mean maximum depth of -2.40m to -4.79 m (Figure 3-5, Figure 3-6, Appendix D2).

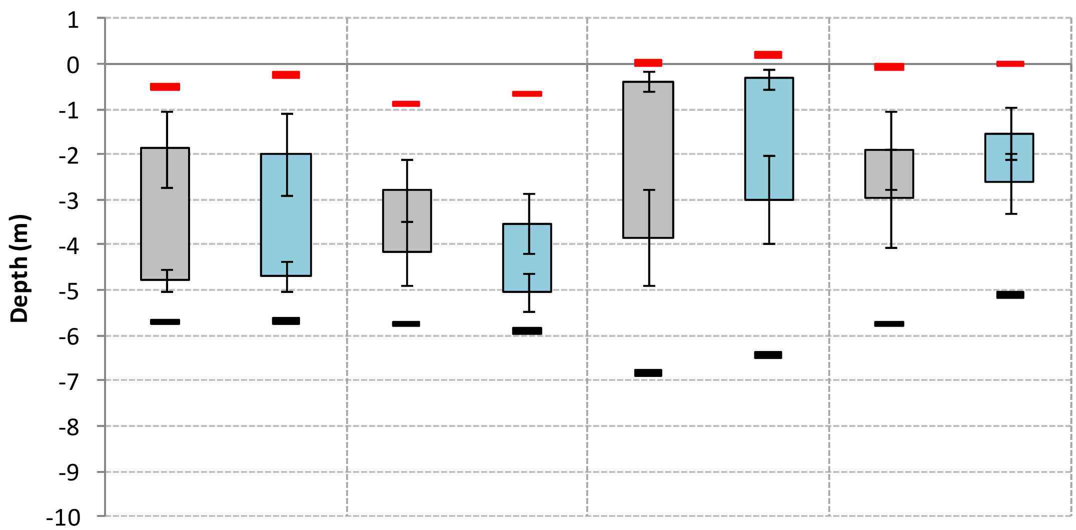

Figure 3-5. *Z. marina* mean minimum and mean maximum depth distribution (m) in 2008 (grey bars) and 2009 (blue bars). Red (shallow edge) and black (deep edge) bars represent extreme *Z. marina* observations. Error bars are 95% confidence intervals.

Figure 3-6 visually depicts the distinct differences in depth distribution among all sites surveyed. Sites with the most similar *Z. marina* depth distribution are sjs0179 and sjs0176, which are located at the entrance of the Westcott Bay Complex. At these sites, *Z. marina* was distributed relatively consistently from the shallow to deep areas, with a slightly greater proportion occurring in the shallow subtidal. In contrast, the sites inside the Westcott Bay Complex show a strong decrease in minimum depth and maximum depth, and a peak in *Z. marina* distribution along a narrow depth range in the shallow subtidal.

In the four other embayments, *Z. marina* showed a marked bimodal distribution, with large proportions of *Z. marina* occurring near the shallow and deep depth extremes. This pattern was previously observed at flats sites in the San Juan Straits (Selleck et al. 2005). In contrast, *Z. marina* depth distribution at fringe sites tends to be broadly spread over the depth range with a slightly higher proportion in the shallow subtidal, similar to sjs0179 and sjs0176.

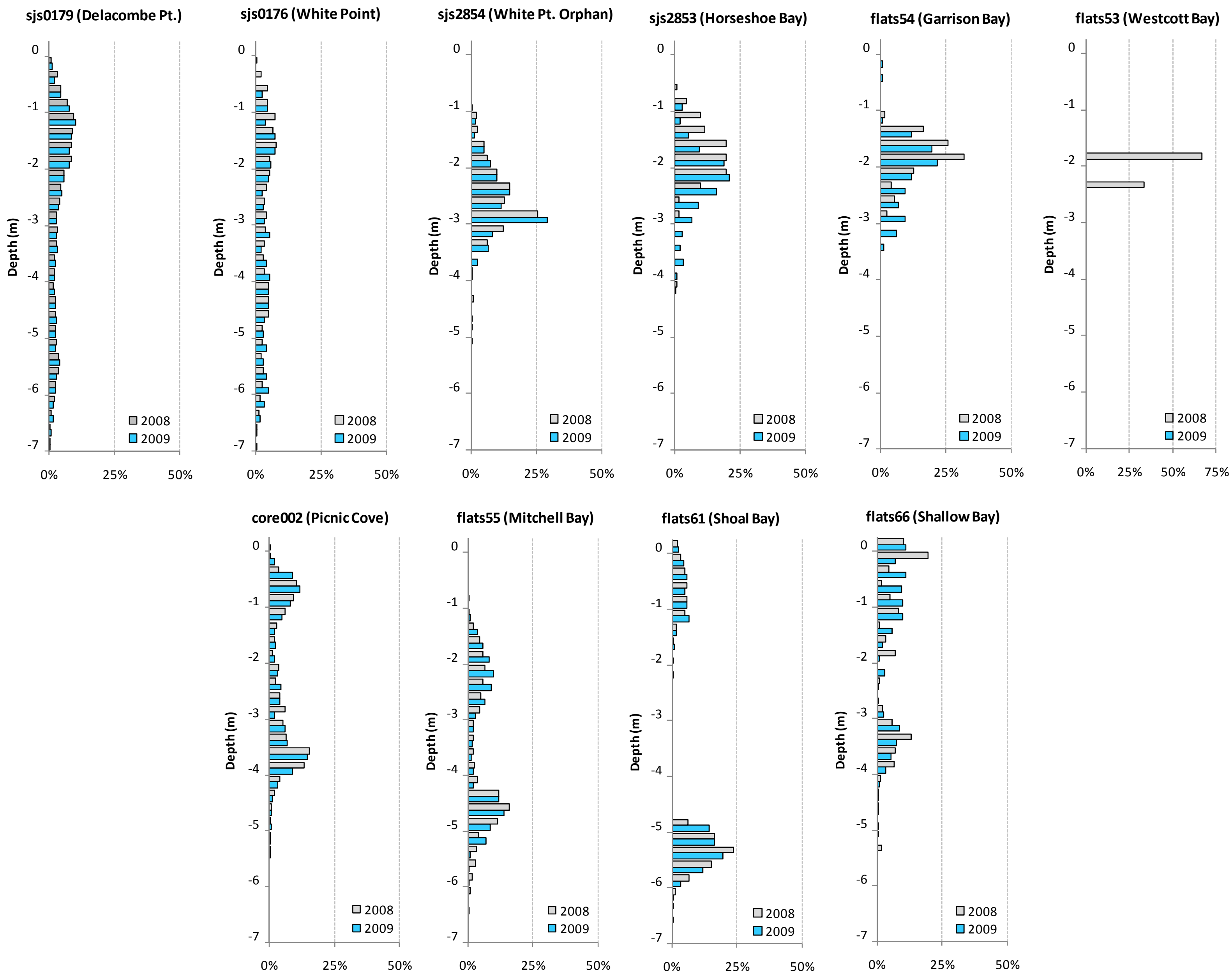

Figure 3-6. ***Z. marina*** **depth distribution (m) at all sites surveyed in 2008 (blue) and 2009 (grey) depth (m) distribution of *Z. marina* at all sites surveyed. At *Flats53 – Westcott Bay*, the 2008 depth distribution is based on survey observations of approximately three plants and is not an accurate depiction of *Z. marina* depth distribution at the site.**

3.5 *Year-to-Year Change in Z. marina (2008-2009)*

3.5.1 *Abundance*

All sites sampled were tested for changes in *Z. marina* area between 2008 and 2009 at the site level. One site (*Flats55 – Mitchell Bay*) showed a significant change in area from 2008 – 2009 when tested at α=0.20, while the remaining sites showed no significant year-to-year change in area (Figure 3-7). At *sjs2583 – Horseshoe Bay,* the magnitude of change and associated error bars are very large because the total area of *Z. marina* present at the site is very small. Similarly, *flats55 – Mitchell Bay* experienced a high relative change percentage from 2008 to 2009; however, the total change in *Z. marina* area was much larger than *sjs2853 – Horseshoe Bay* and the amount of change is more precise, as shown by the associated error bars.

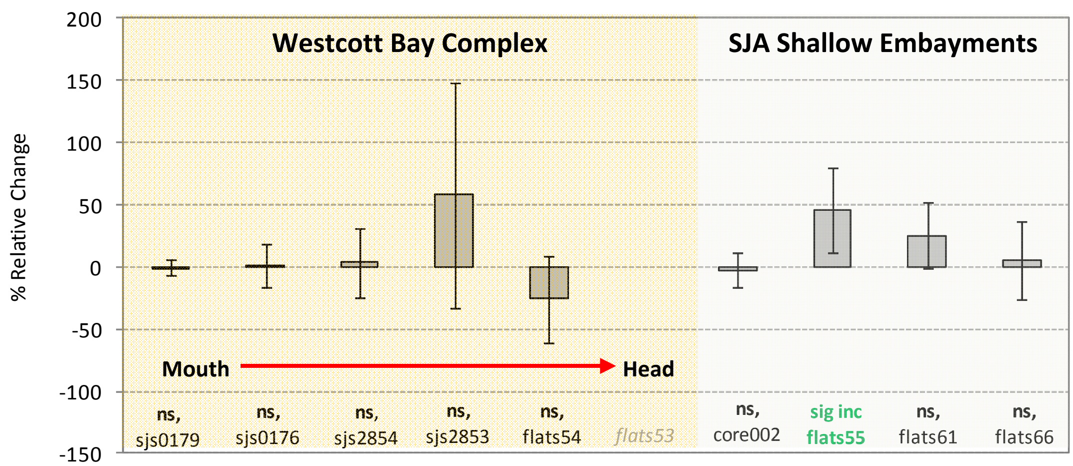

Figure 3-7. Estimated relative change in *Z. marina* area from 2008 to 2009. Significant change (α=0.20) was detected only at *flats55 – Mitchell Bay*. Relative change analysis was not performed at *flats53 –Westcott Bay* in 2009 due to trace *Z. marina* presence. Error bars are associated 80% confidence intervals.

3.5.2 *Depth Distribution*

Sites were also tested for significant changes in mean minimum and mean maximum depths between 2008 and 2009 but no significant changes were observed when tested at α=0.20 (Appendix E).

3.6 *Trends in Site-Level Z. marina*

3.6.1 *Z. marina Abundance*

Core002 – Picnic Cove experienced a significant declining trend in abundance from 2000 – 2009 of 0.2 ha yr^{-1}, when tested at α=0.05 (Figure 3-8A). A significant trend was measured at *flats53 – Westcott Bay,* where a massive, 99% decline of *Z. marina* occurred from 2000 –

2003; however, *Z. marina* area did not experience further changes between 2003 and 2009 (α=0.05, Figure 3-8B). Despite a significant year-to-year increase in *Z. marina* area from 2008 to 2009 at *flats55 – Mitchell Bay* (α=0.20, Figure 3-7, Figure 3-8C-dashed line), a declining trend in *Z. marina* area was observed at the site from 2003 to 2008 (α=0.05, Figure 3-8C). *Shoal Bay – flats61* and *Shallow Bay – flats66* did not experience a measurable change in abundance from 2003 to 2009 (Figure 3-8D&E).

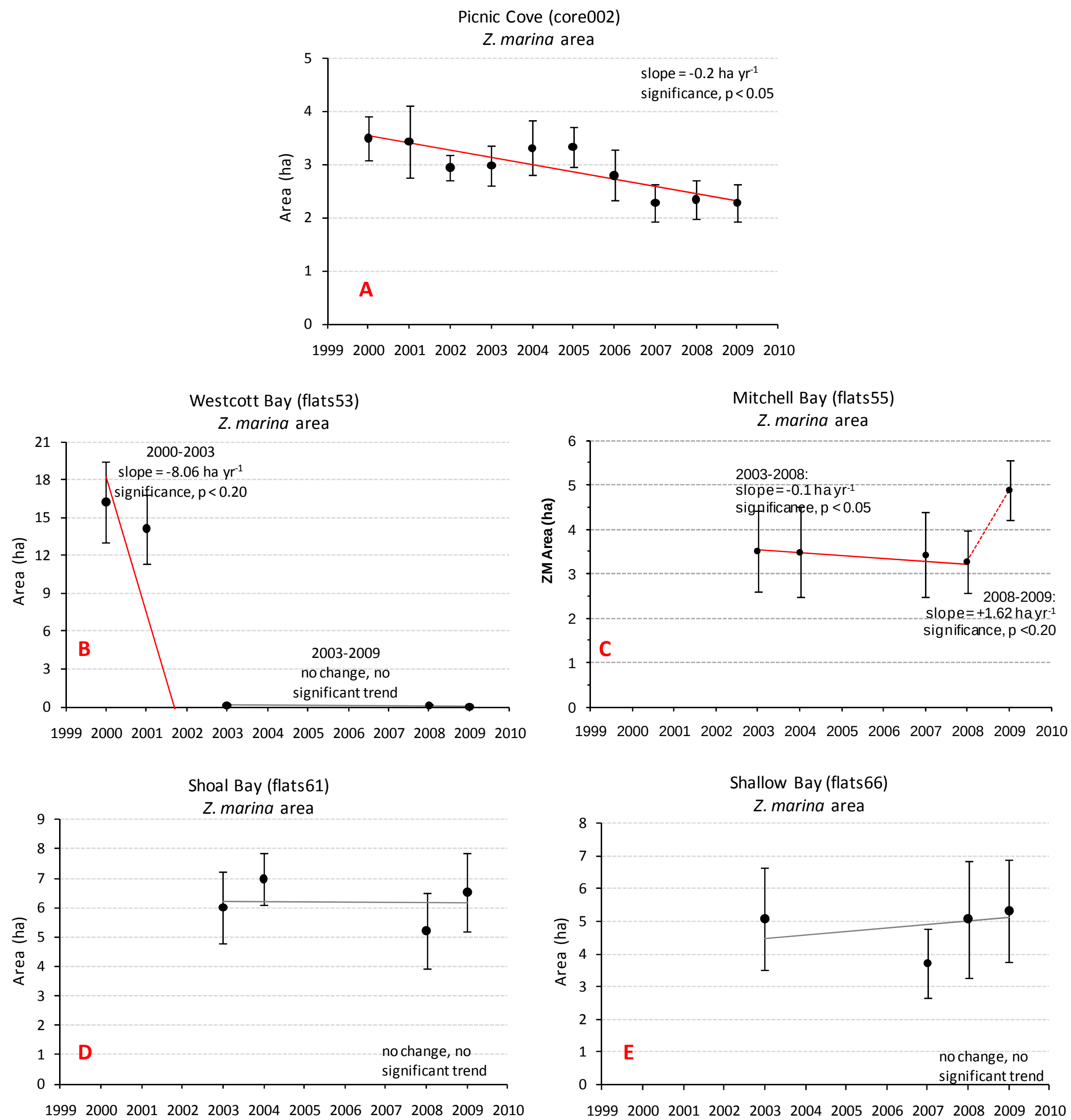

Figure 3-8. *Z. marina* area trend analysis at sites with four, or more, years of data. Estimated trends are based on regression slope and were determined to be significant at α=0.05 (A & C) and α=0.20 (B & C). Error bars are 95% (A, C, D, & E) and 80% (B) confidence intervals. Dashed line in Figure 3-9C indicates significant year-to-year relative change (α=0.20).

3.6.2 *Z. marina Depth Distribution*

Sites with four or more years of data were analyzed for trends and changes in depth distribution at the shallow and deep edge of *Z. marina* beds. Significant trends were detected at *Core002 – Picnic Cove* from 2000 to 2009 (Figure 3-10A), where the shallow edge of the bed is growing at deeper depths. No significant trends or changes were detected in *Z. marina* depth distribution in beds at other sites over the data record (Figure 3-10B, C, D).

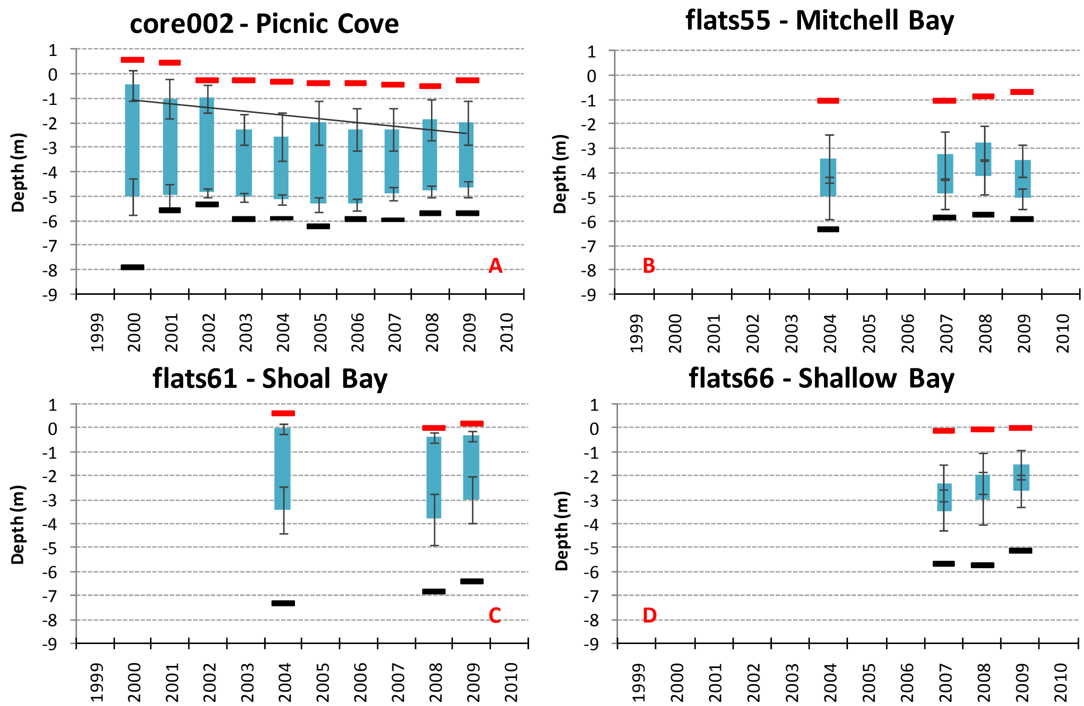

Figure 3-10. Site level mean minimum and maximum depth range (meters) of *Z. marina* (blue bars). Red (shallow edge) and black (deep edge) bars represent extreme *Z. marina* observations. Trend analysis of *Z. marina* depth range was performed at sites with four, or more, years of depth data (A, B). Estimated trends are based on regression slope (α=0.05) and were determined to be significant at one site (A). Error bars are 95% confidence intervals (A, B, C, D).

4 Discussion

4.1 *Status of Z. marina in the Westcott Bay Complex*

It not known when *Z. marina* declines began in the Westcott Bay Complex and the extent of losses that have occurred since that time; however, multiple sources suggest declines may have been triggered sometime between 1998 and 2000 (Dethier and Ferguson 1998, Wyllie-Echeverria et al. 2003). There is currently very little *Z. marina* growing in the Westcott Bay Complex relative to the amounts observed at the head of the bay in 2000 and 2001 by the SVMP. *Z. marina* abundance in the Westcott Bay Complex has not experienced significant changes from 2003 to 2009. While *Z. marina* is not exhibiting signs of recovery, the remaining population continues to persist and appears not to be impacted by the event that triggered previous losses.

The Westcott Bay Complex has a distinct gradient of decreasing *Z. marina* abundance and depth distribution from the mouth to the head of the bay, coinciding with recent findings of the DNR's ES-RP (Schanz et al. 2010). Nearly 80% of the *Z. marina* observed in the 2008/2009 surveys is confined to the narrow fringing sites (*sjs0176 – White Point* and *sjs0179 – Delacombe Point*) located at the entrance of the Westcott Bay Complex (Figure 3-1, Figure 3-3). Similarly, depth distribution is greatest at narrow fringe sites and the depth range decreases toward the head of the bay (*flats53 – Westcott Bay* and *flats54 – Garrison Bay*). The 2008 and 2009 surveys, show depth range is reduced by roughly 80% from the entrance to intermediate sites in the Complex (*sjs2853 – White Point Orphan* and *sjs2854 – Horseshoe Bay (Orphan)*) and is diminished by 90% at sites in the head of the bay (*flats53 – Westcott Bay* and *flats54 – Garrison Bay*) (Figure 3-4). This suggests that environmental stressors that support *Z. marina* distribution are minimized at the head of the Westcott Bay Complex.

It is beyond the scope of this study to identify stressors associated with *Z. marina* losses in the bay or factors driving current patterns of *Z. marina* distribution. The ES-RP has been investigating causal factors of *Z. marina* declines in Westcott Bay since 2005 (Dowty et al. 2007, Dowty and Ferrier 2009). Recent findings suggest a suite of environmental stressors contributed to declines and continue to prevent recolonization of *Z. marina* in the head of Westcott Bay (Schanz et al. 2010). Research continues and additional findings will be presented in future reports.

4.2 *Status and Trends of Z. marina in SJA Embayments*

Limited information is available on historical abundance and distribution of *Z. marina* in the San Juan Archipelago. Comparison of historic maps from 1978 suggests substantial losses of *Z. marina* habitat at the shallow edge of many beds throughout the SJA between 1978 and when monitoring began by the SVMP (Puget Sound Environmental Atlas 1987). It is possible that embayments surveyed in this study could have experienced changes similar to those observed in the Westcott Bay Complex over the same time period; however, different methodologies and resolution of data limit the ability to compare results. It is important to acknowledge the geomorphological similarities the embayments share and the unique characteristics that influence the abundance and distribution of *Z. marina* at each site.

Core002 – Picnic Cove is a site with the longest (and most continuous) data record available in the SJA, with sampling conducted annually since 2000. Although the proportion of site vegetated with *Z. marina* has not changed substantially since monitoring began, there has been a significant declining trend in *Z. marina* abundance suggesting that bed fragmentation is occurring. Additionally, significant declines have been documented at the shallow edge of the bed (Figure 3-10), and confirmed by other studies (Wyllie-Echeverria, personal communication). This strongly suggests degradation in the quality of habitat higher in the intertidal zone. *Z. marina* declines occurred in Picnic Cove at the same time as losses at the head of Westcott Bay, but a population crash did not occur. Nonetheless, these trends emphasize the need to closely monitor sites where declines are actively occurring to better understand the nature of losses in the region.

Flats55 – Mitchell Bay is closest in proximity to the Westcott Bay Complex and is the most geomorphologically similar. Substantial losses in the shallow portion of the Mitchell Bay are known to have occurred prior to 2003 (Appendix G.8, Puget Sound Environmental Atlas 1987). It is not known if the difference in distribution affected *Z. marina* area, but it is clear that *Z. marina* no longer inhabits the shallow waters at the head of Mitchell Bay, similar to findings observed in the Westcott Bay Complex. *Z. marina* has not re-colonized the shallow extents of the embayment it once occupied, but the increase of *Z. marina* from 2008-2009 may be an early indication of recovery at the site. Increases of *Z. marina* area in Mitchell Bay could suggest that recovery is possible in the Westcott Bay Complex, given their close proximity.

Flats61 – Shoal Bay and *Flats66 – Shallow Bay* are farthest away and least similar from the Westcott Bay Complex, with *Z. marina* growing higher in the intertidal than other embayments surveyed in this study. Due to their size, geomorphology and location in the SJA, these sites experience greater tidal flushing than the other embayments surveyed. *Z. marina* at Shoal and Shallow Bay has remained stable in abundance and depth distribution from 2003 to 2009 and historic maps are consistent with these observations (Puget Sound Environmental Atlas 1987).

Despite similarities in *Z. marina* trends at these sites, the beds are distinctly different. Shoal Bay is a dynamic site with *Z. marina* growing in two distinct beds. There is a shallow, narrow fringing bed lining the shoreward portion of the site and a deeper, separate bed persisting on a subtidal shoal at the mouth of the bay (Figure 3-3, Figure 3-10). Of sites surveyed, *Z. marina* grows highest in the intertidal at Shallow Bay and also has the greatest proportion of *Z. marina* occupying the site polygon compared to other sites monitored in this study (Figure 3-3, Appendix F).

4.3 ***Future Work***

These data provides a useful baseline inventory on the status of *Z. marina* in several SJA shallow embayments. In the future this information will increase the ability to track and better understand changes at these sites. This study utilized the SVMP sampling methodology in order to monitor status and trends in *Z. marina* at sites of concern. The strengths of the SVMP protocol are that it is rigorous, well-developed and produces comparable data at sites throughout Greater Puget Sound. However, the monitoring protocol was not designed to track status and trends at extremely small beds, such those currently found in Westcott and Garrison Bays. In the future, if highly precise surveys are required to in these areas in order to track small changes, the program should consider methodological additions to the standard SVMP monitoring protocol.

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APPENDICES

Appendix A *Z. marina* area (hectares) in the Westcott Bay Complex

1. 2008

Site Code	Location	*Z. marina* area (ha)	*Z. marina* 95% CI	Date Sampled	# Transects	*Z. marina* Fraction	*Z. marina* area std error (ha)	*Z. marina* variance (ha)	CV
flats53	Westcott Bay	0.11	0.22	19-Jun-08	19	0.0027	0.11	0.012	1
flats54	Garrison Bay	0.43	0.2	20-Jun-08	23	0.1087	0.1	0.01	0.24
sjs0176	White Point	4.46	0.89	19-Jun-08	11	0.5991	0.46	0.207	0.1
sjs0179	Delacombe Point	6.23	0.43	20-Jun-08	16	0.7563	0.22	0.049	0.04
sjs2853	White Point Orphan	1.07	0.74	21-Jun-08	11	0.1486	0.38	0.144	0.36
sjs2854	Horseshoe Bay	0.8	0.22	20-Jun-08	12	0.3321	0.11	0.013	0.14

2. 2009

Site Code	Location	*Z. marina* area (ha)	*Z. marina* 95% CI	Date Sampled	# Transects	*Z. marina* Fraction	*Z. marina* area std error (ha)	*Z. marina* variance (ha)	CV
flats53	Westcott Bay	* tr	-	17-Jul-09	22	-	-	-	-
flats54	Garrison Bay	0.32	0.18	16-Jul-09	34	0.0842	0.09	0.008	0.28
sjs0176	White Point	4.51	0.73	16-Jul-09	11	0.5987	0.37	0.138	0.08
sjs0179	Delacombe Point	6.21	0.46	16-Jul-09	15	0.7486	0.23	0.055	0.04
sjs2853	White Point Orphan	1.69	0.92	17-Jul-09	15	0.2209	0.47	0.219	0.28
sjs2854	Horseshoe Bay	0.83	0.25	17-Jul-09	15	0.2853	0.13	0.016	0.15

*** tr = trace *Z. marina* at this site. The site was visited and reconnaissance video transects found small amounts of *Z. marina* present at the site but it was absent where random video transects were surveyed. The amount of *Z. marina* at the site was too small to estimate area according to the SVMP protocol.**

Appendix B *Z. marina* area in select SJA shallow embayments.

1. 2008

Site Code	Location	***Z. marina* area (ha)**	***Z. marina* 95% CI**	**Date Sampled**	**# Transects**	***Z. marina* Fraction**	***Z. marina* area std error (ha)**	***Z. marina* variance (ha)**	**CV**
core002	Picnic Cove	2.34	0.3	24-Jun-08	14	0.5063	0.18	0.031	0.07
flats55	Mitchell Bay	3.35	1.0	22-Jun-08	17	0.3194	0.52	0.270	0.16
flats61	Shoal Bay	5.21	1.3	23-Jun-08	21	0.5249	0.66	0.436	0.13
flats66	Shallow Bay, Sucia	5.07	1.8	15-Jul-08	15	0.3592	0.91	0.821	0.18

2. 2009

Site Code	Location	***Z. marina* area (ha)**	***Z. marina* 95% CI**	**Date Sampled**	**# Transects**	***Z. marina* Fraction**	***Z. marina* area std error (ha)**	***Z. marina* variance (ha)**	**CV**
core002	Picnic Cove	2.28	0.4	23-Jun-09	14	0.4860	0.18	0.034	0.08
flats55	Mitchell Bay	4.89	0.9	22-Jul-09	19	0.4326	0.45	0.199	0.09
flats61	Shoal Bay	6.52	1.3	23-Jun-09	21	0.5733	0.68	0.466	0.10
flats66	Shallow Bay, Sucia	5.33	1.5	25-Jun-09	20	0.3708	0.79	0.618	0.15

Appendix C *Z. marina* depth distribution in the Westcott Bay Complex.

1. 2008

		Minimum *Z. marina* Depth						**Maximum *Z. marina* Depth**					
Site Code	**Location**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**
flats53*	Westcott Bay	1	-9999	-2.04	-9999	-9999	-9999	*1	-9999	-2.69	-9999	-9999	-9999
flats54	Garrison Bay	12	-1.73	-1.40	0.04	0.06	0.12	12	-2.30	-3.14	0.13	0.10	0.21
sjs0176	White Point	11	-0.89	-0.49	0.06	0.08	0.15	11	-5.71	-6.98	1.49	0.37	0.72
sjs0179	Delacombe Point	16	-0.94	-0.33	0.14	0.09	0.19	16	-5.50	-7.06	1.92	0.35	0.68
sjs2853	White Point Orphan	7	-1.55	-0.99	0.23	0.18	0.35	7	-2.51	-3.15	0.16	0.15	0.30
sjs2854	Horseshoe Bay	11	-1.96	-1.40	0.14	0.11	0.22	12	-3.57	-4.71	0.42	0.19	0.37

*** *Z. marina* was only observed in one transect at *Flats53 – Westcott Bay*, with two instances of *Z. marina* from which absolute depths were obtained. There was not sufficient *Z. marina* observed in random video transects to characterize depth distribution at the site.**

2. 2009

		Minimum *Z. marina* Depth						**Maximum *Z. marina* Depth**					
Site Code	**Location**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**
flats53	Westcott Bay	0	-9999	-9999	-9999	-9999	-9999	0	-9999	-9999	-9999	-9999	-9999
flats54	Garrison Bay	13	-1.83	-1.44	0.14	0.10	0.20	13	-2.40	-3.45	0.32	0.16	0.31
sjs0176	White Point	11	-0.99	-0.76	0.03	0.05	0.10	11	-6.43	-7.20	0.40	0.19	0.37
sjs0179	Delacombe Point	15	-0.93	-0.37	0.09	0.08	0.15	15	-5.83	-7.28	1.74	0.34	0.67
sjs2853	White Point Orphan	11	-1.85	-1.16	0.53	0.22	0.43	11	-3.08	-4.50	0.87	0.28	0.55
sjs2854	Horseshoe Bay	15	-2.06	-1.26	0.21	0.12	0.23	15	-3.61	-5.00	0.28	0.14	0.27

Note: -9999 = *Z. marina* absent in random video transects used to calculate depth statistics.

Appendix D *Z. marina* depth distribution in select SJA shallow embayments.

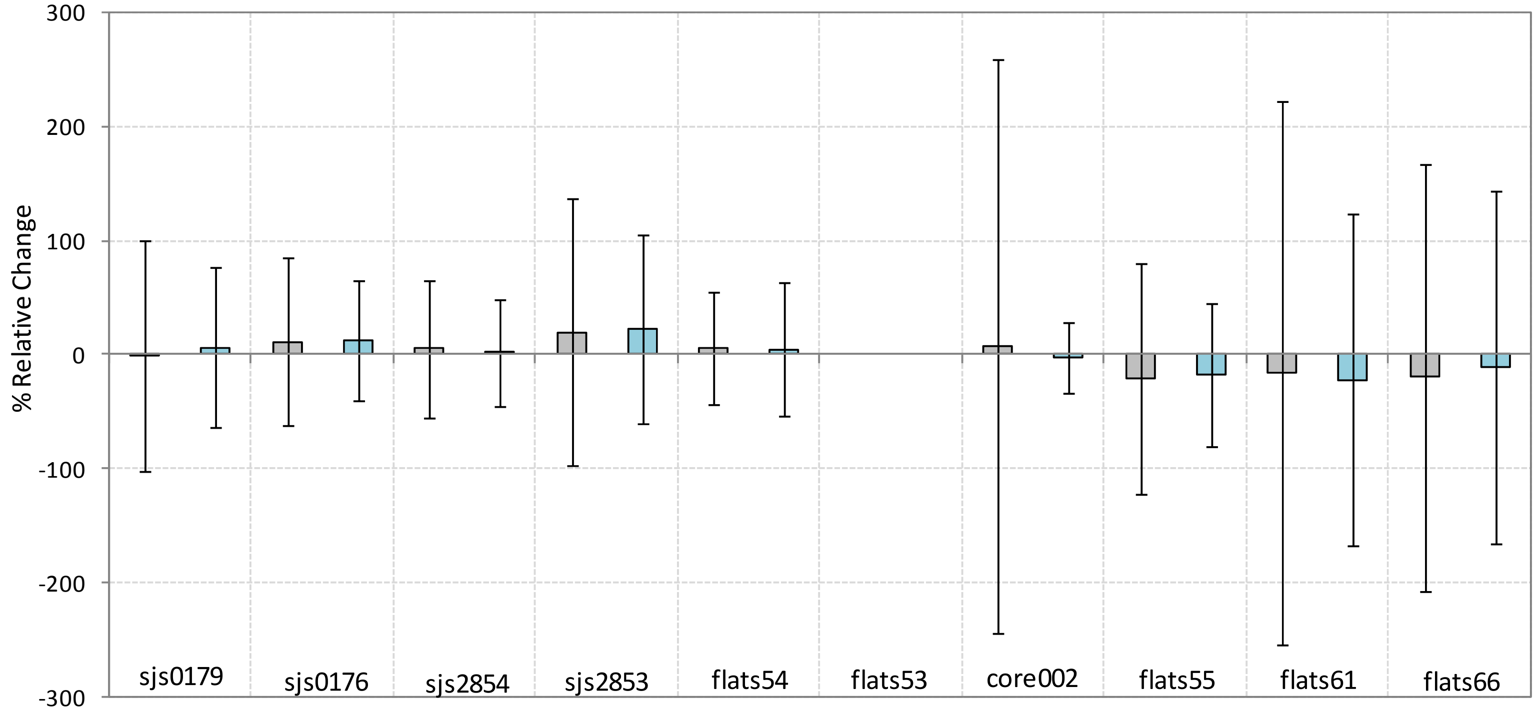
1. 2008

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site Code	**Location**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**
core002	Picnic Cove	14	-1.88	-0.52	2.58	0.43	0.84	14	-4.79	-5.70	0.22	0.13	0.25
flats55	Mitchell Bay	15	-2.79	-0.88	1.93	0.36	0.70	15	-4.19	-5.75	2.01	0.37	0.72
flats61	Shoal Bay	9	-0.40	0.01	0.11	0.11	0.22	19	-3.85	-6.84	5.53	0.54	1.06
flats66	Shallow Bay	13	-1.92	-0.05	2.42	0.43	0.85	13	-2.95	-5.75	3.97	0.55	1.08

2. 2009

		Minimum *Z. marina* Depth						Maximum *Z. marina* Depth					
Site Code	**Location**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**	**n**	**Mean Depth (m)**	**Absolute Depth (m)**	**Variance**	**Standard Error**	**95% Confidence Interval**
core002	Picnic Cove	13	-2.01	-0.24	2.84	0.47	0.92	13	-4.70	-5.68	0.35	0.16	0.32
flats55	Mitchell Bay	19	-3.53	-0.67	2.21	0.34	0.67	19	-5.06	-5.91	0.88	0.22	0.42
flats61	Shoal Bay	13	-0.33	0.20	0.16	0.11	0.22	19	-3.01	-6.42	4.72	0.50	0.98
flats66	Shallow Bay	20	-1.54	-0.01	1.80	0.30	0.59	20	-2.63	-5.11	2.32	0.34	0.67

Appendix E 2008 – 2009 Relative changes in *Z. marina* depth distribution



Estimated relative change in *Z. marina* depth distribution from 2008 (grey bars) to 2009 (blue bars). No significant trends were detected. Error bars are associated 95% confidence intervals.

Appendix F General site condition as observed during video data collection of *Z. marina* transects.

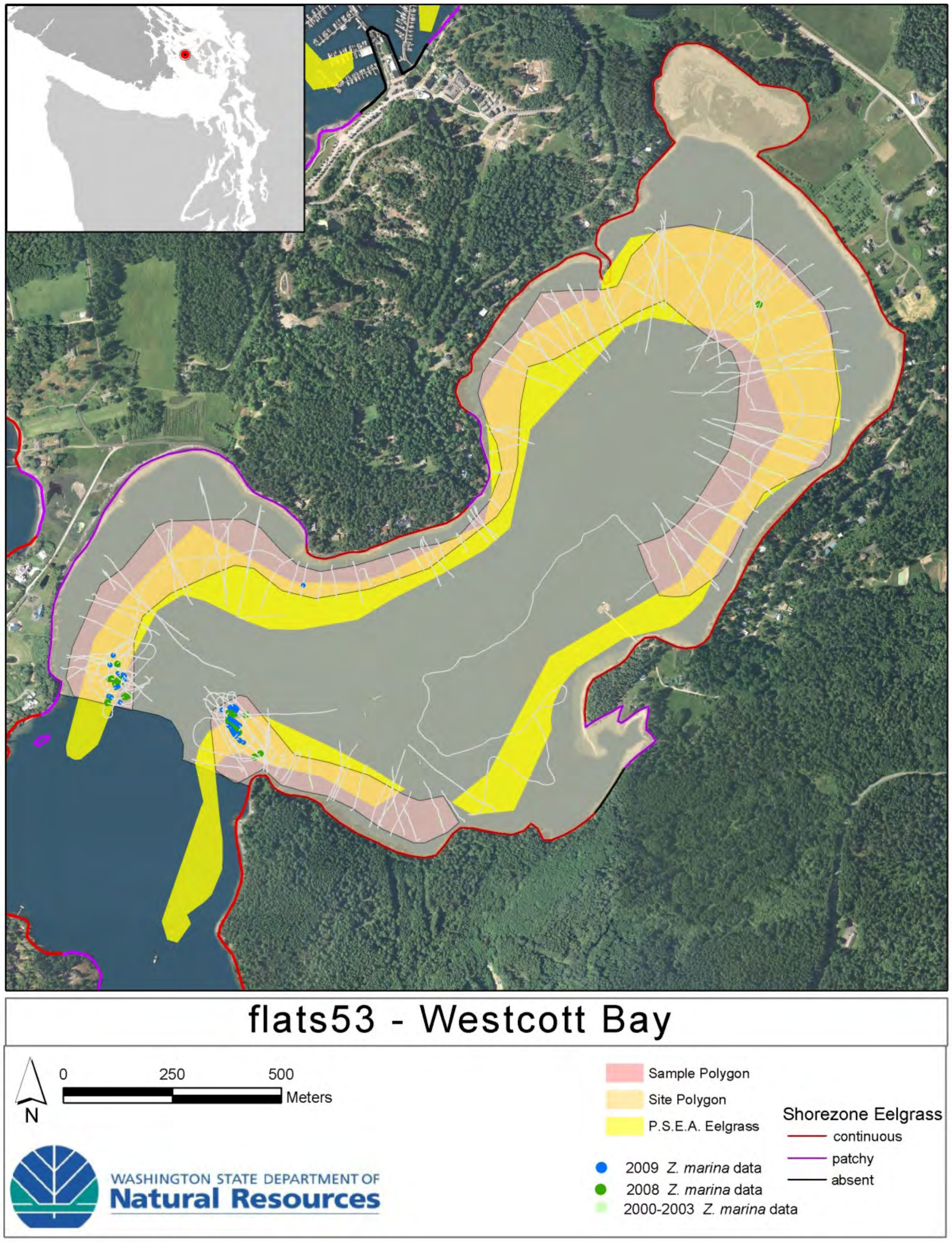
	Site Characteristics				General Site Observations						Visual Observations*	
	Site Code	Site Area (ha)	Sampling Area (ha)	Sampling Area % of site	Distribution	Epiphytes Intertidal	Epiphytes Subtidal	Sediment Composition Intertidal	Sediment Composition Subtidal	Observed Submerged Aquatic Vegetation	Water clarity	Current/ Flow
Westcott Bay Complex	sjs0179	9.2	8.3	90%	dense, continuous	mod	none	cobble	sand	ulvoids, kelp, brown & red algae, sargassum	clear	high
	sjs0176	8.5	7.5	88%	patchy, dense	mod	mod	mixed coarse	sand	ulvoids, kelp, brown & red algae, sargassum	clear	high
	sjs2853	11.8	7.7	65%	patchy	mod-high	mod-high	mixed coarse/ cobble	sand/mud	ulvoids	murky	low/mod
	sjs2854	5.8	2.9	50%	patchy	high	mod	mixed coarse	sand	ulvoids, kelp	clear	low/mod
	flats54	80.8	3.8	5%	patchy, sparse	mod	mod	mixed coarse, mud	sand/mud	ulvoids, brown algae	murky	very low
	flats53	158.8	9.6	6%	patchy, sparse	mod	mod	mixed fine/mud	mud	ulvoids (mouth)	murky	very low
SJA Shallow Embayments	core002	7.96	4.7	59%	patchy, sparse	high	high	mixed fine/mud	sand	ulvoids, kelp	clear	low/mod
	flats61	83.1	11.3	14%	sparse	high	mod	sand	sand	ulvoids, kelp, red algae	murky	low/mod
	flats55	66.9	11.3	17%	patchy, dense	mod	mod	gravel/ sand	sand/mud	ulvoids, kelp	clear	low
	flats66	23.4	14.4	62%	patchy, sparse	high	high	sand	sand	ulvoids, kelp, sargassum	clear	very low

Site Characteristics are parameters which are generally stable from year to year. Sampling area refers to the general area (ha) *Z. marina* was observed at a site and associated relative percentage it occupies at a given site. General Site Observations are physical variables of the site that are subject to change over short periods of time (e.g. days, weeks, season). *Visual Observations describe parameters subject to constant change throughout each day. All parameters are subject to interpretation of scientist collecting data.

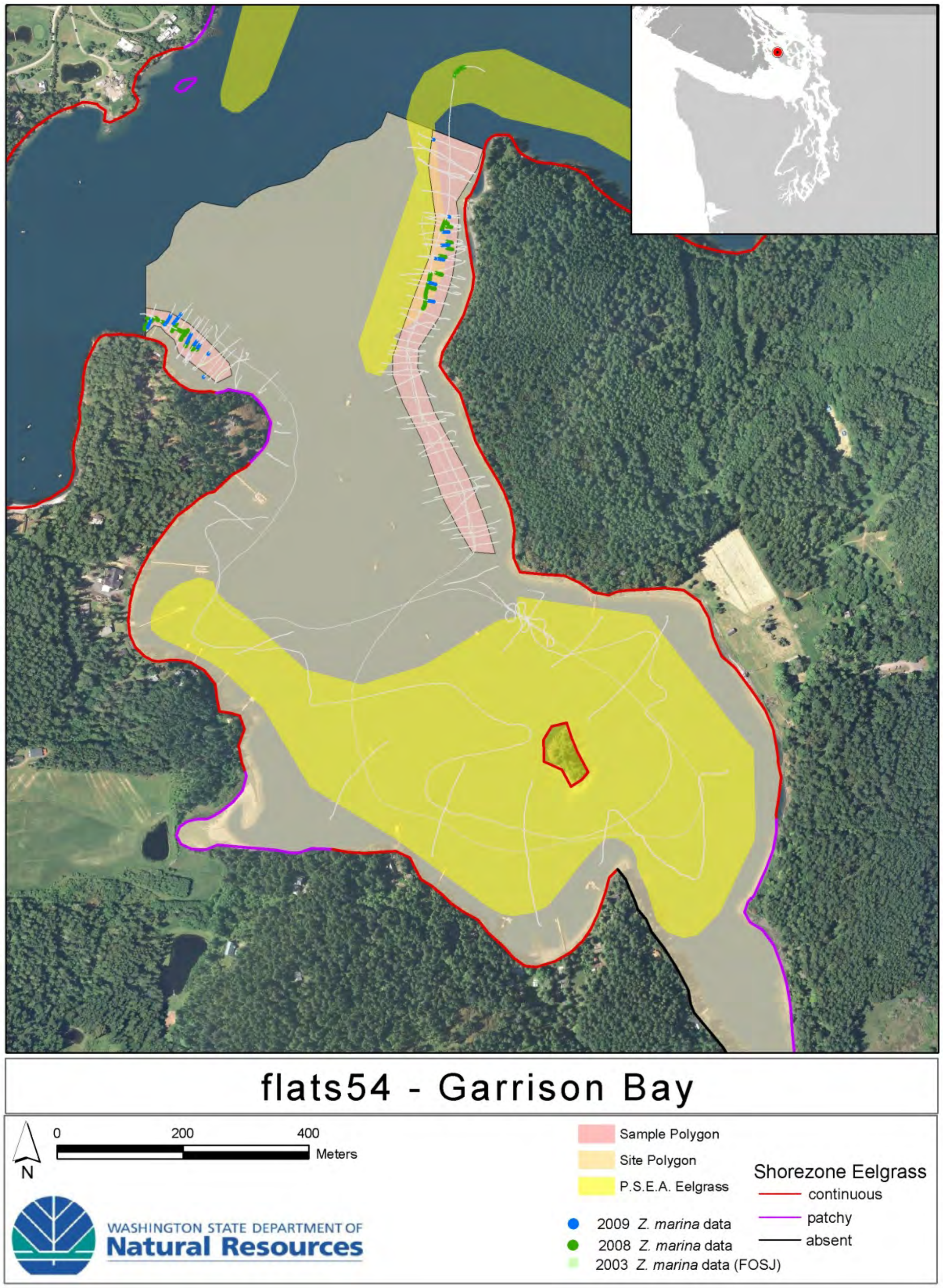
Appendix G Site Maps of Eelgrass (*Z. marina*) Data

Data were collected at 10 sites sampled in 2008 and 2009 in the San Juan Archipelago using SVMP sampling methodology. Maps include eelgrass data from the Puget Sound Environmental Atlas (P.S.E.A. 1987) and Washington State ShoreZone Inventory (2001).

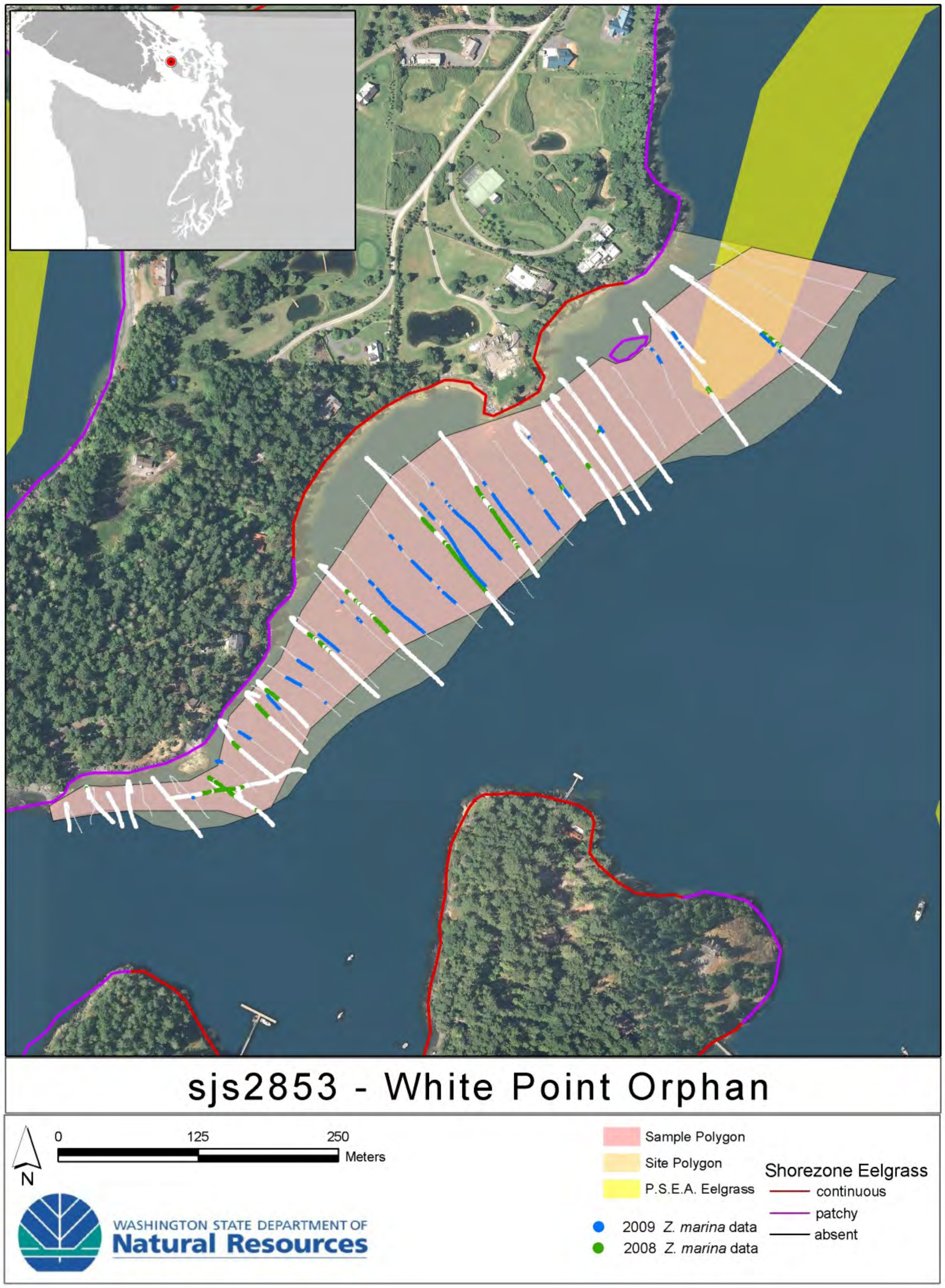
G.1. flats53 – Westcott Bay



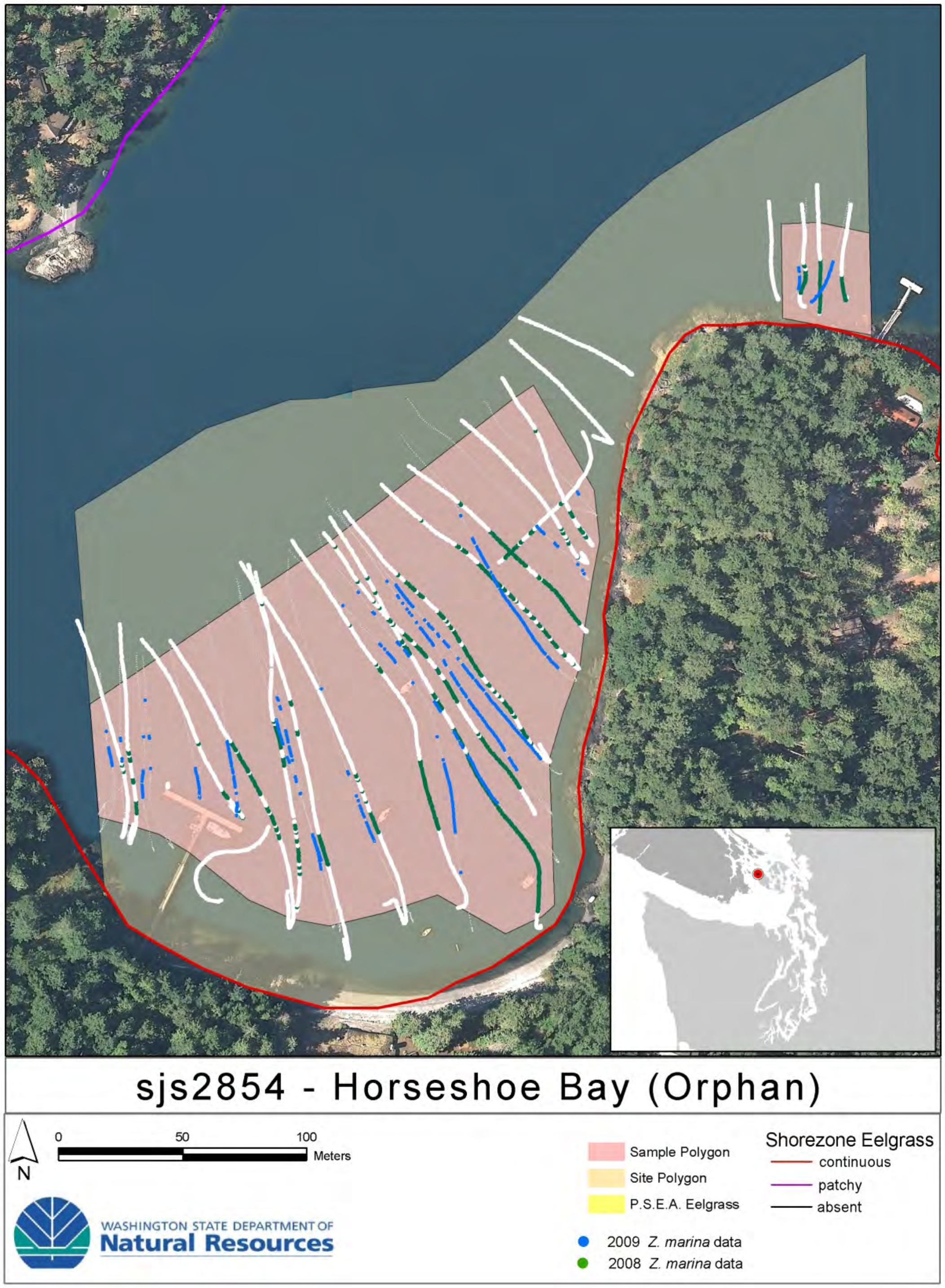
G.2. flats54 – Garrison Bay



G.3. sjs2853 – White Point (Orphan)

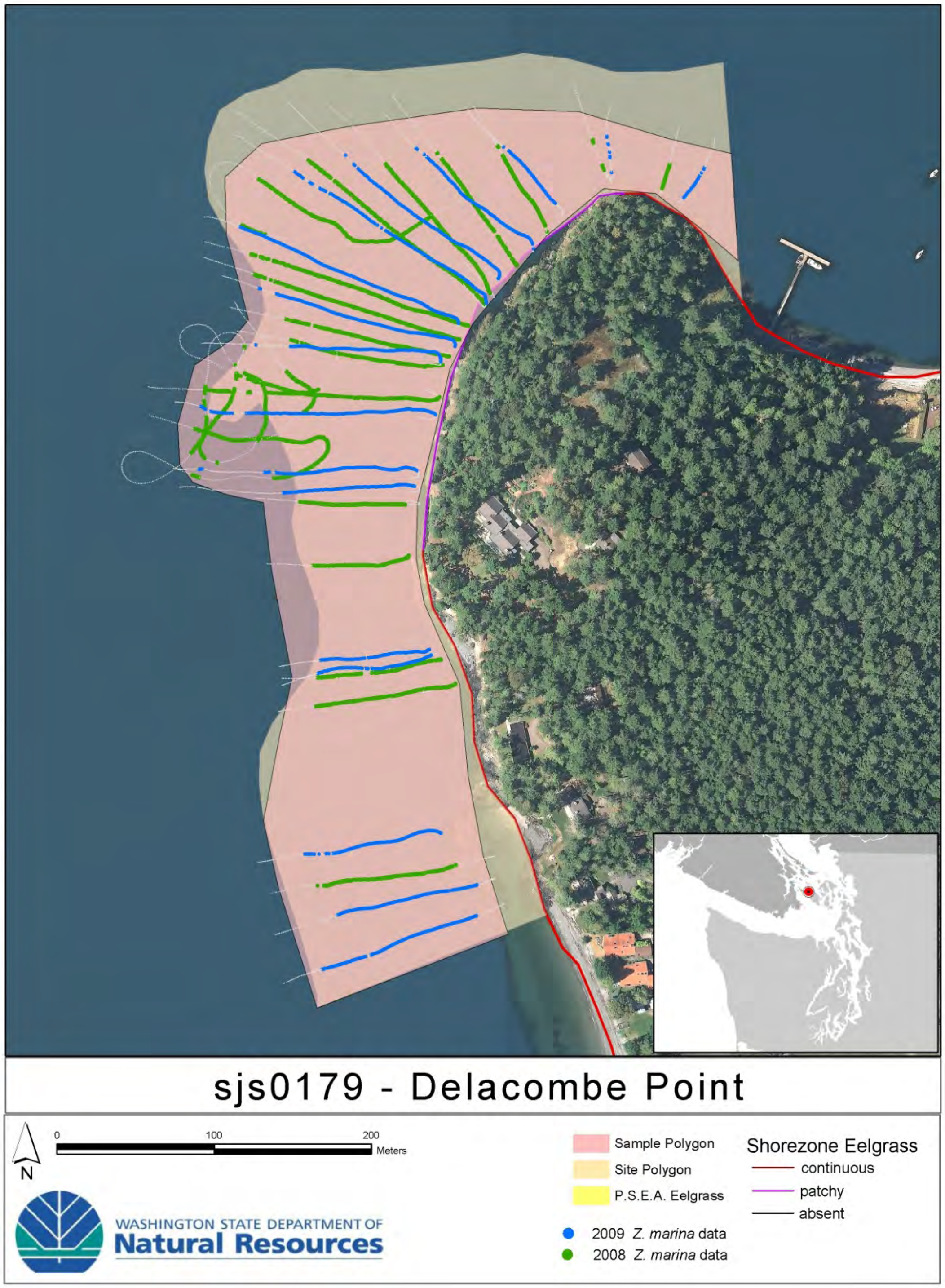


G.4. sjs2854 – Horseshoe Bay

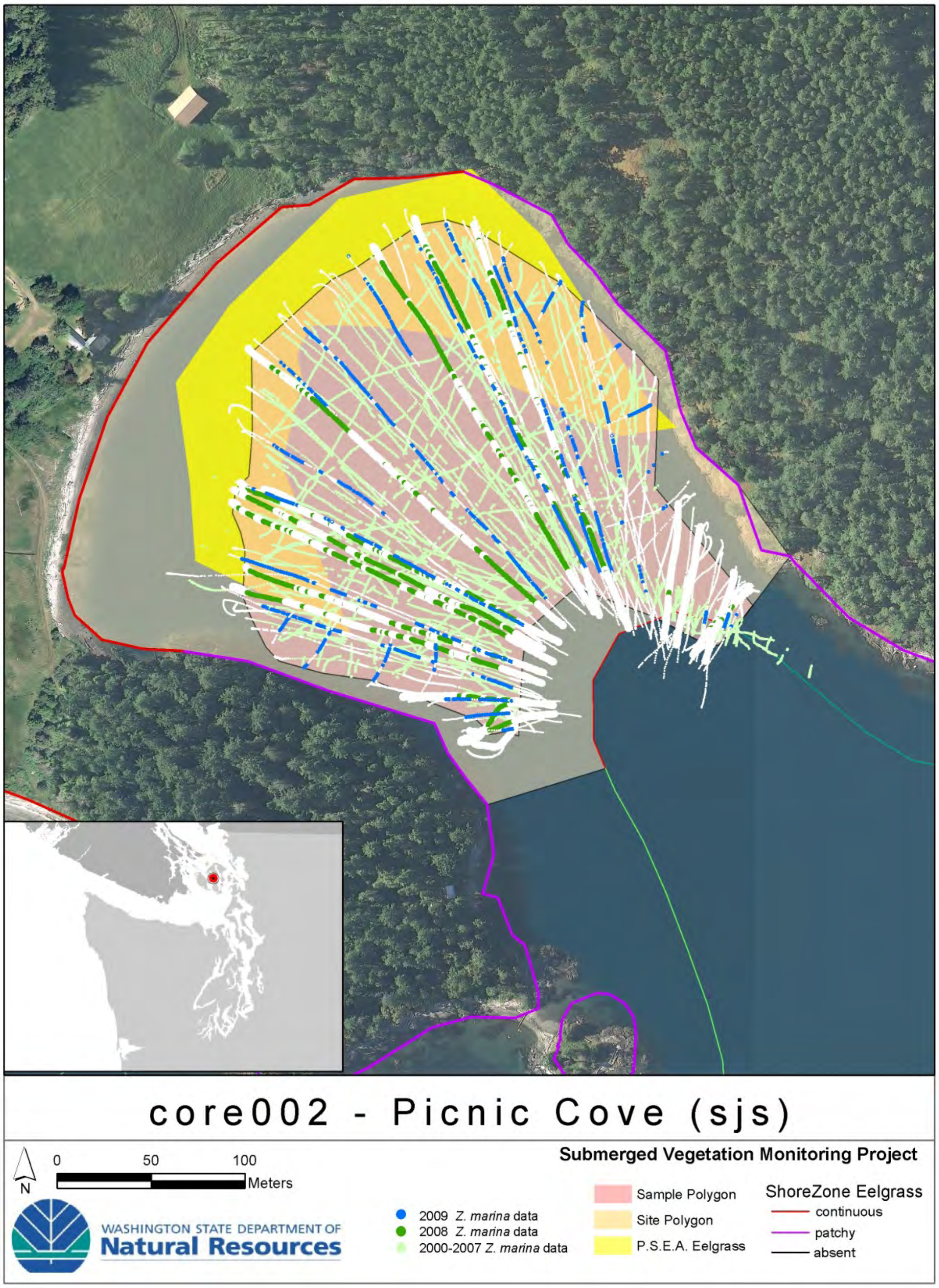


G.5. sjs0176 – White Point

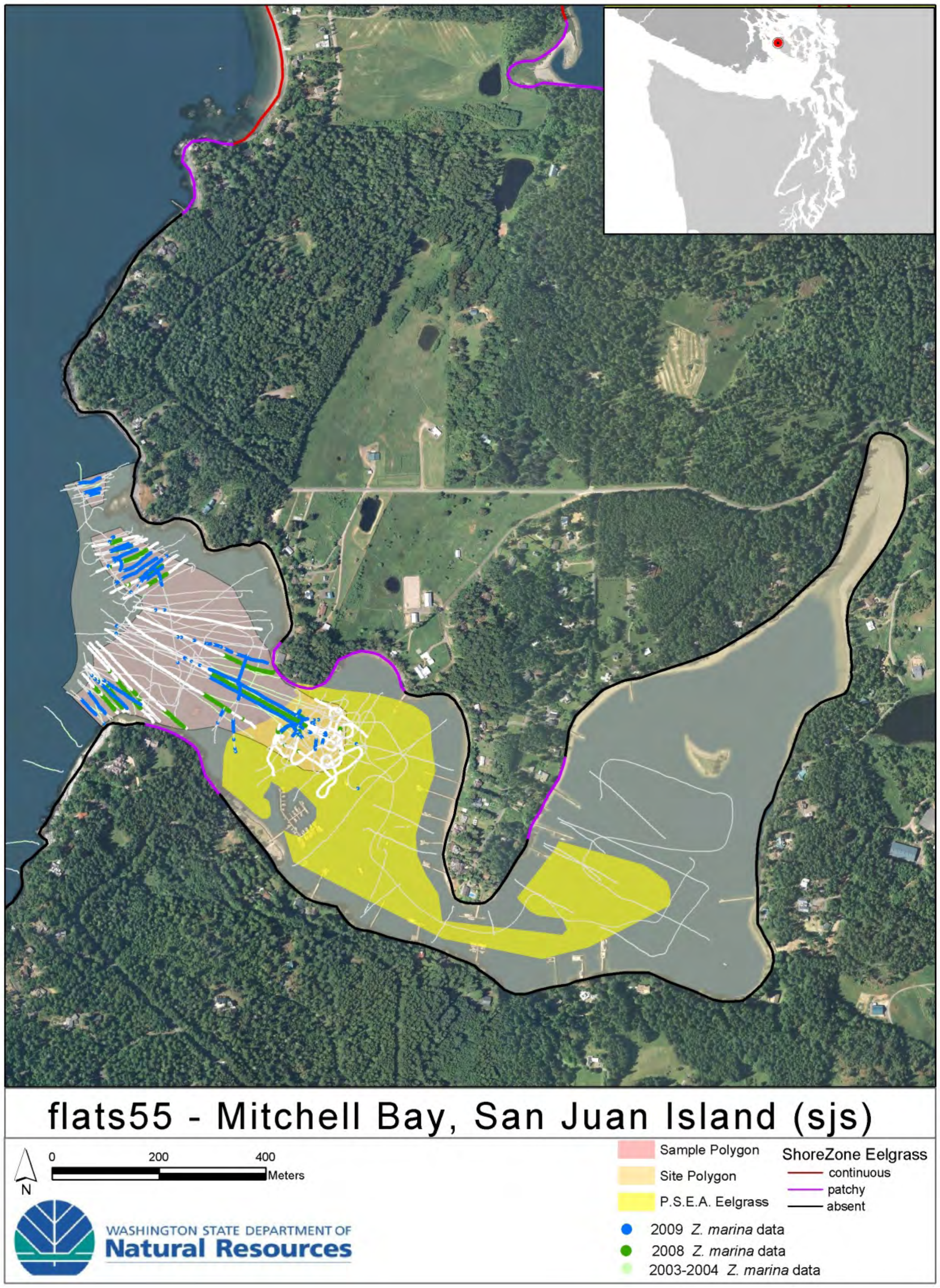
G.6. sjs0179 – Delacombe Point



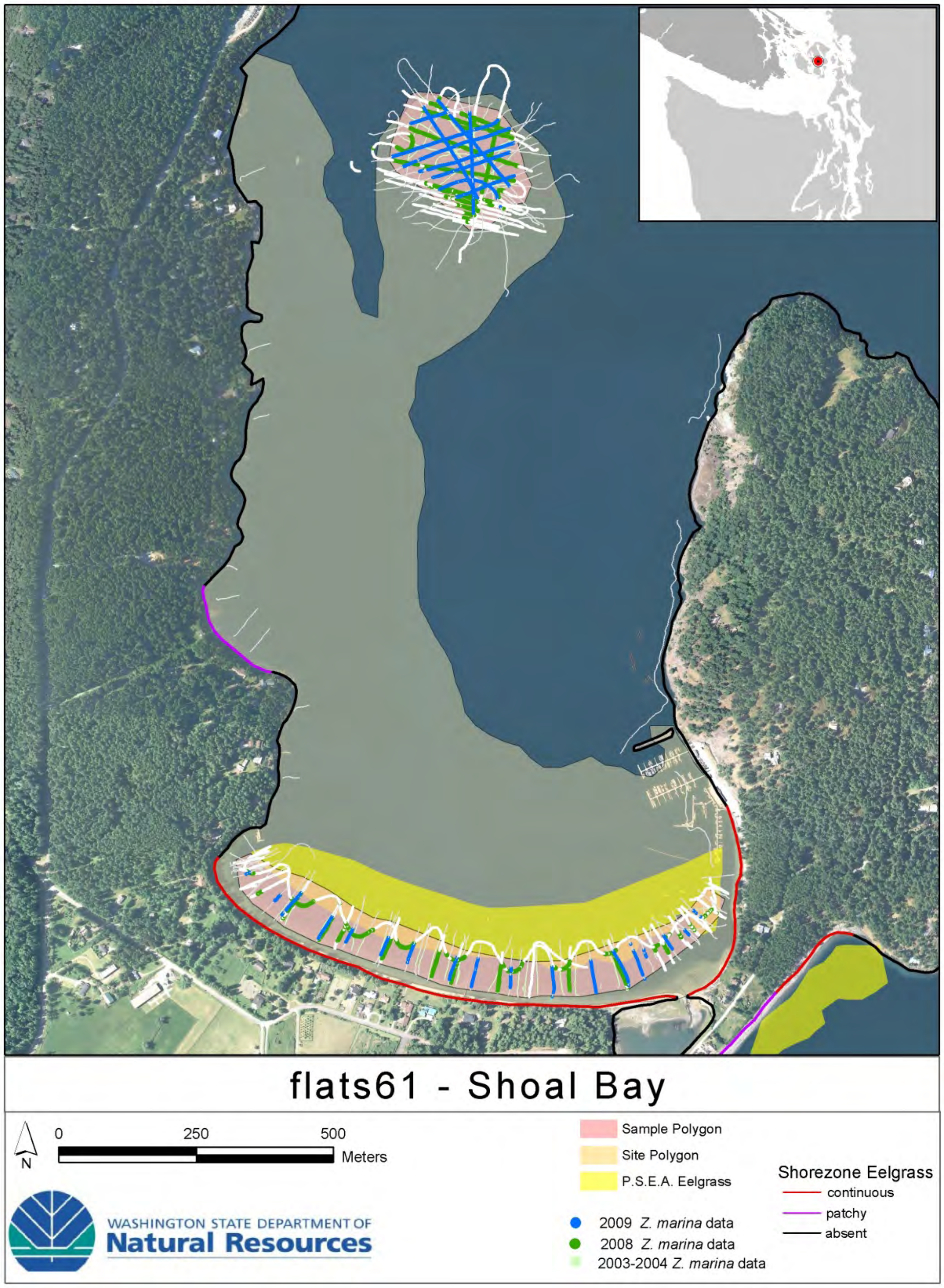
G.7. core002 – Picnic Cove



G.8. flats55 – Mitchell Bay



G.9. flats61 – Shoal Bay



G.10. flats66 – Shallow Bay