NATURAL RESOURCES

Puget Sound Submerged Vegetation Monitoring Program

2014 Report

March 5, 2016

PUGET SOUND ECOSYSTEM MONITORING PROGRAM

WASHINGTON STATE DEPARTMENT OF Natural Resources
Peter Goldmark - Commissioner of Public Lands

The Submerged Vegetation Monitoring Program is funded by the Washington State department of Natural Resources as part of the agency's work as steward of public lands to ensure environmental protection (http://www.dnr.wa.gov/). It is a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (http://sites.google.com/site/pugetsoundmonitoring/).

Cover Photo: Intertidal eelgrass bed West of Dumas Bay, King County. Bart Christiaen, DNR

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Acknowledgements

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The following document fulfills DNR's Eelgrass Monitoring performance measure. It also fulfills tasks in the Puget Sound Partnership's Action Agenda by providing information on the status and trends of one of the selected indicators of environmental health in Puget Sound.

The principal authors of this report include Bart Christiaen, Pete Dowty, Lisa Ferrier, Helen Berry, and Jeff Gaeckle. Several people played a critical role in the video data collection and post-processing for the work summarized in this report including Jessica Stowe and Evan Sutton.

The Nearshore Habitat Program would like to give special recognition to Ian Fraser and Jim Norris of Marine Resources Consultants who continue to play a significant role in the success of the project. Marine Resources Consultants showed great dedication and logged many hours of sea time collecting data for the project.

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Copies of this report may be obtained from:
http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-publications

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Executive Summary

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of state-owned aquatic lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of native seagrasses such as eelgrass (*Zostera marina*), an important component of nearshore habitats in greater Puget Sound. DNR monitors the status and trends of native seagrass abundance and depth distribution throughout the region using underwater videography. Monitoring was initiated in 2000 and results are used by the Puget Sound Partnership as one of 21 vital signs to track restoration progress (PSP 2014).

Key Findings:

1. Eelgrass (*Zostera marina*) is common throughout the region, but is most abundant in Northern Puget Sound. Eelgrass is by far the dominant native seagrass species in greater Puget Sound.
2. Approximately 50% of native seagrass grows on tidal flats, and 50% grows on narrow fringes along the shore. Seagrasses predominately occur on tidal flats in Northern Puget Sound (NPS) and the Saratoga/Whidbey Basin (SWH). Fringe sites are more common in Hood Canal (HDC), Central Puget Sound (CPS), and the San Juan Islands and the Strait of Juan de Fuca (SJS).
3. The 2014 estimate of soundwide native seagrass area is slightly higher than the 2000-2008 baseline. Current conditions have not yet met the Puget Sound Partnership's target for a 20% increase in area by 2020 (Figure C).
4. A total of 392 sites have been sampled as part of the Submerged Vegetation Monitoring Program; 313 sites were sampled over multiple years, and were analyzed for change. Approximately 72% of sites with multi-year data were stable, 13% had no native seagrass, 7% showed long-term increases, and 8% showed long-term declines. Many of the sites with long-term declines were located in lower Hood Canal, the San Juan Islands, and the southern part of central Puget Sound (Figure A).
5. Seagrass conditions improved in recent years. Between 2010 and 2014, approximately 12% of sites with multiyear data showed short-term increases, and only 1.4% showed short-term declines (Figure B). The recent reversal in trend is most pronounced in lower Hood Canal. The reason remains unknown; it could be a short-term anomaly or part of a longer-term pattern.
6. The non-native seagrass *Zostera japonica* was detected at approximately 20% of sites sampled. *Z. japonica* grows in the upper intertidal zone, and is less prevalent in high energy environments, such as the San Juan Islands and the Strait of Juan de Fuca.

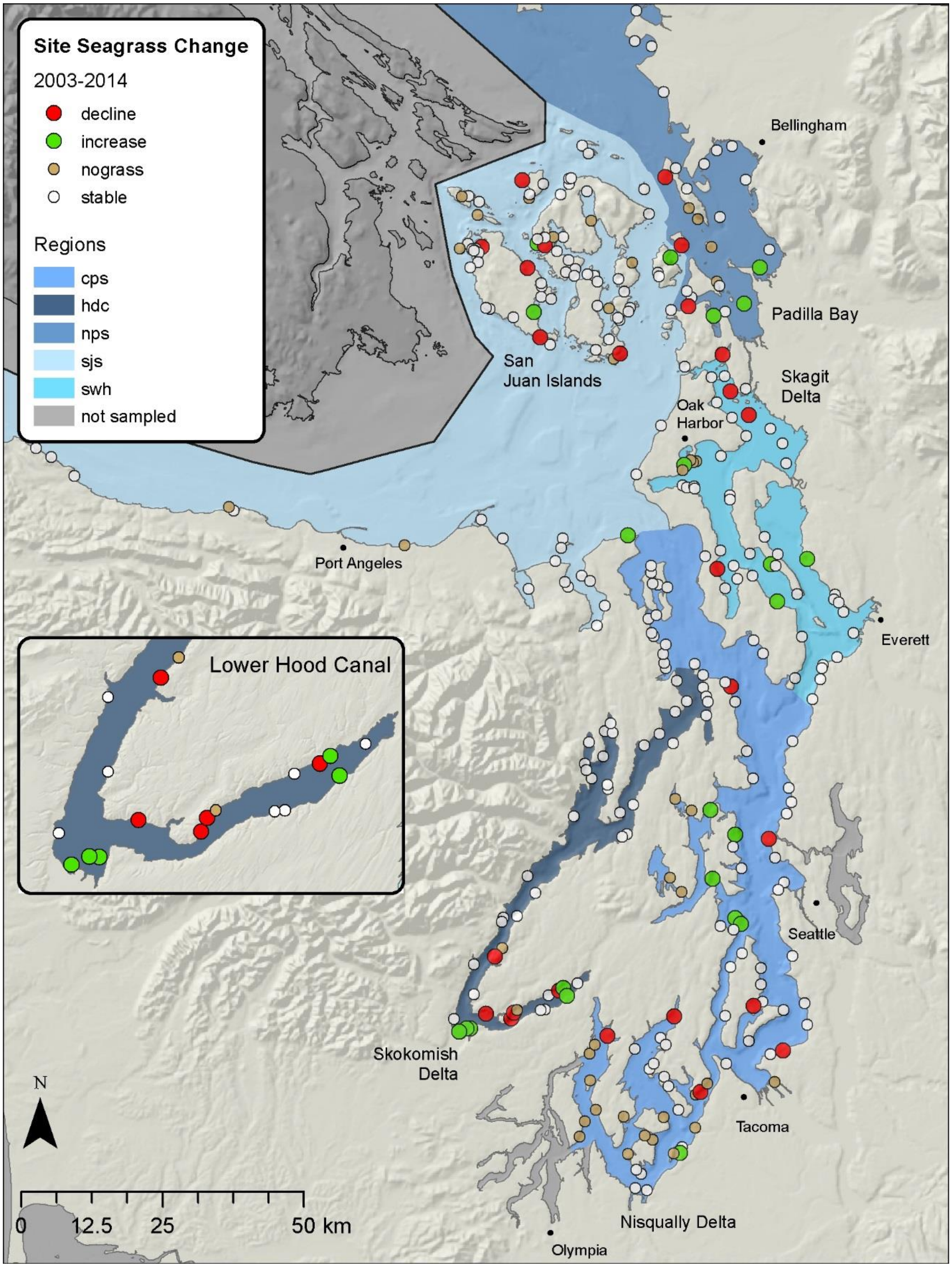


Figure A: Sites with significant trends in native seagrass area between 2003 and 2014.

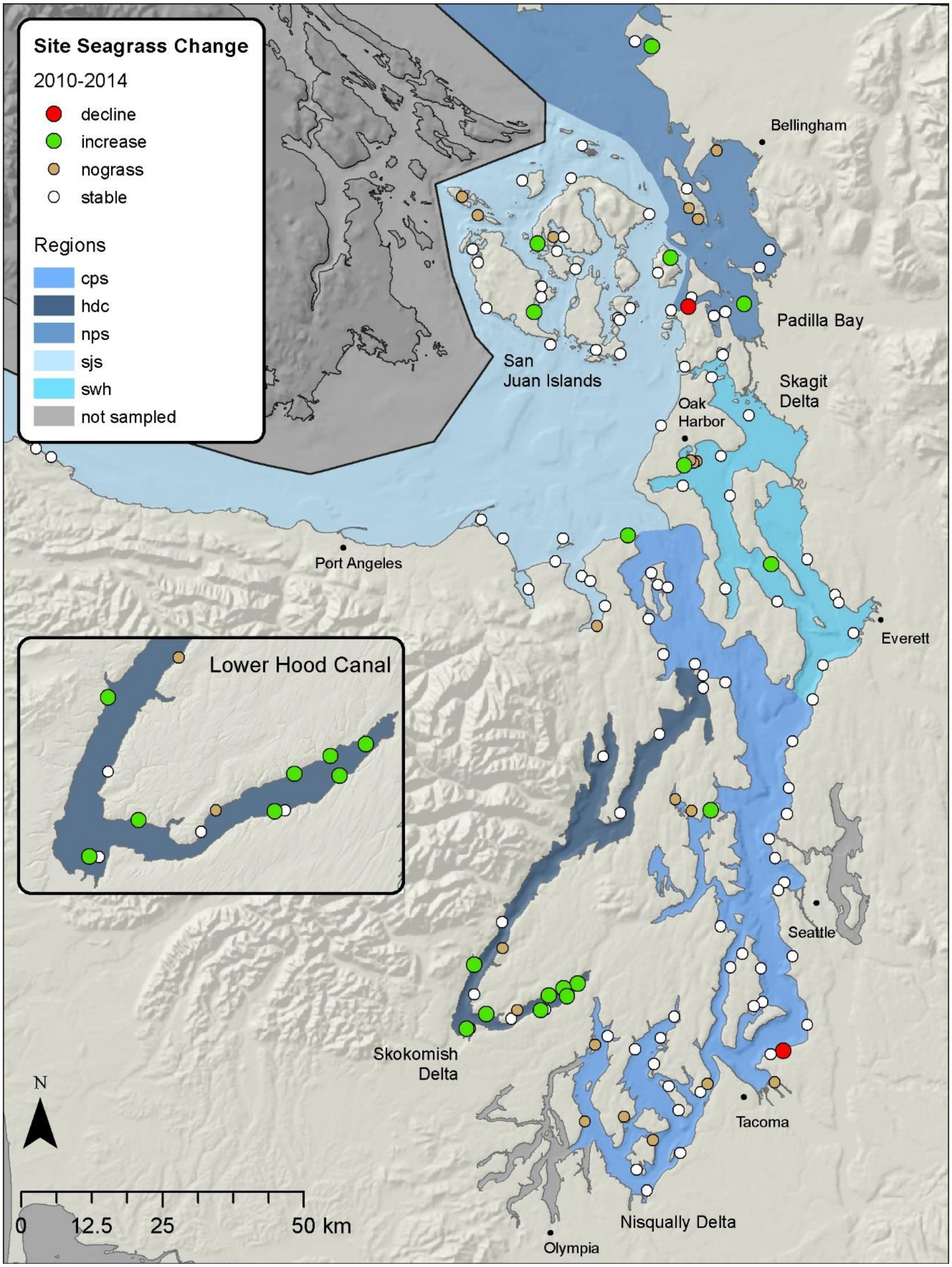


Figure B: Sites with significant trends in native seagrass area between 2010 and 2014

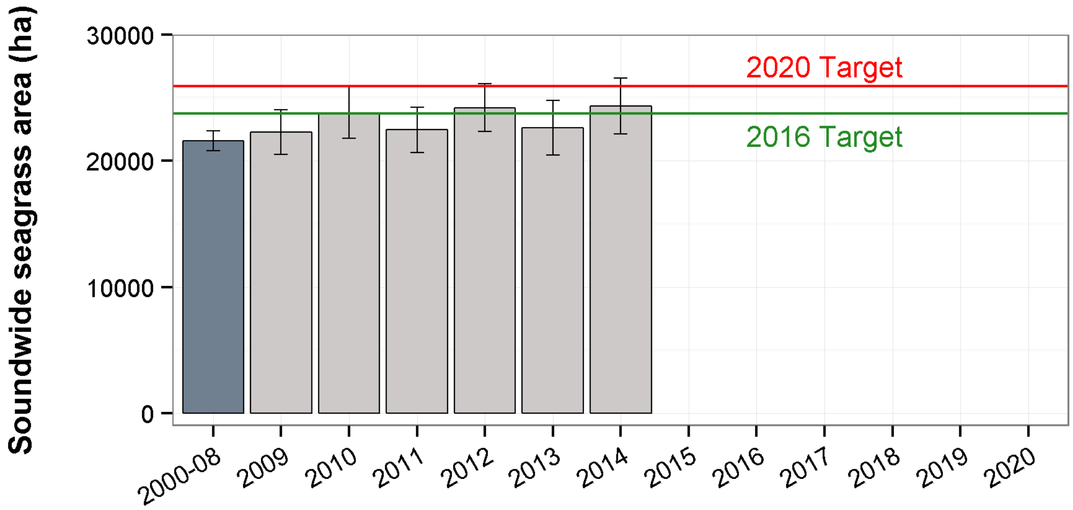


Figure C: Long-term trend in soundwide area of native seagrasses in greater Puget Sound. The dark grey bar represents the 2000-2008 baseline, the light grey bars represent annual soundwide area estimates, the green line is the 2016 interim target for Results Washington[1], and the red line is the long-term management target by the Puget Sound Partnership: a 20% increase in soundwide area relative to the baseline by 2020.

Priorities:

1. Continue to monitor the status and trends in native seagrasses throughout Puget Sound to meet goals defined by DNR and the Puget Sound Partnership. Increase the monitoring program's ability to detect long-term trends in seagrass area by enhancing the sample protocol at the site-level.
2. Provide technical support and data to scientists and managers on the status and trends in native seagrass, and on sites and regions of concern in Puget Sound.
3. Collaborate with other researchers to further assess changes in sites of particular interest, including those listed in the 2014 Puget Sound Eelgrass Recovery Strategy (Goehring et al. 2015). Initial focus will be on sites:
    a. in Quartermaster Harbor, an area with documented long-term declines in seagrass cover;
    b. in lower Hood Canal where recent increases in seagrass contrast with long-term declines;
    c. near the Skagit delta, where a recent avulsion has changed where the north fork of the Skagit River impacts local seagrass beds;
    d. near the delta of the Nisqually and the Skokomish, where seagrass beds increased coinciding with delta restoration projects.

[1] Results Washington is a strategic framework aimed at building a more responsive, data-driven state government. For more information, see http://results.wa.gov/

1 Introduction

1.1 The SVMP Program

Eelgrass (*Zostera marina*) provides a wide range of important ecosystem services. In Puget Sound, eelgrass offers 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). In addition, eelgrass provides valued hunting grounds and ceremonial foods for Native Americans and First Nation People in the Pacific Northwest (Suttles 1951, Felger and Moser 1973, Kuhnlein and Turner 1991, Wyllie-Echeverria and Ackerman 2003). Eelgrass responds quickly to anthropogenic stressors such as physical disturbance, and reduction in sediment and water quality due to excessive input of nutrients and organic matter. This makes eelgrass an effective indicator of habitat condition (Dennison et al. 1993, Short and Burdick 1996, Lee et al. 2004, Kenworthy et al. 2006, Orth et al. 2006). Research has generated an abundance of peer-reviewed literature and brought significant ecological and political attention to the species (e.g., Phillips 1984, Orth and Moore 1988, Krause-Jensen et al. 2003, Kemp et al. 1983, 2004, Moore and Short 2006, Waycott et al. 2009).

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. As part of its stewardship responsibilities, DNR monitors the native seagrass population (predominantly eelgrass, *Zostera marina*) across the nearshore of greater Puget Sound. DNR's seagrass monitoring is conducted on an annual basis by the Submerged Vegetation Monitoring Program (SVMP) – a component of the Nearshore Habitat Program in DNR's Aquatic Resources Division. The SVMP is one component of the broader Puget Sound Ecosystem Monitoring Program (PSEMP), a multi-agency monitoring program coordinated by the Puget Sound Partnership. The monitoring data is used to characterize the status of native seagrass and is one of 21 vital signs used by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound (PSP 2014). Earlier ecosystem indicator efforts in Puget Sound also included results from the seagrass monitoring data (PSP 2013, 2010; PSAT 2007, 2005, 2002). In February 2011, the Partnership adopted a restoration target for native seagrass that reflects a 20% gain in soundwide area by 2020 (PSP 2011) compared to a 2000-2008 baseline. In order to identify approaches to reach the target, the Partnership and DNR facilitated development of a multi-agency strategy for protection and restoration of eelgrass in 2014 (Goehring et al. 2015).

While eelgrass is the most abundant, it is not the only native seagrass species in greater Puget Sound. There are two species of surfgrass that are native to the area and tracked by the SVMP: *Phyllospadix scouleri* and *P. serrulatus*[2]. Observations of the seagrass *Zostera japonica* are also recorded as part of monitoring but these are excluded from SVMP area estimates because this species is non-native and has a number of distinct resource management issues (Bando 2006, Mach et al. 2010, Shafer et al. 2014, Hannam and Wyllie-Echeverria 2015). Because *Z. japonica* is excluded from SVMP area estimates, native seagrass area is referred to as seagrass area for the remainder of this report.

Other Washington State agencies also recognize the value of seagrass beds as an aquatic resource. The Washington State Department of Fish and Wildlife designated seagrass beds as habitats of special concern (WAC 220-110-250) under its statutory authority over hydraulic projects (RCW 77.55.021). Similarly, the Washington State Department of Ecology designated eelgrass areas as critical habitat (WAC 173-26-221) under its statutory authority to implement the state's Shoreline Management Act (RCW 90.58).

This report summarizes the methods and key results from the latest SVMP analysis. This analysis is based on the most recent version of the monitoring dataset that spans 15 years (2000-2014) and includes data from approximately 23,600 transects and over 8 million points where eelgrass has been classified.

1.2 Data Access

The SVMP monitoring database and a User Manual are available through the DNR GIS data download web page. The data is also accessible through an online data viewer. The User Manual (NHP 2014) includes a more detailed description of project methods than are included in this report.

http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-eelgrass-monitoring

http://data-wadnr.opendata.arcgis.com/

http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/puget-sound-eelgrass-monitoring-data-viewer

[2] A third species, *Phyllospadix torreyi*, is present on the outer coast but has not been observed in greater Puget Sound by the SVMP.

2 Methods

A comprehensive presentation of SVMP methods is available in the User Manual distributed with the digital dataset (see section 1.2 p.6). Here, a brief overview of methods is presented and recent developments are highlighted.

2.1 Overview of SVMP methods

The SVMP is a regional monitoring program, initiated in 2000, designed to provide information on both the status and trends in native seagrass area in greater Puget Sound. This program uses towed underwater video as the main data collection methodology, in order to provide reliable estimates of seagrass area for subtidal seagrass beds in places where airborne remote sensing cannot detect the deep edge of the bed. Video data is collected along transects that are oriented perpendicular to shore and span the area where native seagrasses grow at a site. The video is later reviewed and each transect segment of nominal one-meter length (and one-meter width) is classified with respect to the presence of *Z. marina*, *Phyllospadix sp*. and *Z. japonica*. Survey results include seagrass area, mean minimum and maximum depth, and species distribution.

Because this sample technique is labor intensive, the SVMP uses a statistical framework to provide regional estimates of seagrass area in greater Puget Sound based on data from a subset of sites. The data for this framework is gathered through annual stratified random sampling. All of the potential seagrass habitat in greater Puget Sound was divided into 2,467 sample sites. These sites were divided into 5 strata: core, persistent flats (flp), rotational flats (flr), narrow fringe (frn) and wide fringe (frw). The core and persistent flats strata contain a small number of sites (n= 6 and n=3 respectively) that are visited each year. For the other strata (rotational flats, wide fringe and narrow fringe), a random sample of sites is visited each year. These strata are subject to a rotational sample design, where 20% of sites are replaced by new randomly selected sites each year. Sites remain in the sample for 5 consecutive years before rotating out. Further details on the stratified design can be found in the User Manual (NHP 2014).

The statistical framework, used to generate the soundwide and regional estimates, extrapolates the average of all measured site values per stratum based on the total potential area where native seagrass can grow for the stratum (rotational flats), or based on the length of shoreline for the entire stratum (narrow fringe and wide fringe). The calculations of variance around the mean for each stratum are detailed in Skalski (2003). The soundwide seagrass estimate consists of the sum of all stratum estimates, and the variance around the soundwide estimate is calculated as the sum of the variances for each individual stratum.

From 2004 to 2012, supplemental sites were sampled each year in one of five sub-regions of the study area in order to produce estimates at the sub-region, or focus area, scale with a return every five years to the same focus area. The sub-regions are central Puget Sound (CPS), Hood Canal (HDC), the San Juan Islands and the Strait (SJS), Northern Puget Sound (NPS) and the Saratoga Whidbey Basin (SWB). This work is referred to as the “focus area study”. In 2013 and 2014, new site survey methods were tested at a subset of sites to evaluate techniques to improve the precision of site results. In addition to special studies implemented by the program, the SVMP frequently completes surveys to characterize the status of local seagrass beds, often in collaboration with other research, resource management, and citizen groups. Results from these site surveys are outside the regional design and do not contribute to estimates of soundwide seagrass area.

2.2 Recent methodological developments

2.2.1 Multiyear estimates on a sub-regional spatial scale

Our previous estimates of seagrass area for the sub-regions was solely based on data collected in the year of the focus study in that sub-region. However, it is possible to increase the sample size for this calculation by combining the focus area study with data collected over several years as part of the SVMP. In order to use these data, we calculate averages of annual seagrass area estimates at each site, and calculate the variance around these mean values as the pooled variance of all the annual estimates (Table 1). These values are then used as input for a calculation similar to the statistical framework for the soundwide SVMP estimate. By doing so, we increase the sample size from 52 to104 for Central Puget Sound, 31 to 51 for the Saratoga Whidbey Basin, 41 to 56 for Hood Canal, 45 to 103 for the San Juan Islands and the Strait, and 38 to 59 for Northern Puget Sound (Table 2). For all sub-regions, the seagrass estimate is now based on a sample of at least 12% of the total number of sites for the sub-region.

Table 1 : **Calculation of mean and pooled variance for individual sites.**

Mean seagrass area for site X, sampled for k years. X_i = mean seagrass area at site X for year i	Pooled Variance for site X, sampled for k years, with n_i = the sample size for year i, and s_i^2 the variance for year i
$\overline{X} = \frac{\sum_{i=1}^{k} Xi}{k}$	$Pooled\ Var = \frac{\sum_{i=1}^{k}(n_i - 1){s_i}^2}{\sum_{i=1}^{k}(n_i - 1)}$

There are several assumptions for using the calculation described in Table 1. By using the pooled variance, we assume that for individual sites, the variance of the annual estimates of seagrass area is the same. In addition, we assume that the mean of several annual estimates of site area is representative of the mean seagrass area at the site for the entire period of the monitoring program (2000-2014). This is a reasonable assumption, as only 7% of all sites monitored for the SVMP showed long-term increases and only 8% showed long-term declines. The added benefit of increasing the sample size likely outweighs the loss of temporal resolution introduced by using multiyear estimates to assess the status of seagrass at a sub-regional scale.

Table 2: The total number of sites used to calculate sub-regional estimates of seagrass area for the traditional calculation (left) compared to the multiyear estimates (right)

	Traditional calculation					Multiyear estimate				
	CPS	HDC	NPS	SJS	SWH	CPS	HDC	NPS	SJS	SWH
core	2	1	1	2	0	2	1	1	2	0
flp		0	2	0	1	0	0	2	0	1
flr	4	5	3	10	9	7	5	9	19	9
frn	38	22	24	33	16	83	36	34	68	24
frw	8	13	8	0	7	12	14	13	14	17
Total sampled	52	41	38	45	33	104	56	59	103	51
Sites in sub-region	854	292	200	851	270	854	292	200	851	270
% sites sampled	6.1	14.0	19.0	5.3	12.2	12.2	19.2	29.5	12.1	18.9

2.2.2 Rotational sample strategy

The current sample design is a compromise between estimating status (sample as many sites as possible) and trend (repeat sampling of the same sites). Recent analyses have shown that the 20% rotation in site selection introduces a number of problems for estimating trends in soundwide seagrass area (NHP 2015). Site rotation has an effect on trend estimates because the underlying distribution of site seagrass area is highly skewed rather than approximating a normal distribution (Figure 5). Most sites have small seagrass beds but there are a small number that have very large beds. The SVMP uses a stratified design that accounts for large differences in site area between different strata. However, within these strata there is still significant variability in site seagrass area, and the distribution of site seagrass area remains skewed. When sites with large native seagrass beds rotate in, or sites with small native seagrass beds rotate out of the sample set, the estimated soundwide seagrass area will increase. This increase is solely due to random site selection, and does not represent an actual increase of seagrass area in Puget Sound. As a consequence, it is not possible to interpret small increases or decreases as an actual trend in the dataset, as these represent random noise introduced by site rotation. The observed weaknesses of 20% site rotation in both the soundwide seagrass area estimates and the year-to-year change estimates outweigh the intended benefits of rotation (i.e., more closely representing actual Puget Sound conditions by measuring a larger portion of the population over time). As a result, the SVMP program has been evaluating alternative rotation designs.

From 2015 on, the SVMP program will shift sample effort towards detecting trends, because information on local trends is of critical importance for management of seagrass beds. A first step towards readjusting the priorities of the sample program is to remove the 20% rotation in the site selection. As such, 2014 was the last year sampled with the rotational sample design. From 2015 on, the SVMP will sample based on a 3-year rotational panel of ~240 independent random sites. Every 3 years, we will revisit all sites sampled in either 2004, 2009 or 2014; and use 3-year rolling averages based on all sites sampled, to generate unbiased estimates of soundwide seagrass area in greater Puget Sound. A detailed description of the modification of the SVMP methodology will be published in another report.

3 Results

3.1 Field effort summary

The number of sites sampled for the SVMP between 2000 and 2014 are shown in Table 3. In 2013, the SVMP regional focus study was suspended and this effort was reallocated to sampling at demonstration sites using developmental site survey methods.

Table 3: Number of SVMP sites sampled and the allocation over different studies from 2000 to 2014. The number of sites visited but not sampled due to obstruction are listed in the last column.

Year	Number of Sites Sampled				Sites Visited but Obstructed
	Soundwide Study	Focus Study	Special Studies	Demonstration Sites	
2000	62	0	0	0	5
2001	72	0	0	0	3
2002	73	0	0	0	3
2003	76	0	7	0	0
2004	79	28	4	0	0
2005	78	32	0	0	2
2006	79	24	3	0	0
2007	79	32	5	0	0
2008	76	29	32	0	3
2009	80	28	18	0	0
2010	78	30	40	0	2
2011	77	24	11	0	2
2012	77	32	28	0	2
2013	78	0	25	42	1
2014	79	0	100[3]	41	0

[3] In 2014, 95 sites were sampled as part of an agreements with an external funding source (DNR Stressor Response Program, IAA 1517 DNR-Suquamish). Results from this additional sampling will be published in a separate report.

3.2 Seagrass in greater Puget Sound: a status update

Native seagrasses (predominantly eelgrass or *Zostera marina*) are common in greater Puget Sound. Over 83% of sites sampled had *Z. marina* present. Eelgrass does not occur in the extreme reaches of southern Puget Sound and Liberty Bay, and is relatively sparse in Dyes Inlet, Bellingham Bay near the Nooksack River delta, and along the Strait of Juan de Fuca (

Figure 2). In terms of areal cover, eelgrass is most abundant in Northern Puget Sound, the Saratoga Whidbey Basin and the San Juan Islands (Figure 1).

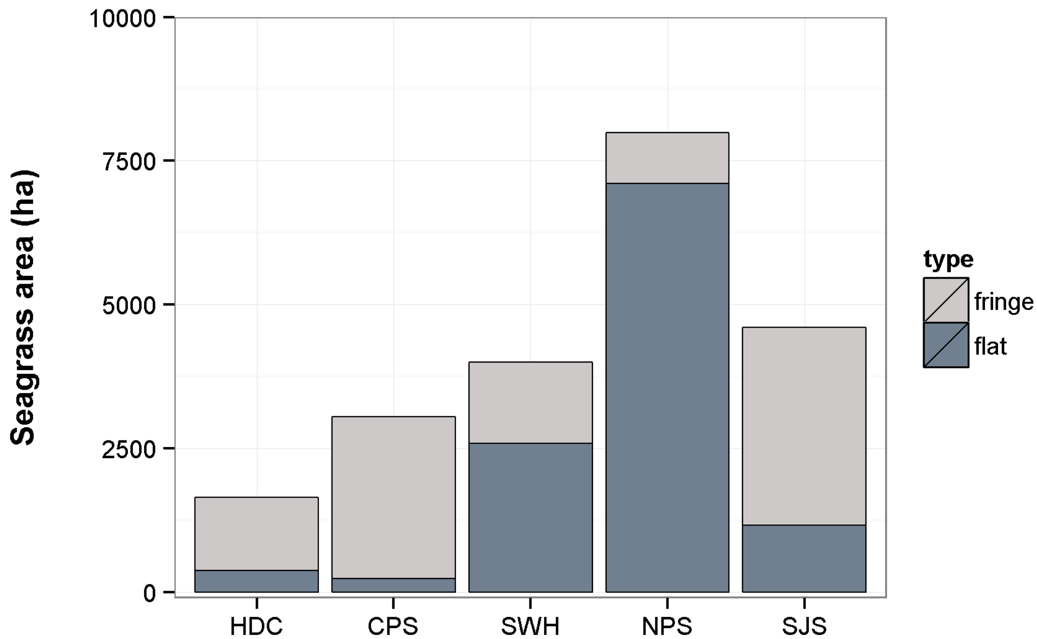


Figure 1: Native seagrass area (ha) in the different sub-regions of greater Puget Sound. The darker color represents the fraction that grows on flats. The lighter color indicates the amount of seagrass at fringe sites. HDC stands for Hood Canal, CPS is Central Puget Sound, SWH is Saratoga Whidbey Basin, NPS is North Puget Sound, and SJS is the San Juan Islands and the Strait of Juan de Fuca.

The size distribution of seagrass beds in greater Puget Sound is skewed (Figure 5). Approximately 50% of native seagrass grows on tidal flats. Seagrass beds at these sites tend to be larger (median size 28 ha, range 0.1 – 3,275 ha), but are relatively few in number (74 total). The remaining 50% grows in smaller fringe beds in narrow bands along the shoreline. While these beds are small (median size 3.17 ha, range 0.03 - 60.23 ha), they are abundant (2,393 sites total). In Northern Puget Sound and the Saratoga Whidbey Basin, most of the seagrass grows on flats sites. In Hood Canal, Central Puget Sound and the San Juan Islands and the Strait, the majority of seagrass grows in fringe sites. The largest seagrass beds are in Padilla Bay and Samish Bay. These two locations contain approximately 20% of all native seagrass in greater Puget Sound (Figure 6).

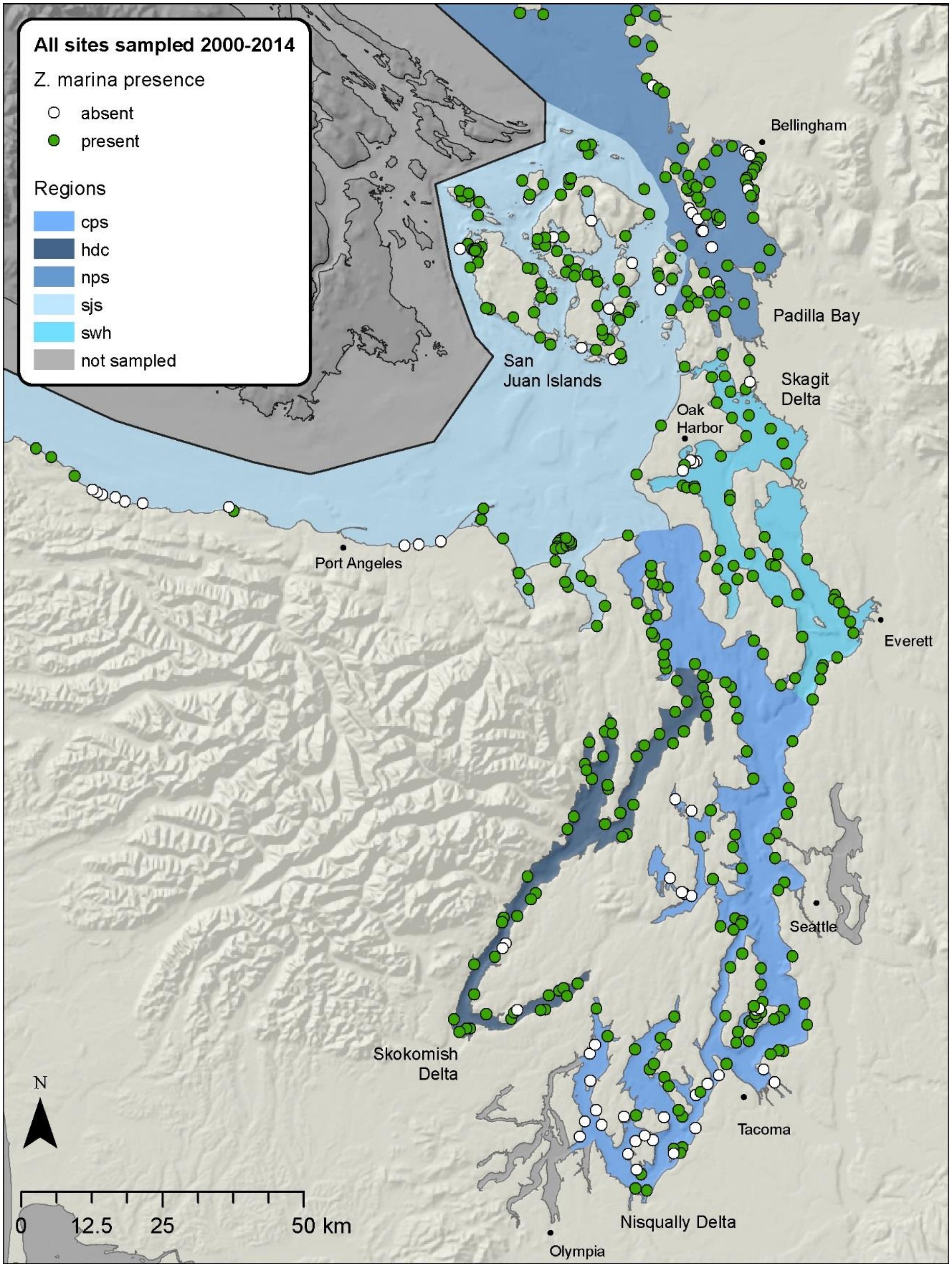


Figure 2: Presence of eelgrass (*Zostera marina*) at sites throughout Puget Sound. The 95 sites sampled for the Suquamish project in 2014 (Table 3) are not indicated on the map, and will be published in another report.

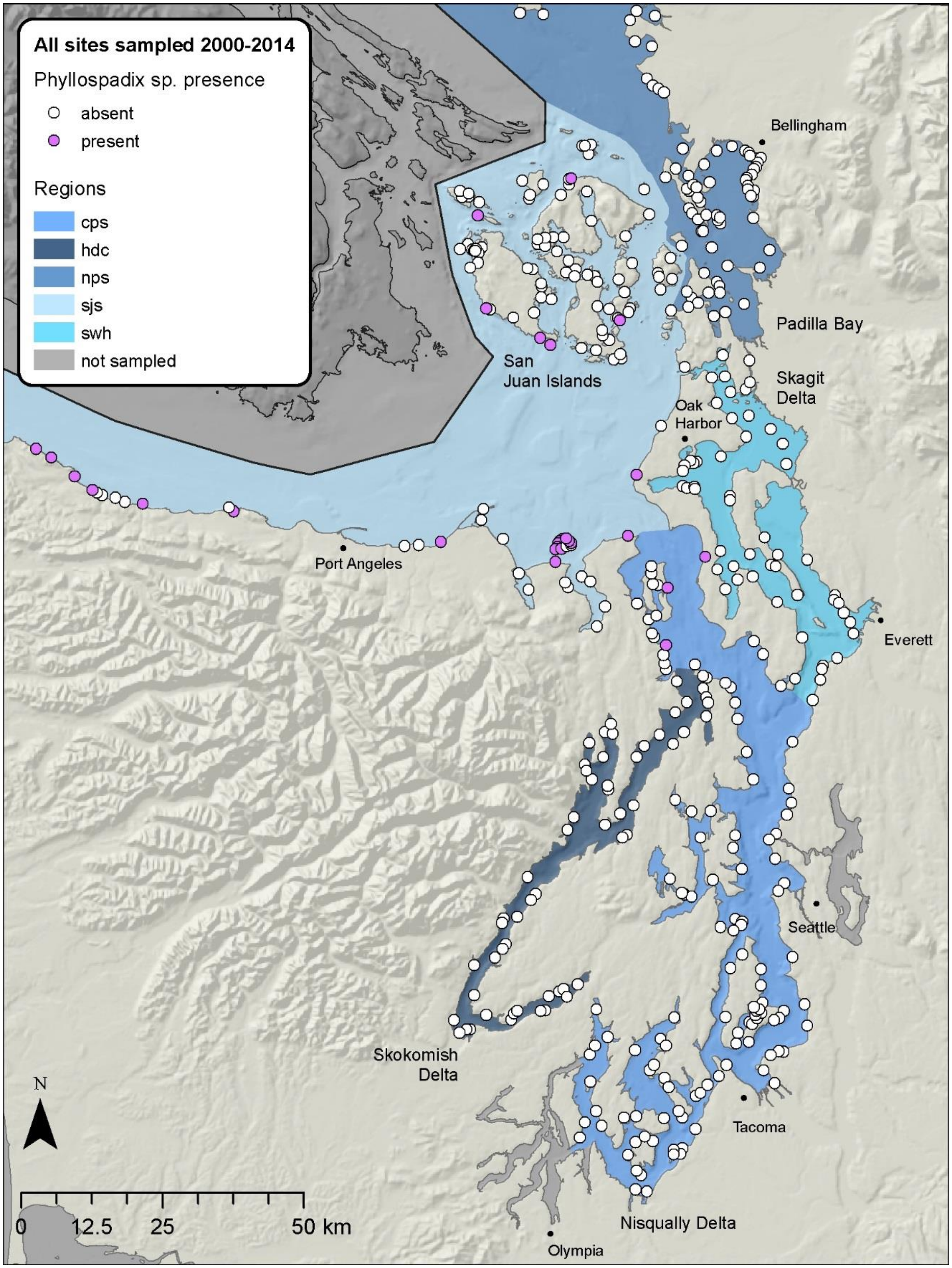


Figure 3 : Presence of surfgrass (*Phyllospadix sp.)* at sites throughout Puget Sound.

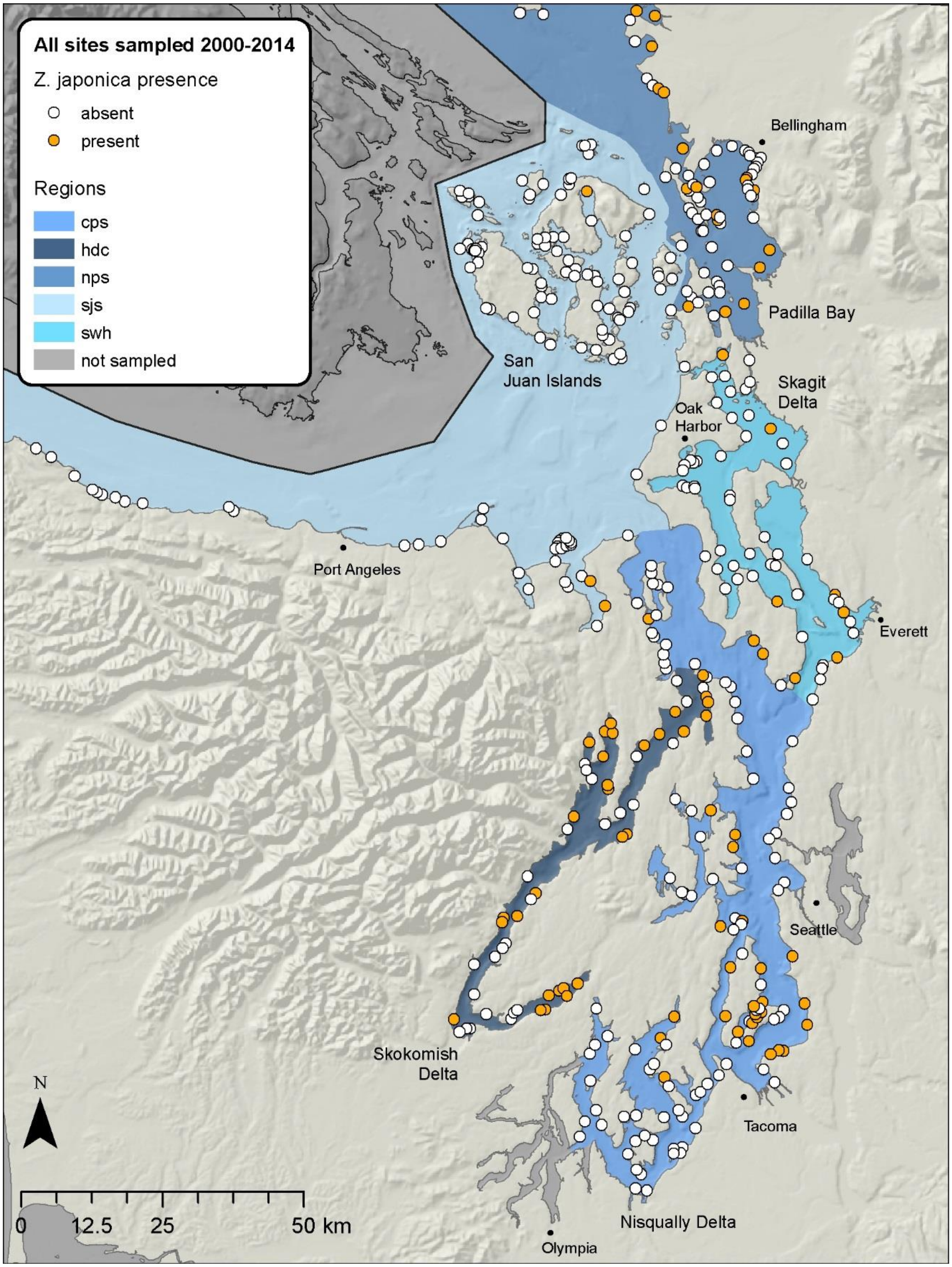


Figure 4 : Presence of Japanese dwarf eelgrass (*Zostera japonica*) at sites throughout Puget Sound.

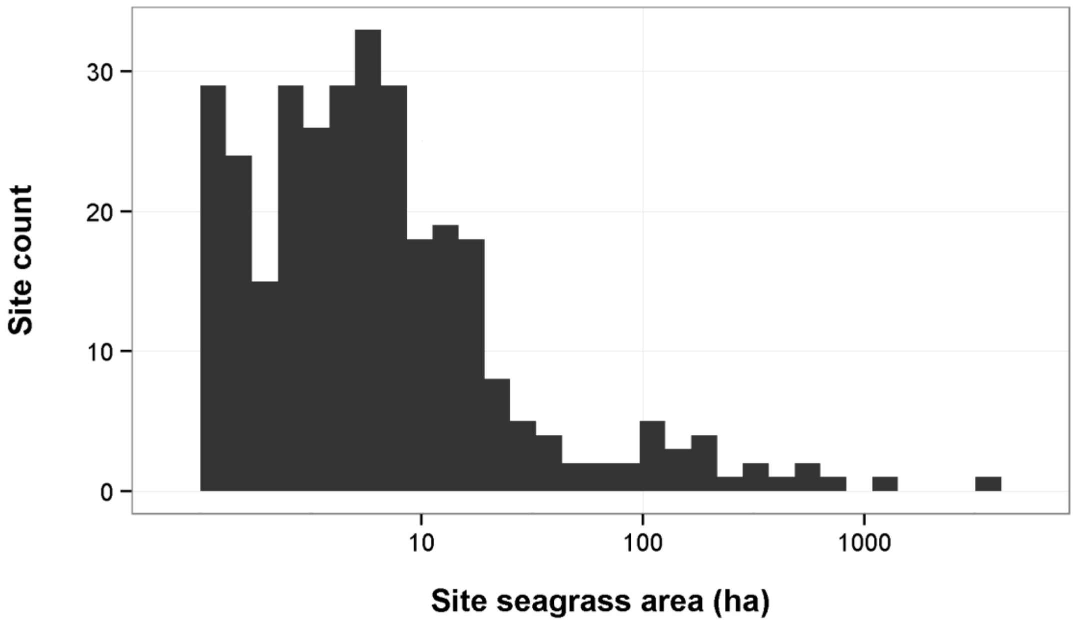


Figure 5: Skewed size distribution of native seagrass beds in greater Puget Sound: most of the sites sampled by the SVMP between 2000 and 2014 are relatively small. Sites without seagrass were excluded this figure.

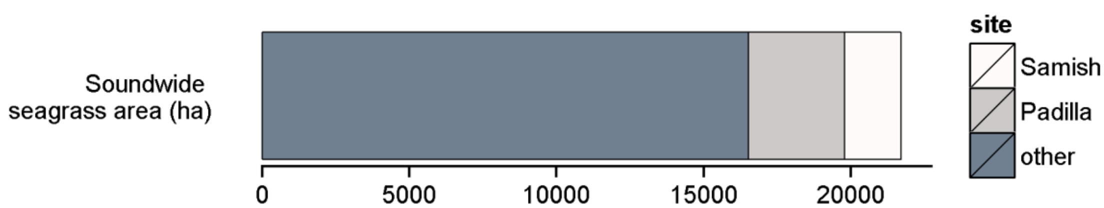


Figure 6 : Skewed size distribution of native seagrass beds in greater Puget Sound: over 20% of all seagrass in greater Puget Sound grows in Padilla Bay and Samish Bay.

Seagrasses of the genus *Phyllospadix* are only detected in the Strait of Juan de Fuca, the San Juan Islands, and the northern reaches of Central Puget Sound (

Figure 3). These seagrasses mostly grow on hard substrate, and are generally found in the surf zone on exposed rocky coasts and in tide pools. The non-native *Zostera japonica* was detected at approximately 20% of sites sampled. *Z. japonica* tends to grow in the upper intertidal zone, and is less prevalent in high energy environments, such as the San Juan Islands and the Strait of Juan de Fuca (

Figure 4). Our estimates are likely an underestimation of the upper edge of either *Phyllospadix sp.* or *Z. japonica* in Puget Sound. Even though SVMP sampling is conducted at high tides, these seagrass species grow predominantly in the upper intertidal, and are often out of reach for our vessel. For this reason, we are not able to provide accurate area estimates for *Z. japonica* or *Phyllospadix sp*. Furthermore, our assessment of the spatial extent of these two species is restricted by the program's random sample design and limited resources to sample all the sites in a region or the study area.

3.3 Depth distribution

Eelgrass is found between +1.4m and -12m relative to mean lower low water (MLLW). The optimal depth range for these plants appears to be between 0 and -2m relative to MLLW in greater Puget Sound. There is a lot of variability in the maximum depth at which eelgrass is found, both among individual sites and among regions (Hannam et al. 2015b). Eelgrass tends to have a greater maximum depth near the San Juan Islands and the Strait of Juan de Fuca (

Figure 8), but it does not grow as shallow as in other regions (
Figure 9). There is also a difference in maximum depth among habitat types. Eelgrass extends to greater depths at fringe sites, but it does not grow as shallow at these sites compared to flats (Hannam et al. 2015b).

We classify eelgrass as either intertidal or subtidal. We define the boundary between intertidal and subtidal as -1 m (relative to MLLW), which is a biologically relevant estimate of Extreme Low Tide depth in the Puget Sound region. For more details on this calculation, see Hannam et al. (2015b). When comparing to this boundary, approximately 62% of all eelgrass in Puget Sound grows in the subtidal, and 38% grows in intertidal habitat (Figure 7).

Other seagrasses in greater Puget Sound, such as *Phyllospadix spp*. and the non-native *Zostera japonica* have a different depth distribution as compared to *Zostera marina*. However, we do not have good estimates of these distributions because both species tend to grow in the upper intertidal and out of sample reach for our research vessel.

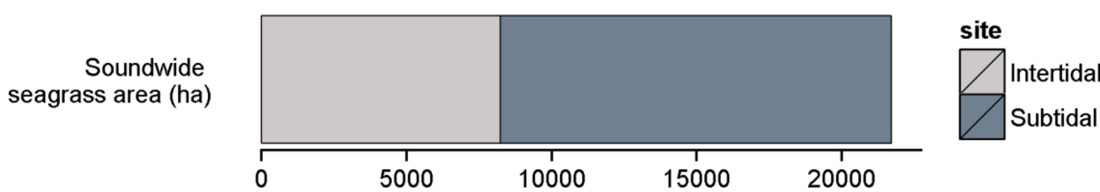


Figure 7 : Approximately 62% of native seagrass in greater Puget Sound grows in the subtidal. This estimate is based on *Z. marina* only, since we have incomplete data on the depth distribution of *Phyllospadix sp*. In greater Puget Sound.

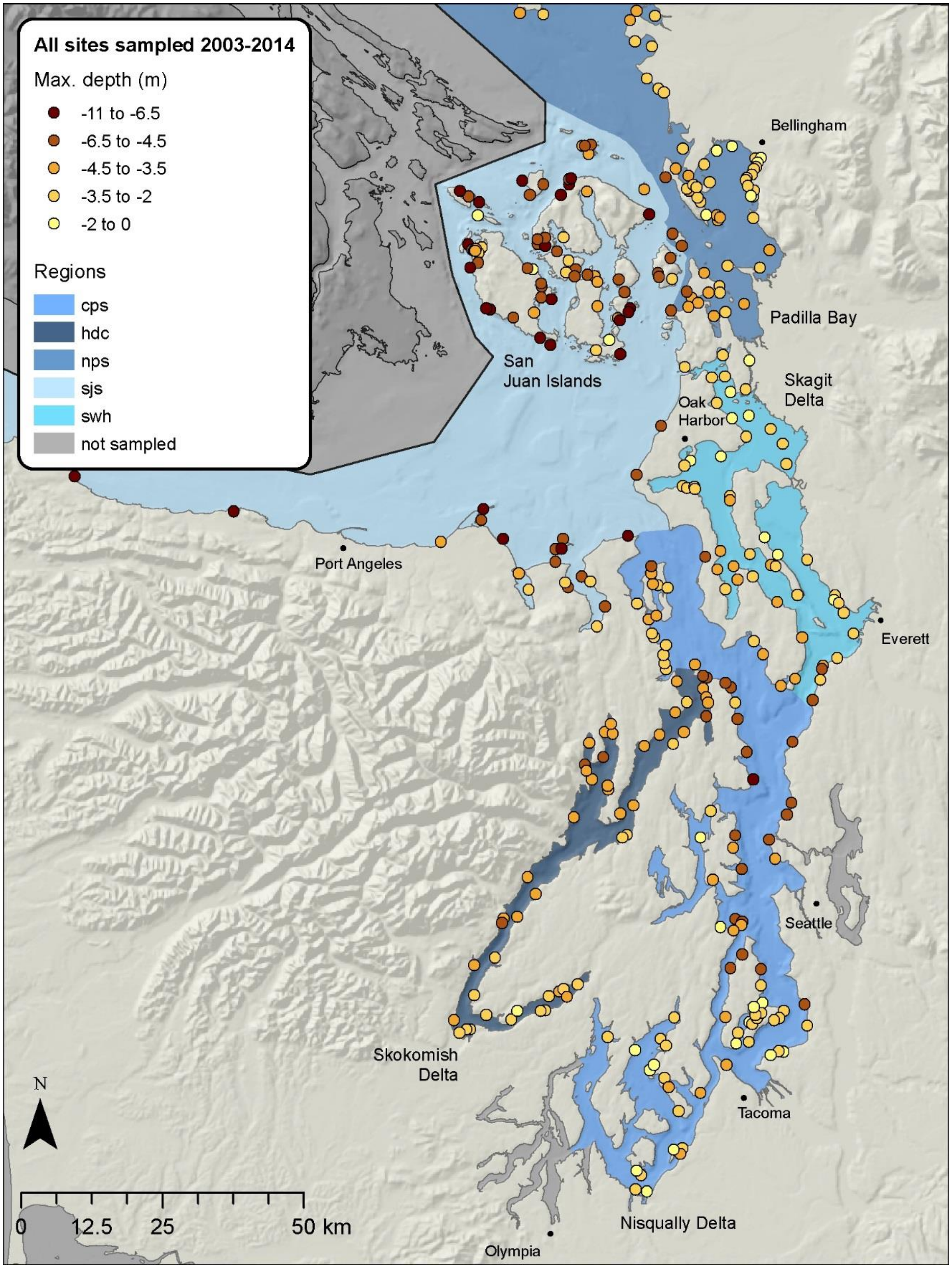


Figure 8 : Maximum depth where eelgrass occurs at all sites sampled as part of the SVMP and focus studies.

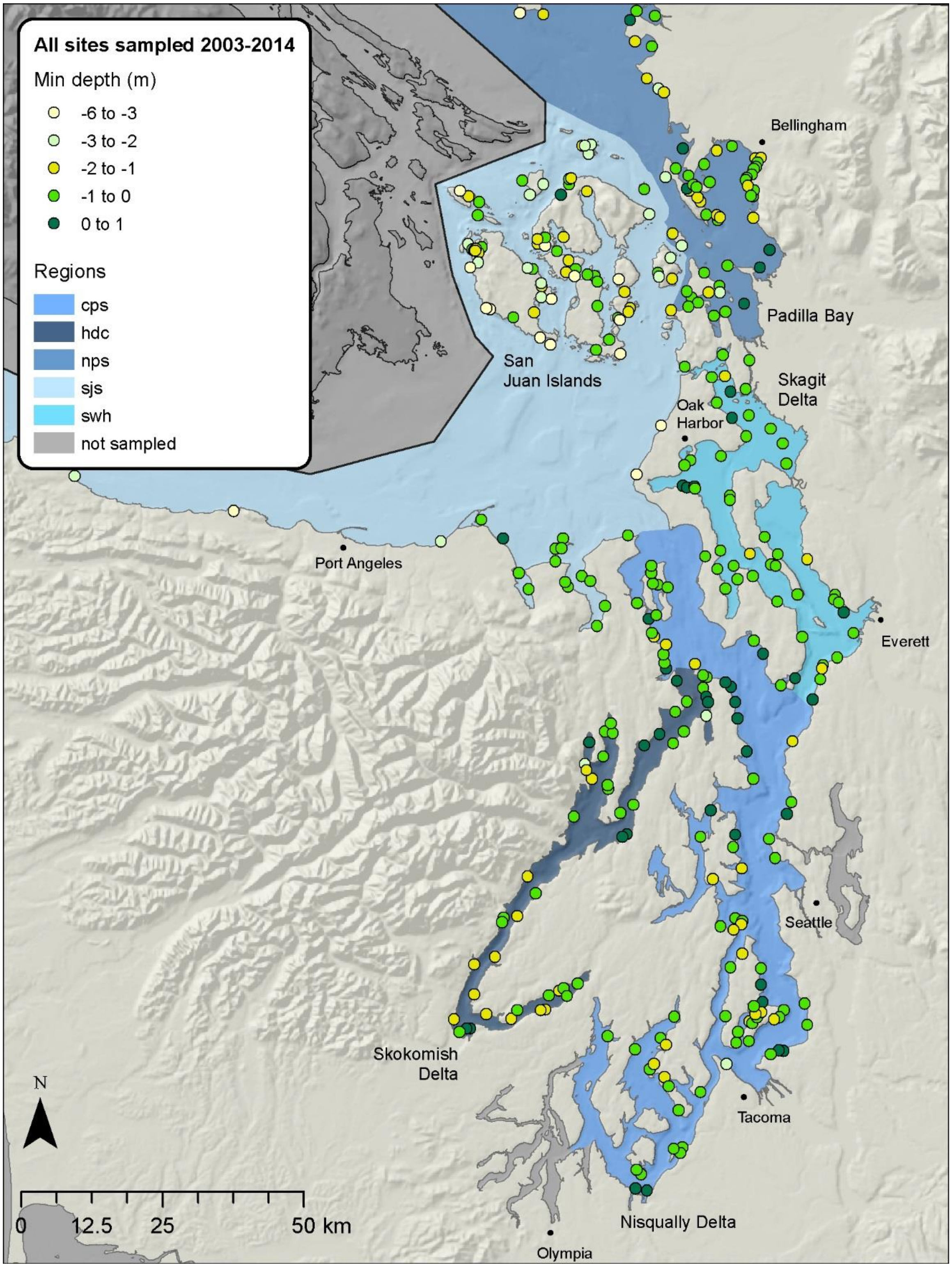


Figure 9 : Shallowest depth where eelgrass occurs at all sites sampled as part of the SVMP and focus studies.

3.4 Trends in seagrass area

3.4.1 Soundwide estimate

Figure 10 shows the long-term trend in soundwide seagrass area relative to a 2000-2008 baseline (NHP 2015). In 2014, the soundwide estimate rose to approximately 24,300 ± 2,200 ha (Table 4). This value is slightly higher than the 2012 estimate, and exceeds the 2016 interim target of 23,730 ha, as defined by Results Washington[4]. This estimate is still short of the 2020 target of 20% increase established by the Puget Sound Partnership. While Figure 11 suggests that soundwide seagrass area may be increasing, there is a high amount of inter-annual variability in the soundwide estimate. As was reported in the previous SVMP report (NHP 2014), this inter-annual variability is partly due to site rotation. Every year 20% of all sites are rotated out of the sample pool, and replaced by new randomly selected sites. As a consequence, the dataset from 2000 to 2014 consists of random sites that are studied for a 5 year period. The SVMP sampling protocol was designed to provide estimates of both status and trends for soundwide native seagrass area. As such, it is a compromise between a design aimed at providing status (random sampling of sites throughout the sound) and trend (repeat sampling of the same sites over time). The fact that each annual estimate is generated on a dataset that overlaps 80% with previous year, generates some variability in the dataset. In addition, there is the potential for inter-annual variability in seagrass growth, due to differing climatic influences, such as precipitation, temperature and the amount of light available to the plants.

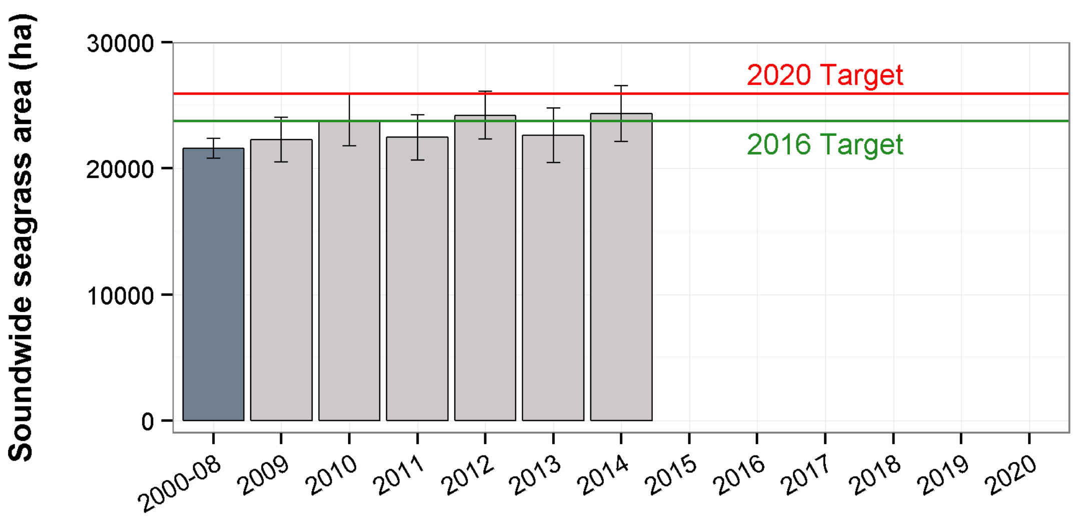


Figure 10 : Long-term trend in soundwide area of native seagrasses in greater Puget Sound. The dark grey bar represents the 2000-2008 baseline, the light grey bars represent annual soundwide area estimates, the green line is the 2016 interim target for Results Washington, and the red line is the long-term management target by the Puget Sound Partnership: a 20% increase in soundwide area relative to the baseline by 2020. *Z. japonica* is not included in the area estimates.

[4] We consider that a target has been met, if the mean value of our estimate meets or exceeds the target value.

Table 4 : Soundwide and stratum native seagrass area estimates and standard errors. Early in the monitoring project, the stratification of sites changed. Consequently, stratum estimates from the early monitoring years are not directly comparable to estimates from later years in the altered strata. Values with an * indicate early years where stratification was different from the later years. The core and flats strata listed represent distinct strata that differed in 2000, 2001-2003 and 2004-2013. The persistent flats stratum is combined with core starting in 2004.

	Total	std err	core	std err	flats	std err	frn	std err	frw	std err
2000	18,812	7,227	1,343*	61	11,257*	7,061	5,499*	1,457	713*	500
2001	22,246	6,407	3,722*	110	9,342*	6,241	3,958	745	5,224	1,236
2002	21,666	5,860	3,958*	156	8,461*	5,723	4,460	770	4,787	986
2003	21,323	5,607	3,534*	208	7,760*	5,469	5,402	828	4,628	895
2004	21,555	1,544	6,260	212	3,695	875	6,603	984	4,997	777
2005	20,567	1,684	6,271	223	3,859	1,087	6,817	1,087	3,621	651
2006	22,179	1,875	6,178	189	4,583	961	8,378	1,523	3,041	489
2007	21,564	1,893	5,631	276	4,887	735	8,880	1,652	2,165	488
2008	22,809	2,299	6,395	185	5,971	1,399	8,526	1,726	1,917	561
2009	22,263	1,778	5,896	239	7,710	815	7,311	1,502	1,346	430
2010	23,803	2,026	6,020	280	8,858	1,105	7,102	1,463	1,822	814
2011	22,440	1,807	5,864	176	8,793	1,192	5,813	1,051	1,970	841
2012	24,201	1,901	6,503	174	8,266	1,153	5,916	1,118	3,515	1,002
2013	22,610	2,166	6,559	203	6,179	1,517	6,401	1,140	3,470	1,025
2014	24,343	2,204	6,421	160	5,559	1,528	6,927	1,188	5,436	1,042

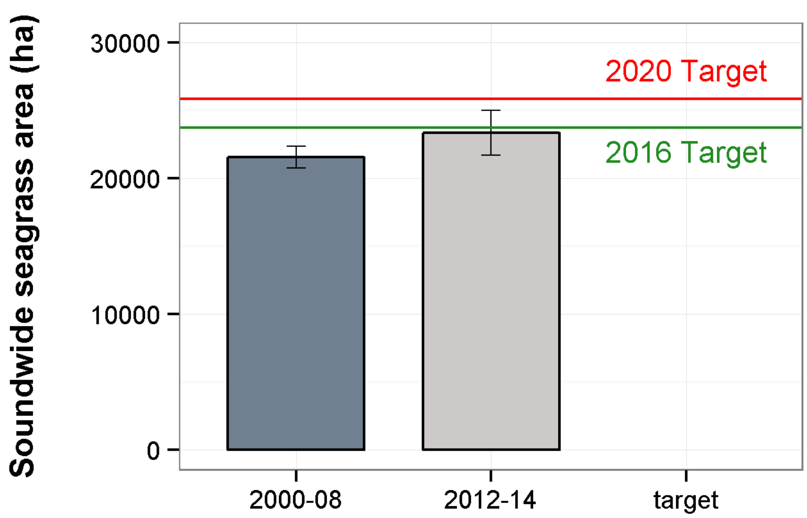


Figure 11 : Multiyear average of all SVMP sites for the 3 most recent years sampled (light grey), relative to the 2000-2008 baseline (dark grey), the 2016 management target by Results Washington (green line) and the 2020 target specified by The Puget Sound Partnership (20% increase relative to the baseline by 2020, red line). *Z. japonica* is not included in the area estimates.

In order to minimize the site rotation effect, we calculated the 3-year average of soundwide seagrass area based on average seagrass area per site for all sites sampled from 2012 to 2014. These values filter out inter-annual variability due to random error and sampling effects, and provide a better metric for assessing whether management goals have been achieved. The 3-year average indicates that between 2012 and 2014, soundwide seagrass area is at the level of the 2016 management goal specified by the Results Washington Goal Council. The 2020 target has not yet been met (Figure 11).

3.4.2 Trends on the site level

Between 2003 and 2014, a total of 392 sites have been sampled as part of the SVMP, the focus study program, and additional special projects. From these sites, 313 sites were sampled over multiple years, and were analyzed for change. Approximately 72% of sites with multi-year data were stable throughout the entire monitoring record, 13% of the sites had no native seagrass, 7% showed long-term increases and 8% showed long-term declines (Table 5). Many of the sites with long-term decreases were located in lower Hood Canal, the San Juan Islands, and the southern part of central Puget Sound (
Figure 12). Sites with long-term increases include 3 sites near the Skokomish delta, where increases coincide with the timing of delta restoration activities. Padilla Bay and the southern portion of Samish Bay, two of the largest sites in overall seagrass area, also show a small, but statistically significant increase over time. For a complete overview of all sites with significant long-term trends, see Table 6.

Between 2010 and 2014, there are 138 sites with multiple years of data. Approximately 12% of these sites showed short-term increases, and only 1.4% showed short-term declines. This suggests that recent years have been relatively good for seagrass growth in greater Puget Sound. This reversal in trajectory is most pronounced in lower Hood Canal, where several sites showed an upward trend after 2010 (
Figure 13). However, the majority of sites in lower Hood Canal are relatively small, and the recent gains have little impact on the soundwide estimate. For a complete overview of all sites with significant short term trends, see Table 7.

Table 5 : Trends in seagrass area for all sites that were sampled during multiple years from 2003-2014 (long-term) and from 2010-2014 (short-term).

Site-level trends in seagrass area					
counts	increase	decline	stable	no grass	total
03-14	22	25	225	41	313
10-14	17	2	99	20	138
%	increase	decline	stable	no grass	
03-14	7.0	8.0	71.9	13.1	
10-14	12.3	1.4	71.7	14.5	

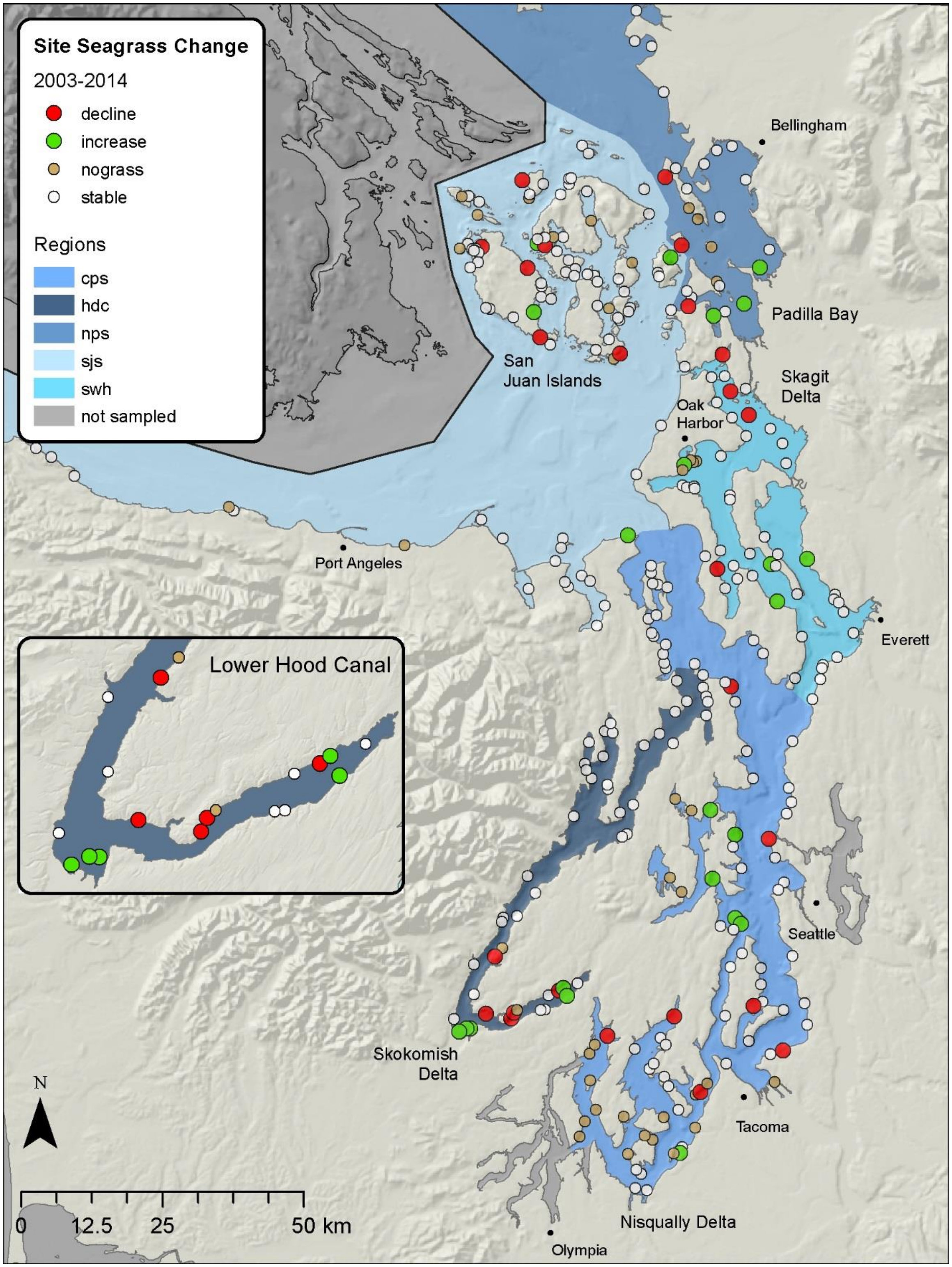


Figure 12 : Sites with significant trends in native seagrass area between 2003 and 2014.

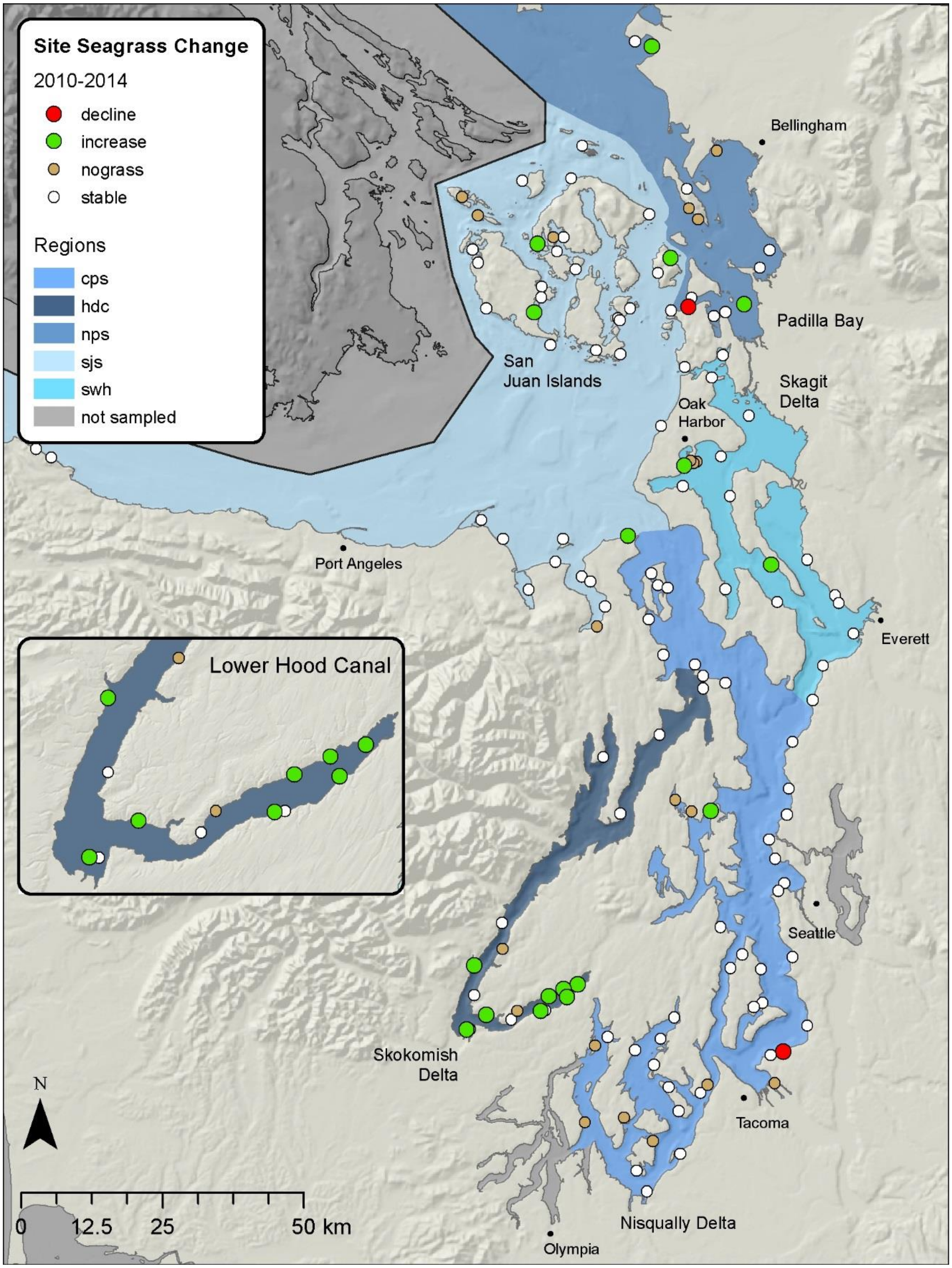


Figure 13 : Sites with significant trends in native seagrass area between 2010 and 2014.

Table 6 : Individual sites with significant long-term trends (2003-2014) in greater Puget Sound.

Site code	Region	Site name	Years sampled	03-14 trend
core005	Central Puget Sound	Dumas Bay, Federal Way	15	decreasing
core006		Burley Spit, Henderson Bay	15	decreasing
cps1967		Sunshine Beach, Vaughn	8	decreasing
cps2068		NE of Point Fosdick, Gig Harbor	4	decreasing
cps2221		Point No Point Lighthouse South	6	decreasing
cps1686		Discovery Park, Seattle	10	decreasing
flats33		Quartermaster Harbor, Vashon	3	decreasing
cps1821		Eastward, Steilacoom	7	increasing
cps1035		NE of Point White, Bainbridge	6	increasing
cps1054		Agate Passage SE, Bainbridge	5	increasing
cps1066		Rolling Bay, Bainbridge	2	increasing
cps1108		Blake Isl. West	2	increasing
cps1114		Blake Isl. South	2	increasing
hdc2345	Hood Canal	SE of Jiggs Lake, Tahuya	4	decreasing
hdc2323		N of Dewatto Bay	2	decreasing
hdc2355		Stimson Creek, Belfair	2	decreasing
hdc2338		S of Wildberry Lake, Tahuya	10	decreasing
hdc2344		East of Wheeler Lake, Tahuya	8	decreasing
hdc2356		NE of Stimson Creek, Belfair	4	increasing
hdc2359		SW Lynch Cove, Belfair	10	increasing
hdc2383		Indian Hole, Anna's Bay	6	increasing
hdc2380		Skokomish Flats East	4	increasing
hdc2381		Skokomish Flats West	4	increasing
nps0059	North Puget Sound	Sinclair Island	7	decreasing
nps1363		S Village Point, Lummi Isl.	6	decreasing
nps1487		Loveric's, Anacortes	6	decreasing
core001		Padilla Bay	14	increasing
flats12		Samish Bay S	11	increasing
flats15		Fidalgo Bay North	6	increasing
sjs0635	San Juan Islands and Straits	San Juan Islands and Straits	8	decreasing
sjs0351		North Bay S, Waldron Isl.	6	decreasing
flats53		Westcott Bay, San Juan Isl.	6	decreasing
sjs0205		American Camp East, San Juan Isl.	5	decreasing
sjs0154		SW of Neck Point, Lopez Isl.	2	decreasing
sjs0557		North Coon Isl.	2	decreasing
flats69		Eagle Harbor, Cypress Island	4	increasing
sjs2605		North Beach County Park, Port Townsend	6	increasing
sjs0544		West Reef Isl.	5	increasing
sjs0133		Merrifield Cove, San Juan Isl.	5	increasing
flats20	Saratoga Whidbey Basin	Skagit Bay N	15	decreasing
flats19		La Conner	6	decreasing
swh0922		Greenbank, SE Whitbey	2	decreasing
flats18		Similk Bay	11	decreasing
swh0955		West Langley, SE Whitbey	8	increasing
swh0885		Blower's Bluff North, Whidbey	4	increasing
swh1574		Camp Diana West, South Camano	3	increasing
swh1615		Sunny Shores N, Tulalip	4	increasing

Table 7 : Individual sites with significant short-term trends (2010-2014) in greater Puget Sound.

Site code	Region	Site name	Years sampled	03-14 trend
core005	Central Puget Sound	Dumas Bay, Federal Way	15	decreasing
cps1054		Burley Spit, Henderson Bay	5	increasing
core004	Hood Canal	Lynch Cove, Hood Canal	15	increasing
hdc2353		NE Landon Road, Belfair	4	increasing
hdc2365		W of Forest Beach, Twanoh	4	increasing
hdc2398		S of Lilliwaup Bay	4	increasing
hdc2356		NE of Stimson Creek, Belfair	4	increasing
hdc2359		SW Lynch Cove, Belfair	10	increasing
hdc2380		Skokomish Flats East	4	increasing
hdc2338		S of Wildberry Lake, Tahuya	4	increasing
nps1487	North Puget Sound	Loveric's, Anacortes	6	decreasing
core001		Padilla Bay	14	increasing
flats03		Birch Bay	5	increasing
flats69	San Juan Islands and Straits	Eagle Harbor, Cypress Island	4	increasing
sjs2605		North Beach County Park, Port Townsend	6	increasing
sjs0544		West Reef Isl.	5	increasing
sjs0133		Merrifield Cove, San Juan Isl.	5	increasing
swh0885	Saratoga Whidbey Basin	Blower's Bluff North, Whidbey	4	increasing
swh1574		Camp Diana West, South Camano	3	increasing

3.5 Sites of particular interest [5]

3.5.1 Skagit Bay N

While there is some *Ruppia maritima* near the mouth of the Skagit River, eelgrass is by far the dominant native seagrass at Flats 20 (Skagit Bay N). This site has shown signs of a long-term decease in eelgrass area between 2003 and 2014. While there is some uncertainty due to variation in transect placement, the consistent pattern lends credibility to the observed decline during this period of time. Flats 20 has been extensively sampled in January and August 2015, using a BioSonics Echosounder, by DNR's Aquatics Assessment and Monitoring Team (AAMT). Both the long-term SVMP data and the BioSonics data from AAMT show a distinct pattern in the spatial distribution of eelgrass at this location. Eelgrass tends to be sparser near the outflow of the N-fork of the Skagit River, and forms a lush meadow in the center of the Bay (Figure 14). At the end of 2014, a large fraction of the flow from the N-fork of the Skagit River was rerouted through a newly formed channel, created by an avulsion through a coastal wetland, 1.5 miles SE of the river mouth. A recent study by the EPA has documented the presence of *Zostera japonica* and *Ruppia maritima* in the intertidal zone in the center of the bay (Kaldy and Mochon-Collura, 2015). The extremely sparse nature of the *Zostera japonica* bed and the presence

[5] For more information on sites sampled during the SVMP, use the online Eelgrass Data Viewer, available at http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/puget-sound-eelgrass-monitoring-data-viewer

of large flocks of migratory birds nearby suggest that this bed is in the initial stages of colonization, and that avian vectors may have contributed to the introduction of *Z. japonica* at this location.

Figure 14 : Top: extent of eelgrass in Skagit Bay N, measured with BioSonics (AAMT). The red arrow indicates sparse eelgrass near the mouth of the outflow of the N. fork of the Skagit River.

Middle: the red arrow indicates the location of the avulsion. Red and green circles indicate the areas where changes in the eelgrass bed may occur due to the redirection of flow in the North Fork of the Skagit River. The *Z. japonica* bed is located southeast of the tip of the red arrow.

Bottom: long-term trend in eelgrass area.

3.5.2 The Skokomish Delta

At three sites near the Skokomish delta in lower Hood Canal (hdc2380, hdc2381 and hdc2383), eelgrass beds increased by over 80 ha between 2005 and 2014 (Figure 15). The eelgrass beds expanded towards shore, indicating that the upper subtidal and lower intertidal became better habitat for eelgrass growth. The expansion is more pronounced at site hdc2380, on the east side of the delta.

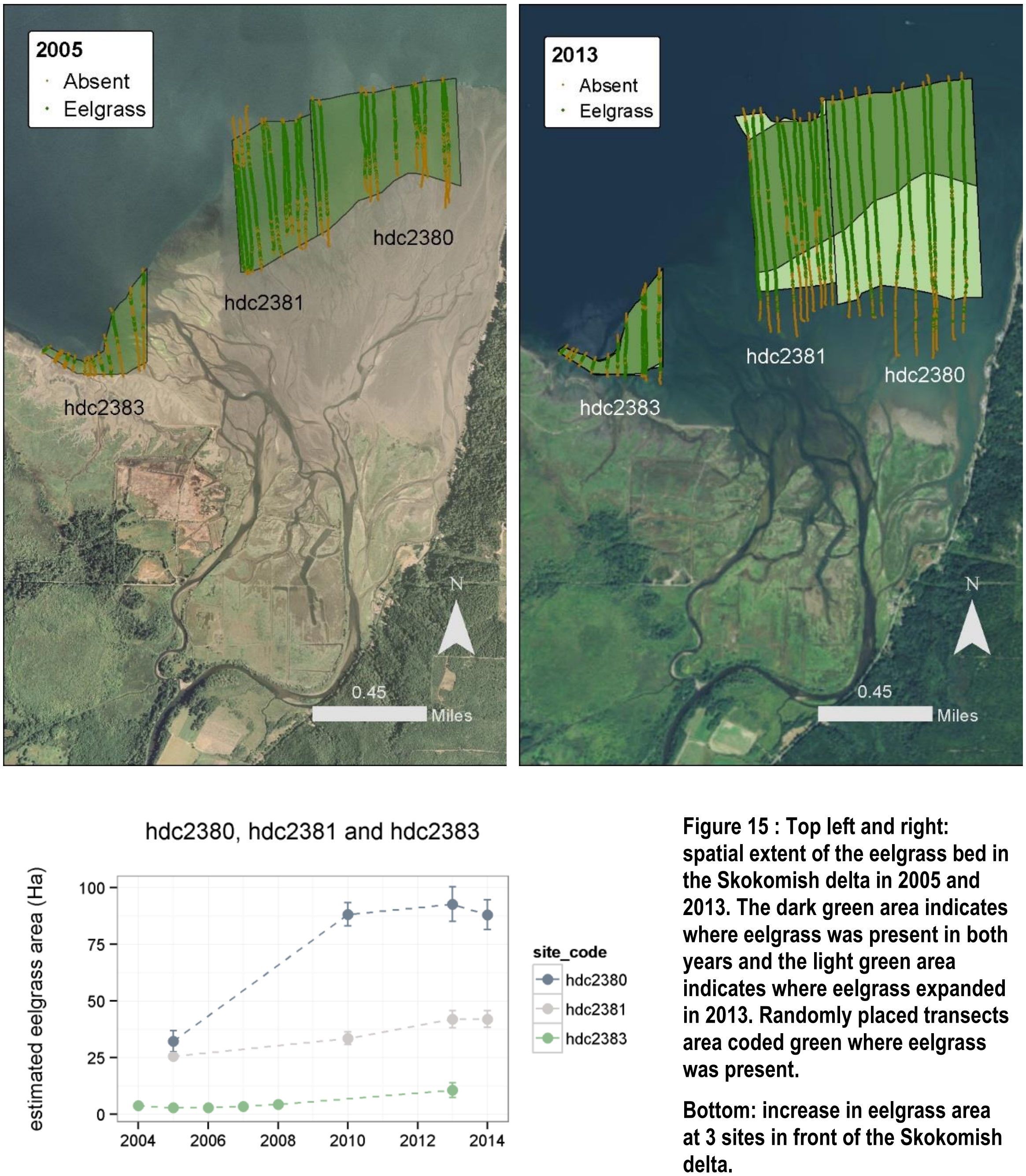
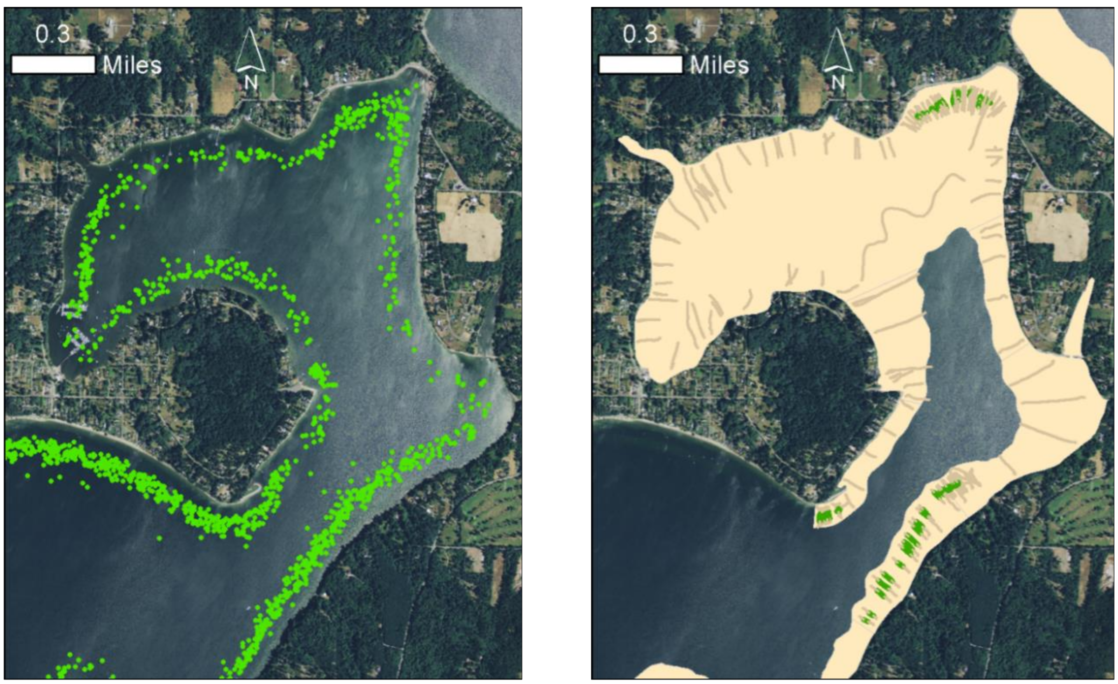


Figure 15 : Top left and right: spatial extent of the eelgrass bed in the Skokomish delta in 2005 and 2013. The dark green area indicates where eelgrass was present in both years and the light green area indicates where eelgrass expanded in 2013. Randomly placed transects area coded green where eelgrass was present.

Bottom: increase in eelgrass area at 3 sites in front of the Skokomish delta.

3.5.3 Quartermaster Harbor

Quartermaster Harbor is a relatively small, semi-enclosed system between Vashon Island and Maury Island. This embayment is located within the DNR Maury Island Aquatic Reserve. The shoreline is predominantly rural, and the waterfront is characterized by low intensity residential development. Long term herring spawn survey data from the Washington Department of Fish and Wildlife have shown an ongoing decline in eelgrass in the inner part of the harbor. Between 1981 and 1989, eelgrass was present throughout the entire shoreline of this bay (Figure 16). SVMP data show that in the inner part of the harbor (flats33), eelgrass extent is currently limited to a small bed at northern part of the site, with evidence of a decline between 2004 and 2014 (Figure 16).



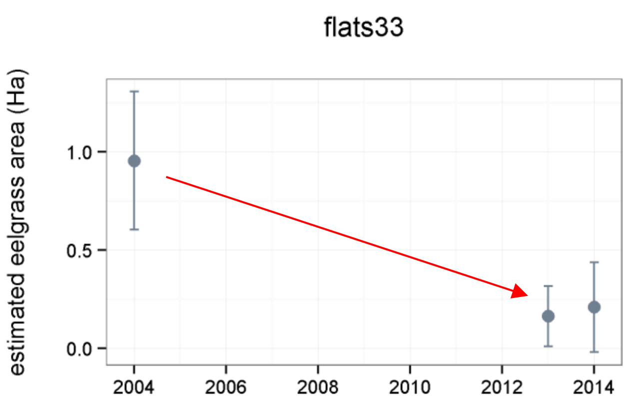


Figure 16 : Top left: locations were eelgrass was detected during herring surveys from the WDFW between 1981 and 1989. Top right: current extent of eelgrass at Quartermaster Harbor (2014 SVMP data). Bottom: Seagrass decline in Quartermaster Harbor between 2004 and 2014.

3.5.4 Lower Hood Canal

Hood Canal is a deep and narrow fjord that separates the Olympic and Kitsap peninsulas. Lower Hood Canal extends from the Skokomish delta to Lynch Cove. This area is lined by single family residential development, and has extensive shoreline modification (bulkheads, floating docks, etc.). Between 2003 and 2014, 19 sites were sampled in lower Hood Canal. Five sites showed a long-term increase in native seagrass area, 5 sites showed a decline, 2 sites were devoid of native seagrasses and 7 sites were stable over time. Between 2010 and 2014, only 14 sites were sampled. Eight of these showed a short-term increase in seagrass area, 2 sites were devoid of seagrass and 4 sites were stable. One pattern that stands out is that many sites showed a reversal in trend after 2010 (Figure 17).

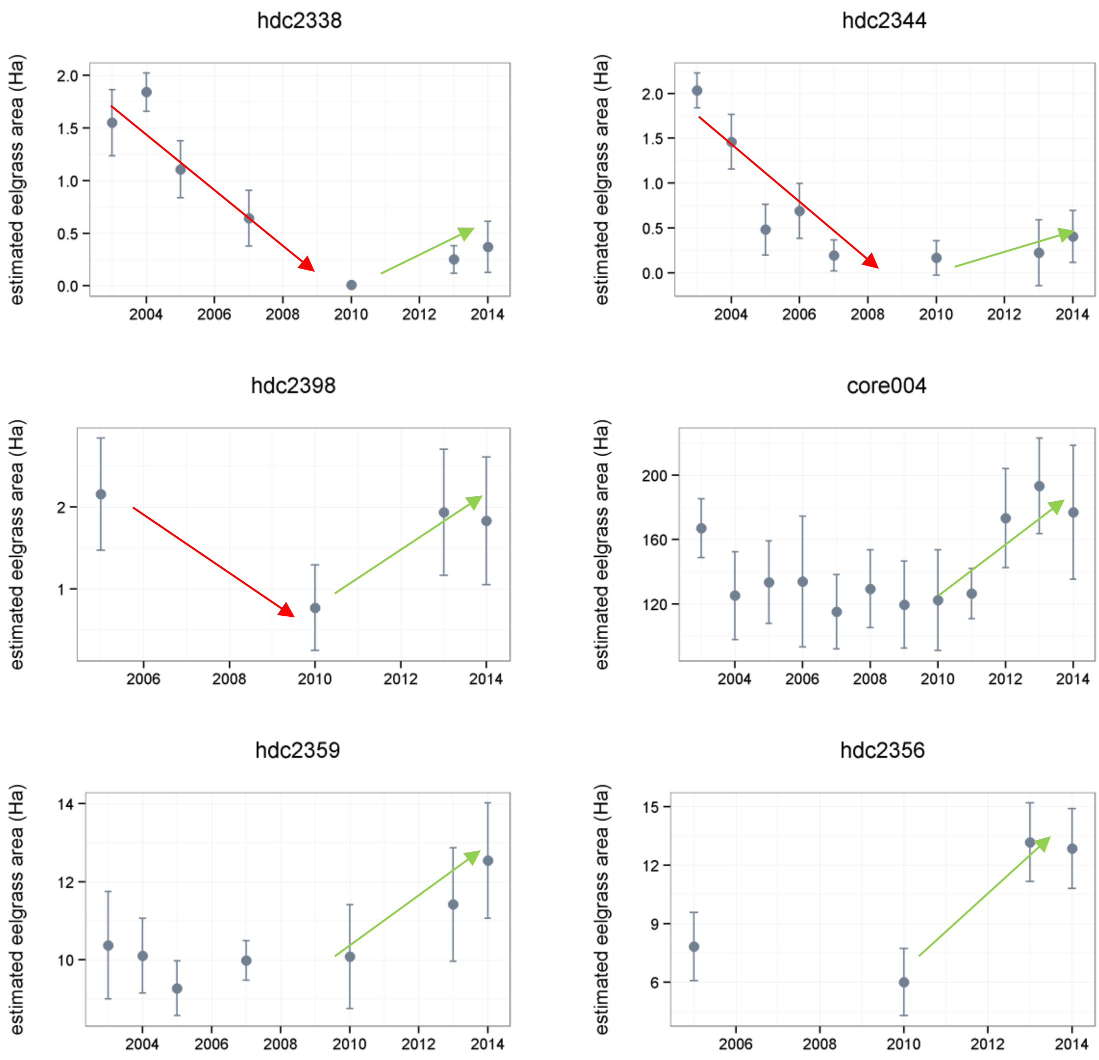


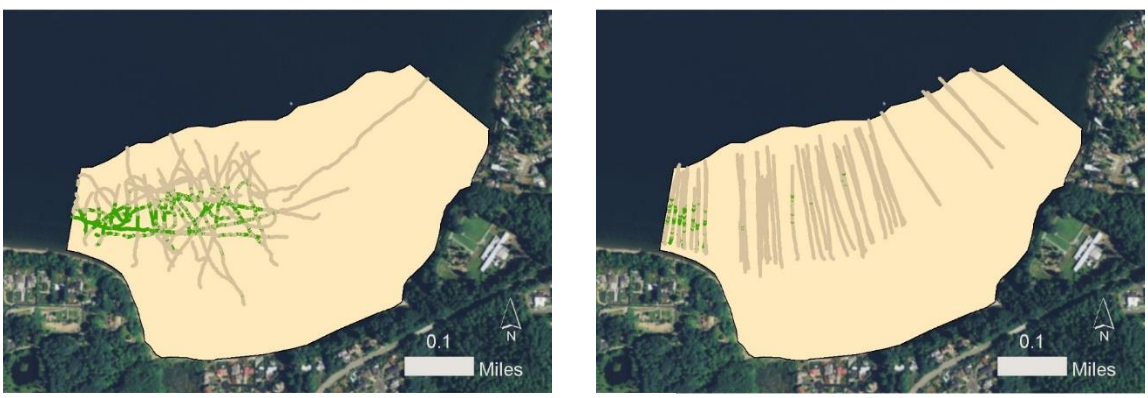
Figure 17 : Examples of a reversal in trend at sites in lower Hood Canal: hdc2338, hdc2344 & hdc2398 changed from a declining to an increasing trend over time. Core004, hdc2359 and hdc2356 changed from stable to increasing after 2010.

3.5.5 Dumas Bay

Dumas Bay (core005) is located near Federal Way, in King County. This small bay is bordered by eroding bluffs on the western side, and is surrounded by a mix of single family, medium and high density homes. There is also a golf course in the catchment area. Dumas Bay has experienced a significant decline in seagrass habitat, from approximately 2.3 ha in 2000 to less than 0.5 ha in 2013 and 2014 (

Figure 18). The eelgrass bed has receded substantially to the western corner of the bay. A separate long-term study (SeagrassNet) adjacent to Dumas Bay (cps2906) has also documented declines in eelgrass density over the last six years.

In 2005, excessive amounts of ulvoid macroalgae on the beach caused odor problems for residents in surrounding neighborhoods of Dumas Bay (ECY 2012).While the levels of macroalgae are generally similar to other sites in Central Puget Sound (Nelson et al. 2009), Dumas Bay differs in that there are 3 small streams that flow into the bay that keep algae moist at low tides, which facilitates their growth and ability to form nuisance blooms.



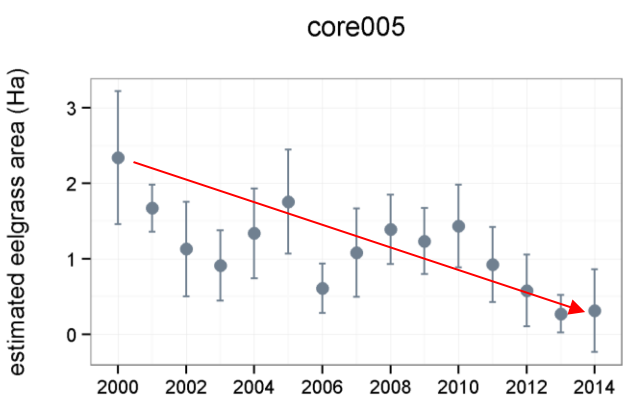


Figure 18 : Top left: extent of eelgrass in Dumas Bay in 2000 and 2001. Top right: extent of eelgrass in 2013 and 2014. Bottom: long term decline in seagrass area in Dumas Bay.

4 Discussion

Seagrasses are an important bio-indicator of ecosystem health – both globally and within Puget Sound. Long-term trends in distribution can signal localized and/or regional changes in ecological conditions (e.g., water quality and sediment transport) within the nearshore environment. Large scale seagrass loss can lead to significant changes in bottom habitat and water quality, particularly in sediment composition and the amount of suspended sediment in the water column. Changes of this magnitude can impact nearshore ecosystems for years, and potentially inhibit natural recolonization and even restoration of seagrass in the area. The SVMP was designed to monitor the distribution of native seagrasses, predominantly *Zostera marina*, in greater Puget Sound and to identify trends in seagrass area on different spatial scales.

4.1 Status and trends of seagrass in greater Puget Sound

4.1.1 Status of seagrass populations

The 2014 soundwide seagrass area estimate is consistent with the seagrass area estimated in previous years (Figures 10 and 11). The annual area estimates have fluctuated around a mean value of approximately 22,000 ha, which is probably due to both inter-annual variability in environmental drivers and the rotational sample design, which brings an element of uncertainty into the long-term estimates of seagrass at the regional and soundwide scale. The current best estimates indicate that approximately 50% of seagrass grows on tidal flats, while 50% grows a large number of small beds at fringe sites. In certain regions, such as Hood Canal, Central Puget Sound, and the San Juan Islands, the majority of seagrass is found at fringe sites, while in Northern Puget Sound and the Saratoga Whidbey Basin, the majority of seagrass grows on flats. This has important implications for the function and the stability of native seagrass beds at these locations, and for management actions.

Small seagrass beds at fringe sites may provide different ecosystem services than large contiguous seagrass beds growing on flats sites. Large contiguous seagrass beds tend to harbor more stable nekton communities over time, as they provide enough habitat to sustain a wide variety of species (Hensgen et al. 2014). Smaller beds at fringe sites are important for habitat connectivity, and provide corridors for out-migrating salmon. Seagrasses are eco-engineers. They modify the abiotic conditions of their habitat by changing the organic matter content of the sediment, and inhibiting the resuspension of sediments to the water column. This creates positive feedbacks, which allows the plants to grow in areas that would otherwise not be suitable for survival (Van der Heide et al. 2011). These positive feedbacks are likely to increase with the size of the seagrass bed. Several studies have shown that larger seagrass patches spread faster and have better survival (Duarte and Sand-Jensen 1990; Olesen and Sand-Jensen 1994; Vidondo et al. 1997; Kendrick et al. 2005). Small, narrow seagrass beds are more vulnerable to disturbance from hydrodynamic forces (Koch 2001; Greve and Krause-Jensen 2005). Large, dense seagrass beds may be more resistant to high concentrations of ammonium or sulfides, due to the effect of growth dilution or density dependent oxidation by radial oxygen loss from their roots (Van der Heide et al. 2010). In addition, larger seagrass beds have a greater ability to recruit new shoots through both sexual and asexual reproduction (Greve and Krause-Jensen 2005).

In greater Puget Sound, eelgrass is found between 1.4m and -12 m (MLLW), but the optimal depth range for these plants appears to be between 0 and -2m (MLLW). Approximately 62% of all eelgrass in greater Puget Sound grows subtidal (deeper than -1 m MLLW), and approximately 50% of eelgrass grows deeper than the Extreme Low Tide Line[6]. This has implications for the protection of eelgrass, since the ELT line forms the boundary between tidelands and bedlands for a large part of Puget Sound. Virtually all bedlands in Washington are owned by the State, while only 29% of Washington State's tidelands remain in public ownership (Ivey 2014). This suggests that a large proportion of eelgrass is found on state owned aquatic lands, which emphasizes the importance of continued stewardship activities by DNR.

Within greater Puget Sound, there is a regional pattern in the maximum depth at which eelgrass is found. *Z. marina* tends to grow to deeper depths at sites along the Strait of Juan de Fuca, the San Juan Islands and the northern part of Central Puget Sound. Seagrass beds do not extend as deep in North Puget Sound, the Saratoga Whidbey Basin, Hood Canal, and the southern part of Central Puget Sound. The maximum depth of seagrass beds is often limited by the amount of light that is able to penetrate throughout the water column (Duarte 1991). As such, a reduction in the maximum depth of eelgrass beds is a possible indicator of water quality impairments (Burkholder et al. 2007). However, many factors can influence water clarity in areas such as Puget Sound, including sediment resuspension due to wave action and input of sediments from glacial fed rivers. Further research is needed to ascertain a potential link between water quality, light attenuation, and spatial patterns in the maximum depth extent of eelgrass beds in greater Puget Sound.

[6] For the purpose of designating ownership boundaries, the federal government defined the Extreme Low Tide line (ELT) as the line below which it might be reasonably expected that the tide would not ebb. In the Puget Sound area of Washington State this line is estimated by the federal government to be a point in elevation 4.5 ± 0.5 feet below the datum plane of MLLW (Ivey 2014).

The non-native seagrass *Z. japonica* was introduced to this area early in the 20th century, with the cultivation of Japanese oysters in Samish Bay (Shafer et al. 2014), and has since spread throughout much of Puget Sound. *Z. japonica* was detected at approximately 20% of sites sampled. This is an underestimation of the actual distribution of this non-native species, since our sampling is vessel-based, while *Z. japonica* often grows relatively high up in the intertidal. *Z. japonica* is morphologically different than its congener *Z. marina*: it typically has a smaller canopy height and narrower leaf width. *Z. japonica's* fast growth rates, small size and high reproductive output make this species a successful colonizer of previously unoccupied mud flats. Despite these characteristics, there is little to no direct competition between *Z. japonica* and the native *Z. marina* (Shafer et al., 2014). With a few exceptions (such as Padilla Bay), there is little overlap in the vertical distribution of both species in greater Puget Sound. In the intertidal, *Z. marina* is physiologically restricted from elevated areas, which can be colonized by *Z. japonica*, but *Z. marina* is a better competitor in depressions that remain wet at low tide (Hannam et al., 2015a). In general, the two species do not have negative effects on each other in areas where they co-occur (Harrison 1982; Hahn, 2003).

4.1.2 Trends in seagrass area

The 2014 estimate of soundwide seagrass area is at the level of the 2016 management target as defined by Results Washington (23730 ha by 2016). However, there is some uncertainty around the annual estimates of soundwide seagrass area, as illustrated by the standard error around the estimate (Figure 10). Our estimates also show significant inter-annual variability. These could be the result of inter-annual variability in climatic influences, or inaccuracies introduced by the rotational aspect of the site selection of the SVMP. As such it is not possible to interpret whether a small increase or decrease in soundwide seagrass area is an actual trend in the dataset. The 3-year average provides a more robust estimate of soundwide seagrass area. The 3-year average suggests that soundwide seagrass area has reached the level of the 2016 management target defined by Results Washington, but that we have not yet achieved the 20% increase target by the Puget Sound Partnership. Based on the current data, we are not able to predict whether the soundwide seagrass area will meet the 2020 target, but recent increases provide reason for cautious optimism in this respect.

The results from the soundwide area estimate are reinforced by our data on site level trends. When looking over longer periods of time (2003-2014), there were the same number of sites with increases and declines, but in recent years this pattern has changed. Between 2010 and 2014, there were more sites with increases than declines. This reversal in trend is most pronounced in lower Hood Canal, where several sites that were either stable or declining before 2010, showed modest increases in eelgrass areas between 2010 and 2014. This indicates that recent years have been beneficial for seagrass growth. However, the exact nature and longevity of this reversal is as of yet unclear.

4.2 Sites of particular interest

4.2.1 Seagrass associated with river deltas

Seagrass beds near river deltas are influenced by a wide range of stressors, including freshwater pulses, higher concentrations of nutrients and suspended sediments (Czuba et al. 2011), and changes in sediment deposition and erosion at the delta flat. These stressors can affect seagrass beds in multiple ways. Higher light attenuation below a sediment plume can limit the maximum depth to which eelgrass grows (Olesen 1996), but increased retention of water on the delta flat can protect eelgrass from desiccation at low tides (Boese et al. 2005). Increases in sediment organic matter content can increase sulfide concentrations in the pore water, but are also linked to increased seedling recruitment, and therefore resilience of eelgrass beds at these locations (Yang et al. 2013). Sediment deposition can create additional soft bottom habitat suitable for eelgrass growth, but channelization of flow and sediment discharge can contribute to fragmentation of eelgrass beds. Changes in river flow and delta morphology can therefore significantly alter seagrass beds growing on the delta flat.

In greater Puget Sound, recent delta restoration efforts at the Skokomish and Nisqually deltas appear to have had a beneficial effect on nearby eelgrass beds (NHP 2015). At the Skokomish delta, a recent increase in eelgrass area coincided with a project aimed at restoring tidal wetlands, distributary channels, and natural sediment delivery transport processes. The first and second phases of this project were completed in 2007 and 2011 respectively, and led to an increase of approximately 120 ha of tidal wetlands. It is possible that the restoration project directly contributed to the increase in eelgrass area by changing sediment delivery and flow patterns on the delta flat.

Skagit Bay is another site where changes in river flow have the ability to significantly alter the distribution of seagrass beds. At the end of 2014, a large fraction of the flow from the north fork of the Skagit River was rerouted through a newly formed channel, created by an avulsion of the river through a coastal wetland, 1.5 miles SE of the river mouth. Preliminary data indicates the formation of new channels in the tidal flat near the location of the avulsion. As of 2015, these channels did not extend into the nearby eelgrass meadow, but if they develop further they may fragment the contiguous eelgrass bed at the center of Skagit Bay. The lower flow rate through the river mouth of the north fork near La Conner could have a beneficial impact on the seagrass growing at this location.

The effects of the dam removal on the Elwha River on seagrass beds growing near the Elwha River delta are less pronounced. Seagrass did not occur on the delta flat. When comparing data collected at adjacent sites before and after dam removal, there is some evidence that seagrass area remained constant near the outflow of the Elwha River, but that there were slight increases over time at larger distances from the river mouth (Ferrier et al., 2015). However, more data is needed to assess the long-term impacts of dam removal on native seagrass beds in the Strait of Juan de Fuca. Seagrass beds at river deltas will remain a priority for SVMP monitoring in years to come.

4.2.2 Quartermaster Harbor Focus Area

Quartermaster Harbor is one of several locations that has experienced significant declines in eelgrass cover. As with other locations, the reason for this loss remains undetermined. However, the decline in eelgrass area is likely related to local water quality issues. Marine waters within Quartermaster Harbor have been listed on the 303(d) list of impaired waters[7] for low dissolved oxygen levels. Nearby shellfish growing areas have been closed in response to high levels of fecal coliforms, and parts of the harbor have been designated as a Marine Recovery Area to assess problems with on-site septic systems (RCW 70.118A). Although marine inputs are the dominant source of nitrogen in Quartermaster Harbor, the contribution of anthropogenic nitrogen loading to low dissolved oxygen and harmful algal blooms remains uncertain (King County 2014). Additional research is needed to determine how nutrients, light attenuation, and low oxygen affect seagrasses at this location.

It is possible that observed losses within vulnerable populations, such as Quartermaster Harbor, are an early indicator of a larger, regional issue. While conceptual models of eelgrass stressors do exist, it is critically important to understand what is driving eelgrass trends on local spatial scales, in order to elucidate the relative importance of several stressors associated with population declines. One particular gap in our understanding of eelgrass dynamics in Puget Sound is the role of light attenuation through the water column at local and regional spatial scales. Up to the date of writing of this report, there have been relatively few measurements of photosynthetically active radiation (PAR) in nearshore habitats in greater Puget Sound. In 2016, the Department of Natural Resources will start deployments of PAR sensors in the Quartermaster Harbor focus area and at other locations in Puget Sound to evaluate light levels and determine whether these levels are adequate to support eelgrass growth.

4.2.3 Lower Hood Canal

Lower Hood Canal has received much attention in previous SVMP reports, as a region with many sites with long-term declines in seagrass area (Gaeckle et al. 2007, 2011; Short et al. 2014). Lower Hood Canal is susceptible to low water quality. Parts of this area are listed on the 303(d) list of impaired waters for both low dissolved oxygen and fecal coliforms, and the entire shoreline has been designated as a Marine Recovery Area to address potential pollution from on-site septic systems. In 2012, the new Belfair waste water treatment plant was completed, which helped reduce nutrients and bacteria inputs into Lynch Cove. As with most large bodies of water in Puget Sound, marine inputs are considered the dominant source of nutrient inputs into the system (Cope & Roberts 2013). Nevertheless, anthropogenic derived nutrients could impact sensitive nearshore habitat, such as seagrass beds within lower Hood Canal.

Analyses based on recent data indicate a reversal in trend at several sites in lower Hood Canal, starting in 2010. The timing of this increase does not correspond with the increase in eelgrass area at the sites near the Skokomish delta, and the exact cause of this apparent

[7] http://www.ecy.wa.gov/programs/wq/303d/index.html

trend remains unclear. The majority of sites in lower Hood Canal will be resampled in the near future to determine if the reversal in trend is permanent or a temporary phenomenon.

4.3 Review of current methodology

Previous reports and recent analyses have identified a number of concerns regarding the power to detect trends in eelgrass area on both local and soundwide spatial scales. These are consequences of the design of the SVMP, which compromises between generating a status estimate (spreading sample effort over as many transects/sites as possible) and detecting trends (which requires resampling of the same transects/sites over longer periods of time). The current SVMP dataset provides a very solid estimate of status of native seagrass in greater Puget Sound, but is less powerful in terms of detecting trends. Based on the current needs of management, and the requirement to test if soundwide native seagrass area will meet the 2020 Recovery Target, DNR has decided to reduce the sample effort dedicated to the status estimate, and improve the SVMP's ability to detect trends. In order to accomplish this, two major changes will be implemented in the SVMP.

The first change involves the site selection for the soundwide seagrass estimate. A recent analysis of the 20% rotational design (Dowty et al., 2016, in prep.) indicates that the introduction of a 20% rotation in site selection severely reduces the precision of trend estimates over periods of 20 years. Starting 2015, the SVMP will sample based on a 3-year rotational panels with a total of ~240 independent random sites. Every 3 years, we will revisit all sites sampled in either 2004, 2009 or 2014; and use 3-year rolling averages based on all sites sampled, to generate unbiased estimates of soundwide eelgrass area in greater Puget Sound.

A second change is the departure of sampling sites using new randomly selected transects every time a site is visited. From 2013-2015, we tested repeat sampling of the same transects at a number of demonstration sites throughout greater Puget Sound. The results of this analysis will be presented in a separate report. Repeat sampling of the same transects greatly improves our ability to detect trends at local levels. Starting in 2016, we will employ this sample technique for all sites sampled as part of the SVMP. The statistical analysis of repeat transects will be presented in a separate report.

4.4 Research and Monitoring Priorities

In addition to completing ongoing monitoring, the SVMP will continue to improve long-term monitoring methods in order to most effectively and efficiently address scientific and management priorities for Puget Sound. We have identified the following priorities to guide our future efforts:

1. Continue soundwide monitoring and special studies to increase our knowledge of current seagrass distribution. Implement and evaluate the proposed improvements to the current design for estimation of soundwide seagrass area, including:

a. Assess the 2015 results of repeat sampling of the 2004 sample frame, for detecting long-term change in seagrass area on site level and sound-wide spatial scales.
b. Complete the paired transect analysis of data from the 2013-2015 demonstration sites to assess the possible impacts of the anomalous environmental conditions throughout greater Puget Sound in 2015.

2. Provide technical support and data to scientists and managers on the status and trends in native seagrass, and on sites and regions of concern in Puget Sound.
3. Collaborate with other researchers to further assess changes in sites of particular interest, including those listed in the 2014 Puget Sound Eelgrass Recovery Strategy (Goehring et al. 2015). Initial focus will be on sites:
    a. in Quartermaster Harbor, an area with documented long-term declines in eelgrass cover;
    b. in lower Hood Canal where recent increases in eelgrass contrast with long-term declines;
    c. near the Skagit delta, where a recent avulsion has changed where the North fork of the Skagit River impacts local eelgrass beds;
    d. near the delta of the Nisqually and the Skokomish, where eelgrass beds increased coinciding with delta restoration projects.

A major component of monitoring at these sites will be relating trends in seagrass area, patchiness and depth distribution to environmental drivers, in particular water clarity. The SVMP will assist DNR's Eelgrass Stressor Response Program to measure PAR (photosynthetically active radiation) along a gradient of disturbance in the Quartermaster Harbor Focus area, and plan PAR measurements on larger spatial scales throughout greater Puget Sound.

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