N A T U R A L R E S O U R C E S

Puget Sound Seagrass Monitoring Report

Monitoring Year 2015

3/17/2017

PUGET SOUND ECOSYSTEM MONITORING PROGRAM

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
HILARY S. FRANZ | COMMISSIONER OF PUBLIC LANDS

The Submerged Vegetation Monitoring Program is a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (https://sites.google.com/a/psemp.org/psemp/home).

Cover Photo: Eelgrass at Alki Beach, Seattle. Photo credit: Lisa Ferrier.

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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 are Bart Christiaen, Lisa Ferrier, Pete Dowty, Jeff Gaeckle and Helen Berry. Several people played a critical role in the video data collection and post-processing for the work summarized in this report including Cailan Murray, Olivia Mitchell, Jessica Olmstead, Rose Whitson and Evan Sutton.

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Contents

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*) and surfgrass (*Phyllospadix spp.*), important components of nearshore ecosystems in greater Puget Sound. Through the Submerged Vegetation Monitoring Program (SVMP), DNR monitors the status and trends of native seagrass abundance and depth distribution throughout greater Puget Sound using underwater videography. Monitoring was initiated in 2000. The monitoring results are used by the Puget Sound Partnership as one of 25 vital signs to track restoration progress (PSP 2017).

Key findings:

- SVMP data suggests soundwide native seagrass area remained relatively stable over the last 15 years. In 2015, the soundwide estimate was approximately 23,150 ± 1,640 ha. The 3-year soundwide average for 2013-2015 is 22,810 ± 1,260 ha. Soundwide seagrass area has not yet achieved the Puget Sound Partnership's target for a 20% increase by 2020 (Figure A).
- A total of 514 sites have been sampled by the SVMP between 2000 and 2015; 358 sites have been sampled over multiple years, and were analyzed for change. Approximately 69% of sites with multi-year data were stable, 15% had no native seagrass, 8% showed increases, and 8% showed declines between 2000 and 2015 (Figure B). Many of the sites with declines were located in lower Hood Canal, the San Juan Islands, and the southern part of Central Puget Sound.
- Seagrass conditions have improved in recent years. Between 2010 and 2015, approximately 10% of sites with multiyear data showed short-term increases, and only 2% showed short-term declines (Figure C). The recent recovery is most pronounced in lower Hood Canal.
- The pattern of overall stability with significant changes on smaller spatial scales corresponds well with a recent study on long-term trends (1970 – 2012) of eelgrass in the herring spawn areas of Puget Sound (Shelton et al. 2017). Both datasets suggest that eelgrass beds near heads of inlets and bays are particularly vulnerable. Areas with significant long-term declines in eelgrass cover include inner Quartermaster Harbor, Port Gamble Bay, Westcott Bay, Garrison Bay, Blind Bay, Swifts Bay, Watmough Bay, and sites at the head of Case Inlet and Carr Inlet.
- An analysis of eelgrass depth distribution data from 2004 and 2015, two years with good comparative data, suggests a subtle shoreward expansion of the upper edge of eelgrass beds in Northern Puget Sound, the Saratoga Whidbey Basin and to a lesser degree Hood Canal. Overall, the depth distribution changed little between these two years.

Implications for management:

- Soundwide native seagrass area has remained relatively stable since 2000. This is reassuring and sets Puget Sound apart from many other developed areas, where substantial system-wide declines are ongoing.
- The long-term loss of eelgrass in sensitive areas of Puget Sound (such as heads of bays and inlets) is concerning. Further study is needed to identify what drives these declines. Continued loss in these areas could eventually result in local collapses of eelgrass populations due to lack of bed maintenance from vegetative expansion and seed production.
- At this point in time, it is difficult to predict whether the goal of 20% increase by 2020 will be met. Site level trends between 2010 and 2015 provide some reason for optimism, but there is no clear indication of an increase in seagrass area on a larger spatial scale. The stressors on eelgrass in Puget Sound will likely need to be reduced to see significant sound-wide gains in seagrass area, depth distribution and overall health.

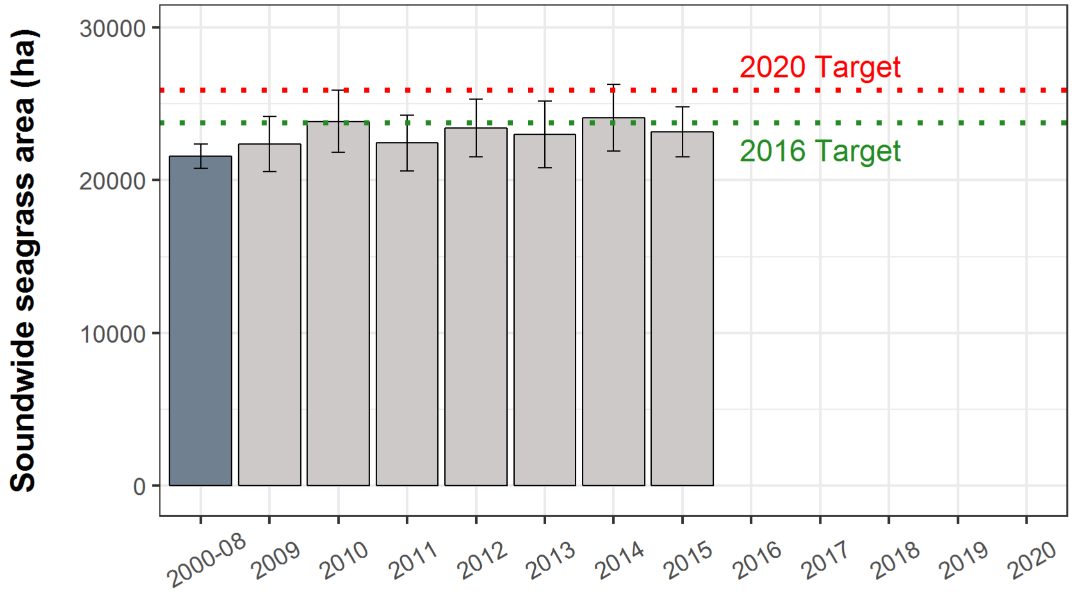


Figure A: Long-term trend in soundwide area of native seagrasses in greater Puget Sound. The darker bar represents the 2000-2008 baseline, the lighter bars represent annual soundwide area estimates, the dotted green line is the 2016 interim target set by Results Washington, and the dotted red line is the long-term management target by the Puget Sound Partnership: a 20% increase in soundwide area relative to the baseline by 2020.

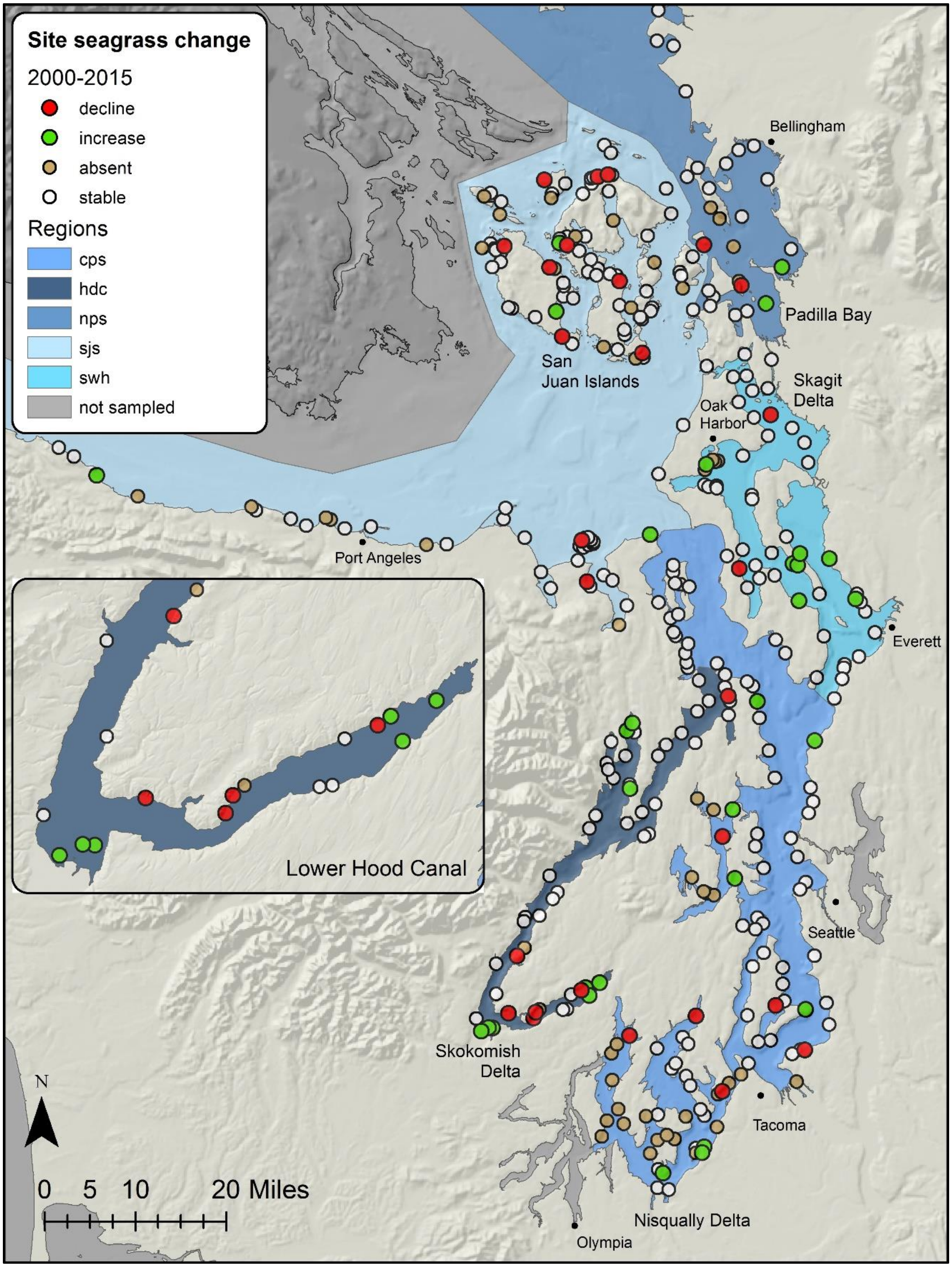


Figure B: Sites with clear trends in native seagrass area between 2000 and 2015

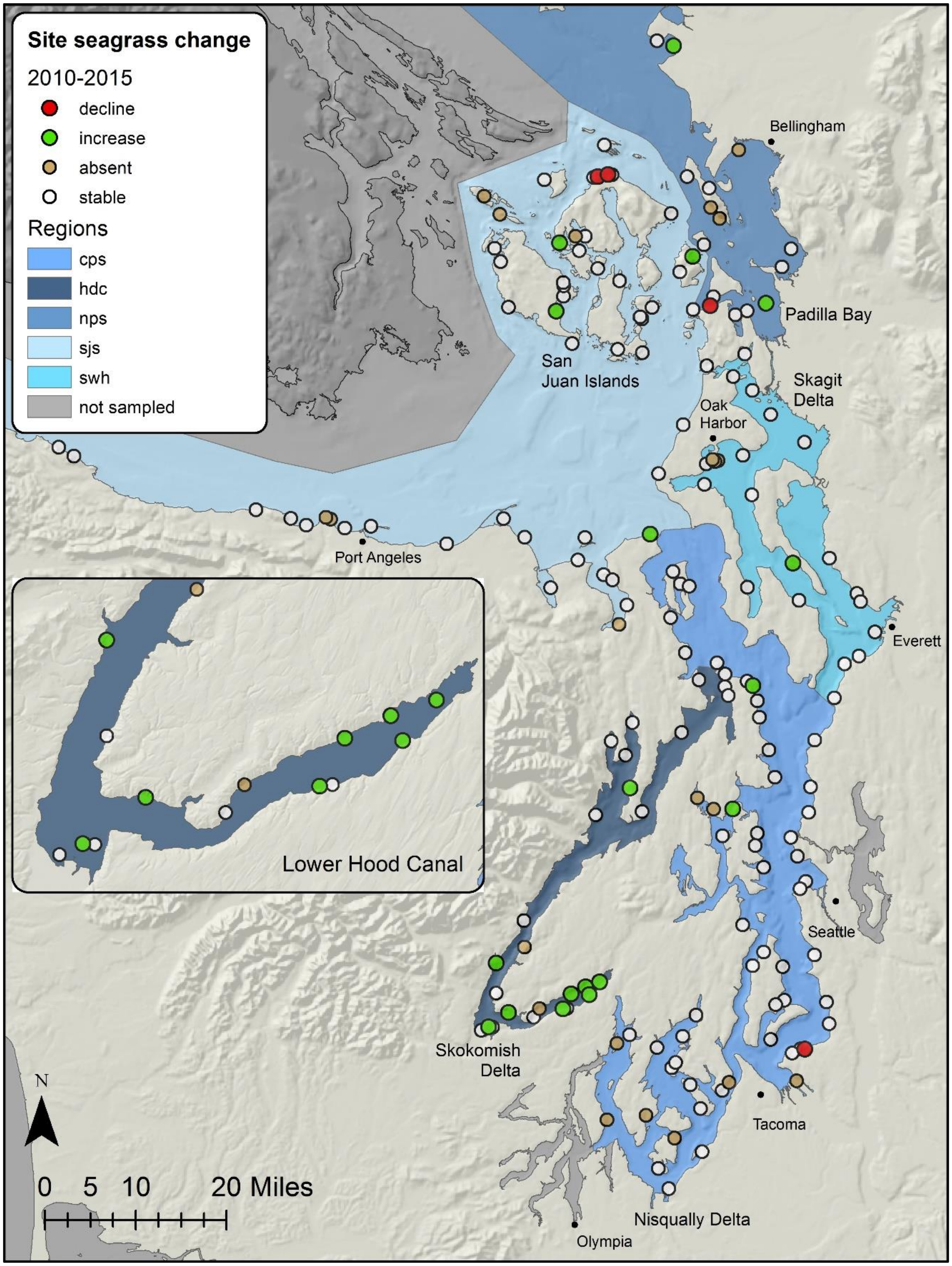


Figure C: Sites with clear trends in native seagrass area between 2010 and 2015

1 Introduction

1.1 The role of seagrass beds

1.1.1 On a global scale

Seagrasses are flowering plants that grow submerged in marine environments. These plants flower, fertilize and set seeds underwater, but often spread through vegetative growth (Cox 1998, Kendrick et al. 2012). There are approximately 60 species worldwide, which belong to 4 plant families[1] (Den Hartog and Kuo 2006, Green and Short 2003). Despite their limited diversity, seagrass beds play an important role in the food-webs of coastal ecosystems throughout the world. They are ranked among the most productive and valuable habitats in the biosphere (Costanza et al. 1997), and provide food and shelter for a wide variety of animal species, including benthic invertebrates, commercially important fish species, wading birds, turtles, dugongs and manatees (Orth et al. 1984, Gillanders 2006, Bertelli & Unsworth 2014). Seagrasses are able to reduce erosion and improve water quality by stabilizing sediments with their roots and rhizomes (de Boer 2007). They are an important sink for carbon on a global scale (Fourqurean et al 2012), and have the potential to mitigate some effects of ocean acidification (Unsworth at al. 2012, Manzello et al. 2012, Hendriks 2014). Recent studies also suggest that seagrass beds are able to reduce the relative abundance of potentially pathogenic bacteria from the water column (Lamb et al. 2017), and that algicidal bacteria associated with seagrass leaves may influence the abundance of harmful algae in nearshore environments (Inaba et al. 2017).

While seagrass beds provide valuable habitat, they are vulnerable to anthropogenic stressors such as physical disturbance, and reductions in sediment and water quality due to excessive input of nutrients and organic matter. For these reasons, seagrass beds are effective indicators of habitat condition (Dennison et al. 1993, Short and Burdick 1996, Lee et al. 2004, Kenworthy et al. 2006, Orth et al. 2006). In many regions of the world, seagrass beds are in decline (Waycott et al. 2009). This is often attributed to increased human development in coastal watersheds, which has led to elevated inputs of nutrients to marine ecosystems in many regions of the world (Vitousek et al. 1997). Evidence of global declines has brought significant ecological and political attention to seagrass ecosystems. In several areas of the world, seagrasses are now protected (Duarte 2002; Orth et al. 2006).

[1] 5 families if you classify the *Ruppia maritima* as a seagrass (for the purpose of this report, we consider *R. maritima* a seagrass)

1.1.2 In greater Puget Sound

There are 6 seagrass species in Washington State: *Zostera marina*, *Zostera japonica*, *Phyllospadix serrulatus, Phyllospadix scouleri*, *Phyllospadix torreyi* and *Ruppia maritima. Zostera marina* (eelgrass) is by far the most abundant seagrass species in greater Puget Sound. Eelgrass provides similar ecosystem services as other seagrass species. In particular, it 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 beds are 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). Similar to other seagrass species, eelgrass responds quickly to anthropogenic stressors. Because of this, eelgrass has been selected as one of 25 vital signs used by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound (PSP 2017)

1.2 DNR’s seagrass monitoring program (SVMP)

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 (PSP).

SVMP data is used to determine the status of the PSP’s eelgrass Vital Sign (PSP 2017). Earlier ecosystem indicator efforts in Puget Sound also included results from the SVMP (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*. 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 [2] (Bando 2006, Mach et al. 2010, Shafer et al. 2014, Hannam and

[2] *Phyllospadix torreyi*, is present on the outer coast but has not been observed in greater Puget Sound by the SVMP. *Ruppia maritima* grows at sparse density in parts of Padilla Bay (Bulthuis, 1995a) but is not tracked by the SVMP.

Wyllie-Echeverria 2015a). 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 construction projects in state waters (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 16 years (2000-2015) and includes data from 1,930 site visits, 27,455 transects, and 9,719,816 points where eelgrass has been classified.

1.3 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 2017) includes a more detailed description of project methods than are included in this report.

https://fortress.wa.gov/dnr/adminsa/DataWeb/dmmatrix.html

http://file.dnr.wa.gov/publications/aqr_nrsh_svmp_databse_user_manual.pdf

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

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.

2.1.1 Equipment

Field sampling is generally conducted from May to August. DNR charters an 11 m research vessel *R/V* Brendan D II. The *R/V* Brendan D II is equipped with an underwater video camera mounted in a downward-looking orientation on a weighted towfish. Parallel lasers mounted 10 cm apart created two red dots in the video images for scaling reference. The towfish is deployed directly off the stern of the vessel using an A-frame cargo boom and hydraulic winch. The weight of the towfish positions the camera directly beneath a DGPS antenna, ensuring that the data accurately reflected the geographic location of the camera. Time, differential global positioning system (DGPS) data, Garmin and BioSonics echo sounder data are acquired simultaneously during sampling. Differential corrections are received from the United States Coast Guard public DGPS network using the WSG 84 datum. Table 1 lists the equipment used to conduct video sampling and acquire eelgrass depth data.

2.1.2 Site selection

The SVMP uses a statistical framework to provide regional estimates of native 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.

Until 2014, sites were sampled using a rotational sample design where 20% of sites were replaced by randomly selected sites each year. Sites remained in the sample pool for 5 years before rotating out (Berry et al. 2003, NHP 2015). 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 Cypress Island (SJS-Cyp[3]), Northern Puget Sound (NPS) and the Saratoga Whidbey basin (SWH). 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.

From 2015 onwards, sites are selected using a 3-year rotating panel design (Figure 1), where 3 alternating panels of independent sites are resampled every 3 years. For more information on the rotating panel design, see section 2.2.

2.1.3 Site and sampling polygons

Prior to field sampling, a site polygon is defined for each site, bound by the -6.1 m MLLW bathymetry contour and the ordinary high water mark as described in the SVMP methods (Berry et al. 2003, Figure 3). Fringe sites are 1000 m along the -6.1 m contour, while the segment lengths vary for flats sites (e.g., depending on embayment size). In addition, we delineated sample polygons, which encompass all the eelgrass at a site, based on reconnaissance prior to sampling. At each site, underwater videography is used to sample the presence/absence of eelgrass along transects in a modified line-intercept technique (Norris et al. 1997). Video data is collected along randomly selected transects that are oriented perpendicular to shore and span the entire width of the sample polygon. Each year a site is sampled, a new random draw of transects is selected.

2.1.4 Video processing

Video is reviewed and each transect segment of nominal one-meter length (and one-meter width) is classified with respect to the presence of native (*Z. marina*, *Phyllospadix spp*.) and non-native seagrass species (*Z. japonica)*. All presence and absence classification results are recorded with corresponding spatial information, and stored in an ArcGIS file geodatabase. The fractional cover of eelgrass along transects is used to calculate site eelgrass area. Depth information collected along each transect is used to estimate mean maximum and minimum depth of eelgrass relative to Mean Lower Low Water (MLLW) at each site.

[3] SJS-Cyp is a sub-region of the San Juan Island and the Strait of Juan de Fuca (SJS)

Table 1. Equipment and software used to collect underwater video, depth and positional 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	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 DataVideo DN-700 / DV Hard Disk Recorder

All measured depths are 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). Corrected depth data are integrated with survey data information, so each video frame has an associated date/time, GPS position and depth measurements corrected to MLLW datum.

2.1.5 Data analysis

Native seagrass area at each site was calculated based on survey data using ArcGIS software in the following sequential steps:

1. Calculate the area within the sample polygon;
2. Calculate the fraction of native seagrass along each random line transect;
3. Calculate the mean fraction and associated variance, weighed by transect length;
4. Estimate the overall eelgrass area and variance at the site by extrapolating the mean fraction along random transects over the sample polygon area.

Site area estimates are extrapolated to a soundwide seagrass estimate, for each stratum, based on the statistical framework described in Berry et al. (2003). Mean seagrass area and the associated variance estimates for each of the strata are summed to estimate the total amount of native seagrass and the uncertainty associated with these estimates (variance) in greater Puget Sound and each of 5 sub-regions.

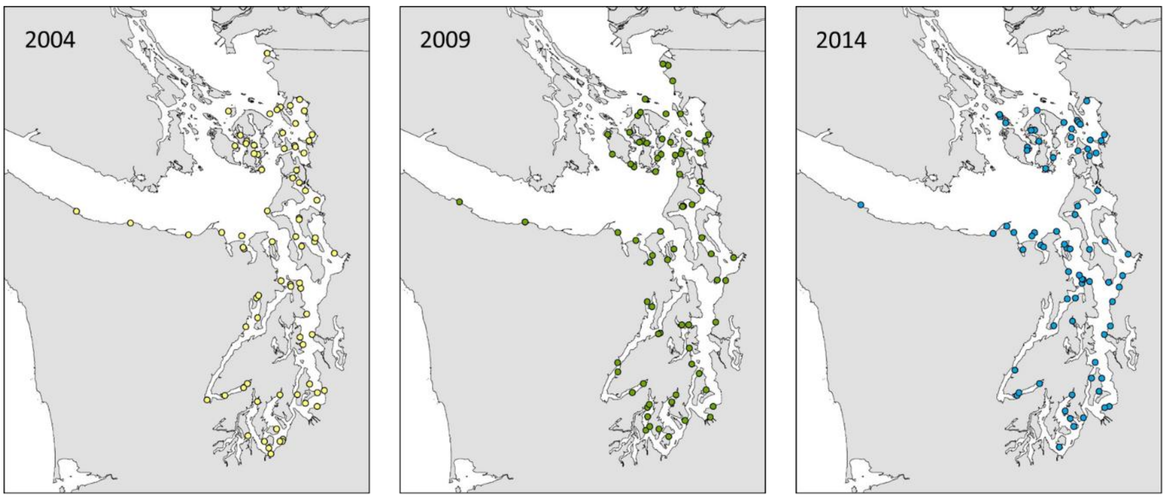
2.2 Rotating panel design

Regional monitoring programs, such as the SVMP, are often unable to census (completely measure) the ecosystem of interest. Instead, a representative sample of sites is visited, and results from this sample are extrapolated to regional scale. Such monitoring programs are either optimized to provide a good mean status estimate of an ecosystem (sample as many sites as possible, for example by taking a new random draw of sites every year the monitoring is conducted, 100% rotation), or to provide a good estimate of trend (resample the same sites over time, 0% rotation). However, each of these designs have weaknesses. Sample designs with 100% rotation are able to provide a good picture of distribution of habitat characteristic over large spatial scales, but regional trend estimates based on a design with 100% rotation have low precision, and there is no ability to generate trend estimates for individual sites. Regional trend estimates based on sample designs without rotation have high precision, but may not be accurate if the number of sites sampled is relatively low compared to the number of potential sample sites in the region: if the sample size is too low, a potential regional trend detected based on this sample may not be representative of the region as a whole.

In order to satisfy the competing goals of estimating status and trends of native seagrass in greater Puget Sound, the SVMP previously employed a design with 20% rotation: sites were randomly selected (within a stratum) and followed for a period of 5 years, after which they were replaced by new randomly selected sites (Section 2.1.2). Because of this, the SVMP was able to sample over 400 different sites throughout greater Puget Sound between 2000 and 2014. In addition, this design made it possible to estimate trends over time on both a site-level and a soundwide spatial scale.

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. 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).

Starting in 2015, the SVMP program has shifted sample effort towards detecting trends, because information on local/regional trends is of critical importance for management of seagrass beds. A first step towards readjusting the priorities of the sample program was 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 fixed, 3-year rotational panel of ~240 independent random sites. Every 3 years, the SVMP 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 (Figure 1).



Sample schedule – SVMP redesign																				REPORT OUT
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Figure 1: Modified site selection: 3-year rotating panel design. In 2015 and 2018, sites from the 2004 panel are resampled. In 2016 and 2019, we resample sites from 2009, and in 2017, we resample sites from 2014.

3 Results

3.1 Field effort summary

The number of sites sampled for the SVMP between 2000 and 2015 are shown in Table 2. In 2013, the SVMP regional focus study was suspended and this effort was reallocated to sampling at demonstration sites using developmental site survey methods. The 2015 stratum for the soundwide study is a repeat of 2004.

Table 2: Number of SVMP sites sampled and the allocation over different studies from 2000 to 2015. 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	61	0	0	6
2001	71	0	0	5
2002	72	0	0	4
2003	75	0	0	1
2004	78	28	4	1
2005	77	3	0	2
2006	79	24	3	0
2007	79	32	5	0
2008	76	32	33	3
2009	80	29	18	0
2010	78	30	34	2
2011	77	24	11	2
2012	78	32	29	2
2013	79	0	63	1
2014	79	0	157[4]	0
2015	79	0	64	0

[4] A large number of sites in the Special Studies and Demonstration sites category is funded by external sources. In 2014, 95 sites were sampled as part of IAA15-17 between DNR and The Suquamish Tribe. Results from this sampling effort have been published in a separate report (Christiaen et al. 2016b).

3.2 Seagrasses of greater Puget Sound

There are 6 seagrass species in Washington State: *Zostera marina*, *Zostera japonica*, *Phyllospadix scouleri*, *Phyllospadix serrulatus*, *Phyllospadix torreyi* and *Ruppia maritima*.

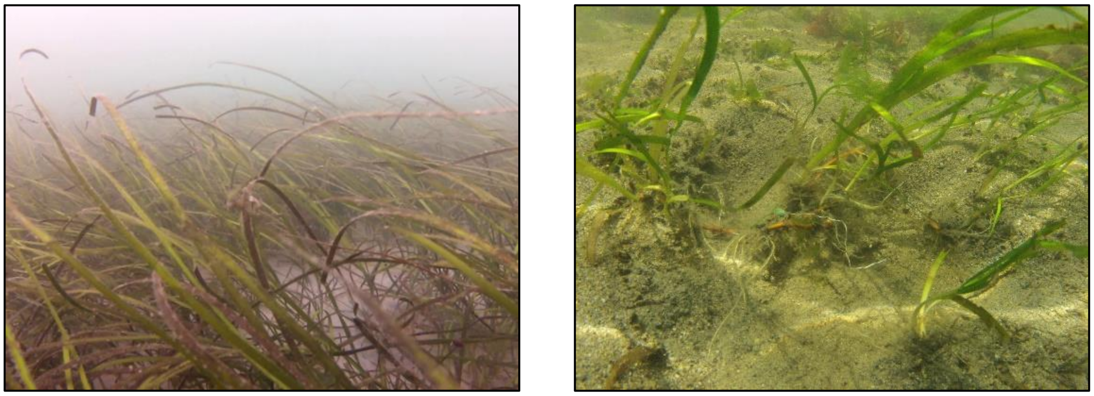


Figure 2: *Zostera marina* (eelgrass) grows primarily on sandy/muddy substrate (left). This species forms dense mats of roots and rhizomes that stabilize the substrate and improve water quality by reducing resuspension of fine sediments (right).

Zostera marina (eelgrass) is by far the most abundant seagrass species in Puget Sound. More than 81% 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 5). *Zostera marina* (Figure 2) grows mostly on sandy and muddy substrates, and is found between +1.4m and -11m relative to MLLW in greater Puget Sound. The plants are morphologically plastic: canopy height ranges from less than 40 cm all the way up to 2m, depending on the depth and the location in Puget Sound.

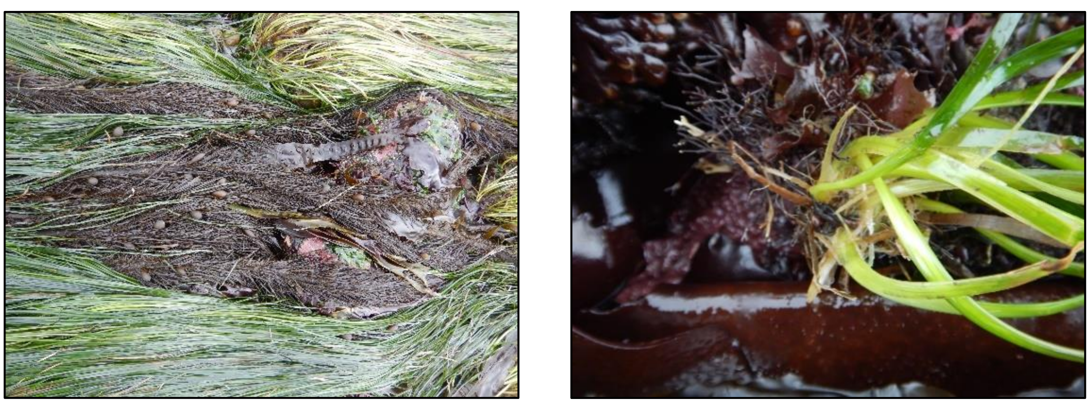


Figure 3: *Phyllospadix scouleri* grows primarily on rocky intertidal habitats (left). The seeds *of Phyllospadix scouleri* are coated in bristles, which help them stick to certain types of macroalgae, which helps the seedlings to establish themselves on rocky substrates (right).

Seagrasses of the genus *Phyllospadix* are only detected on the Pacific coast, the Strait of Juan de Fuca, the San Juan Islands and the northern reaches of Central Puget Sound (Figure 7).

Phyllospadix torreyi and *Phyllospadix scouleri* grow mostly on hard substrate, and are generally found in the surfzone on exposed rocky coasts and in tidepools (Figure 3). *Phyllospadix torre*yi is mostly limited to the Pacific coast, while *Phyllospadix scouleri* can be found along rocky shorelines in the Strait of Juan de Fuca and the San Juan Islands. *Phyllospadix serrulatus* grows amongst cobbles covered with sediment and is sometimes intermixed with *Zostera marina*. These species are difficult to distinguish based on underwater videography, and some misidentification is possible.

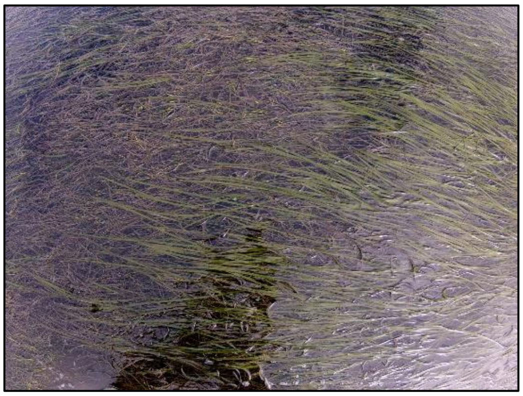



Figure 4: *Zostera japonica* intermixed with *Zostera marina* (left). *Zostera japonica* is generally smaller than *Zostera marina,* but can be hard to distinguish just based on size. One of the differentiating characteristics is that the leaf sheath is open at the base *for Zostera japonica*, but closed at the base for *Zostera marina*. Despite being a non-native species, *Zostera japonica* provides at least some of the same ecosystem services as *Zostera marina* (right)

The non-native *Zostera japonica* (Figure 4) grows at higher tidal elevations than *Z. marina* and is less prevalent in high energy environments, such as the San Juan Islands and the Strait of Juan de Fuca (Figure 6). Even though SVMP sampling is conducted at high tides, *Zostera japonica* beds are often out of reach for our sample vessel. As such, the SVMP can only generate conservative estimates for the presence/absence of *Z. japonica*. Nevertheless, the data suggests that *Z. japonica* is common in Central Puget Sound (CPS) and Hood Canal (HDC).

The sixth seagrass species in greater Puget Sound, *Ruppia maritima,* is a relatively small, colonizing seagrass species that prefers areas with low and intermittent salinities. *Ruppia maritima* is primarily found at Padilla Bay, where it grows at very sparse densities.

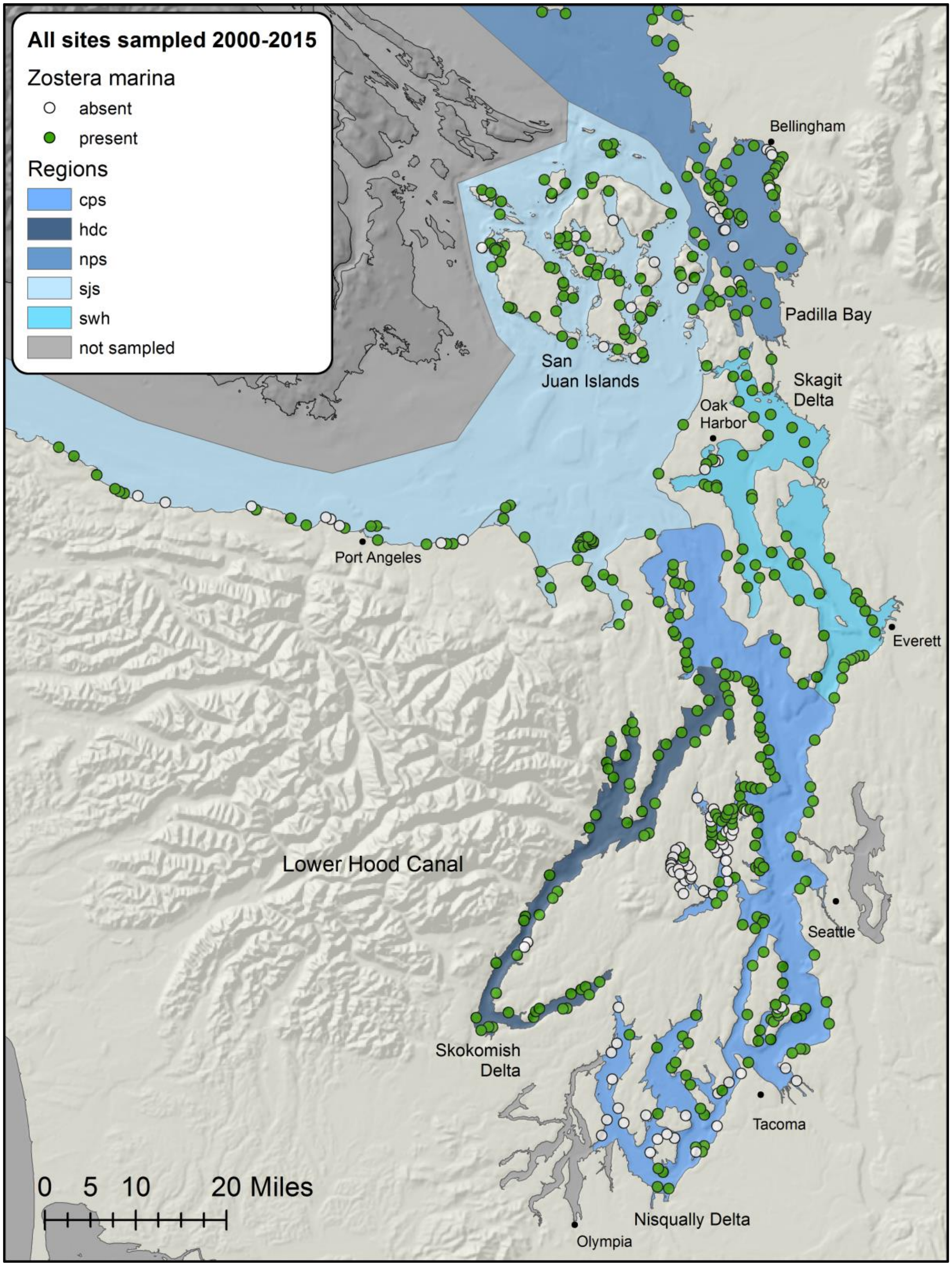


Figure 5: Presence/absence of *Zostera marina* at all sites sampled between 2000 and 2015.

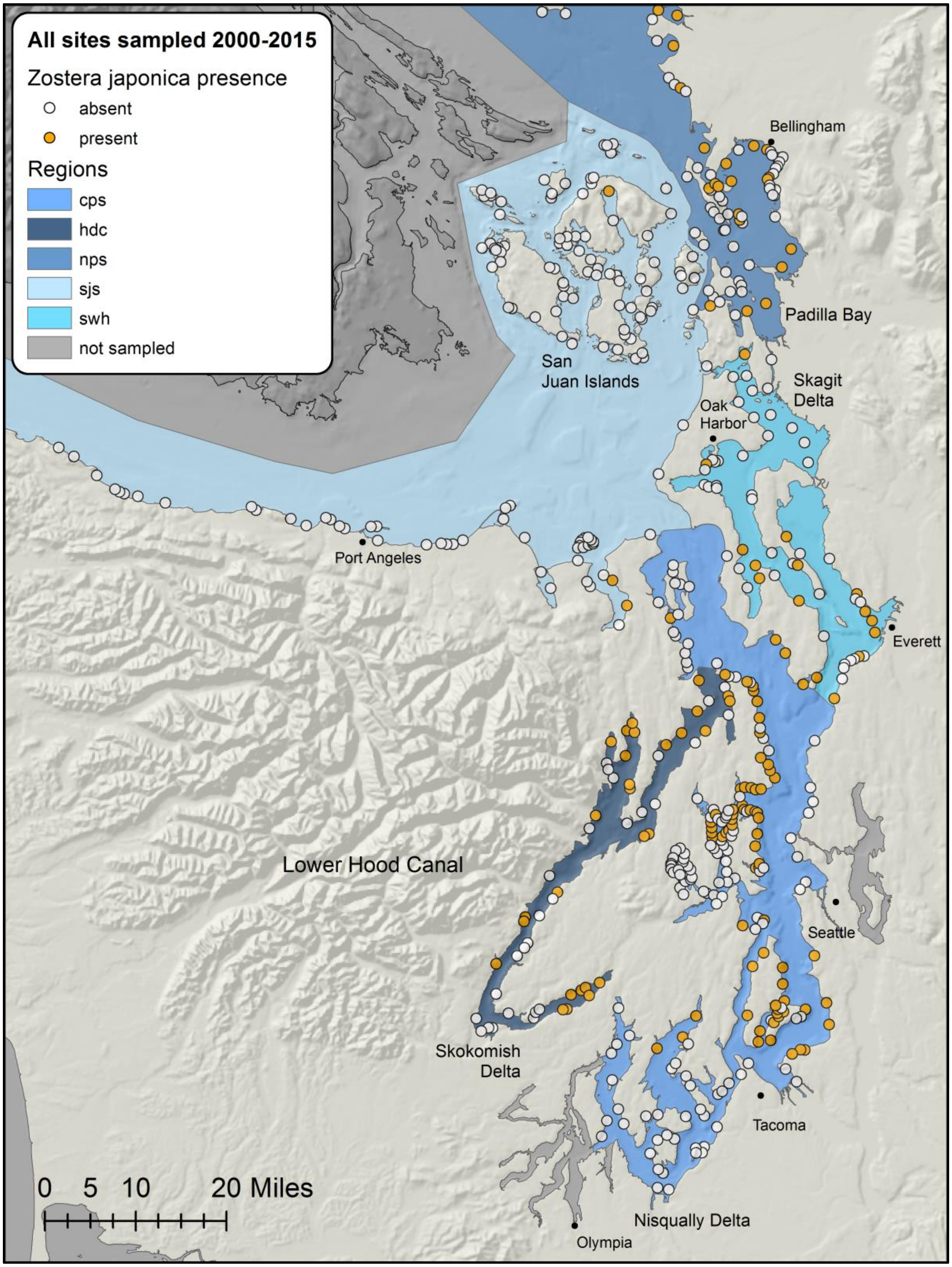


Figure 6: Presence/absence of *Zostera japonica* at all sites sampled between 2000 and 2015.

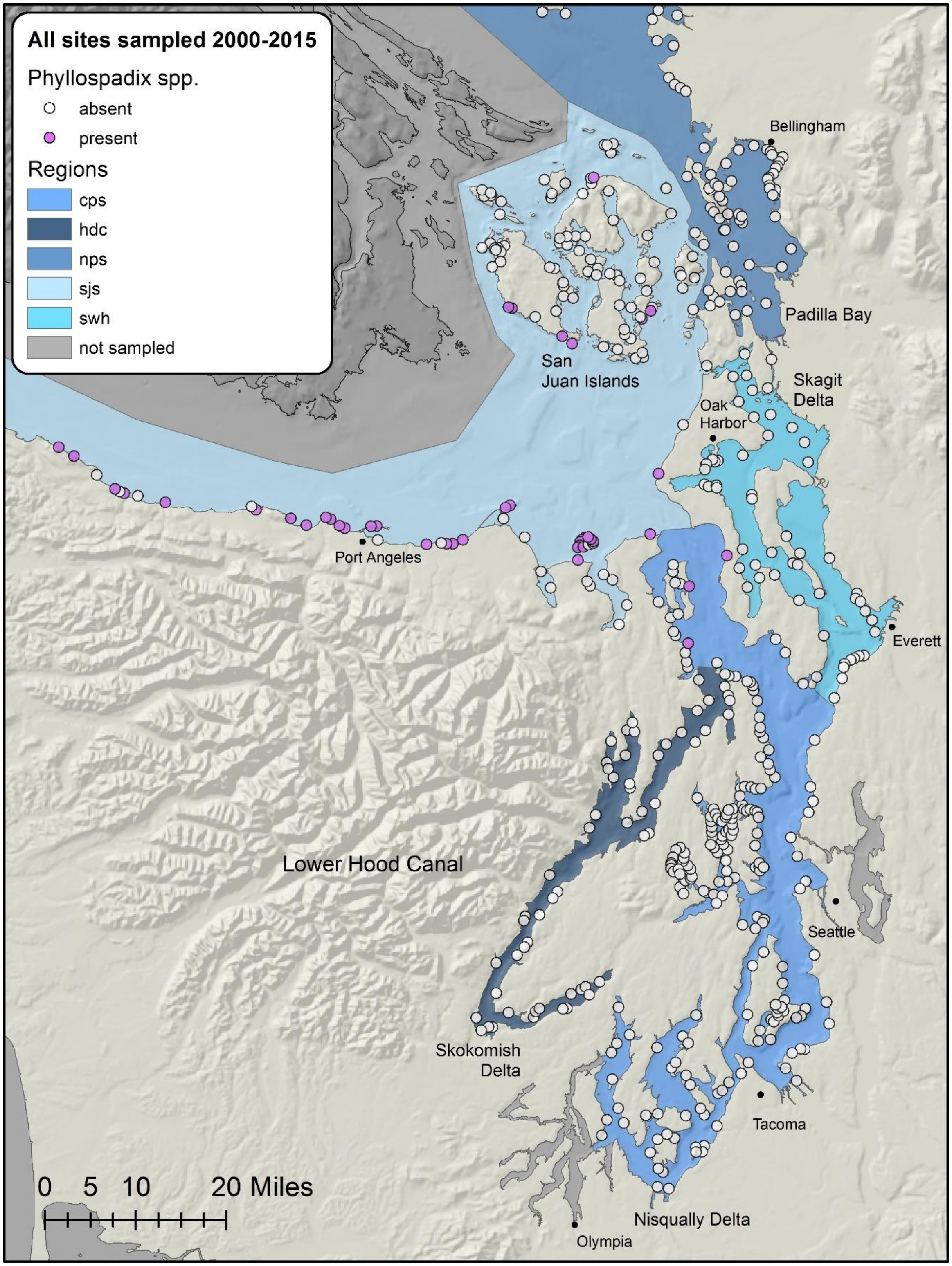


Figure 7: Presence/absence of *Phyllospadix spp.* at all sites sampled between 2000 and 2015.

3.3 Spatial patterns in seagrass distribution

3.3.1 Native seagrass area per region

While most sites sampled have some native seagrass present, the actual area of seagrass measured varies widely between the sites. Approximately 50% of native seagrass in greater Puget Sound grows on tidal flats (Figure 8). Seagrass beds at these sites tend to be larger (median size 27.5 ha, range 0.1 - 3,281 ha), but are fewer in number (74 total). The remaining 50% grows in smaller fringe sites in narrow bands along the shoreline. While these beds are small (median size 3.5 ha, range 0.001 – 75.7 ha), they are abundant (2393 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 more than 20% of all native seagrass in greater Puget Sound.

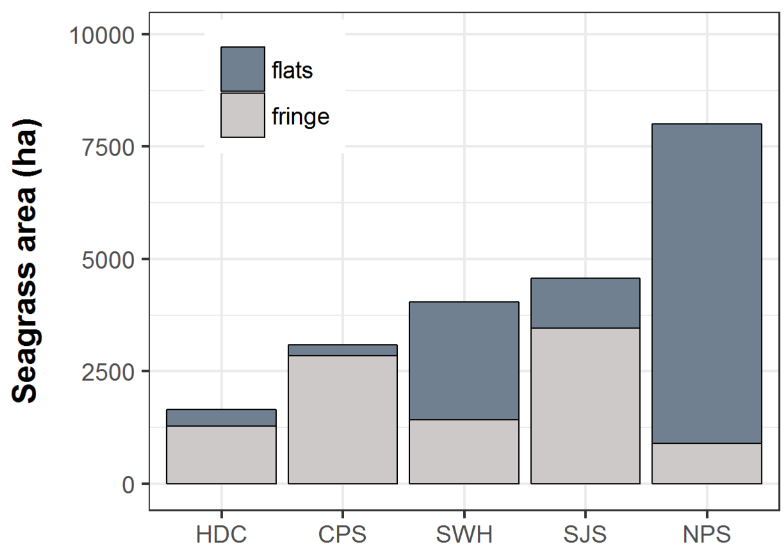


Figure 8: Native seagrass area (ha) in the different sub-regions of greater Puget Sound. The darker color represents the fraction that grows on flats. The lighter color represents the amount of native seagrass growing on fringe sites.

3.3.2 Eelgrass depth distribution

Eelgrass is found between +1.4m and -11m relative to Mean Lower Low Water (MLLW) in greater Puget Sound. The optimal depth range for these plants appears to be between 0 and -2m relative to MLLW. 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 9), but it does not grow as shallow here as in other regions (Figure 10). Eelgrass has a shallower maximum depth in areas with higher levels of turbidity, such as Skagit Bay and Bellingham Bay.

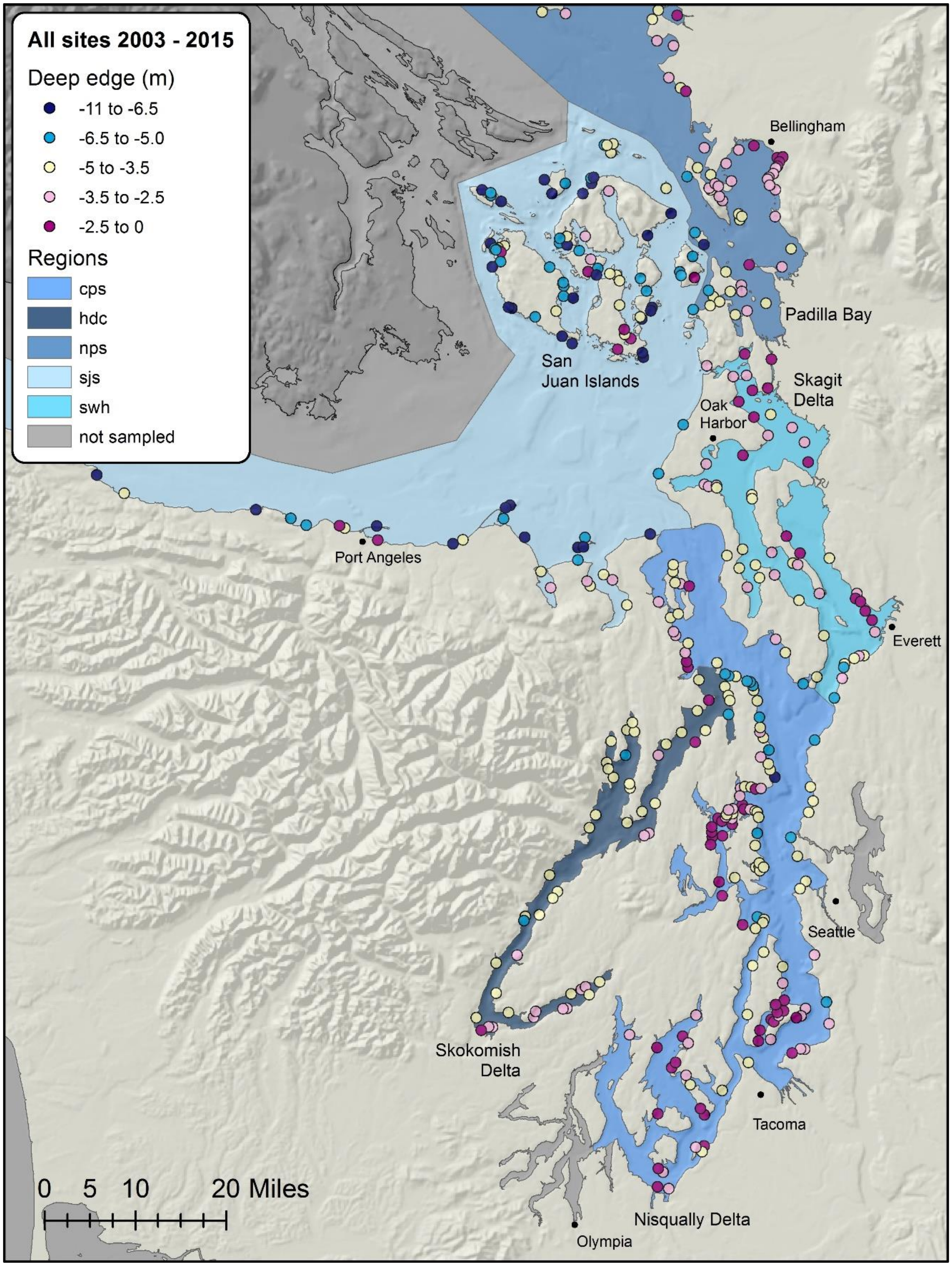


Figure 9: Maximum depth where eelgrass occurs at all sites sampled between 2003 and 2015.

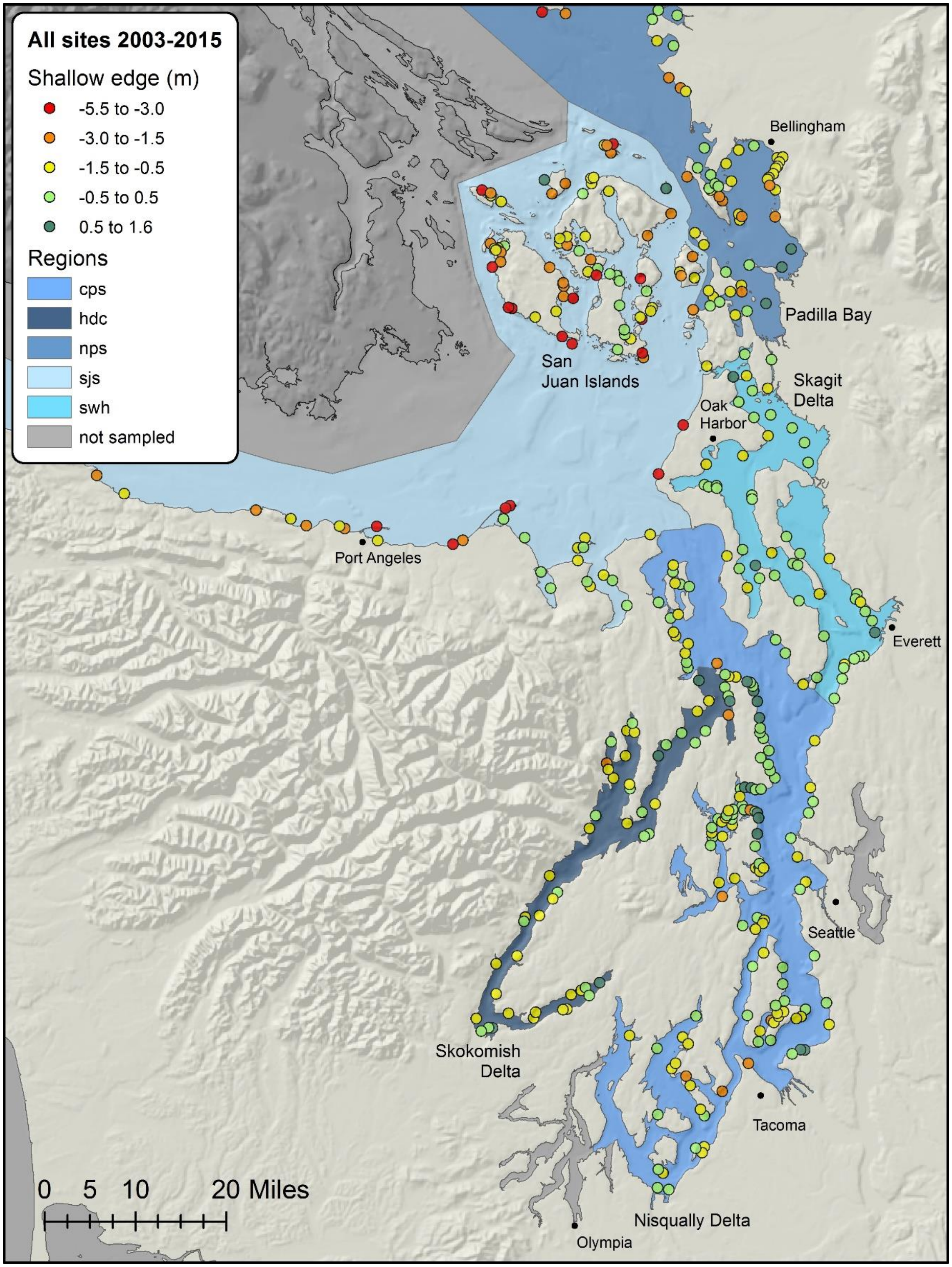


Figure 10: Minimum depth where eelgrass occurs at all sites sampled between 2003 and 2015.

3.4 Trends in soundwide seagrass area

Figure 11 shows the long-term trend in soundwide seagrass area relative to a 2000-2008 baseline (NHP 2015). In 2015, the soundwide estimate was approximately 23,150 ± 1,640 ha (Table 3). While Figure 11 suggests that soundwide seagrass area may be increasing, there is a high amount of inter-annual variability in the soundwide estimate, which is in part due to natural variability, and in part to the rotational sample design. 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 2013 to 2015. 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 2013 and 2015, soundwide seagrass area is not distinguishable from 2016 management goal specified by the Results Washington Goal Council. The 2020 target has not yet been met (Figure 12).

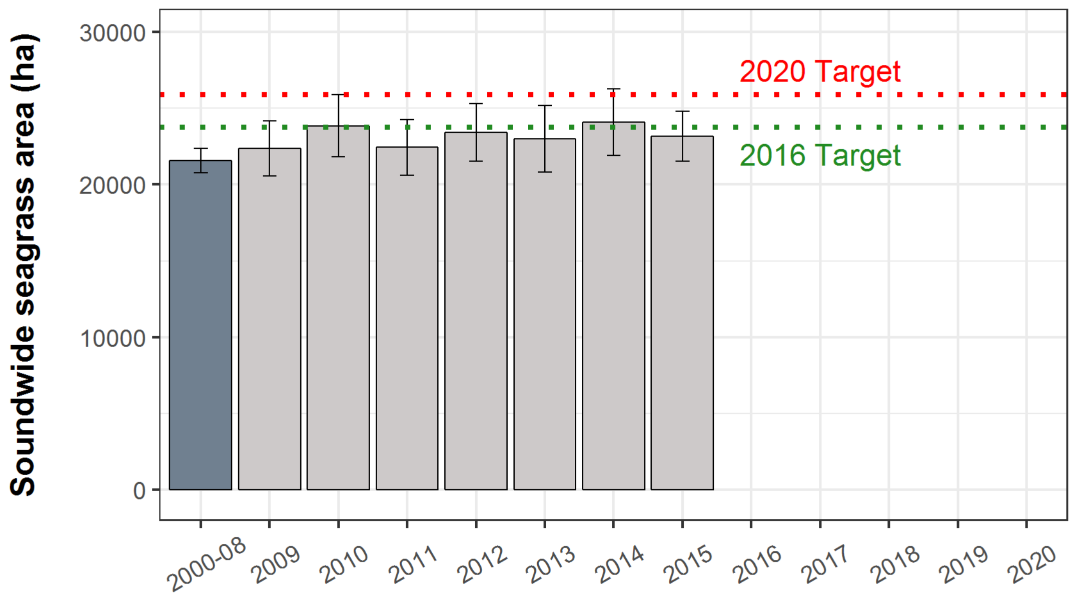


Figure 11: Long-term trend in soundwide area of native seagrass in greater Puget Sound. The darker bar represents the 2000-2008 baseline, the lighter bars represent annual soundwide area estimates, the dotted green line is the 2016 interim target for Results Washington, and the dotted red line is the 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 annual area estimates. Note that some annual estimates have changed slightly compared to previous reports, as our quality control procedures continue to improve.

Table 3: 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. Note that some annual estimates have changed slightly compared to previous reports, as our quality control procedures continue to improve.

	Total	std err	core	std err	flats	std err	frn	std err	frw	std err
2000	18812	7227	1343*	61	11257*	7061	5499*	1457	713*	500
2001	22246	6407	3722*	110	9342*	6241	3958	745	5224	1236
2002	21666	5860	3958*	156	8461*	5723	4460	770	4787	986
2003	21323	5607	3534*	208	7760*	5469	5402	828	4628	895
2004	21520	1542	6212	213	3693	884	6593	979	5021	769
2005	20626	1698	6023	259	3821	1102	6848	1089	3934	647
2006	22188	1880	6122	187	4579	954	8444	1534	3043	483
2007	21568	1899	5580	274	4895	732	8921	1660	2172	489
2008	22823	2297	6319	182	5980	1374	8594	1742	1929	567
2009	22365	1799	5837	238	7767	834	7333	1507	1428	462
2010	23853	2035	5964	280	8919	1103	7106	1465	1864	837
2011	22440	1820	5813	174	8791	1198	5840	1050	1996	863
2012	23418	1900	6435	174	7545	1156	5914	1116	3524	1000
2013	23010	2178	6510	189	6179	1517	6378	1134	3943	1059
2014	24085	2189	6405	157	5561	1529	6696	1162	5423	1040
2015	23151	1642	6458	183	3636	804	7374	1163	5684	813

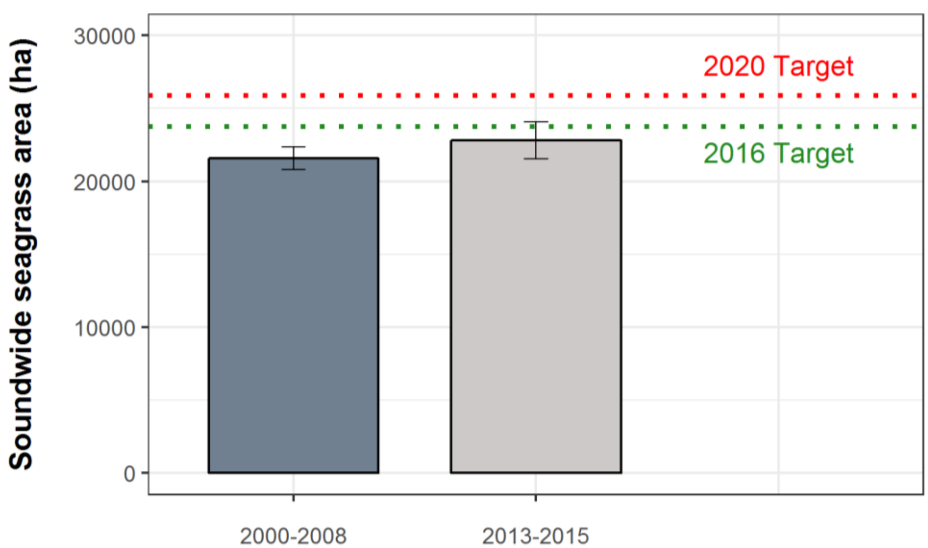


Figure 12: Multiyear average of all SVMP sites for the 3 most recent years sampled (light grey), relative to the 2000-2008 baseline (dark grey), the 2016 management target by Results Washington (dotted green line) and the 2020 target specified by the Puget Sound Partnership (20% increase relative to the baseline by 2020, dotted red line).

3.5 Site trends for all sites sampled between 2000 and 2015

Between 2000 and 2015, a total of 514 sites were sampled as part of the monitoring effort led by the Washington State Department of Natural Resources[5]. Eelgrass was present at the majority of these sites (Figure 5). From these sites, 358 were sampled over multiple years and classified for eelgrass trends over time. It is important to realize that the majority of sites have been sampled for a period of maximum 5 years only, so site trends do not necessarily reflect the entire monitoring period. Also, these numbers incorporate all sample efforts, both at randomly chosen sites and targeted studies.

When looking at site trends measured within the 2000-2015 time period, the majority of sites appear stable (Figure 13 & Figure 14). Twenty-eight sites decreased in native seagrass area, 30 sites increased in native seagrass area, 247 sites experienced no detectable change, and 53 sites did not have seagrass present. SJS is the region with the largest number of sites with documented declines in native seagrass area, and both SJS and CPS contain the largest amount of sites with no native seagrass detected. Several of the sites with declines are located at the heads of bays, such as Westcott Bay, Quartermaster Harbor, Swifts Bay, Watmough Bay, and the heads of Case and Carr Inlets. Many of the sites where no seagrass was detected are also located at heads of bays and in areas with lower flushing rates, such as Liberty Bay, Dyes Inlet, and large parts of South Puget Sound. Lower Hood Canal is more of an exception to this case. Several sites in lower Hood Canal have shown declines in eelgrass beds, but other sites, such as the Skokomish Delta and Lynch Cove, have shown increases.

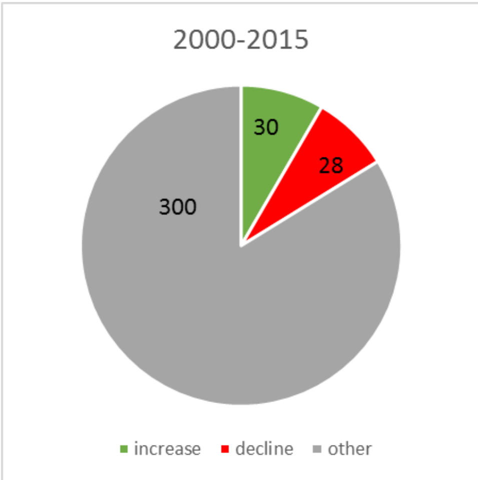
Table 4: Trends in native seagrass area for all sites sampled over multiple years between 2000 and 2015.

Region	increase	decline	stable	no grass	total
CPS	8	6	66	25	105
HDC	9	6	37	2	54
NPS	2	2	19	4	27
SJS	4	12	87	18	121
SWH	7	2	38	4	51

When you focus in on site trends in recent years (2010-2015), seagrass conditions appear to have improved (Figure 13 & Figure 15). Out of the 177 sites sampled more than once between 2010 and 2015, there were more sites with increasing (18) than decreasing (4) native seagrass area. HDC has the largest number of sites with recent increases. The SVMP has expended additional resources to monitor eelgrass at several sites throughout lower Hood Canal, as it was previously listed as an area with a high number of local declines. As such, this area may be over-represented in the dataset in recent years.

[5] The SVMP distribution database, which incorporates data collected by other organizations, such Clallam County or the Friends of the San Juan's, contains data from 528 different sites.

Nevertheless, the fact that we have measured recent increases throughout most of lower Hood Canal is a strong indication that recent years have been good for eelgrass growth at this location.



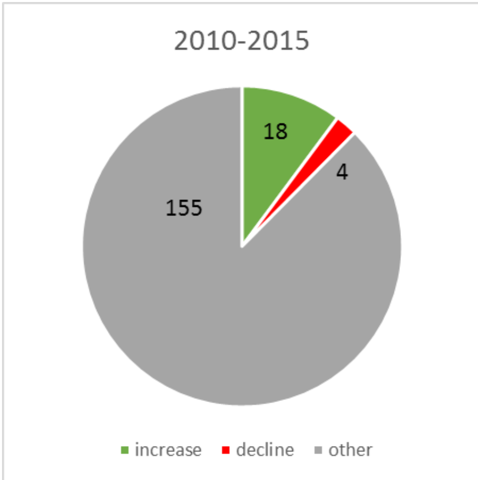


Figure 13: Trends in native seagrass area for all sites sampled between 2000 and 2015, and 2010 and 2015.

For a graphical representation of trends in site-specific native seagrass area, and the location of individual sites with declines/increases, see Appendix 1.

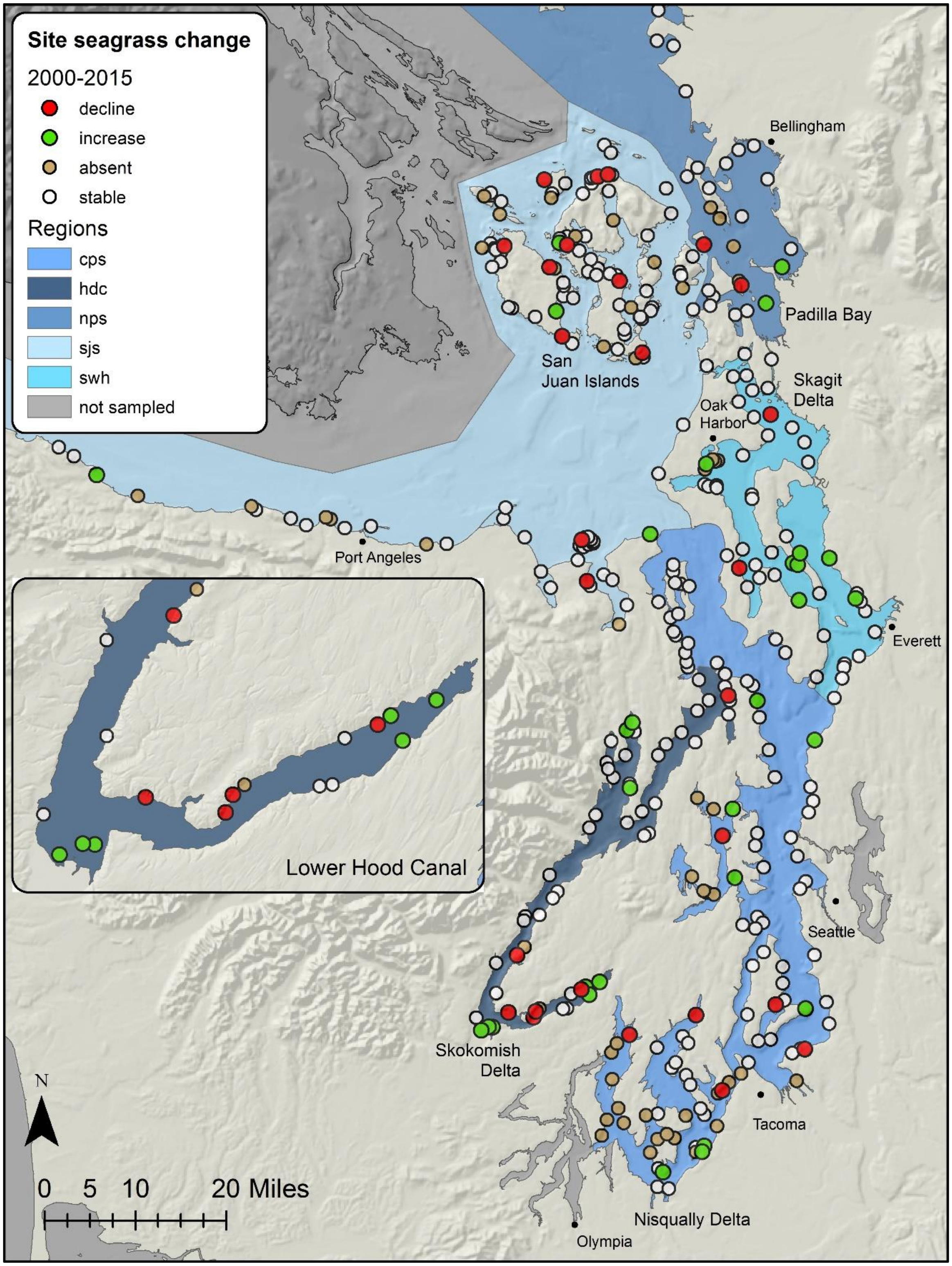


Figure 14: Sites with significant trends in native seagrass area between 2000 and 2015

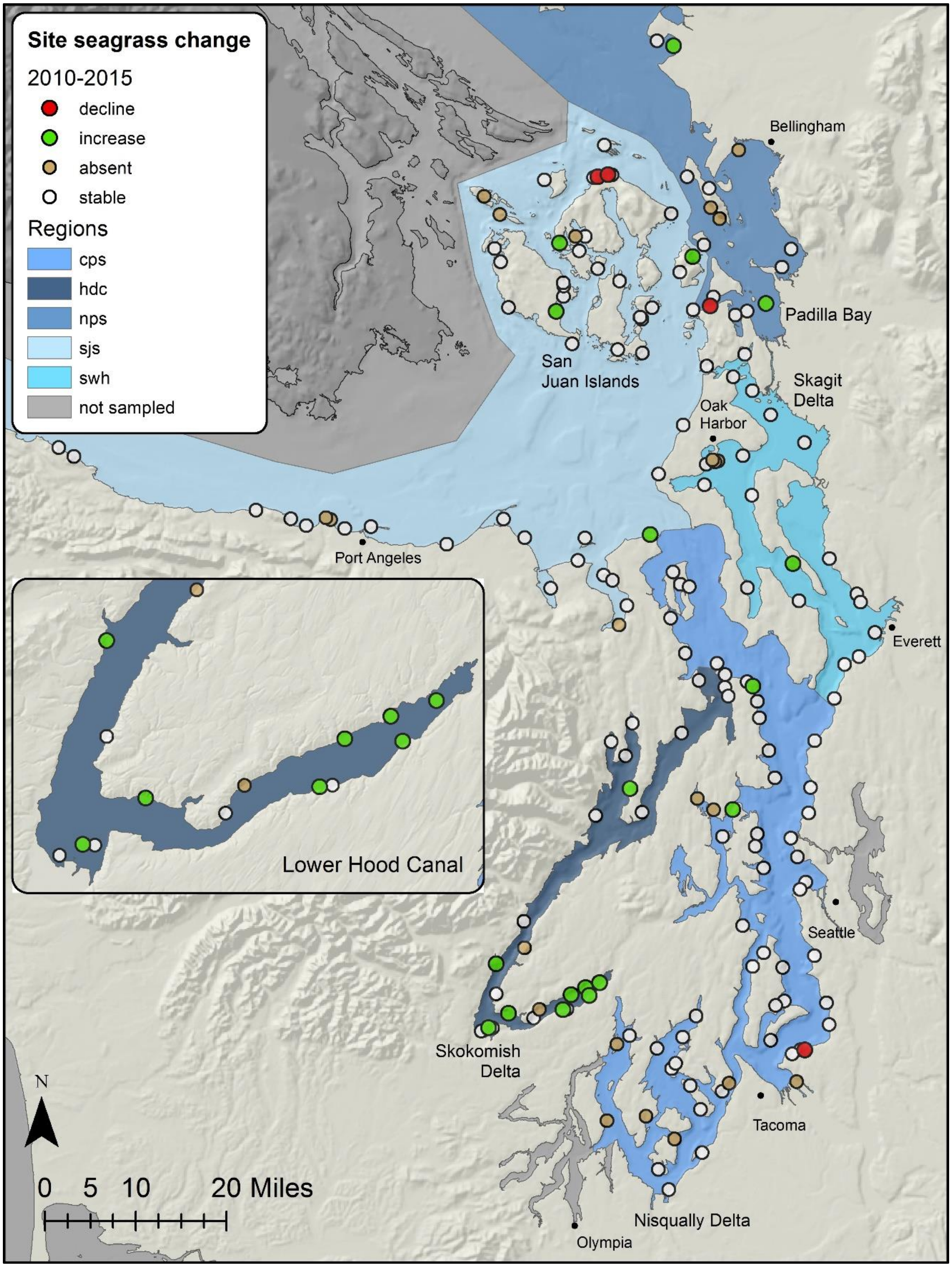


Figure 15: Sites with significant trends in native seagrass area between 2010 and 2015

3.6 Pairwise comparison 2004 - 2015

Starting in 2015, the 20% rotational sample design has been replaced by a 3-year rotating panel design. This allows for better detection of long-term trends, both at the site-level and soundwide. The 2015 panel is an exact repeat of 2004 sample effort, which allows us to do a pairwise comparison of both site area and depth distribution between these two years for all 79 sites sampled as part of the soundwide study.

3.6.1 Site seagrass area

Figure 16 plots site area estimates with associated standard error in 2015 vs 2004. Given the skewed size distribution of native seagrass beds in greater Puget Sound (Christiaen et al. 2016a), we plotted the data on a logarithmic scale. The dotted centerline represents a 1 to 1 relationship between both years (no change in seagrass area). The horizontal/vertical deviation from the centerline represents how much the seagrass area at individual sites declined/increased over time.

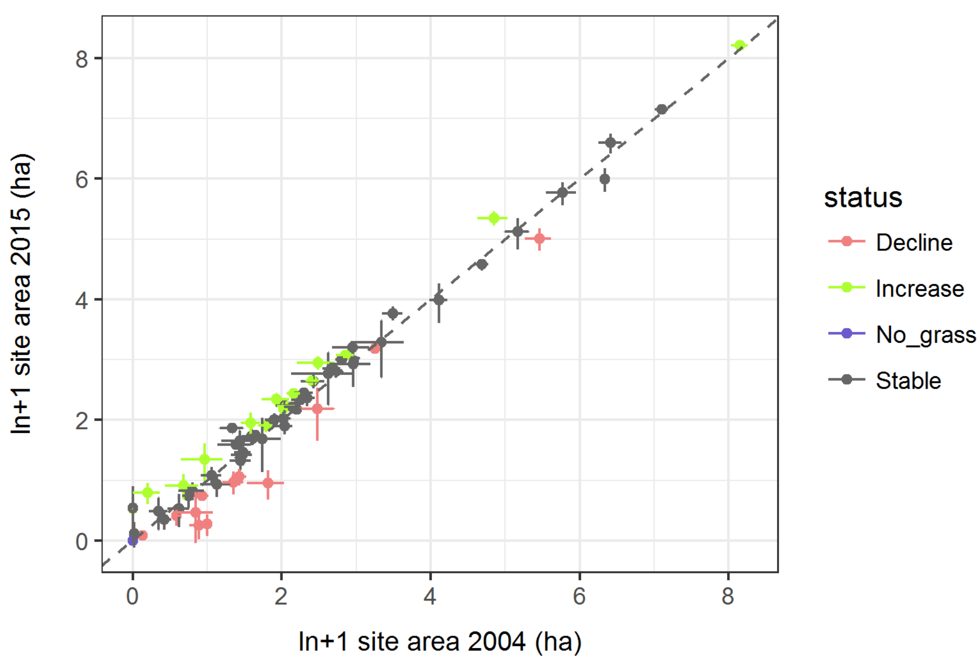


Figure 16: Natural log of site area in 2015 vs 2004 (± the 95% CI). Sites indicated in green had clear evidence of an increase, sites in red had a decline, and no clear change was detected at sites in black.

In order to assess which of these 79 sites significantly increased or declined between 2004 and 2015, we conducted paired t-tests on site seagrass area, weighed for transect length. In addition, we plotted regression lines for sites that were sampled for multiple years between 2004 and 2015, and visually assessed possible increases and declines by plotting transect data using GIS. Out of the 79 sites sampled in both 2004 and 2015, 44 sites were stable, 12 were declining, and 16 showed increases in seagrass area. At 7 sites there was no native seagrass present (Table 5). Total seagrass area per region did not change significantly between 2004 and 2015 (Table 5).

Table 5: Site trends and change in eelgrass area per region between 2004 and 2015. Except for HDC, the majority of sites are stable in each region. In Hood Canal, 6 out of 11 sites showed increases between 2004 and 2015. Total eelgrass area per region did not change significantly over time.

	Site trends				
Region	stable	increase	decline	no grass	total sites sampled
CPS	11	5	3	4	23
HDC	3	6	2	0	11
NPS	10	1	2	1	14
SJS	11	1	4	2	18
SWH	9	3	1	0	13

	Area estimates (ha) ± se		Z-test		
Region	2004	2015	n	Z-score	p-value
CPS	3712 ± 511	4234 ± 584	23	0.67	0.77
HDC	1984 ± 367	2303 ± 539	11	0.49	0.71
NPS	6711 ± 581	7215 ± 587	14	0.61	0.74
SJS	4082 ± 999	3710 ± 899	18	-0.28	0.64
SWH	4072 ± 442	4411 ± 390	13	0.58	0.74

3.6.2 Eelgrass depth distributions

Figure 17 shows the difference in average maximum (red) and minimum (blue) transect depth per site in each of the regions between 2004 and 2015. The median of the site differences in maximum depth is close to zero in each of the regions, which suggests that the maximum transect depth did not change between 2004 and 2015. The range in depth differences is greatest in CPS. This indicates a greater number of sites where maximum depth increased or decreased between 2004 and 2015.

The median of the site differences in minimum depth is significantly different from 0 in NPS and SWH (Table 6). This suggest that eelgrass beds in these regions expanded at the shallow edge between 2004 and 2015. In the other regions, the median of site differences in minimum depth over time was not significantly different from zero. It is interesting to note that the range in differences in minimum depths is generally smaller than the range in differences in maximum depth, which indicates that the deep edge is generally more variable as compared to the shallow edge of eelgrass beds.

Figure 18 shows the depth distribution of eelgrass in flats and fringe sites per region in 2004 (red) and 2015 (blue). Eelgrass grows at the greatest depths in Central Puget Sound (CPS), the San Juan Islands and the Strait of Juan de Fuca (SJS). In most regions, the majority of eelgrass grows between +0.5 and -2.5 m relative to MLLW. However, in SJS the majority of eelgrass grows in the subtidal (deeper than -1m relative to MLLW). When comparing data from the same sites in 2004 and 2015, the depth distributions appears to have shifted to shallow depth over time. This pattern occurs in each of the regions, but seems most pronounced at fringe sites in CPS, HDC and SWH and at flats sites in SWH, NPS and HDC.

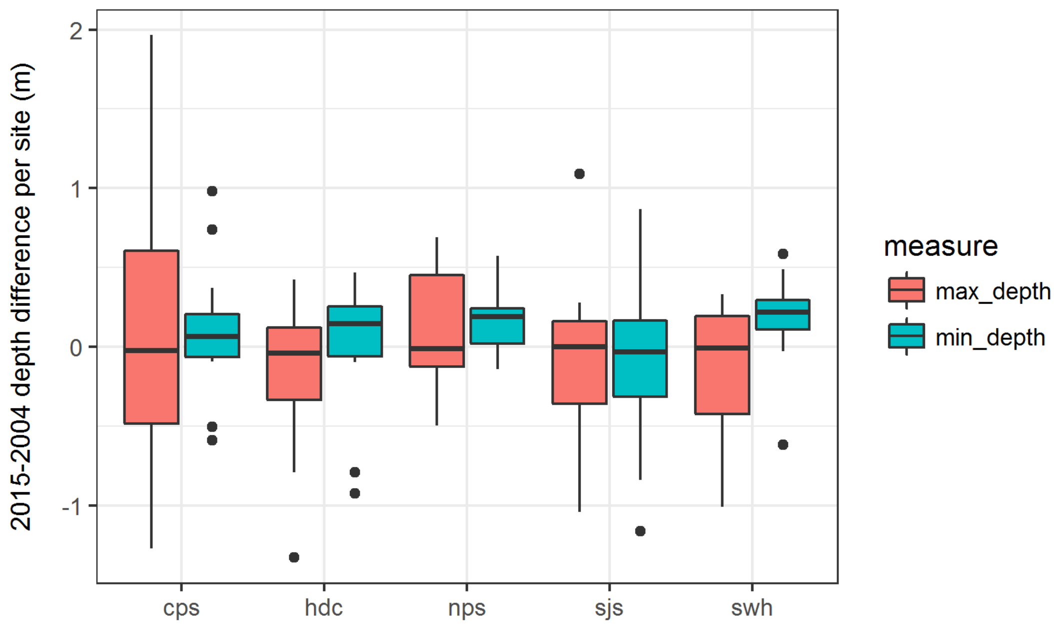


Figure 17: Boxplots of the differences over time (2015-2004) in average maximum and minimum transect depth at individual sites in the different regions of greater Puget Sound

Table 6: 1-sample Wilcoxon signed rank tests, comparing the differences in average maximum and minimum site depths between 2004 and 2015 from zero. There is no significant change in max site depths in any of the regions. In NPS and SWH, the median of the differences minimum site depth between 2004 and 2015 is significantly different from zero (* indicates significant p-value at α = 0.05).

	Max depth			Min depth		
Region	**n**	**Statistic**	**p-value**	**n**	**Statistic**	**p-value**
CPS	19	97	0.953	19	131	0.156
HDC	11	26	0.577	11	42	0.465
NPS	12	46	0.622	12	71	0.009*
SJS	16	60	0.706	16	54	0.495
SWH	13	32	0.376	13	77	0.027*

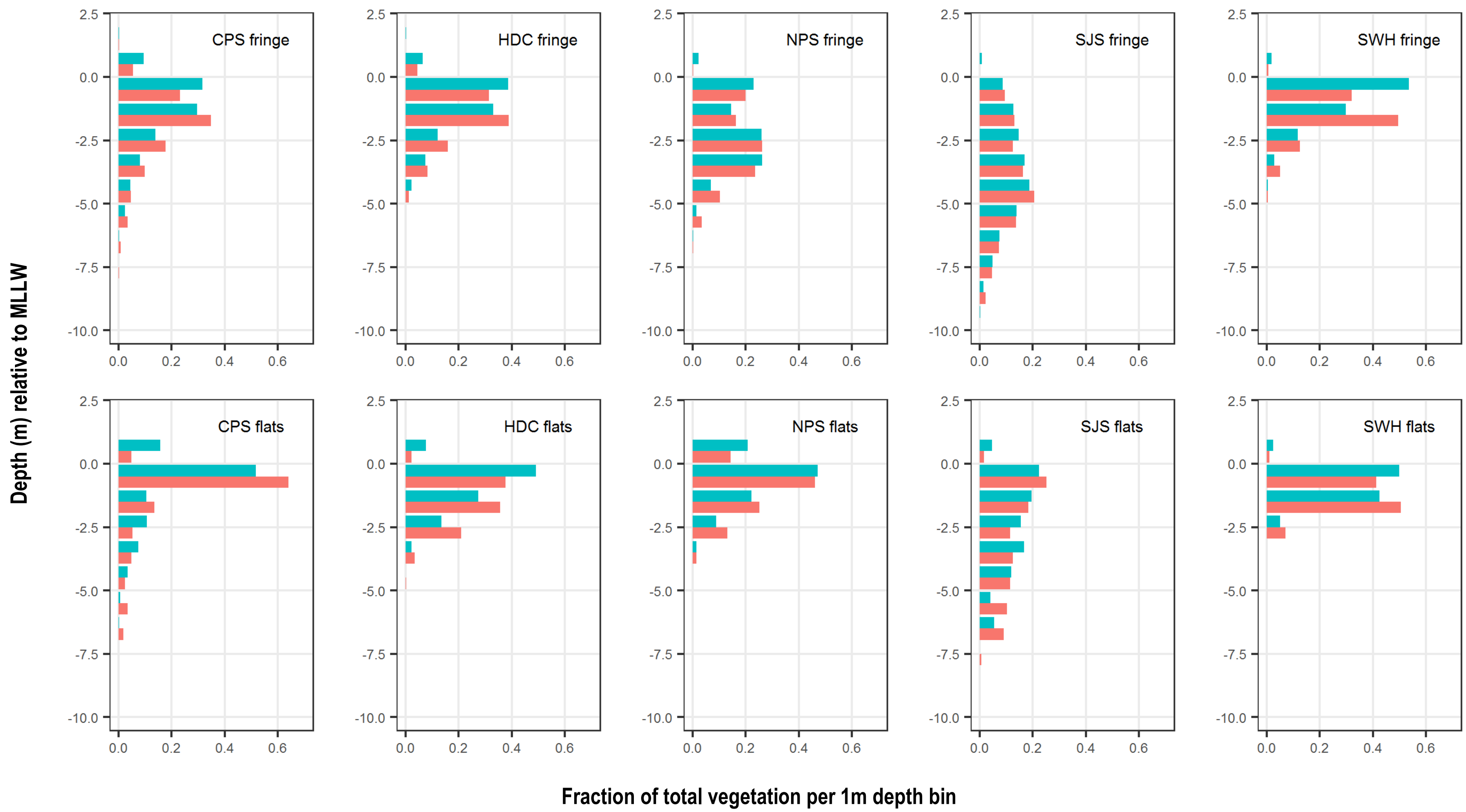


Figure 18: Depth distributions of eelgrass area in individual regions in greater Puget Sound in 2004 (red) and 2015 (blue). The horizontal bars represent the fraction of total eelgrass per 1m depth bin for flats and fringe sites in each of the regions.

4 Discussion

Seagrasses are an important bio-indicator of ecosystem health – both globally and within Puget Sound (Krause-Jensen et al. 2005, Orth et al. 2006, Mumford 2007). 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 benthic habitat and water quality, particularly in sediment composition and the amount of suspended sediment in the water column (Van der Heide et al. 2011). 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 eelgrass (*Zostera marina),* in greater Puget Sound and to identify trends in seagrass area on different spatial scales.

4.1 Trends in seagrass area in greater Puget Sound

4.1.1 Soundwide seagrass estimates 2000-2015

Both the annual soundwide seagrass area estimates and the individual site-level trends indicate that native seagrass area has been relatively stable in greater Puget Sound between 2000 and 2015. The 2015 annual soundwide estimate is slightly lower than the 2014 estimate, but given the uncertainty around the annual estimates, it is not possible to interpret whether small increases or decreases in the annual estimates represent an actual increase/decrease in seagrass area in Puget Sound. As was reported in a previous SVMP report (NHP 2015), the annual estimates of soundwide native seagrass area are sensitive to certain aspects of the previous SVMP sample design. Every year 20% of all sites were 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 was 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 the 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.

In order to minimize the site rotation effect, we calculated the 3-year average of soundwide native seagrass area based on average seagrass area per site for all sites sampled from 2013 to 2015. Multi-year estimates 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 is not significantly different from the 2016 management target defined by Results Washington, and suggests that we have not yet achieved the 20% increase target by the Puget Sound Partnership. Based on our current estimates, we are not able to predict whether the soundwide seagrass area will meet the 2020 target.

Given the wide range of environmental conditions in Puget Sound, it is easier to detect trends at the site level than on a soundwide spatial scale. Approximately 16% of all sites sampled by the SVMP showed significant trends in native seagrass area. When considering the entire dataset (2000-2015), there is an equal number of sites with increases and declines in native seagrass area. However, when you only consider data collected between 2010 and 2015, increases in site eelgrass area vastly outnumber site-level declines. This recovery is most pronounced in lower Hood Canal, where several sites that were either stable or declining before 2010, showed modest increases in seagrass area between 2010 and 2014. The site-level results indicate that recent years have been beneficial for seagrass growth. However, the exact nature and longevity of this reversal is as of yet unclear.

Since 2000, the SVMP has documented several sites where local declines in seagrass area have been profound. Heads of bays seem particularly vulnerable: significant long-term declines have been detected in Quartermaster Harbor, Garrison Bay, Westcott Bay, Swifts Bay, Watmough Bay, and at sites at the heads of Case and Carr Inlets. The majority of sites sampled by the SVMP where no eelgrass was detected were also located within semi-enclosed bays or in areas with lower flushing rates, such as Liberty Bay, Dyes Inlet, and large parts of South Puget Sound. These areas may be more sensitive to low water quality or accumulation of nuisance algae such as *Ulva sp*. This pattern of overall stability with significant local declines agrees with data from a longer-term study on eelgrass abundance in herring spawn areas between 1970 and 2012 (Shelton et al. 2017).

4.1.2 Long-term trends in select areas of Puget Sound (1970-2012)

A recent analysis of data from WDFW herring spawn surveys (Shelton et al. 2017) found that eelgrass in Puget Sound has not experienced major system-wide declines over the past 40 years. This is good news, and it sets Puget Sound apart from many other developed areas, where catastrophic declines have occurred. However, when looking at smaller spatial scales, a more nuanced message appears: out of the 14 herring spawn areas surveyed, 2 areas showed clear increases, 5 areas showed declines, and 7 areas were stable between 1970 and 2012 (Shelton et al. 2017). At local scales, several sites with long-term declines were detected. These significant changes are sometimes masked in large area summaries. Similar to data from the SVMP, substantial losses have been detected at heads of bays, such as inner Quartermaster Harbor and Port Gamble Bay (Shelton et al. 2017). Previous reports based on WDFW herring spawn surveys also mention the complete disappearance of the seagrass beds in Westcott and Garrison Bays, and partial declines in Blind Bay (Stick et al., 2014).

4.1.3 Data from before 1970

Data on eelgrass abundance in Puget Sound pre-1970 are limited, but there is evidence for declines at several locations throughout the Sound. For example, eelgrass losses of 30% and 15% were estimated for Bellingham and the Snohomish River delta, respectively (Thom and Hallum, 1990). These areas have undergone extensive port development, which affected the distribution of eelgrass. There are also anecdotal observations that eelgrass decreased in select sections of central Puget Sound and South Puget Sound (Thom and Hallum, 1990). In general, it is assumed that the extensive development of Puget Sound pre-1970 has led to widespread loss of eelgrass (Shelton el al. 2017). One area where such losses would be expected is the heavily urbanized Everett-Seattle-Tacoma shoreline. The large eelgrass meadow in Padilla Bay is an exception to this pattern. Early data suggests that eelgrass coverage increased substantially at this location. One hypothesis is that the diking of the Skagit River at the South end of Padilla Bay, and the reduced freshwater input from the Skagit to the Swinomish Channel, led to an overall reduction of freshwater inflow in Padilla Bay. This may have led to an overall increase in salinity at the southern end of the bay, and an increase in eelgrass cover at this location (Thom and Hallum, 1990).

4.2 Trends in eelgrass depth distribution in Puget Sound

Recent studies suggest that there have been no recent major declines in the total area of eelgrass in the herring spawn areas between 1970 and 2012 (Shelton et al. 2017), or in Puget Sound as a whole between 2000 and 2015 (this study). However, eelgrass area is only one of many possible metrics of eelgrass health. Measuring other metrics, such as density, biomass, and depth distribution can lead to a more thorough understanding of the status of seagrass beds.

For example, reduction in seagrass abundance at the deep edge of the bed can be indicative of changes in the water quality and nearshore disturbance, as seagrasses are sensitive to reductions in light availability due to their photosynthetic requirements (Duarte, 1991; Krause-Jensen et al., 2000). Eelgrass growing in shallow habitats can be impacted by wave exposure, ice scour, grazing by waterfowl, and desiccation (Koch, 2001). In water bodies such as Puget Sound, which have a relatively large tidal range but are protected from oceanic swell, desiccation is thought to be a common limit to the shallow extent of eelgrass beds (Mumford, 2007).

When looking on a regional scale, there is a clear pattern in the maximum depth of eelgrass beds. Eelgrass tends to grow to greater depths near the San Juan Islands, the Strait of Juan de Fuca and (to a lesser degree) Admiralty Inlet (Figure 9). This is likely due to the inflow of clear water from oceanic sources. Seagrass grows to lesser depths near the mouth of the Skagit, Nooksack and Snohomish Rivers, in enclosed waterbodies such as Sinclair Inlet and Quartermaster Harbor, and in South Puget Sound. This is probably due to lower water clarity caused by sediment loads, longer residence times and the larger tidal range in the Southern parts of Puget Sound. A similar regional trend is noticeable in the shallow edge of eelgrass beds in Puget Sound. The upper edge of eelgrass beds does not extend into the intertidal at sites with high exposure to wave action (such as large parts of the Strait of

Juan de Fuca and the San Juan Islands), or in sites where the coastline has been heavily impacted by port development (such as the City of Bellingham waterfront).

Despite these regional trends, there is a high variability in depth limits between individual sites within a region. As such, it is difficult to compare depth distributions over time, since the majority of the dataset has been sampled with 20% rotation. However, starting in 2015, the SVMP shifted towards sampling with a 3-year rotating panel design. In 2015, we repeated the sample panel from 2004, and in upcoming years, we will repeat the sample panels from 2009 and 2014. This allows us to compare depth distributions between individual years.

There was no significant difference in the maximum depth of individual sites between 2004 and 2015. However, the minimum depth (upper edge of seagrass beds) changed significantly for sites in Northern Puget Sound and the Saratoga Whidbey basin between 2004 and 2015. Results from Hood Canal hint at similar decreases in minimum depth over time, but these were not significant because the high variability in trends between individual sites. These trends are confirmed when looking at the entire depth distribution of eelgrass at flats and fringe sites in each region for 2004 and 2015. In Hood Canal, Northern Puget Sound and the Saratoga Whidbey basin, a higher proportion of total eelgrass area was found at shallower depths in 2015.

In 2015 and 2014, the temperature of the water column in Puget Sound was much warmer than the long-term average, due to a combination of 3 factors: a strong El Nino, local atmospheric heating, and a mass of warm water that entered Puget Sound through the Strait of Juan de Fuca, also called “the blob” (PSEMP Marine Waters Workgroup, 2016). Observations from the University of Washington ORCA mooring buoy program measured water temperatures over 2 ºC warmer than the long-term (10 year) average, with the highest value documented in lower Hood Canal in June 2015 (7 ºC). Increasing water temperature can impact the depth distribution of seagrasses. At higher temperatures, respiration increases relative to photosynthesis (Marsh et al., 1986), so plants may need more light to survive (Bulthuis, 1987; Lee et al, 2007). This can lead to lower growth rates in light limited environments, such as the deep edge of seagrass beds. While the distribution of eelgrass in Hood Canal, Northern Puget Sound and the Saratoga Whidbey Basin seems to have expanded to slightly shallower depths, we did not see a shift in the maximum depth of eelgrass beds in Puget Sound between 2004 and 2015. In Puget Sound, eelgrass grows in waters with temperatures ranging from 6 to 18 ºC, but worldwide it occurs in waters with temperatures ranging from 0 to 32ºC (Bulthuis, 1995b). The average increase of 2 ºC may not have been enough to cause a significant change in maximum depth limits in greater Puget Sound.

The shallower minimum depth limits for eelgrass beds in Northern Puget Sound and the Saratoga Whidbey basin may be related to the 18.6 year tidal cycle. It is likely that in 2015 intertidal eelgrass beds had significantly less exposure to the air over the course of the entire year as compared to 2004. Since the upper edge of eelgrass beds is often limited by desiccation (Koch, 2001), lower exposure to air could allow eelgrass to colonize further up in the intertidal.

4.3 Future prospects for eelgrass in Puget Sound

Over the last 40 years, a wide range of environmental legislation has improved and protected water quality and nearshore ecosystems in Puget Sound. Examples are the Clean Water Act (1972), which gave the US Environmental Protection Agency the authority to regulate waste water discharge in waters of the United States, the Washington State Shoreline Management Act (1972), which is aimed at protecting the shoreline and its natural resources, and the designation of eelgrass as a habitat of special concern by the Washington State Department of Fish and Wildlife (WAC 220-110-250). The fact that eelgrass beds in the herring spawn areas of Puget Sound have endured since the 1970's, despite large increases in human population (Shelton et al, 2017), suggests that these efforts have paid off. However, the long-term declines in approximately one third of the herring spawn areas, and in many localized areas throughout the Sound, are a reason for concern.

Eelgrass shows resilience to relatively wide ranges in natural conditions such as El Niños. However, continued loss of eelgrass in subareas of the Puget Sound could eventually result in a local collapse of eelgrass populations due to a decline in seed production. Continued management efforts will be critical to avoid catastrophic declines and to restore the areas with documented losses in Puget Sound. Ongoing efforts like the WDFW (Shelton et al., 2017) and DNR studies are improving our scientific understanding of eelgrass at these locations.

In order to ensure the protection of eelgrass, the Puget Sound Partnership set a management goal of a 20% increase in eelgrass area by 2020 (relative to a 2000-2008 baseline). The management goal was chosen based on achieved gains in other regions in response to protection and restoration actions. The Puget Sound Partnership and the Washington State Department of Natural Resources developed an Eelgrass Recovery Target Strategy in 2015, to identify pathways towards reaching the management goal by 2020 (Goering et al. 2015). At this point in time, it is difficult to predict whether the goal of a 20% increase by 2020 will be met. SVMP data shows no clear trend in annual estimates of soundwide seagrass area between 2009 and 2015, but there is some uncertainty around the soundwide estimates. Site level trends between 2010 and 2015 suggest that eelgrass conditions have been favorable in recent years, but it is unclear if these conditions will persist. The stressors on eelgrass in Puget Sound will likely need to be reduced to see significant sound-wide gains in eelgrass area, depth distribution and overall health.

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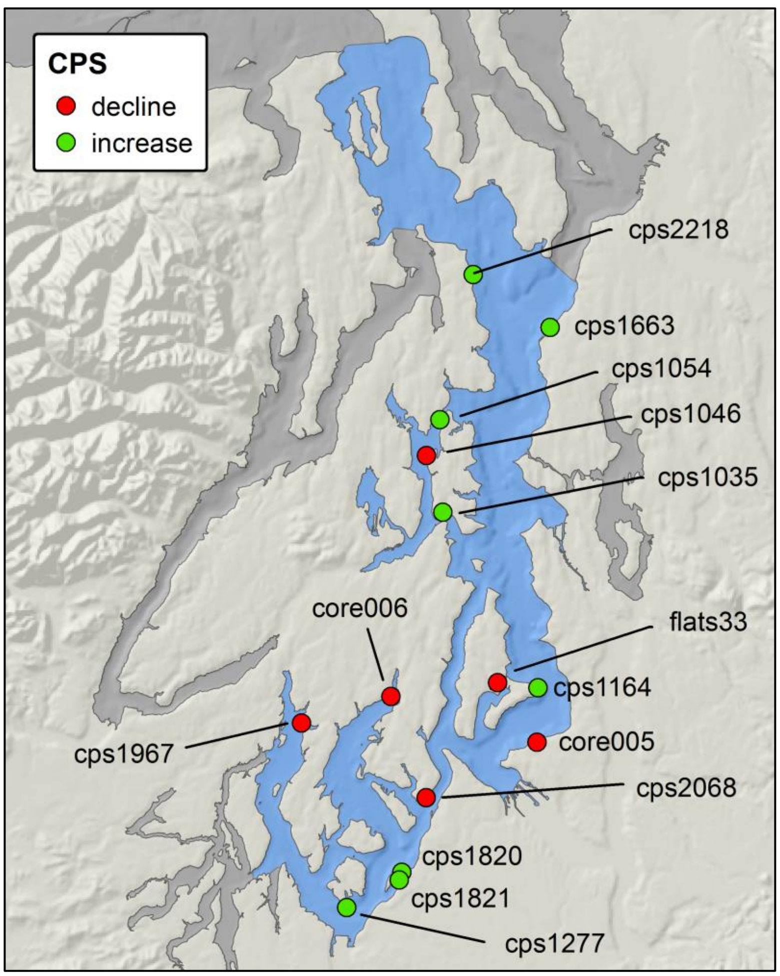
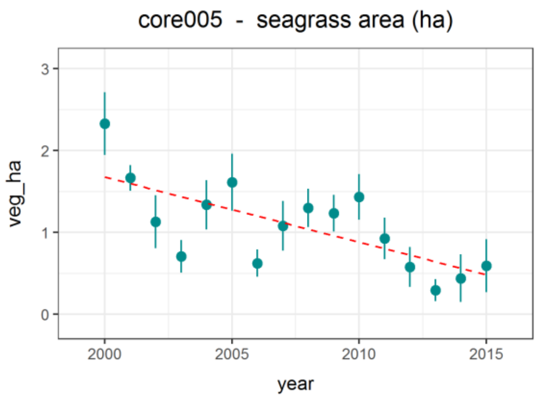
6 Appendix 1:

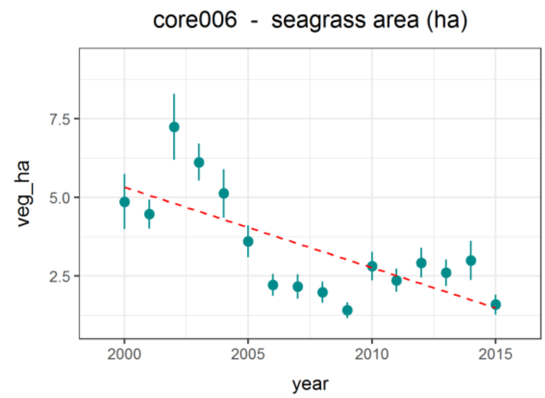
List of sites with documented declines/increases in native seagrass area between 2000 and 2015. Plots depict estimates of site seagrass area in hectares, each year a site was sampled. The error bars are standard error. Red regression lines indicate sites with confirmed declines and green regression lines indicate sites with confirmed increases in native seagrass area.

6.1 Central Puget Sound



Map with the location of all sites with documented increases/declines in Central Puget Sound between 2000 and 2015


core005 - seagrass area (ha)
veg_ha
0
1
2
3
2000
2005
2010
2015
year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veg_ha
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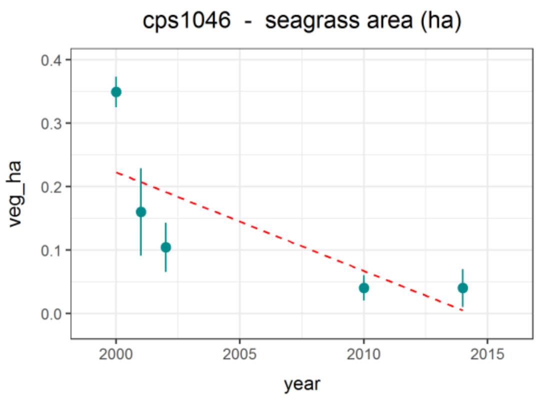
5.0
7.5
2000
2005
2010
2015
year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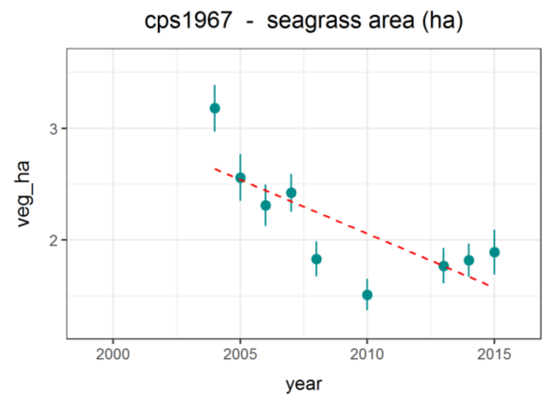
veg_ha
0.0
0.1
0.2
0.3
0.4
2000
2005
2010
2015
year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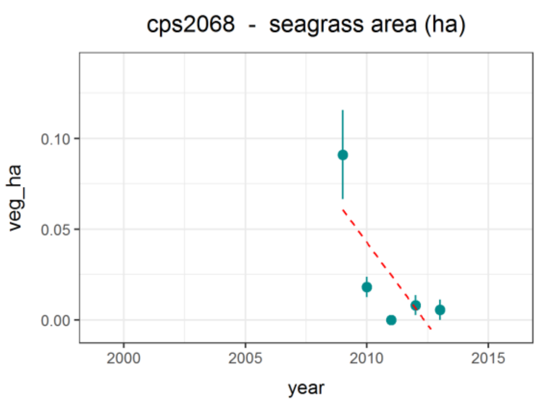
veg_ha
2
3
2000
2005
2010
2015
year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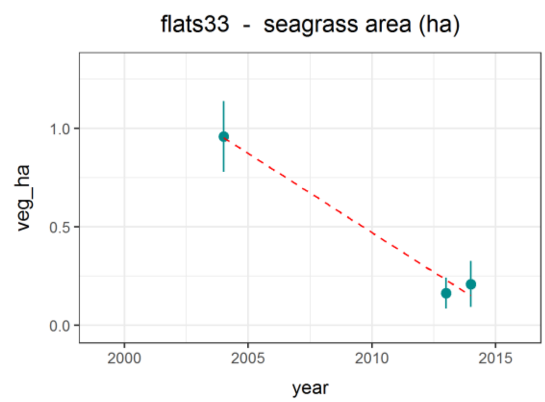
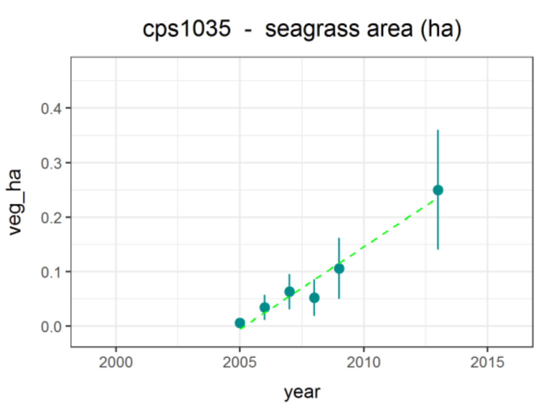
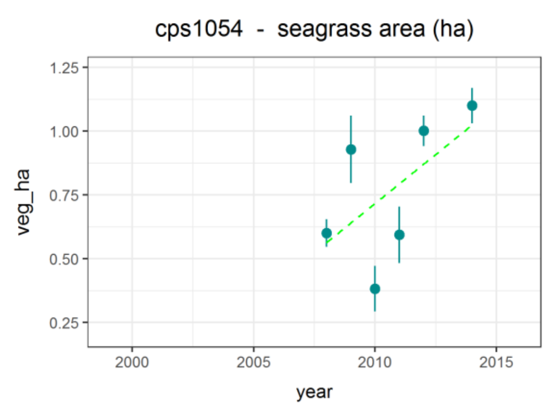
veg_ha
0.00
0.05
0.10
2000
2005
2010
2015
year


flats33 - seagrass area (ha)
veg_ha
0.0
0.5
1.0
2000
2005
2010
2015
year


cps1035 - seagrass area (ha)
veg_ha
0.0
0.1
0.2
0.3
0.4
2000
2005
2010
2015
year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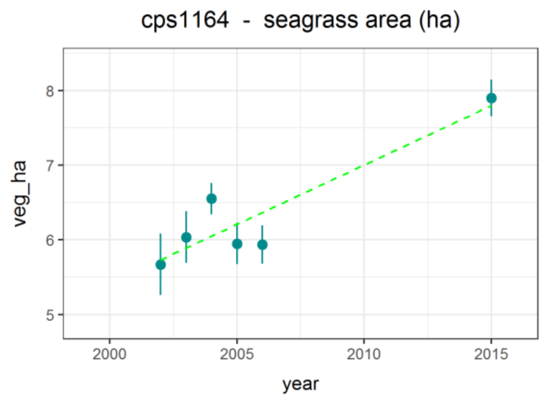
veg_ha
0.25
0.50
0.75
1.00
1.25
2000
2005
2010
2015
year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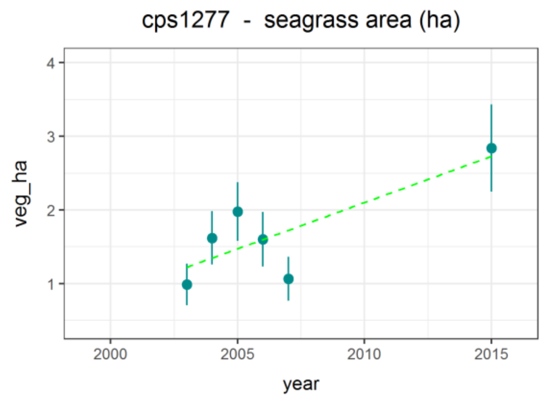
veg_ha
8
7
6
5
2000
2005
2010
2015
year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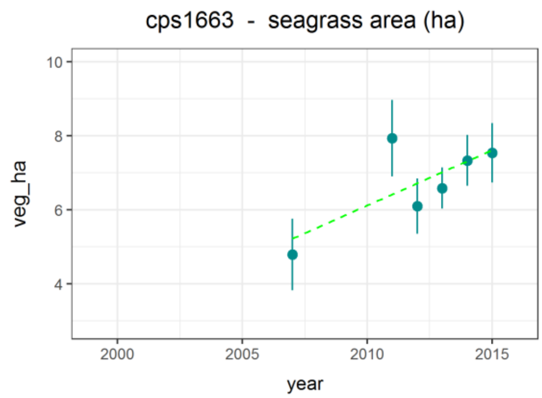
veg_ha
4
3
2
1
2000
2005
2010
2015
year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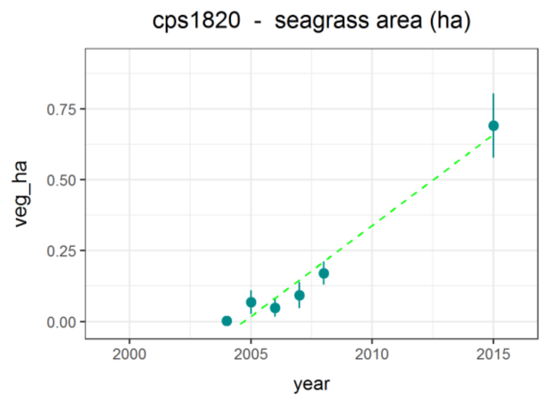
veg_ha
10
8
6
4
2000
2005
2010
2015
year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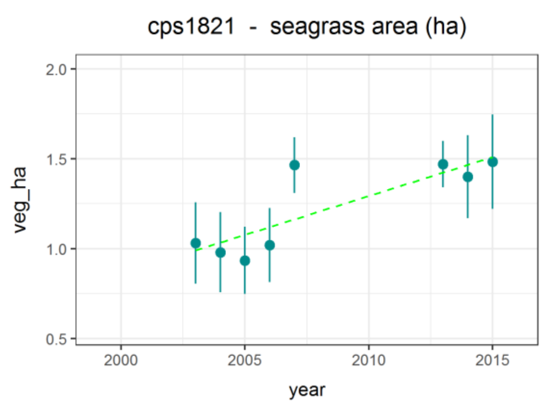
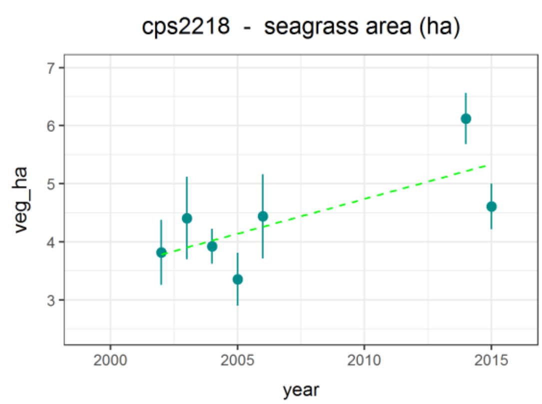
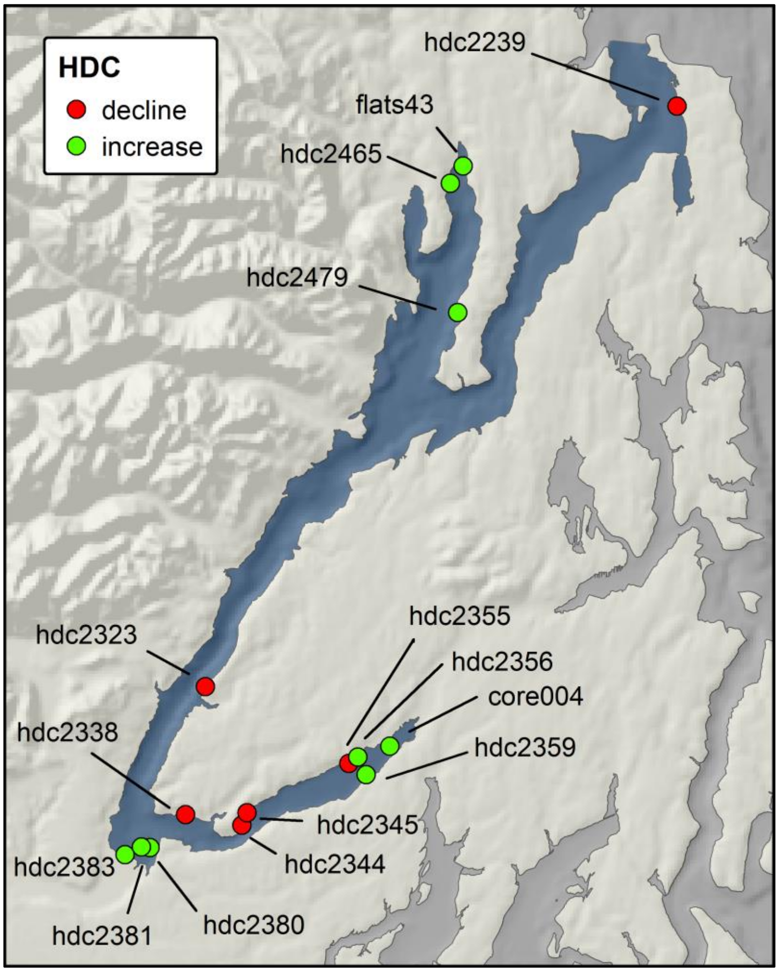
veg_ha
0.75
0.50
0.25
0.00
2000
2005
2010
2015
year

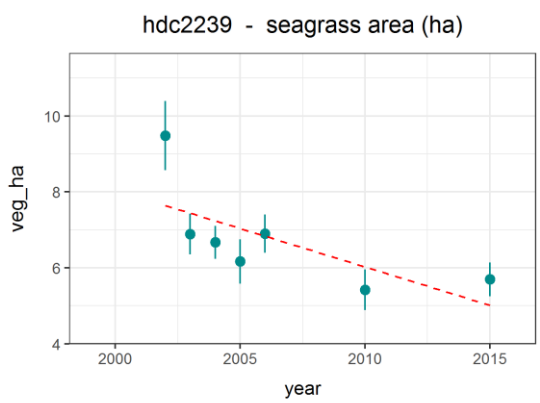

cps1821 - seagrass area (ha)
veg_ha
2.0
1.5
1.0
0.5
2000
2005
2010
2015
year

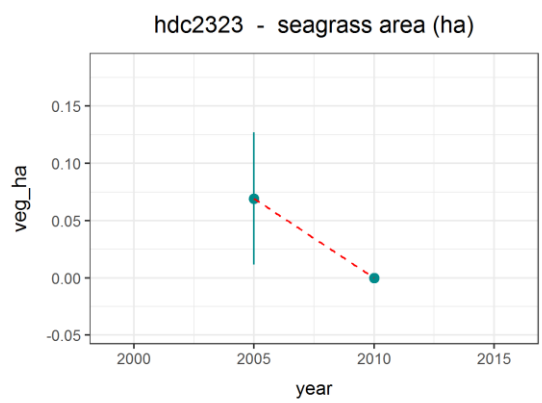

cps2218 - seagrass area (ha)
veg_ha
7
6
5
4
3
2000
2005
2010
2015
year

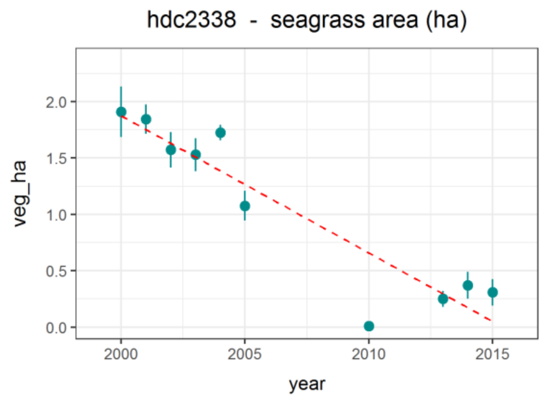
6.2 Hood Canal

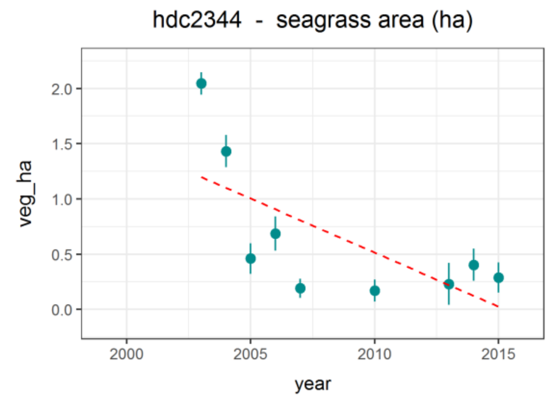


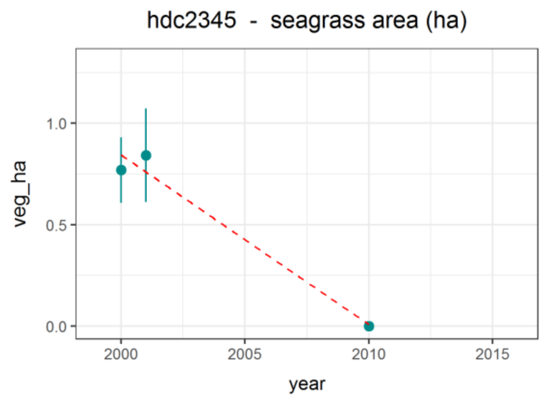
Map with the location of all sites with documented increases/declines in Hood Canal between 2000 and 2015

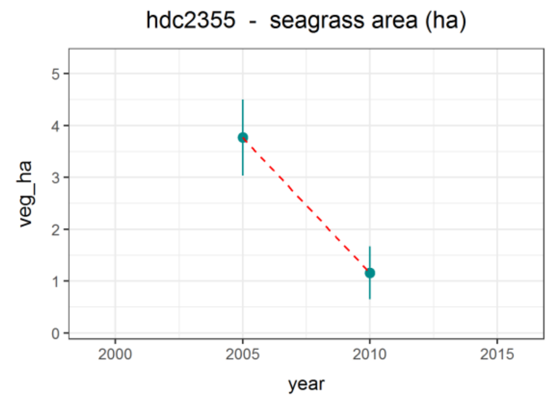


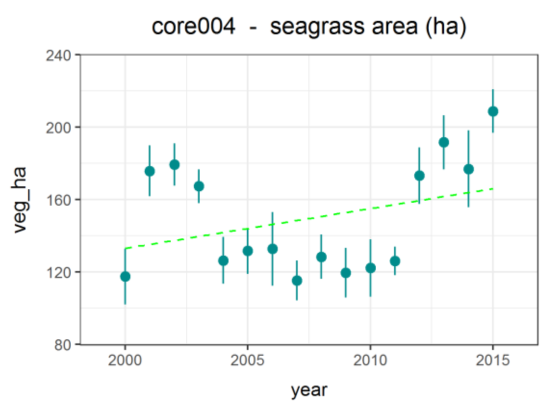


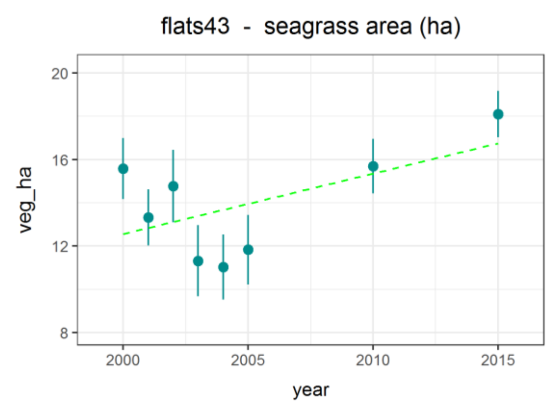

hdc2338 - seagrass area (ha)
veg_ha
2.0
1.5
1.0
0.5
0.0
2000
2005
2010
2015
year

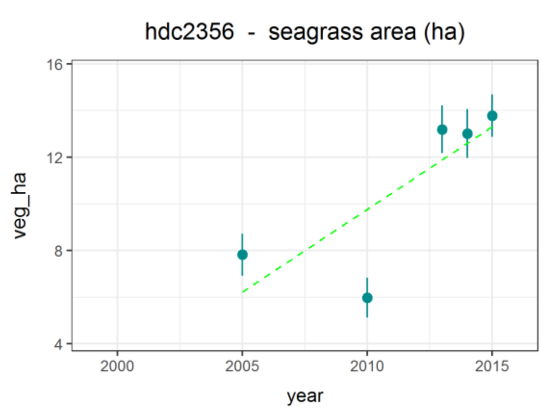

hdc2344 - seagrass area (ha)
veg_ha
2.0
1.5
1.0
0.5
0.0
2000
2005
2010
2015
year

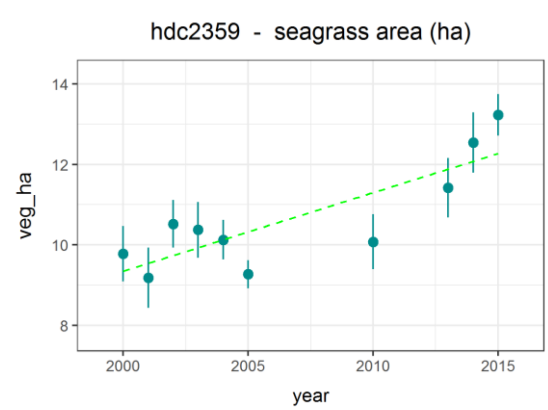

hdc2345 - seagrass area (ha)
veg_ha
1.0
0.5
0.0
2000
2005
2010
2015
year

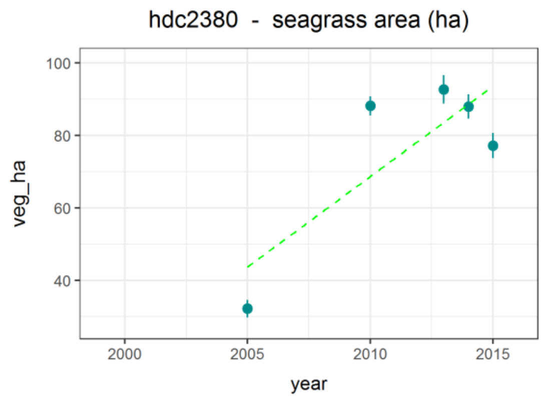

hdc2355 - seagrass area (ha)
veg_ha
5
4
3
2
1
0
2000
2005
2010
2015
year

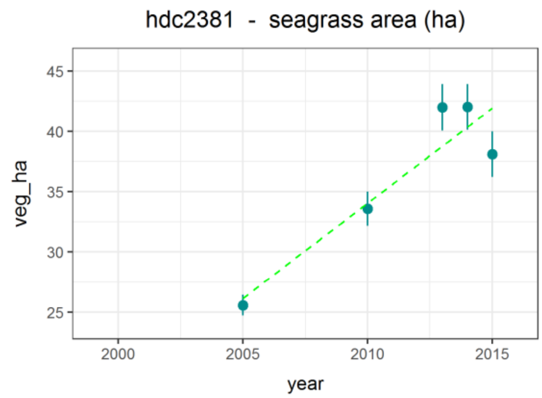

core004 - seagrass area (ha)
veg_ha
240
200
160
120
80
2000
2005
2010
2015
year

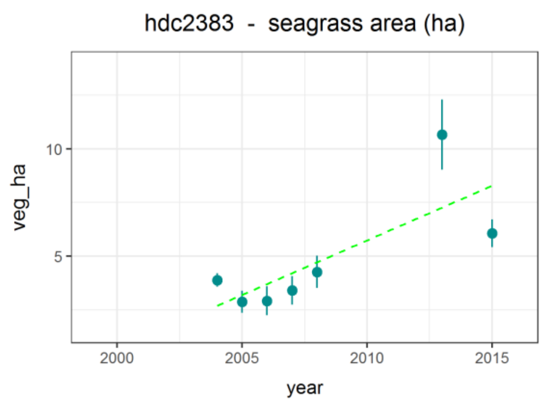

flats43 - seagrass area (ha)
veg_ha
20
16
12
8
2000
2005
2010
2015
year

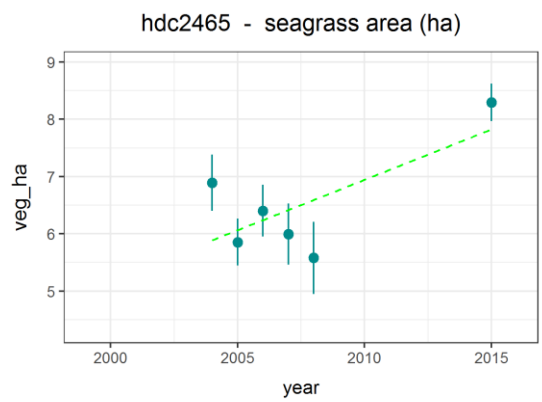

hdc2356 - seagrass area (ha)
veg_ha
16
12
8
4
2000
2005
2010
2015
year

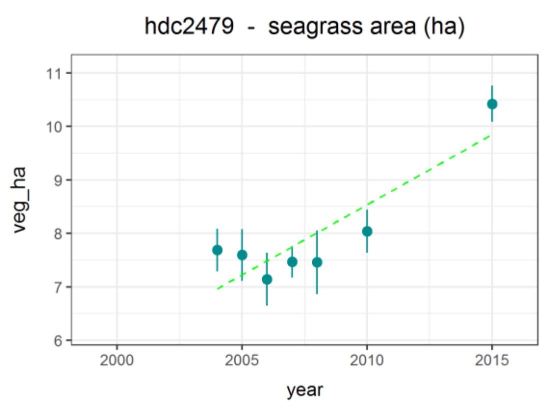

hdc2359 - seagrass area (ha)
veg_ha
14
12
10
8
2000
2005
2010
2015
year


hdc2380 - seagrass area (ha)
veg_ha
year
100
80
60
40
2000
2005
2010
2015

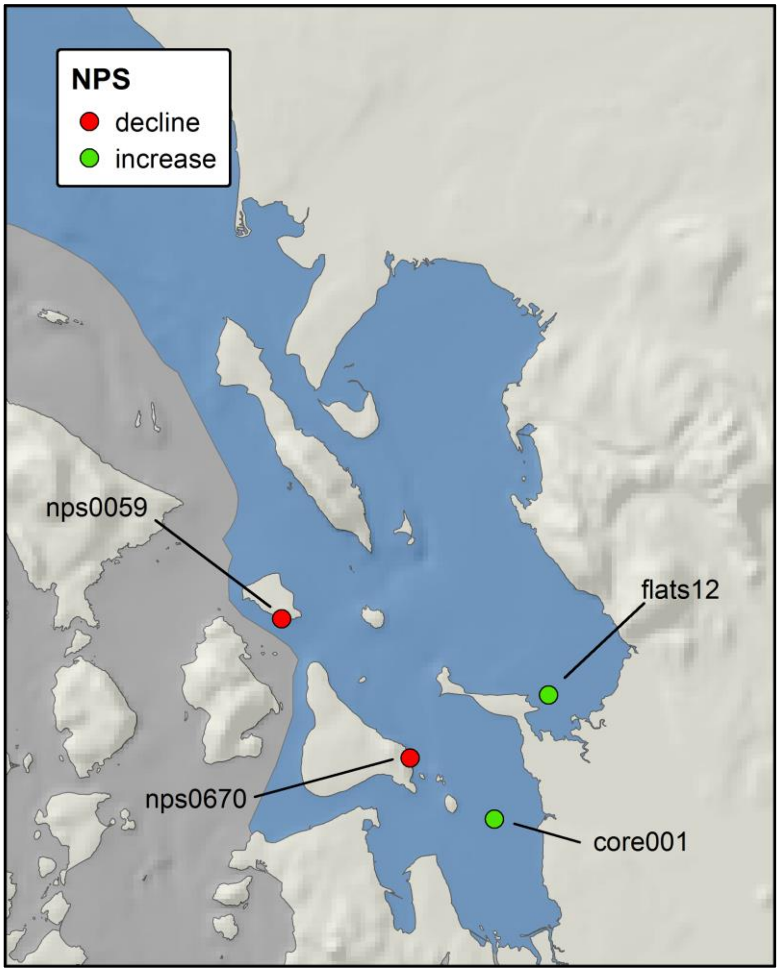

hdc2381 - seagrass area (ha)
veg_ha
year
45
40
35
30
25
2000
2005
2010
2015


hdc2383 - seagrass area (ha)
veg_ha
year
10
5
2000
2005
2010
2015

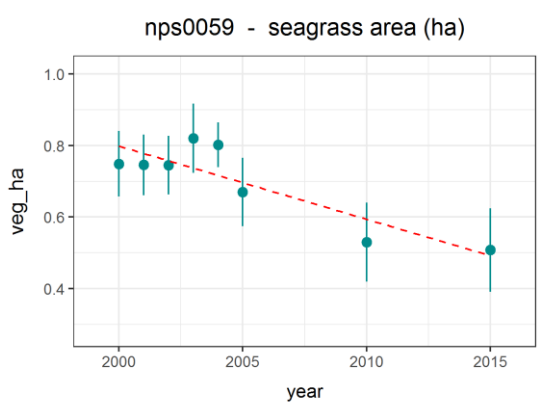

hdc2465 - seagrass area (ha)
veg_ha
year
9
8
7
6
5
2000
2005
2010
2015

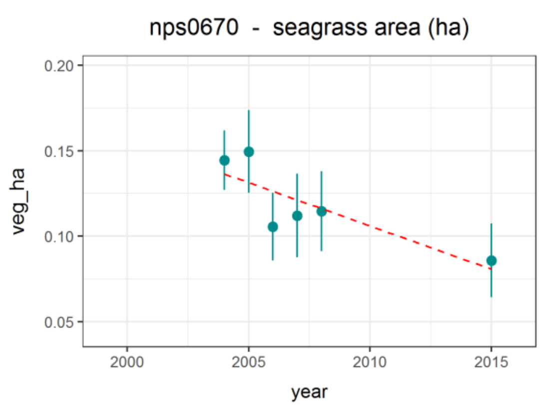

hdc2479 - seagrass area (ha)
veg_ha
year
11
10
9
8
7
6
2000
2005
2010
2015

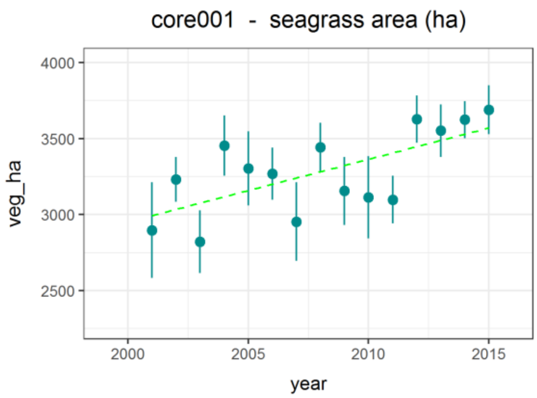
6.3 Northern Puget Sound

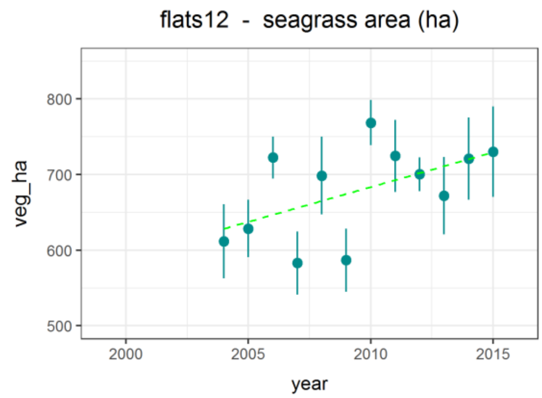


Map with the location of all sites with documented increases/declines in Northern Puget Sound between 2000 and 2015

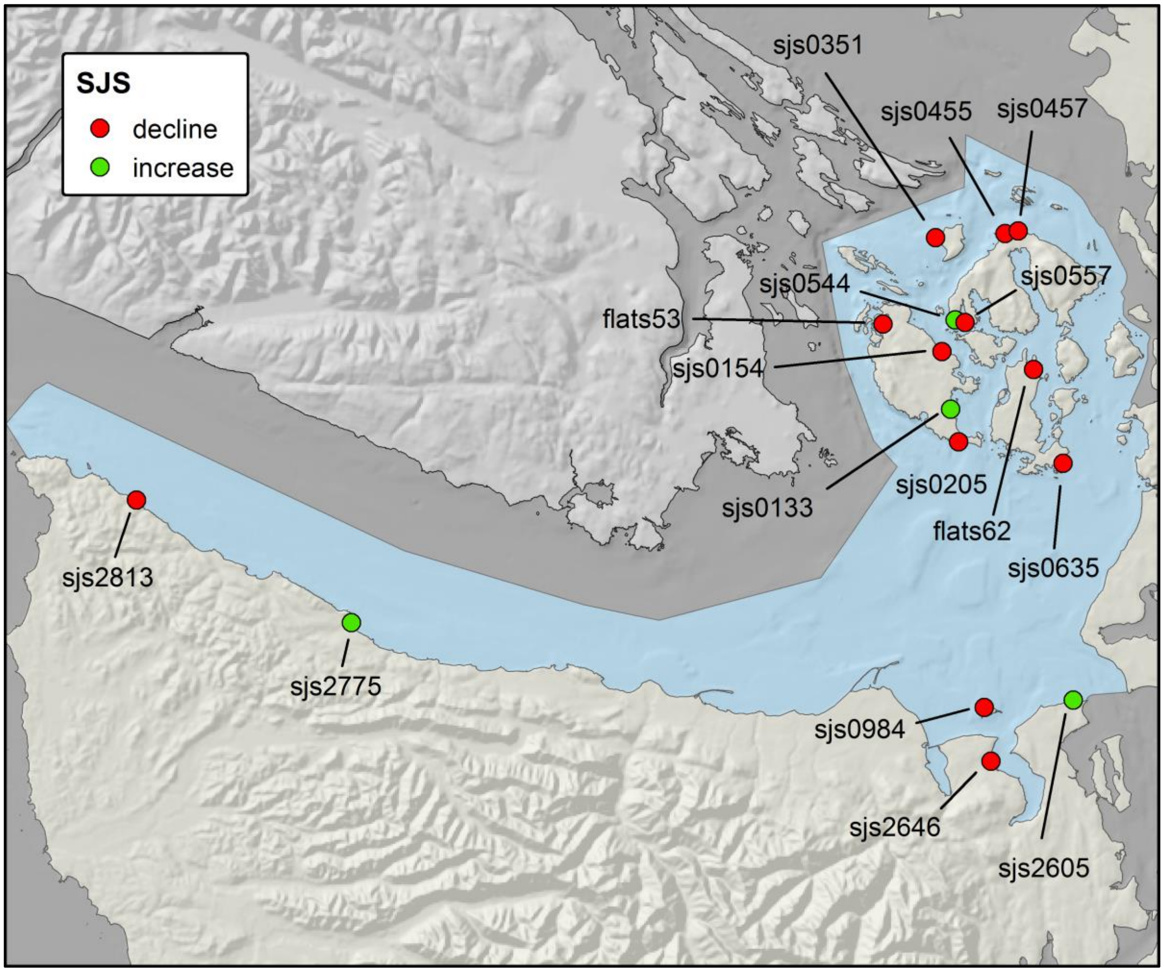




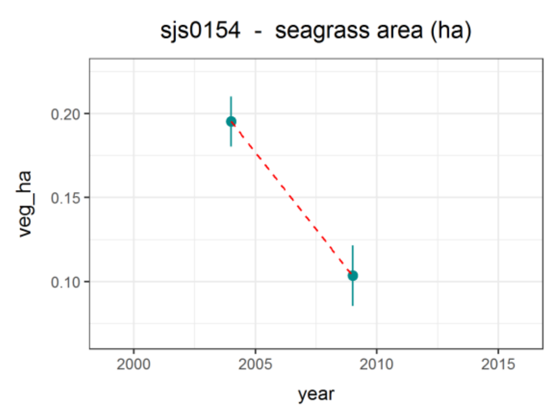

core001 - seagrass area (ha)
veg_ha
4000
3500
3000
2500
2000
2005
2010
2015
year

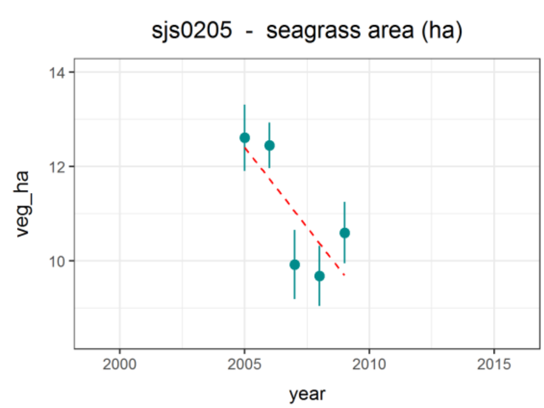

flats12 - seagrass area (ha)
veg_ha
800
700
600
500
2000
2005
2010
2015
year

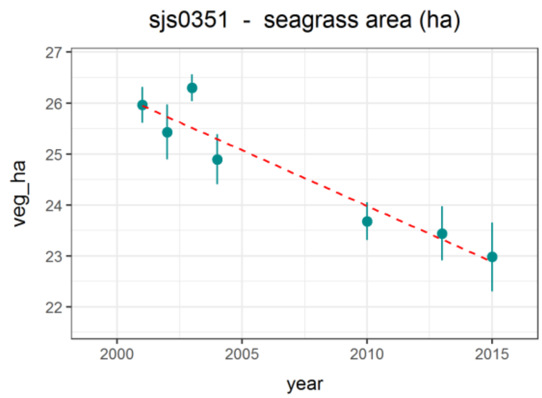
6.4 San Juan Islands and Strait of Juan de Fuca

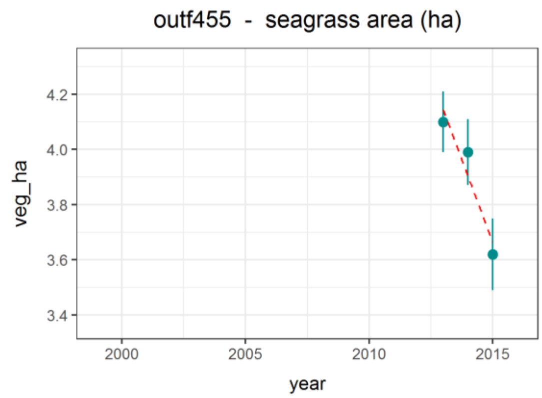


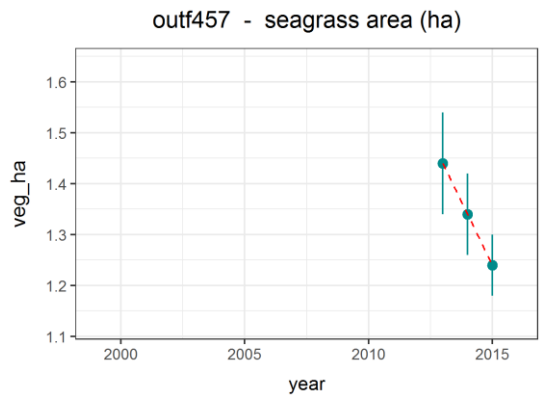
Map with the location of all sites with documented increases/declines in the San Juan Islands and the Strait of Juan de Fuca between 2000 and 2015.

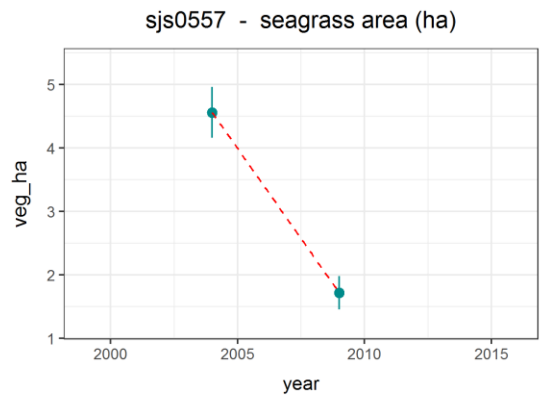


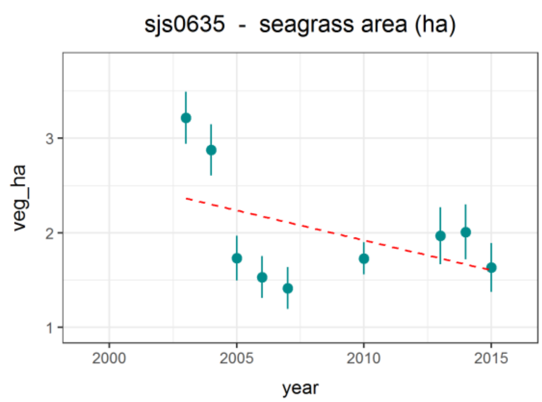


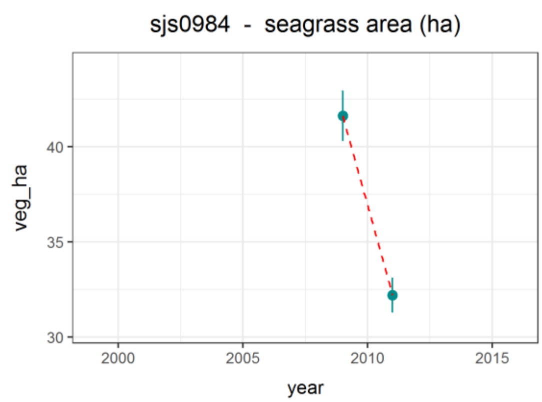

sjs0351 - seagrass area (ha)
veg_ha
27
26
25
24
23
22
2000
2005
2010
2015
year

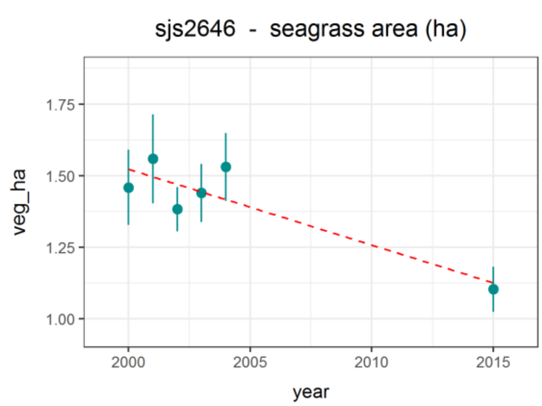

outf455 - seagrass area (ha)
veg_ha
4.2
4.0
3.8
3.6
3.4
2000
2005
2010
2015
year

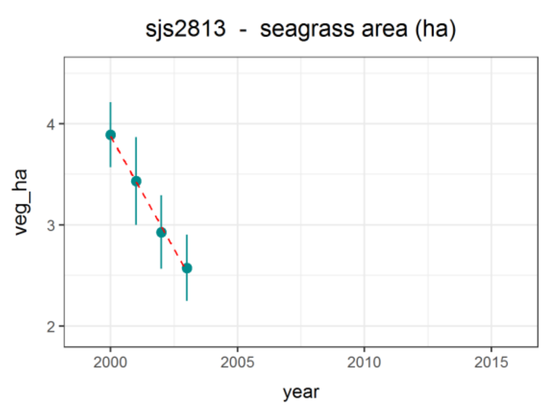

outf457 - seagrass area (ha)
veg_ha
1.6
1.5
1.4
1.3
1.2
1.1
2000
2005
2010
2015
year

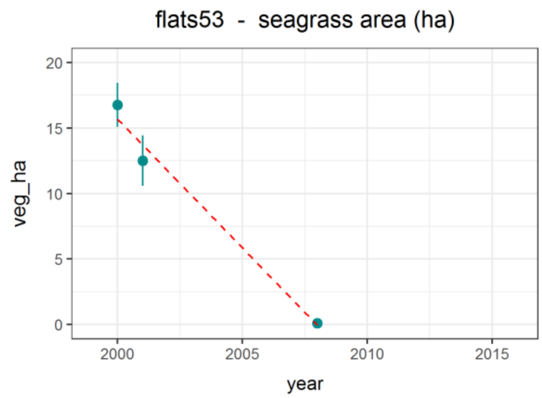

sjs0557 - seagrass area (ha)
veg_ha
5
4
3
2
1
2000
2005
2010
2015
year

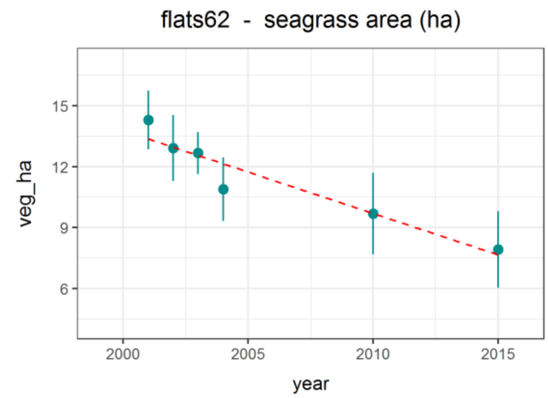

sjs0635 - seagrass area (ha)
veg_ha
3
2
1
2000
2005
2010
2015
year

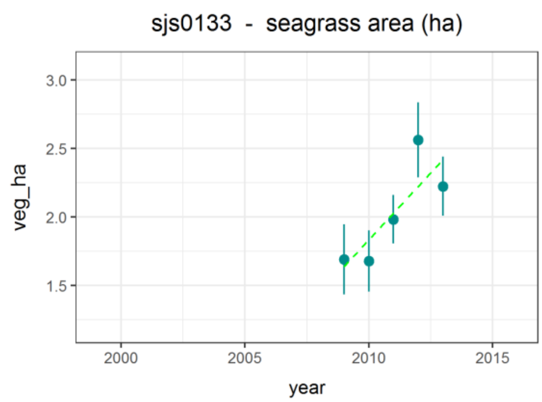

sjs0984 - seagrass area (ha)
veg_ha
40
35
30
2000
2005
2010
2015
year

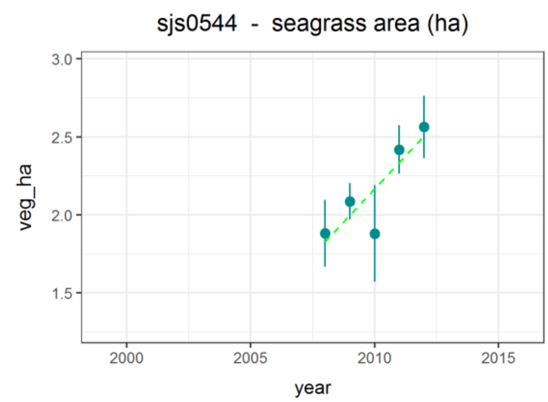

sjs2646 - seagrass area (ha)
veg_ha
1.75
1.50
1.25
1.00
2000
2005
2010
2015
year

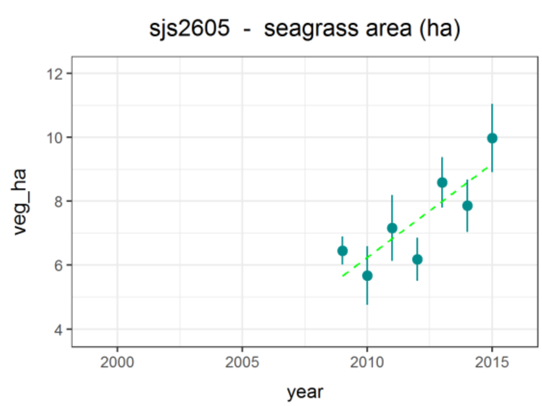

sjs2813 - seagrass area (ha)
veg_ha
4
3
2
2000
2005
2010
2015
year

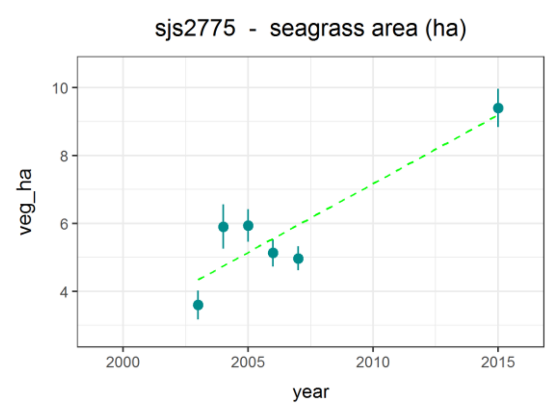

flats53 - seagrass area (ha)
veg_ha
year


flats62 - seagrass area (ha)
veg_ha
year

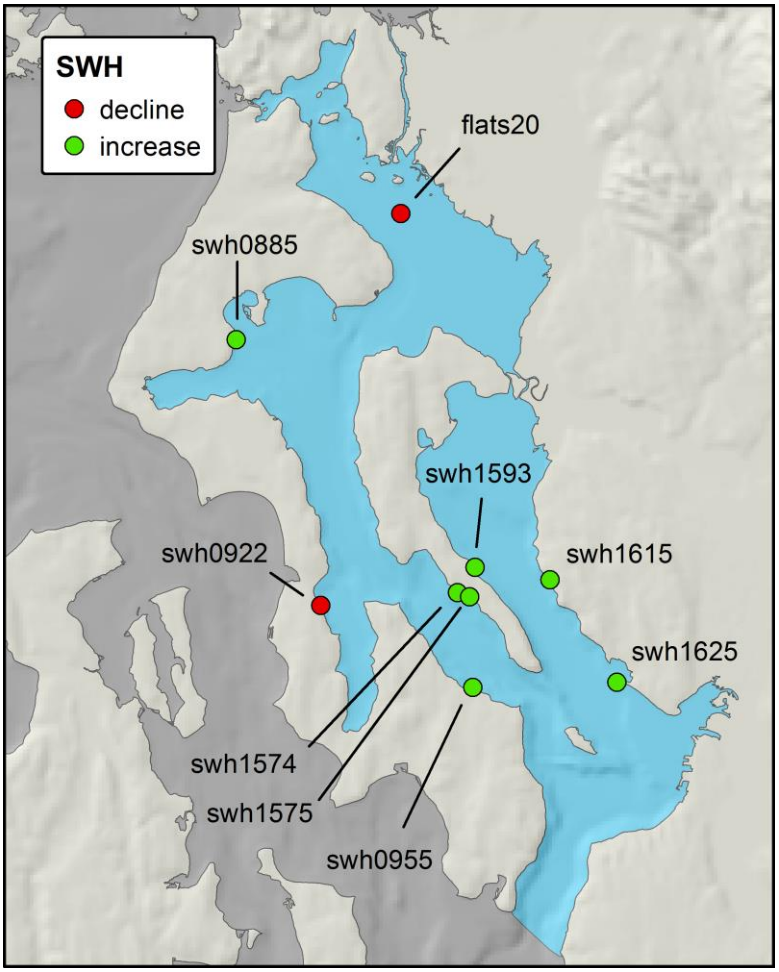

sjs0133 - seagrass area (ha)
veg_ha
year


sjs0544 - seagrass area (ha)
veg_ha
year

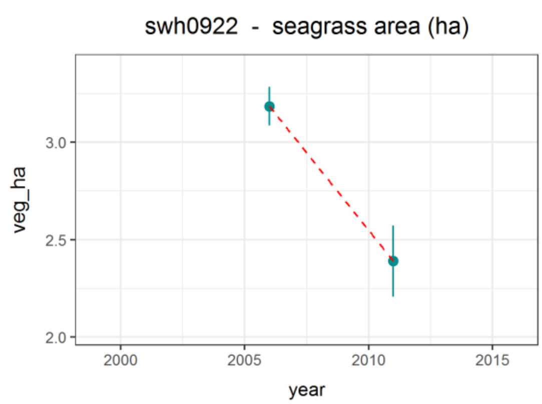

sjs2605 - seagrass area (ha)
veg_ha
year

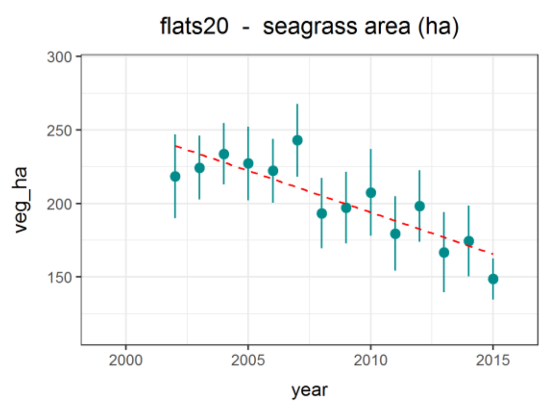

sjs2775 - seagrass area (ha)
veg_ha
year

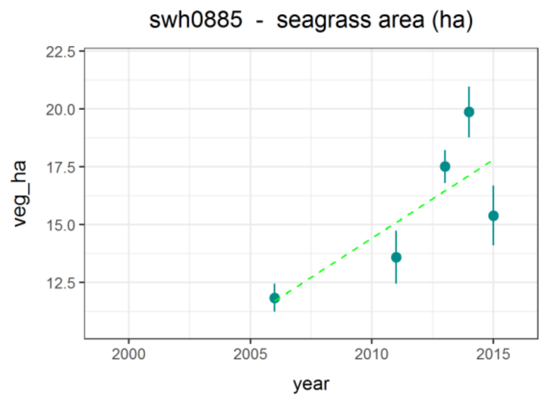
6.5 Saratoga Whidbey Basin

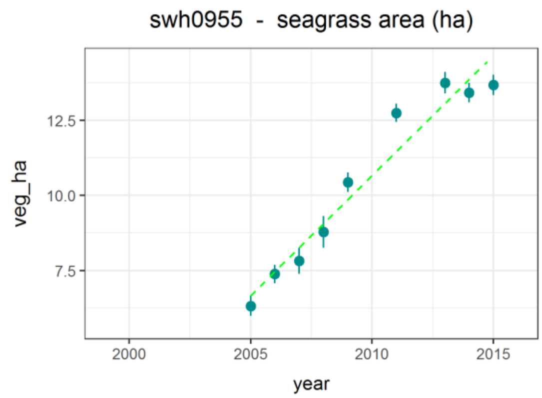


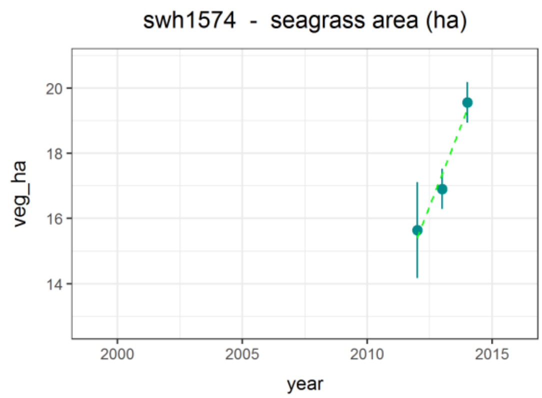
Map with the location of all sites with documented increases/declines in the Saratoga Whidbey Basin between 2000 and 2015

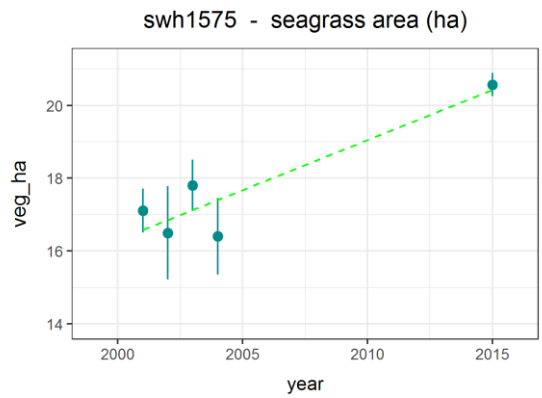


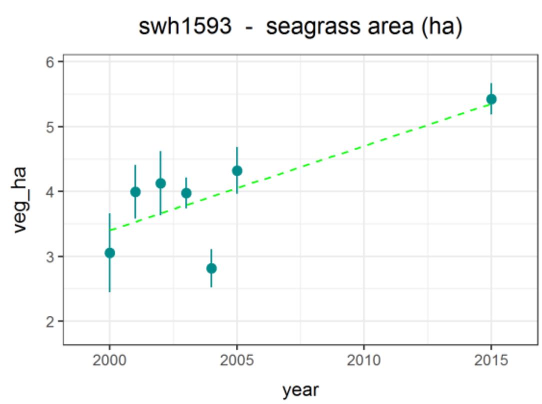


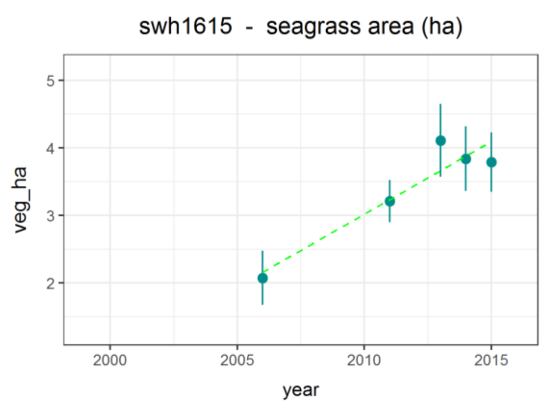

swh0885 - seagrass area (ha)
veg_ha
22.5
20.0
17.5
15.0
12.5
2000
2005
2010
2015
year

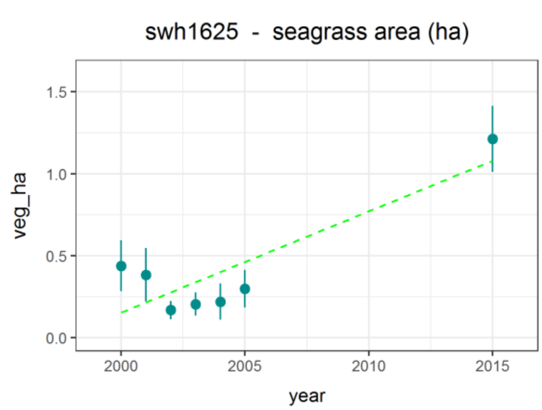

swh0955 - seagrass area (ha)
veg_ha
12.5
10.0
7.5
2000
2005
2010
2015
year


swh1574 - seagrass area (ha)
veg_ha
20
18
16
14
2000
2005
2010
2015
year


swh1575 - seagrass area (ha)
veg_ha
20
18
16
14
2000
2005
2010
2015
year


swh1593 - seagrass area (ha)
veg_ha
6
5
4
3
2
2000
2005
2010
2015
year


swh1615 - seagrass area (ha)
veg_ha
5
4
3
2
2000
2005
2010
2015
year


swh1625 - seagrass area (ha)
veg_ha
1.5
1.0
0.5
0.0
2000
2005
2010
2015
year