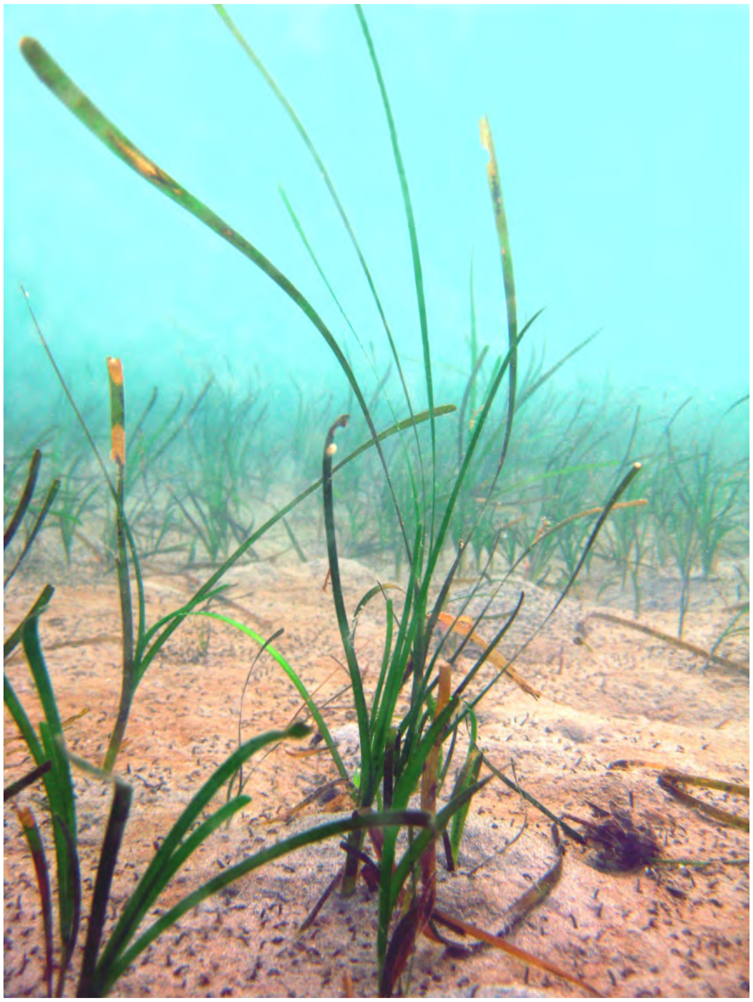
NATURAL RESOURCES

Developing Indicators and Targets for Eelgrass in Puget Sound

A Science Assessment



September 10, 2010

Revised
November 18, 2010

PSAMP
Puget Sound Assessment and Monitoring Program

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

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Cover Photo: Eelgrass bed west of Dumas Bay, King County. Helen Berry, DNR.

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Contents

EXECUTIVE SUMMARY

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. DNR manages these aquatic lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of eelgrass (*Zostera marina*), an important nearshore habitat in greater Puget Sound. There is concern that eelgrass abundance has declined since European settlement. This reflects the perception of broad system decline, and the fact that eelgrass is sensitive to stressors associated with activities that have been practiced extensively throughout Puget Sound.

In late 2009, DNR policy and science staff identified an opportunity to support the development of Puget Sound eelgrass indicators and targets by providing a synthesis of available scientific information to inform policy discussions. Eelgrass has since been selected by the Puget Sound Partnership as one of twenty indicators on the Dashboard of Ecosystem Indicators. It has also been identified as one of three indicators for early development of targets for the Partnership's performance management system. As part of its stewardship activities, DNR conducts soundwide monitoring of eelgrass. The Puget Sound Partnership and other organizations use these data to evaluate ecosystem health.

The work described in this report had five components:

- Develop case studies of five other estuary programs with seagrass targets.
- Assemble all readily available information on historical and contemporary changes in eelgrass in greater Puget Sound.
- Compare different eelgrass indicators and metrics for use in Puget Sound.
- Develop alternative strategies for establishing eelgrass targets and highlight key issues for each strategy.
- Identify a recommended strategy for consideration in policy discussions.

Key findings in this report include:

- Case studies from other estuaries found that seagrass area, and specifically eelgrass area, was commonly used as a measure of ecosystem health.
- All cases studies relied on historical condition as a central factor in setting seagrass targets. In some cases, developed areas that were considered non-restorable were subtracted from the historical abundance.
- Other estuaries achieved gains in seagrass area in response to management actions – up to 107 percent over 31 years in Chesapeake Bay. However, the dynamics of these cases are very different from Puget Sound and the results achieved do not necessarily indicate potential trajectories for this region.
- There are currently no reliable soundwide estimates of historical or potential eelgrass area for greater Puget Sound.

- There is evidence in the DNR monitoring dataset (from 2000) that greater Puget Sound is currently experiencing eelgrass decline, but the magnitude of the decline appears to be relatively minor in comparison to the current abundance and distribution of eelgrass. For every year of monitoring since 2000, except one, the number of sites with declines has been larger than those with increases. However, most sites do not exhibit a significant change.
- There are major gaps in eelgrass monitoring. The soundwide eelgrass abundance indicator measures an ultimate outcome. Intermediate outcomes are needed to directly and rapidly assess management actions. Tracking progress toward these outcomes will require other types of monitoring including compliance, project effectiveness and validation monitoring.

Recommended Strategy

A phased strategy is recommended.

Phase I – Provides an indicator and a 2020 target for immediate implementation:

- We recommend soundwide eelgrass abundance as the indicator to track progress toward a desired ultimate outcome related to eelgrass. The associated metric is area, which measures total areal extent. This indicator and metric are a nationally recognized measure of submerged aquatic vegetation abundance.
- Based on current scientific knowledge, we recommend the target to be a ‘stable or increasing trend’. This ‘reference direction’ approach to target setting acknowledges current limitations in our understanding of both historical abundance and the amount required to support essential ecosystem services. In addition to our recommendation, we discuss several alternatives.

Phase II – Identifies short-term activities that we consider fundamental to meeting Partnership needs for comprehensive monitoring of eelgrass:

- Information related to intermediate eelgrass outcomes is needed by the Partnership to provide direct, rapid feedback on the Action Agenda strategies, and to link to long-term results measured by the status-and-trends indicator. These measures could be identified by the Partnership as part of its coordinated regional ecosystem monitoring program or by another appropriate group.
- With respect to DNR’s existing status-and-trends indicator, we propose some refinements to the Phase I indicator. These activities are planned and funded within DNR’s carry-forward budget.

With regard to future phases, we summarize four broad areas of needs:

- Increase understanding of historical distribution through collecting historical information on eelgrass abundance and distribution at individual sites.
- Define targets for the recommended soundwide indicator and adjust based on improved historical data and expert knowledge.
- Determine eelgrass requirements to support ecosystem services, and design indicators, metrics and targets based on Integrated Ecosystem Assessment.
- Assess eelgrass stressors and integrate stressors into the assessment of eelgrass in the Partnership’s performance management system.

1 Introduction

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. DNR manages these aquatic lands for the benefit of current and future citizens of Washington State. Eelgrass (*Zostera marina*) is an important component of the public and private nearshore aquatic lands in greater Puget Sound. Eelgrass and other seagrasses are known to provide extensive ecosystem services worldwide (Costanza et al. 1997, Green and Short 2003, Larkum et al. 2006). In Puget Sound specifically, eelgrass provides spawning grounds for Pacific herring (*Clupea harengus* pallasi), out-migrating corridors for juvenile salmon (*Oncorhynchus* spp.) and important feeding and foraging habitats for waterbirds such as the Black Brant (*Branta bernicla*) and Great Blue Heron (*Ardea herodias*) (Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995, Butler 1995). Eelgrass also improves water quality by reducing particle loads, acts as a sink for nutrients (Short and Short 1984, Risgaard-Petersen and Ottosen 2000, Asmus and Asmus 2000), and stabilizes sediment, thus counteracting erosion processes (Harlin et al. 1982, Fonseca 1996).

The State of Washington recognizes the importance of eelgrass to the marine ecosystem by giving eelgrass beds special protections. The Washington Department of Fish and Wildlife (WDFW) has designated eelgrass areas 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 has designated eelgrass as critical habitat (WAC 173-26-221) under its statutory authority in implementing the state Shoreline Management Act (RCW 90.58).

On July 30, 2010, the Puget Sound Partnership's Leadership Council selected eelgrass as one of twenty indicators on the Dashboard of Ecosystem Indicators to assess the Partnership's progress toward restoring Puget Sound by 2020. Indicators will be part of a performance management system that is designed to drive outcome-oriented natural resource management and to improve accountability for ecosystem outcomes (Priority E.1 of the Action Agenda, Puget Sound Partnership 2009; Neuman et al. 2009). To meet program goals, both indicators and quantitative targets need to be defined in the near future through a joint effort that includes policymakers and scientists.

In 2009, DNR policy and science staff identified the need for technical information to support the Partnership's indicator development and target setting efforts. DNR is actively engaged with the Partnership through the membership of the Commissioner of

Public Lands on the Ecosystem Coordination Board and the participation of other agency staff in various working groups and committees.

DNR has strategic interest in developing an eelgrass target because of its statutory role in the stewardship of state-owned aquatic lands (RCW 79.105.030). Furthermore, the agency's annual eelgrass monitoring project provides the Puget Sound eelgrass indicators used by the state (Puget Sound Partnership 2010; Gaeckle et al. 2009; Puget Sound Action Team 2007a, 2005, 2002).

1.1 Purpose, Scope, and Objectives

This report is intended to support policy development of eelgrass indicators and associated targets for greater Puget Sound. It provides a synthesis of currently available scientific information and evaluates how this information might support various approaches to indicator development and target setting. The scope of this report is focused only on readily available information and only on the first step in making an eelgrass indicator a meaningful component of a performance management system.

As the Partnership's work progresses, it will be critical to understand the roles of various stressors on eelgrass in greater Puget Sound. It will also be necessary to adopt specific management targets, identify management actions that will be implemented if the targets are not met, and enhance monitoring so that the effectiveness of the specific management actions can be evaluated. These aspects are beyond the scope of this report. The purpose of the work reported here was to rapidly synthesize available information in order to accommodate the Partnership's schedule for the performance management system – specifically the setting of initial targets. Due to significant gaps in the readily available information, this report also includes a prioritization of information needs.

The design of new monitoring programs tailored to meet the needs of particular eelgrass indicators is not considered in the scope of this report. Rather, it is assumed that the existing eelgrass monitoring effort conducted by DNR will continue for the foreseeable future. In this context, the ability of candidate indicators to utilize this existing data stream is viewed as a benefit. In the future, as a more complete adaptive management framework is activated, it will likely be necessary to complement the existing monitoring so that specific stressors, actions, or locations can be monitored.

DNR's existing Submerged Vegetation Monitoring Program is not evaluated in this report. The monitoring program's objectives, methods and statistical framework are described in detail in multiple reports, including Berry et al. (2003), Dowty (2005), Dowty et al. (2005), Gaeckle et al. (2007), Gaeckle et al. (2008), and Gaeckle et al. (2009).

The specific objectives of the report include:

- Synthesize readily available information to support eelgrass indicators, metrics, and target development in greater Puget Sound.

- Recommend a specific strategy for selecting eelgrass indicators, metrics and targets.
- Prioritize future work to provide improved scientific information and support the refinement of this synthesis.

The geographic scope of this work is greater Puget Sound. This consists of all marine waters of Washington State that are inland of Cape Flattery, including Central Puget Sound, the southern reaches of Puget Sound, the southern Strait of Georgia, the waters of the San Juan Archipelago, Hood Canal and the Strait of Juan de Fuca.

1.2 Definition of Terms

Terminology related to indicator development has been used with varying meanings in different publications and legislation, and there is no universal set of definitions. In order to promote clarity, definitions adopted for this report are provided below.

Ecosystem attribute – A component of an ecosystem that is characteristic of the system. Under this definition, "eelgrass" is an example of an attribute of the marine nearshore ecosystem of greater Puget Sound. Ideally, an attribute captures:

- Major ecological characteristics of an ecosystem;
- Characteristics that define structure, composition, and function.

Indicator – A particular aspect of an attribute that can be quantified and tracked over time. For the eelgrass attribute in Puget Sound, a measure of soundwide eelgrass abundance would be an indicator. Another indicator would be restoration effort that leads to expansion of eelgrass.

Metric – A specific parameter that can be evaluated numerically given the appropriate measured data. Multiple metrics may exist for a given indicator. The soundwide eelgrass abundance indicator, for example, could be measured using the total area of eelgrass as a metric, or using length of shoreline that supports eelgrass as a metric.

Target – A single numeric value associated with a specific metric that represents the desired level for that measure.

2 Case Studies

Target setting efforts in several other estuaries were reviewed in order to provide context for this effort in greater Puget Sound (Figure 2-1). Specifically, the purpose was to assess how other estuary programs have approached the selection of seagrass indicators and numeric targets and dealt with the challenges of limited data and considered constraints on restoration potential. This section is not intended as a comprehensive review of the use of seagrass targets in other estuaries, but rather as a review of a tractable number of prominent and well-documented cases.

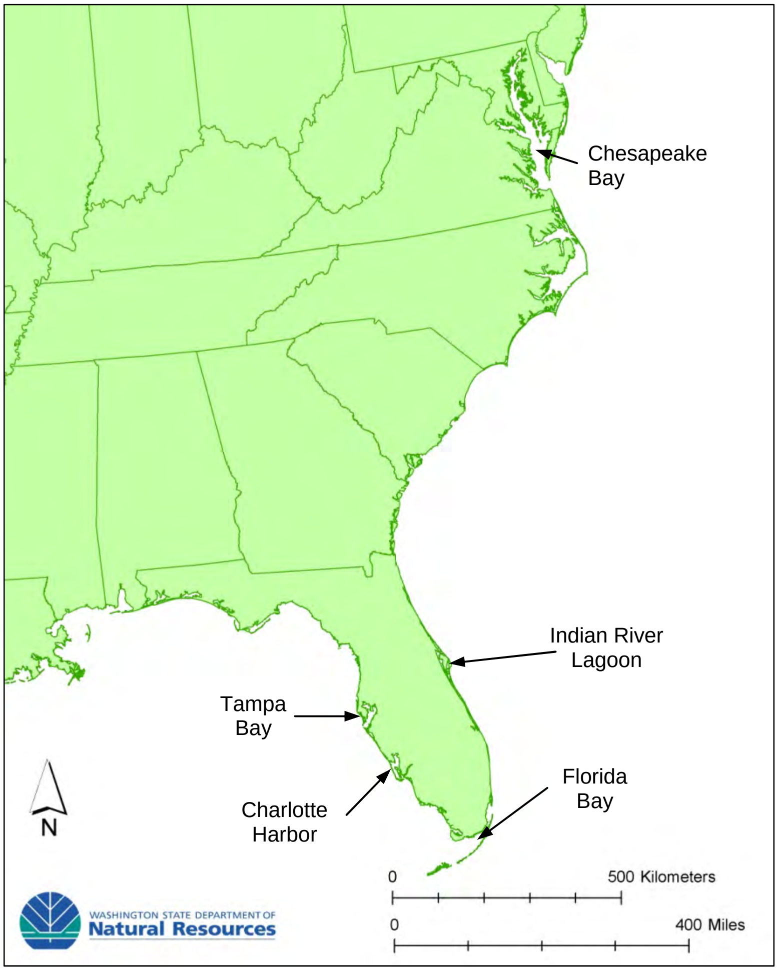

Figure 2-1. Estuaries that have established seagrass management targets that were reviewed for this study.

2.1 Chesapeake Bay

The Chesapeake Bay has a long-established estuary program (Chesapeake Bay Program, est. 1983) with baywide surveys of submerged aquatic vegetation (SAV[1]) that stretch back to 1978 (Figure 2-2). Three characteristics of the Chesapeake case are particularly relevant to the development of SAV targets.

1. Sharp historical declines in SAV have been well documented – in the 1930s, based on published, qualitative reports and again in the 1960s to early 1970s, based on field and aerial surveys (Orth and Moore 1983, 1984).
2. SAV grows predominantly at shallow depths[2] (< 2 m).
3. The stressors responsible for declines in aquatic vegetation are relatively well understood – high nutrient inputs have been identified as the principal stressor across the system as a whole (Batiuk et al. 1992, 2000).

The ecological importance of SAV in Chesapeake Bay and the documentation of significant past declines makes recovery of SAV beds a logical choice as a management goal. The strong linkage between SAV decline and nutrient inputs has lent support to the focus of management actions on reductions in nitrogen and phosphorus inputs and also contributed to setting complementary targets for water quality indicators.

The importance of the second point above is that the shallow depths mean that vegetation beds are discernable in aerial photographs. Comprehensive mapping of SAV on an annual basis is therefore feasible. This capability allows for the tracking of SAV area and the setting of associated targets within any number of sub-regions – most recently 78 in Chesapeake Bay (Batiuk et al. 2000).

The approval of the Chesapeake Bay Submerged Aquatic Vegetation Management Plan in 1989 was the first formal step in the development of SAV targets (Orth et al. 2010). The stated goal of the plan was a net gain in SAV distribution, abundance, and diversity. The first numeric targets for SAV area were set in 1993 for each of 45 sub-regions delineated at that time. These targets were based on the documented area of SAV in aerial surveys between 1971 and 1990 (Batiuk et al. 1992, Chesapeake Executive Council 1993). The overall baywide target of 46,000 ha (114,000 ac) was to be reached by 2005. This target represented an 90 percent increase over 12 years based on 1990 results (24,000 ha ≈ 60,000 ac; Chesapeake Bay Program 2010).

In 2003, new targets were adopted based on analysis of historical aerial photographs that extended the documentation of SAV distribution back to 1938. The targets were developed for a new division of the study area into 78 sub-regions. The sum of

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[1] The Chesapeake surveys cover several species in addition to eelgrass, including freshwater species. The abbreviation SAV refers collectively to all these species. Only rooted, flowering aquatic plants are included; algal species are excluded.

[2] The datum used in the depth values is not clear in the analysis supporting Chesapeake SAV targets (e.g., Batiuk et al. 1992, 2000). Kemp et al. (2004) state that the work of Batiuk et al. (1992, 2000), and hence the targets, are relative to mean low water (MLW).

segment targets led to a higher baywide target (75,000 ha ≈185,000 ac) to be reached by 2010 (Chesapeake Executive Council 2003). This target represents a 106% increase over seven years based on the 2002 status (25,700 ha = 63,500 ac). Achievement of the targets would be based on the single highest SAV area within the most recent three years of survey results (Chesapeake Executive Council 2003). The most recent results available show that the 2010 baywide target will not be met (Figure 2-2), although these results (2009) represent an 107 percent gain over the earliest baywide survey in 1978.

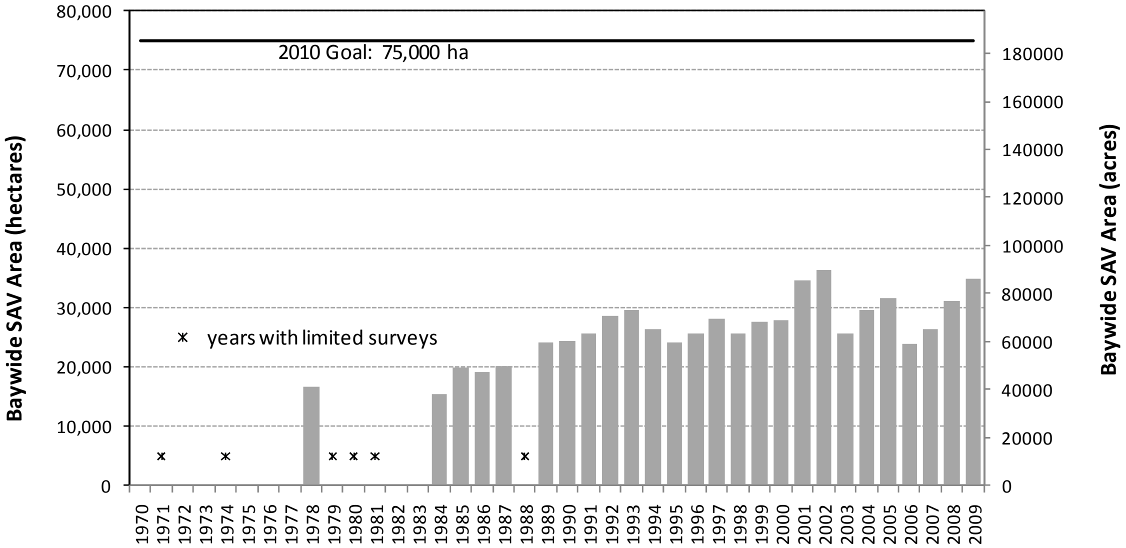

Figure 2-2. Survey results of Chesapeake Bay submerged aquatic vegetation (SAV) and the 2010 target of 75,000 hectares (ha) adopted in 2003 (data from Chesapeake Bay Program 2010).

2.2 Charlotte Harbor

The Charlotte Harbor National Estuary Program (CHNEP) was established in 1995. The original Comprehensive Conservation and Management Plan (CCMP) was adopted in 2001 (Hilgendorf 2002) and was subsequently updated in 2008 (CHNEP 2008). CHNEP identified three general issues with the estuarine and watershed system: hydrologic alterations, water quality degradation, and fish and wildlife habitat loss. Quantifiable objectives were developed to assess the general issues and determine strategies to improve the health of the system. One of the general objectives was to “increase the extent and improve the quality of habitats in the study area, including native submerged aquatic vegetation… ” (Hilgendorf 2002). Another objective was to “reduce propeller damage to seagrass beds… within the study area by 2010.” (Hilgendorf 2002).

Corbett (2006) summarized estimates of long-term change in Charlotte Harbor seagrasses. The two main estimates were restricted to the core of the CHNEP study area and exclude the northern (Lemon) and southern (Estero) bays. Harris et al. (1983) (cited by Corbett 2006) reported a 29 percent decrease in seagrass area between 1945-

1951 and 1982. Corbett et al. (2005) reported a further 6 percent decrease between 1982 and 1999.

Seagrass targets for the Charlotte Harbor were adopted in 2009 by a seagrass subcommittee of CHNEP (Janicki et al. 2009). The supporting data, including historical seagrass area estimated from 1950 aerial photographs, estimates of non-restorable areas (e.g., dredged-filled areas), and current seagrass area estimates from aerial photographs for each of the 14 Charlotte Harbor sub-regions, are summarized in Janicki et al. (2009). A seagrass target was set for each of the 14 sub-regions that was the greater of (A) the adjusted baseline seagrass area (1950 aerial photography estimates minus the estimated non-restorable area) or (B) the mean seagrass area for all recent surveys (1988, 1994, 1999, 2001, 2004, and 2006) in each segment (Table 2-1, Janicki et al. 2009). This approach took into account that seagrass in some sub-regions had declined (target based on historical seagrass area) while it had increased in other sub-regions (target based on recent area estimates).

The overall seagrass target over the CHNEP study area was determined to be the cumulative area from the 14 sub-regions and equal to 26,700 ha (66,100 ac) of seagrass (Table 2-1, Figure 2-3). This target represents a 6 percent overall increase in seagrass area relative to the 2006 data (Janicki et al. 2009). Janicki et al. (2009) did not discuss a specific timeframe for reaching this target. It is not clear why this target (6 percent gain) does not represent a larger proportional gain given that Harris et al. (1983) reported a 29 percent decline between ~1940s and 1982. Beyond the fact that two different historical assessments are involved (Harris et al. 1983, Janicki et al. 2009), the material reviewed does not explain this discrepancy.

Table 2-1. Charlotte Harbor NEP seagrass targets for the 14 harbor sub-regions. The adjusted baseline reflects estimates of 1950 seagrass area (acres) minus estimates of non-restorable area (modified from Janicki et al. 2009).

Segment	Adjusted Baseline (A)	Mean Annual Extent All recent years (B)	Higher of B and A	Protective Target	Restoration Target	Total Target
Dona & Roberts Bay	112	91	A	91	21	112
Upper Lemon Bay	880	1,009	B	1,009		1,009
Lower Lemon Bay	2,882	2,502	A	2,502	380	2,882
Tidal Myakka	344	456	B	456		456
Tidal Peace	975	384	A	384	591	975
West Wall	2,106	1,907	A	1,907	199	2,106
East Wall	3,898	3,465	A	3,465	433	3,898
Cape Haze	5,670	6,998	B	6,998		6,998
Lower Charlotte Harbor	2,964	3,342	B	3,342		3,342
Pine Island Sound	23,757	26,837	B	26,837		26,837
Matlacha Pass	9,315	7,582	A	7,582	1,733	9,315
San Carlos Bay	3,118	4,372	B	4,372		4,372
Tidal Caloosahatchee	93	87	A	87	6	93
Estero Bay	3,662	3,071	A	3,071	591	3,662
Total	59,776	62,103		62,103	3,954	66,057

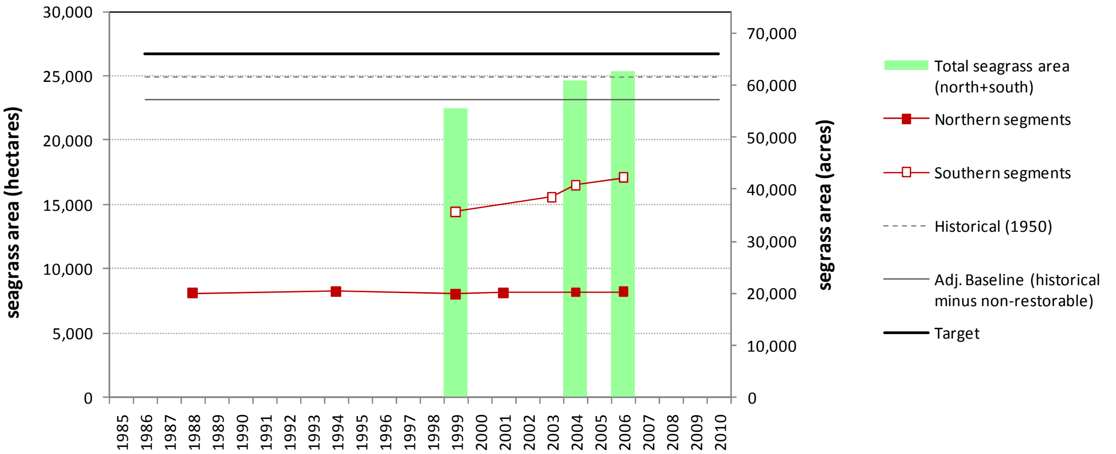

Figure 2-3. Recent seagrass survey data and the overall seagrass target from the Charlotte Harbor NEP. The estimate of historical (1950) seagrass area and the adjusted baseline (historical minus estimated non-restorable area) are also shown. Note that the target area exceeds the historical area. This reflects the results showing that current seagrass area in some sub-regions represents an increase relative to historical conditions.

2.3 Florida Bay

Submerged aquatic vegetation (SAV) is one of 23 indicators selected to evaluate Florida Bay and adjacent bays under the Comprehensive Everglades Restoration Plan (CERP)(RECOVER 2005). The desired outcome for SAV restoration is to establish and sustain diverse seagrass communities (RECOVER 2005). CERP is a multi-billion dollar federal-state partnership that seeks to restore historical hydrological attributes of the Everglades. CERP identified alteration of freshwater hydrology over the last century to be the major regional threat that has led to declines across the landscape. The overall South Florida ecosystem restoration program, which includes CERP and other South Florida restoration efforts, encompasses over 200 components addressing water management and ecosystem restoration needs over the southern third of peninsular Florida.

Seagrasses were chosen as an indicator because they are considered to be integral to ecological function in Florida Bay, and they have experienced large declines. A conceptual model was developed to explain these declines based on paleoecological studies, anecdotal history, and recent research and monitoring, including results on salinity tolerances (RECOVER 2004). The essence of the model is that reduced freshwater inputs to Florida Bay through the Everglades over the past century have reduced the estuarine character of the bay by increasing salinities. This has led to the expansion of turtle grass (*Thalassia testudinum*) and the formation of dense, monospecific beds at the expense of the abundance of shoal grass (*Halodule wrightii*) and widgeon grass (*Ruppia maritima*) (Madden et al. 2009). These dense turtle grass beds are not as stable as the previous species composition, as evidenced by the widespread die-offs in 1987 that impacted 30 percent of the turtle grass population (Robblee et al. 1991).

With respect to SAV, it is hypothesized that increased freshwater flows will create a more natural estuarine salinity gradient in Florida Bay, and lead to the following changes in seagrass communities (Madden et al. 2009):

- Seagrass community structure (cover, distribution, and composition) will change in response to the increased freshwater inputs.
- Responses to restoration will include an expansion of widgeon grass and shoalgrass, and a reduction in the dominance of turtle grass (extent of change will vary by area). Restoration of seagrass species diversity will result in improved habitat function.

An initial set of 7 seagrass indicators was recommended with specific targets for each of 16 sub-basins (RECOVER 2004). The targets do not reflect a historical reconstruction of seagrass conditions, but rather the best professional judgment of several marine ecologists (RECOVER 2005) based on the historical conditions that would be consistent with the conceptual model as well as predictions from a numerical seagrass model (Madden et al. 2009). Madden et al. (2009) streamlined the original indicators into four indices and set targets for a different subdivision of 19 basins. Madden et al. (2009) also devised an approach for spatially aggregating the indices at the basin level to the bay scale. The revised indicators are measures of spatial extent (cover), seagrass abundance (density), species composition (dominance), and the frequency of the target species. These are dimensionless indicators whose values can range from 0 to 1.

SAV monitoring data is collected using quadrats at probabilistically selected sites. Summary results are presented in biennial reports.

Development and adaptation to the CERP continues and there is no stated completion date for recovery. However, the CERP outlines restoration efforts through at least 2039. Additionally, the CERP web site notes that multi-disciplinary workshops are underway to refine performance measures. These and other updates will be integrated into future revisions of the Comprehensive Plan (http://www.evergladesplan.org/about/rest_plan_pt_06.aspx).

2.4 Tampa Bay

The Tampa Bay Estuary Program (TBEP) was established in 1990 and by 1998 a suite of partners signed the Interlocal Agreement that pledged their support for the Comprehensive Conservation and Management Plan (Holland et al. 2006). Macro-algae beds and seagrass meadows were identified as the key living resources for submerged vegetative habitats. However, seagrasses were the primary focus for setting targets. Research demonstrated that seagrasses were critical habitat in the Tampa Bay estuary and needed attention to help restore and protect the estuary (Janicki et al. 1995). There are five seagrass species of importance.

One of the primary focuses of TBEP was to reduce nutrient loading to the system through the Nitrogen Management Strategy for Tampa Bay that was completed in 1998. The goal was to 'hold the line' at 1992-1994 nitrogen loading levels. The actions outlined would improve water quality and clarity throughout the estuary and facilitate the natural recovery of seagrass. Yearly "report cards" are produced for each of the bay areas to determine whether water clarity targets are achieved.

TBEP established a seagrass area target based on 95 percent of the area of seagrass determined from 1950 aerial photographs less the physically altered or non-restorable areas, 16,200 ha (40,000 ac). This resulted in a current target of 15,400 ha (38,000 ac) (Figure 2-4, Tampa Bay NEP 2009). As of 2006, Tampa Bay supported 11,500 ha (28,300 ac) of seagrass, representing a 27 percent increase relative to seagrass area estimates in 1982 (Tampa Bay NEP 2009). To achieve the target will require a 34 percent increase over the 2006 seagrass area estimate (Figure 2-4). Restoration and protection areas are identified based on persistent seagrass absence or presence, respectively, from a comparison of 1950 and 1990 aerial photographs. Seagrass surveys occur every 2-3 years depending on available funding and there is no specific date to reach the seagrass target.

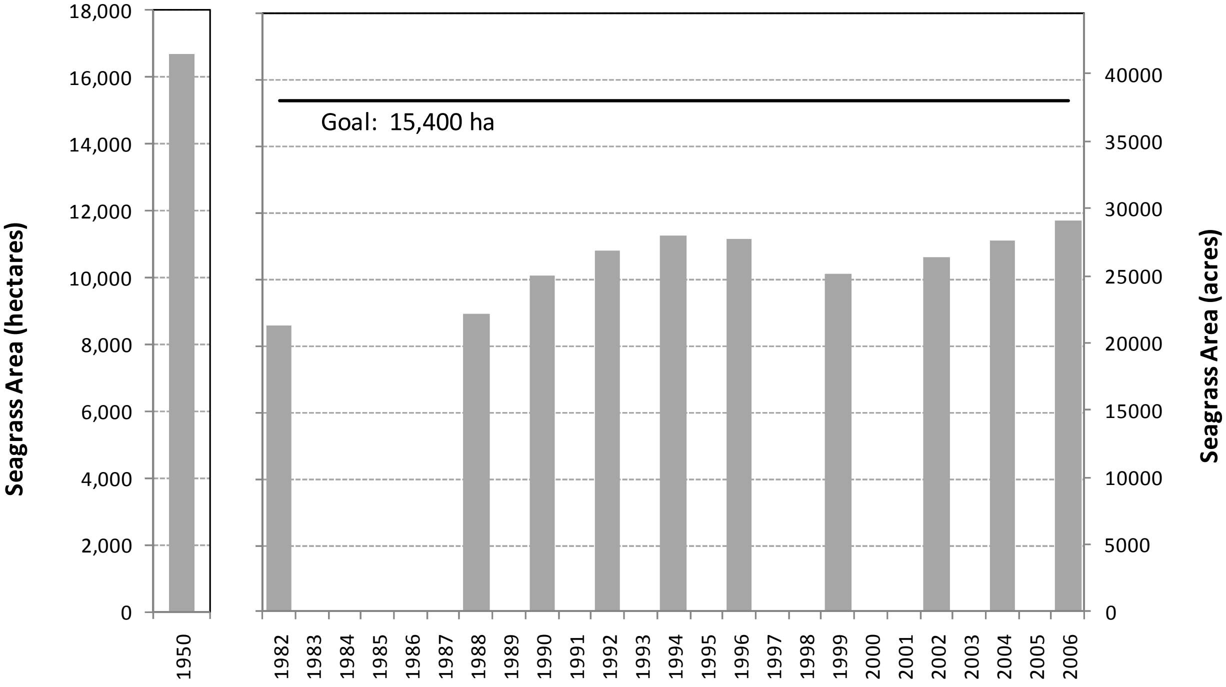

Figure 2-4. The historical seagrass abundance (1950), the current goal and the seagrass monitoring results from Tampa Bay (redrafted from Tampa Bay NEP 2009).

2.5 Indian River Lagoon

The Indian River Lagoon National Estuary Program (IRLNEP) was established in 1990. By 1992, the IRLNEP set into action the Submerged Aquatic Vegetation

Initiative that was designed to maintain and enhance submerged aquatic vegetation. It was understood that seagrass distribution in the Indian River Lagoon (IRL) was controlled by available light and, therefore, goals of enhancing the suitable habitat could be achieved by maximizing water clarity to allow seagrass to grow to a depth of 2 m (6.7 ft) (Woodward-Clyde Consultants1994).

The IRLNEP study area was divided into six sub-regions based on hydrologic, infrastructure, and geomorphological characteristics. Each sub-region was separated into smaller units to develop more detailed seagrass assessments and improved target estimates (Woodward-Clyde Consultants 1994, Virnstein and Morris 2000). Woodward-Clyde Consultants (1994) completed a thorough investigation of changes in seagrass abundance and depth distribution for each subsegment based on aerial photography that dated back to the 1940s and NOAA bathymetry data.

More refined seagrass targets were developed by Virnstein and Morris (2000) to establish water quality and pollution-loading targets. The quantitative seagrass area targets described by Virnstein and Morris (2000) included:

- Potential = to a depth of 1.7 m (5.6 ft)
- Historical = to the maximum extent of where seagrass was mapped based on 1943 photos
- Critical minimum = to the maximum extent of where seagrass has been mapped in at least half of the non-1943 mappings

In the 1940s, there was approximately 25,100 ha (62,000 ac) of submerged aquatic vegetation (SAV) in IRL. By 1992, the amount of SAV decreased by roughly 1,600 ha (4,000 ac). In 2007, the most recent survey year, there was more than 28,300 ha (70,000 ac) of SAV in IRL (http://www.epa.gov/region4/water/watersheds/documents/indian_river_lagoon.pdf, Steward pers. comm.). Most of the changes in SAV area are driven by water quality issues, specifically pollutants that increase total suspended solids, total nitrogen and total phosphorus, and affect the distribution at the deep edge of the bed (Steward and Green 2007).

2.6 Other Estuary Programs

Most of the 28 designated National Estuary Programs (NEP) in the US recognize seagrass or submerged aquatic vegetation in their management plans as priority habitat to monitor, protect, and restore (e.g., Mobile Bay NEP, MBNEP 2002; Piscataqua Regions Estuaries Partnership, Trowbridge 2009; Morro Bay NEP, MBNEP 2000). Four estuary programs discussed above (i.e., Tampa Bay NEP, Charlotte Harbor NEP, Florida Bay, Chesapeake Bay) in addition developed specific targets and metrics to measure the status of the seagrass indicators.

The six west coast NEPs were reviewed for this section but are not described in detail for these reasons: 1) only Morro Bay, Tillamook Bay, and the Puget Sound NEPs include seagrass habitat in their management plans, and 2) only Tillamook Bay has a

baseline estimate of eelgrass abundance and a specific target (Tillamook Bay NEP 1999).
The Morro Bay National Estuary Program (MBNEP) was established in 1995. Eelgrass is addressed in the Action Plans for various Priority Issues outlined in the CCMP (MBNEP 2000). Action Plan HAB-8 Eelgrass, pertains specifically to the implementation of restoration activities to improve the quality and quantity of eelgrass habitat.

Chapter 6 of the CCMP discusses the Action Plan performance measures. HAB-5 Beneficial Dredging has a programmatic objective of acres of habitat protected or restored and specifically emphasizes an increase in eelgrass density per square meter as the environmental objective. The environmental objective of HAB-8 Eelgrass is to monitor the percent change in eelgrass habitat area (increase or decrease) and to monitor eelgrass bed width, shoot density, and turbidity, but there is no programmatic objective in this Action Plan.

The 2009 area estimate of eelgrass in Morro Bay was 97 ha (240 ac), down from the 2006 (117 ha, 288 ac) and the 2007 (139 ha, 344 ac) estimates (Gillespie *in prep*). No eelgrass target has been set due to the highly variable eelgrass estimates (Gillespie *in prep*). MBNEP continues to use eelgrass as an ‘indicator’ and monitors its extent throughout Morro Bay with aerial photography every one to two years (Gillespie pers. comm.).

The Tillamook Bay National Estuary Project (TBNEP) was established in 1994. Under the Key Habitat Action Plan (TBNEP 1999), TBNEP developed an objective of no net decline in eelgrass beds to manage the loss and degradation of this essential habitat. Eelgrass monitoring and protection is included in five separate Key Habitat Action Plans (HAB – 17, 18, 19, 20, and 25, TBNEP 1999, Chapter 4).

In 1995, eelgrass abundance and distribution was determined using multispectral airborne imagery (Strittholt and Frost 1996). The survey identified 363 ha (897 ac) of eelgrass (*Zostera* spp.) in the Tillamook Bay Estuary. Using the 363 ha of eelgrass as the baseline, the TBNEP CCMP objective states no net decline in eelgrass beds (Chapter 10, TBNEP 1999)).

The Puget Sound National Estuary Program (PSNEP) was established in 1987. Seagrass was a major habitat type in the PSNEP CCMP that was approved in 1991. There have been efforts to monitor habitat types (Berry and Ritter 1997), seagrass distribution (ShoreZone Inventory 2001), and status and trends (Berry et al. 2003, Dowty et al. 2005, Gaeckle et al. 2007, 2008, and 2009) as part of the Puget Sound Assessment and Monitoring Program (Puget Sound Action Team 2007b)(formerly the Puget Sound Ambient Monitoring Program). DNR conducts annual monitoring of eelgrass throughout greater Puget Sound through its Submerged Vegetation Monitoring Project (SVMP). SVMP utilizes underwater video transects at randomly selected sites to produce annual estimates of overall eelgrass area. This approach does not produce a comprehensive vegetation map, but it does capture the relatively deep extent of eelgrass in greater Puget Sound. It also provides excellent species discrimination, thereby avoiding the potentially large error associated with misclassification of algae and other aquatic vegetation species. In 2004, the SVMP initiated a focus area effort to produce estimates within five sub-regions in addition to the overall estimate for greater Puget Sound.

There are three other National Estuary Programs on the west coast of the United States: Lower Columbia River Estuary Partnership, San Francisco Estuary Partnership, and Santa Monica Bay Restoration Commission, but none of these NEPs include eelgrass as an indicator in its CCMPs. The San Francisco Estuary Partnership addressed strategies to improve subtidal habitat, including eelgrass, through effective management and restoration activities in its regional wetland management plan. Eelgrass is present in the Lower Columbia River Estuary, but its distribution is not well documented (Judd et al. 2009). There was no mention of eelgrass or seagrass in the Santa Monica Bay documents reviewed.

2.7 Summary

The value of seagrasses and SAV species as indicators of ecosystem health has been well documented (Bricker et al. 2003, Dennison et al. 1993, Orth et al. 2006). Furthermore, nearly all of the National Estuary Programs, with seagrass, in addition to the Chesapeake Bay and Florida Bay programs, recognize its value as an indicator of ecosystem health. The cases presented in more detail provide examples of how other estuary programs approached target development for seagrasses and demonstrate the potential of aggressive management actions in achieving seagrass targets (Table 2-2).

Since the establishment of programs focused on improving the ecological health and sustainability of estuaries, some estuaries have measured profound changes in seagrass abundance and distribution as a result of proactive management actions. Four of the reviewed estuary programs (Charlotte Harbor NEP, Chesapeake Bay Program, Indian River Lagoon NEP, and Tampa Bay NEP) established early seagrass abundance estimates and developed management strategies to increase seagrass abundance and distribution to baseline levels. The system response time varied, but was typically longer than expected. However, aggressive management strategies improved conditions for seagrass and the overall health of these estuaries (Table 2-2).

Table 2-2. Progress of estuary program seagrass management.

Estuary Program	Status Prior to Restoration Activities		Most Recent Status		Years	Percent Change	Annual Rate of Change
	(ha/ac)	(year)	(ha/ac)	(year)		(%)	(%)
Charlotte Harbor NEP	23,470/58,000	1999	26,670/65,900	2006	7	14	1.8
Chesapeake Bay Program	16,760/41,410	1978	34,760/85,900	2009	31	107	2.4
Indian River Lagoon NEP	23,470/58,000	1992	28,330/70,000	2007	15	21	1.3
Tampa Bay NEP	10,000/24,700	1999	11,450/28,300	2006	7	15	2.0
Average					14	43	1.9

It is important to note that these examples represent cases where losses were closely linked with excessive nutrient inputs, and aggressive management targeted anthropogenic nutrient inputs.

There were four important commonalities across the cases reviewed:

1. In each case, the overall area of seagrass within the study area was a primary metric of seagrass condition. The Florida Bay program was the exception in that they use species composition and density metrics in addition to overall area of seagrass.
2. Estimates of area of seagrass under some previous conditions ("historical" seagrass area) provided the main reference point for setting seagrass targets. In some cases, the target was reduced by the amount of potential habitat that was deemed to be permanently lost to development.
3. Complete mapping of seagrasses within the study area was the most common method for evaluating the overall area of seagrass metric. In these cases, this approach was feasible because of relatively shallow seagrass populations that could be mapped by the classification of aerial photography. Again, the Florida Bay program provided the exception through its use of quadrat-based sampling.
4. In each case, the study area was sub-divided into smaller units for target setting, monitoring, and for developing an understanding of stressors and ecological response to management actions.

These findings provide guidance for the effort to select a Puget Sound eelgrass indicator and to set a target for this indicator. The importance of historical estimates in these cases provided part of the motivation for the summary of available historical information in Chapter 3.

These findings also provide useful context for the existing eelgrass monitoring conducted by DNR in greater Puget Sound. DNR's Submerged Vegetation Monitoring Project (SVMP) produces annual estimates of overall eelgrass area. This is consistent with metrics chosen by the other estuary programs reviewed here. In contrast, the use of random sampling by the SVMP, rather than the comprehensive mapping seen in other estuaries, limits the ability to produce meaningful results for a large number of sub-units in the study area. The SVMP currently produces eelgrass area estimates for five sub-regions within greater Puget Sound.

Table 2-3. Aquatic Vegetation Targets – Summary of Case Studies

Estuary	Metric used for vegetation target	Target	Rationale for target	Tracking of progress	Threats & strategies
Chesapeake Bay	Total area of submerged aquatic vegetation (multiple species; excludes algae).	75,000 ha (185,000 ac) by 2010. Set in 2003; represented a 106% increase in 8 years. As of 2009, at 46% of goal.	Based on documented historical distribution based on recent survey data back to 1971 and historical aerial photographs back to 1938.	Annual mapping using aerial photography and field surveys.	Strong emphasis on linkage to nutrient inputs. Nutrient reduction targets set in parallel based, in part, on requirements for aquatic vegetation restoration.
Florida Bay	Submerged aquatic vegetation, represented by seagrass species (excludes algae). 4 indices (spatial extent, abundance, species dominance, presence of desired species).	Performance targets define ranges for poor, fair and good condition. Targets are basin and zone specific.	Derived from historical data and expert knowledge. Indices represent hypothesized characteristics following restoration.	Annual (and more frequent) probabilistic surveys using quadrats.	Main threat considered to be changes in freshwater hydrology and discharge associated with terrestrial water management projects over the last century. Massive project underway to restore terrestrial hydrology.
Charlotte Harbor	Area of submerged aquatic vegetation.	26,700 ha (66,100 ac) of seagrass.	Target is the greater area of the adjusted baseline acreage (1950s survey minus non-restorable areas) or the mean of all recent surveys (1988, 1994, 1999, 2001, 2004, 2006) for each harbor segment.	Aerial mapping every 2 years.	Dissolved and suspended matter from the watershed that decreases water clarity. Detritus, cellular matter and minerals account for 72% of light attenuation, water color (dissolved organic matter) account for 21% and phytoplankton chlorophyll only 4%. Direct physical damage by boats (groundings and propeller scars) has a major impact.
Tampa Bay	Area of submerged aquatic vegetation represented by the five seagrass species (excludes algae).	Goal is 95% of historical seagrass area less non-restorable areas – 15,400 ha (38,000 ac). Currently at 75% of goal.	A comparison of historical (1950s) seagrass extent and the existing (1990), less the physically altered, non-restorable areas used to produce the targets.	Annual mapping using aerial photography and field groundtruthing.	Factors that affect water clarity (e.g., nutrients, sediment loading, algae blooms, phytoplankton concentration, storm water runoff).
Indian River Lagoon	Total area of submerged aquatic vegetation (excluding algae), and seagrass depth.	Segment specific seagrass area cover, depth. Seagrass Area – 35,300 ha (87,200 ac) Depth - > -1.2 to -2.8 m.	Targets were based on a system-wide, stratified approach that spanned years of data to account for spatial and temporal variability.	Aerial photography every 2-3 years and transect data collection every 2 years.	Factors that affect water clarity (e.g., nutrients, sediment loading, dissolved solids, algae blooms, storm water runoff).

3 Changes in Eelgrass in Greater Puget Sound

The historical abundance of seagrass is appealing as a reference point in setting a management target for future abundance. It gives a measure of the potential abundance if all stressors associated with human population growth and urbanization could be mitigated. Also, comparison of contemporary to historical conditions might suggest whether management targets should emphasize recovery of lost vegetation or protection of relatively intact vegetation. The utility of historical abundance estimates is evidenced by their role in setting the seagrass targets in the five examined case studies (Chapter 2).

It is equally useful to know the contemporary trends in eelgrass abundance in order to assess whether the eelgrass population is currently in a state of rapid decline or if it is relatively stable or even expanding. Contemporary trends may reflect a pattern that differs from the broader historical trend. This information is also important for setting achievable eelgrass targets over management-relevant timeframes.

In Puget Sound, there is widespread concern that eelgrass abundance has declined since European contact. There is a reasonable likelihood that losses associated with human activity have occurred because eelgrass is known to be sensitive to a wide range of stressors associated with activities that have been practiced extensively in Puget Sound, including sediment and nutrient runoff, habitat conversion through dredging and filling, physical disturbance, invasive species, disease, commercial fishing practices and aquaculture (Orth et al. 2006). Large-scale losses have been reported world-wide in recent decades, and evaluations suggest that human population expansion is the most serious cause of world-wide seagrass habitat losses (Short and Wyllie-Echeverria 1996, Orth et al. 2006). However, efforts to estimate losses in Puget Sound are hampered by limitations in the historic data record.

The purpose of this chapter is to summarize the available information on past changes in eelgrass abundance in greater Puget Sound. This includes information on changes over historical time scales as well as contemporary trends as reflected in the current monitoring program conducted by DNR since 2000. The first section of the chapter (Section 3.1) presents eelgrass estimates at the soundwide scale. The following section (Section 3.2) presents documented site-level changes at sites where information is available. Section 3.3 discusses site changes in eelgrass associated with alterations in river hydrology as special cases.

3.1 Estimates of Soundwide Eelgrass Area – Historical, Contemporary and Potential

Prior to the start of the DNR eelgrass monitoring project in 2000, there were few estimates of regional or soundwide eelgrass area in greater Puget Sound. Notable exceptions included the work of Ron Phillips and the Coastal Zone Atlas of Washington. In addition there is a current effort underway at NOAA Fisheries to map potential eelgrass areas in Puget Sound (Davies et al. 2009, Davies et al. in prep). These are reviewed below.

3.1.1 Phillips' Eelgrass Area Estimate for Puget Sound Proper

3.1.1.1 Description of Estimates

Ron Phillips estimated the area of potential eelgrass habitat in Puget Sound proper in three slightly different versions (Phillips 1972, 1974; Thayer and Phillips 1977). Phillips defines Puget Sound proper as the marine waters separated from the Strait of Juan de Fuca by a line running from Point Wilson near Port Townsend to Partridge Point on Whidbey Island and at Deception Pass (Phillips 1972, p. 30; Figure 3-1).

Phillips' estimate was based on field surveys of 101 sites conducted in 1962-63 combined with the bathymetric analysis of McLellan (1954). Sixty-five sites were surveyed using SCUBA with the remainder sampled by dredging (Phillips 1972, pp. 26, 30). Thom and Hallum (1990, p. 11) characterized these as qualitative surveys, but Phillips concluded from the surveys that "virtually all measurements made in Puget Sound demonstrate that *Zostera* is restricted to a belt from MLLW (mean lower low water) to a depth of -22 feet (-6.6 meters)" (Phillips 1972, p. 34). Based on this conclusion, Phillips focused his attention on the estimate of the total area in Puget Sound proper between MLLW and three fathoms (-18 ft, -5.5 m MLLW) that was reported by McLellan (1954).

Phillips reported that the area within this depth band is 9 percent of the total area of Puget Sound proper based on the analysis of McLellan (1954). This 9 percent value is reported in each of the three sources, suggesting that they each discuss essentially the same quantity (Phillips 1972, p. 65; Phillips 1974, p. 264; Thayer and Phillips 1977, p. 18). However, there are discrepancies between the reported area values that suggest there are limitations in the accuracy of the reported values. For example, Phillips (1972) reported the area of the depth band in three different units that do not completely agree when converted to the same units (Figure 3-2). Also, Phillips (1972) reports the area of the depth band as 136 square nautical miles while Phillips (1974) reports this value as 131 square nautical miles. Thayer and Phillips (1977, p. 18) reported that the area is "over 125,000 acres", but this lower bound is itself greater than the values reported in the other two sources.

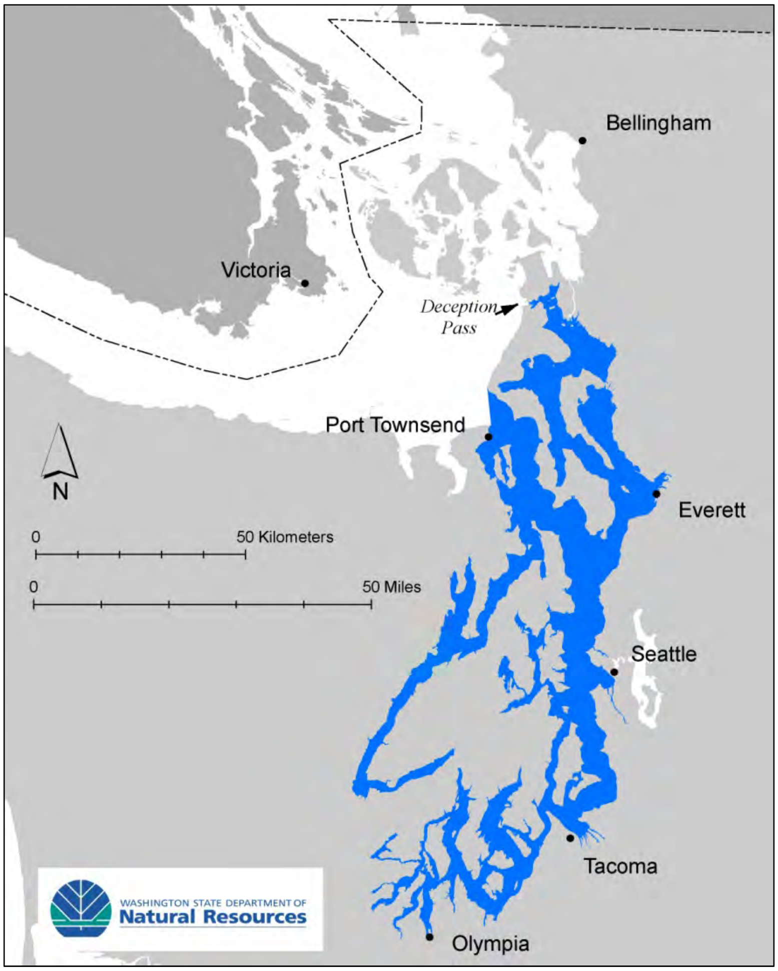

Figure 3-1. Puget Sound proper (in blue) as defined by Phillips (1972).

To compare the individual values, all were converted to units of hectares using conversion factors from the National Institute of Standards and Technology[3] (Thompson and Taylor 2008). The precision of each reported value was taken to be that implied by the significant digits in the value. In essence, the range of values that would round to the reported value given its significant digits was used to represent precision. Overall, the reported values range from 44,500 to 50,800 ha rounded to the nearest hundred. Given the limited accuracy of the reported values implied by this range, as well as the limited accuracy that can be assumed for the underlying 1930s-1940s bathymetry and tidal datum data (McLellan 1954), it is reasonable to think of Phillips' various estimates as being generally in the range of 45,000 – 50,000 ha.

3.1.1.2 Interpretation of Phillips' Estimates

It is important to identify exactly what Phillips' estimate represents. It is characterized variously as the area that "could support eelgrass" (Phillips 1972, p. 65), the area that

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[3] Three conversion factors were used from Thompson and Taylor (2008): 1.852E+03 to convert nautical miles to meters; 1.609344E+03 to convert miles to meters; 4.046873E+03 to convert acres to square meters.

"eelgrass grows over" (Phillips 1974, p. 264) and the area "covered by eelgrass" (Thayer and Phillips 1977, p. 18). The first characterization is clearly the most appropriate because it conveys that this area is *potential* habitat, whereas the latter characterization could be interpreted to mean there is 100 percent cover within Phillips' depth band throughout Puget Sound.

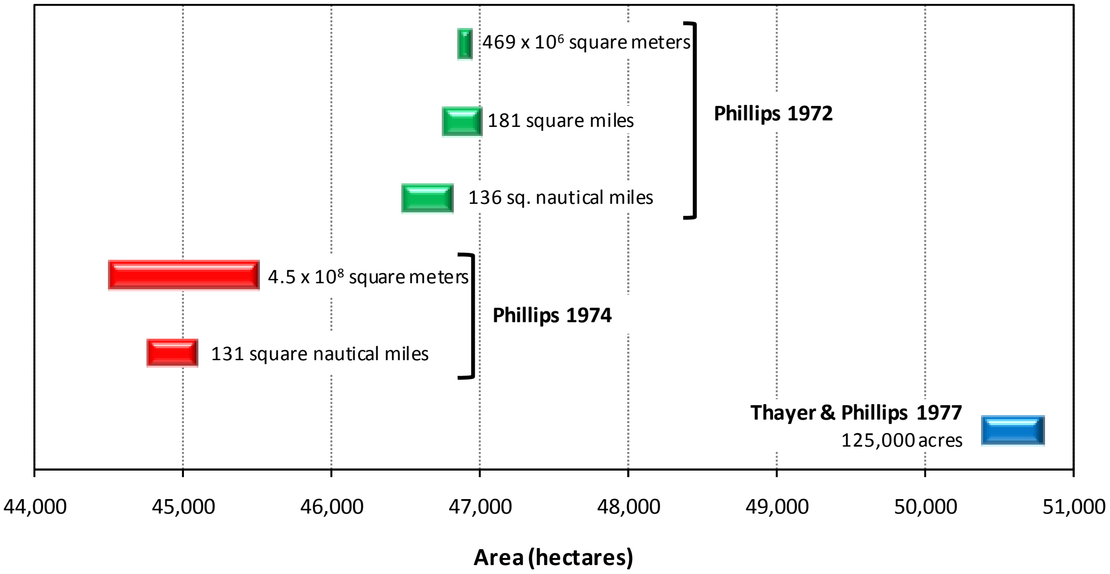

Figure 3-2. Comparison of the values reported by Phillips for the area of potential eelgrass habitat in Puget Sound proper when all values are converted to hectares. In each case, the values were said to represent 9% of the total area of Puget Sound proper. The horizontal width of each bar represents precision of the reported value – essentially the range of values that would round to the reported value. The values as published (in original units) are shown in each case.

Current conditions do not approach 100 percent eelgrass cover regionally within the Phillips' depth band (based on field observations of the authors). Phillips himself discussed the complete absence of eelgrass in the southern reaches of Puget Sound (Phillips 1972, p. 30). He also discussed at length the multiple factors that affect eelgrass presence (e.g., salinity, temperature, pH, substrate, wave energy) in addition to depth (Phillips 1972, pp. 31-36; Phillips 1974, pp. 248-258; Phillips 1984, pp. 13-19). It is clear that Phillips did not mean to suggest that depth alone can be used to delineate areas where eelgrass is found. It is therefore most reasonable to think of Phillips' estimate as a measure of *potential eelgrass habitat* based on depth, with actual eelgrass presence to be a subset of this area depending on several environmental factors.

3.1.1.3 Discrepancy between Phillips (1972, 1974) and McLellan (1954)

The area-volume analysis of McLellan (1954) is the basis for the Phillips (1972, 1974) and Thayer and Phillips (1977) estimates of potential eelgrass area. The spatial extent of McLellan's soundwide value differs slightly from that described by Phillips (1972). The boundary at Admiralty Inlet runs to "Middle Point" rather than Point Wilson near Port Townsend (McLellan 1954, p. 2). Based on McLellan's map (1954, p. 17), it appears that Middle Point refers to what is now referred to as McCurdy Point, west of Port Townsend. This is a minor discrepancy that is ignored here.

McLellan (1954) used US Coast and Geodetic Survey charts from the 1930s and 1940s to delineate mean high water, mean lower low water, and 3-fathom contours. A planimeter was used to determine the areas within different depth zones. Accuracy of the area measurements are limited by the scale of the charts used, the contouring of the depth contours and error associated with planimeter use (McLellan 1954, p. 5-6). Four digits were considered significant for the planimeter measurements (McLellan 1954, p. 6).

There are three different parameters that Phillips reports that were based on the work of McLellan (1954). The values reported by Phillips are compared here to the values in McLellan (1954) to check for consistency. The parameters are total shoreline length of Puget Sound, total area of Puget Sound covered at mean lower low water (MLLW), and the area between MLLW and 3 fathoms below MLLW. When values derived from DNR's GIS data are available, these are also reported. The values are presented in the following text and summarized in Table 3-1.

1. Shoreline length.
   Phillips (1972, p. 30) states "McLellan (1954) reported that the total length of shoreline of Puget Sound was 1,157 nautical miles (2,131 km)." This value in nautical miles agrees exactly with the value reported by McLellan (1954, p. 1): "Total length of shoreline ... 1,157 nautical miles". The conversion to kilometers is slightly different if the NIST conversion factor for nautical miles to meters is used (Thompson and Taylor 2008). Using this factor, 1,157 nautical miles is equivalent to 2,143 kilometers.

   Current GIS data give an estimate of 2,389 km as the total shoreline length of Phillips' Puget Sound proper. This is based on the Water Bodies dataset in DNR's HYDRO database that was current on 4/22/2010. The value reported by McLellan (1954) and Phillips (1972), 1,157 nautical miles, is 10 percent less than the GIS value. Given that some discrepancy is expected (differences in shoreline delineation protocols, improvements in spatial accuracy), these values are comparable.

2. Area covered at MLLW.
   Phillips (1974, p. 264) states "Using the area-depth data from McLellan (1954) . . . there is a total of 1,514 square nautical miles in Puget Sound covered at mean lower low water." This is inconsistent with McLellan (1954, Table 5-E, p. 29) which gives a value of 679.1 square nautical miles. The Phillips value is 123 percent greater than McLellan's value.

   Since Phillips' (1974) value is purportedly based on McLellan (1954), there should be no discrepancy between the two. GIS data was not used directly as a reference point in this case because because of the limited availability of regional bathymetry datasets with MLLW datum. Two additional comparisons clearly indicate that the error is with the Phillips (1974) value. First, McLellan (1954) gives the total area of Puget Sound proper at mean high water (MHW) as 767.6 square nautical miles. The area of Puget Sound at lower tidal stages cannot exceed this value. The Phillips (1974) value is far greater. Second, current GIS data (DNR HYDRO database) give the area of Puget Sound proper as 758.4 square nautical miles, which agrees with the McLellan (1954) value at MHW to within 1 percent. This is less discrepancy than might be expected, considering that the shoreline that delineates Puget Sound in the DNR HYDRO database more closely resembles ordinary high water than MHW.

While the Phillips value is clearly in error, the origin of the error is not clear. The error is particularly difficult to explain since this is not a derived value but is printed explicitly in McLellan's results tables (1954, Table 5-E, p.29). In contrast, there is good agreement between McLellan (1954) and values derived from current DNR GIS data.

3. Area between MLLW and 3 fathoms
   Phillips (1972, p. 65) states "McLellan (1954) estimated the area of Puget Sound proper between MLLW and three fathoms to be 136 square nautical miles." Phillips (1974, p. 264) gives this value as 131 square nautical miles.

   In contrast, when McLellan's (1954, Table 5-E, p. 29) value for the area covered at 3 fathoms (593.3 square nautical miles) is subtracted from the area covered at MLLW (679.1 square nautical miles), the difference, which represents the area between these two elevations, is 85.8 square nautical miles (29,400 ha). This is the result if the methods as described in Phillips (1972, 1974) are followed correctly.

3.1.2 Estimate of Puget Sound Eelgrass Area Derived from the Coastal Zone Atlas

The seagrass spatial data layer in the Puget Sound Environmental Atlas can be used as an additional reference point for Puget Sound eelgrass area (Evans-Hamilton, Inc. and D.R. Systems, Inc. 1987, Needham and Lanzer 1993, Uhrich and McGrath 1997). This data layer was derived from the Coastal Zone Atlas of Washington (Youngmann 1978, 1979, 1980) which relied on aerial photographs from 1973-1974 to delineate seagrass beds (Thom and Hallum 1990). Thom and Hallum (1990, p. 12) refer to the Coastal Zone Atlas data layer as "the most comprehensive distributional information for eelgrass in the study region."

This data layer represents primarily the distribution of eelgrass, but also the more restricted distributions of surfgrass (*Phyllospadix* spp.) and *Zostera japonica*. DNR maintains a version of the seagrass data layer from the Puget Sound Environmental Atlas. The sum of the area of all seagrass polygons in this dataset is 10,877 ha, roughly half the estimates based on DNR's annual monitoring data, although for an area that excludes most of the Strait of Juan de Fuca. However, the seagrass layer in the Coastal Zone Atlas is known to be an underestimate of seagrass area existing at that time (1973-74) because of obvious omissions of expansive beds, notably in Padilla Bay and Lummi Bay, as well as poor representation of subtidal beds (Thom and Hallum 1990). In addition, seagrass polygons in the Coastal Zone Atlas in the Strait of Juan de Fuca west of Dungeness Spit were not incorporated into the Puget Sound Environmental Atlas due to the limited geographic scope of the atlas (Figure 3-3). Furthermore, inspection of the data suggests that shoreline segments associated with tribal reservations were not mapped.

Table 3-1. Area and perimeter measures of Phillips' Puget Sound proper as reported by Phillips (1972, 1974), McLellan (1954), and by agency GIS data maintained by DNR. Bold font indicates the original units of the reported value. Values in the alternate units given were calculated using the conversion factors of Thompson and Taylor (2008). The native unit of the DNR GIS is U.S. survey feet. Empty cells represent values that were not reported or are unavailable.

parameter	Phillips		McLellan (1954)	DNR GIS	units
	source	value			
shoreline length	Phillips 1972	1,157	1,157	1,290	nautical miles
		1,005	1,005	1,484	miles
		2,143	2,143	2,389	kilometers
area covered at MHW			767.6	758	sq nautical miles
			650,575	642,778	acres
			263,279	260,124	hectares
area covered at MLLW	Phillips 1974	1,514	679.1		sq nautical miles
		1,283,182	575,567		acres
		519,287	232,925		hectares
area covered at -3 fathoms			593.3		sq nautical miles
			502,848		acres
			203,496		hectares
area between MLLW and -3 fathoms	Phillips 1972	136	85.8		sq nautical miles
		115,266	72,719		acres
		46,647	29,429		hectares

In addition to the 12 folios that are the core of the Coastal Zone Atlas of Washington (Youngmann 1978, 1979, 1980), a two-volume set of narratives was produced to accompany the folios (Albright et al. 1980). In the narrative regarding eelgrass, it is stated that "roughly 125,000 acres (50,600 hectares) of eelgrass are present in Puget Sound alone" (Albright et al. 1980, Vol. II, p. 517). There is no citation given to support this value, but it is likely that Albright et al. (1980) relied on Thayer and Phillips (1977) and that the geographic scope of this estimate is Puget Sound proper. The latter paper is a general review paper of eelgrass in Puget Sound that would have been a recent publication at the time with the identical value of 125,000 acres (Thayer and Phillips 1977, p. 18).

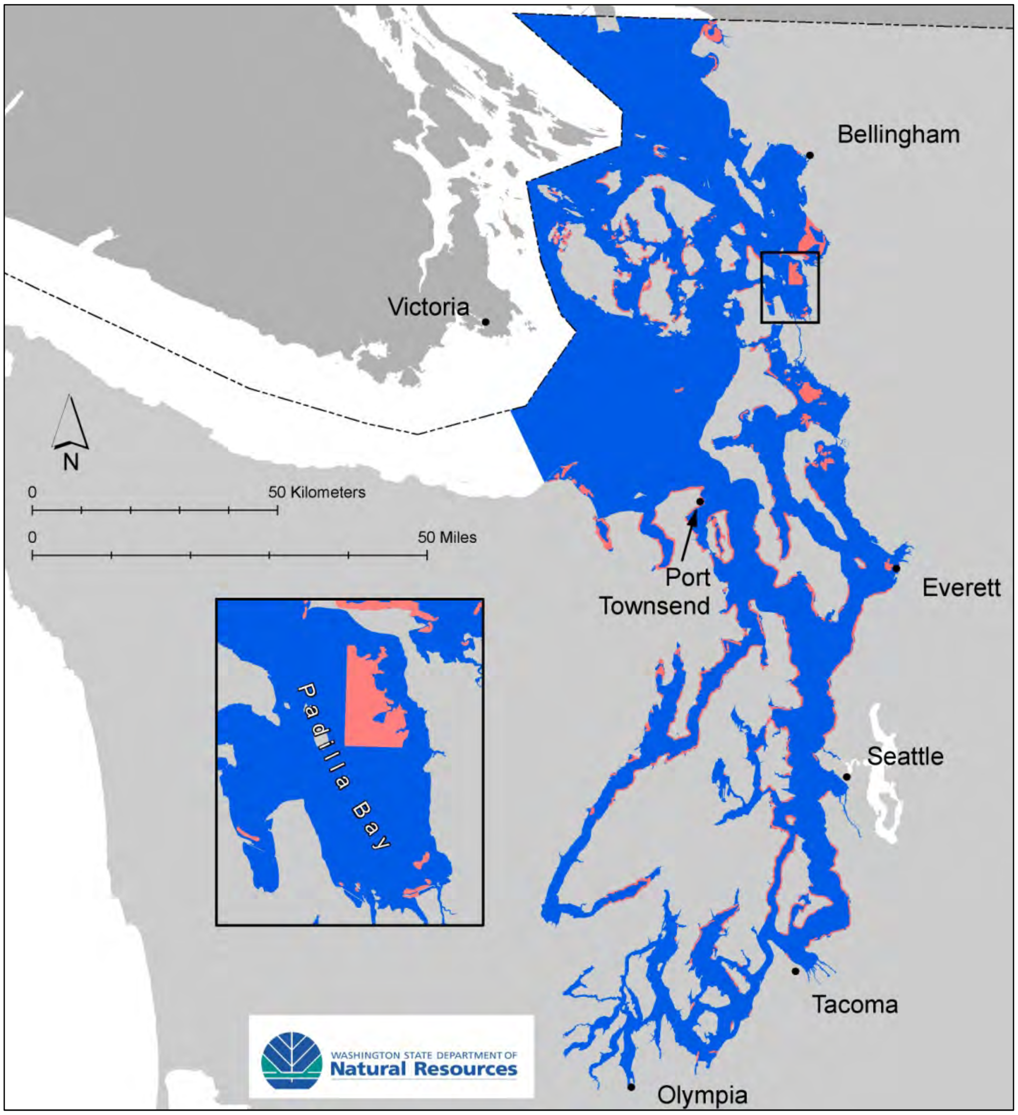

Figure 3-3. The spatial extent (in blue) of the area represented in the Puget Sound Environmental Atlas and the mapped eelgrass polygons (in red). The inset map shows the mapping artifact at Padilla Bay (edges of eelgrass meadows are depicted as straight lines at a right angle).

3.1.3 Potential and Historical Eelgrass Area Estimates from NOAA Fisheries

Davies and colleagues of the Ecosystem Service Program at the Northwest Fisheries Science Center (NWFSC, Montlake, WA) have produced an preliminary estimate of potential eelgrass area for greater Puget Sound (Davies et al. 2009). Guerry et al. (in press) discuss this work. This work is still under development and estimates have not yet been finalized.

3.1.4 *Soundwide Changes in Eelgrass in the Contemporary Monitoring Record*

DNR's eelgrass monitoring has produced two distinct measures of recent change in eelgrass (2000-2008) for greater Puget Sound overall. First, a trend analysis of annual estimates of total eelgrass area produces a slightly increasing trend (270 ha/year; ~ +1 percent/year), but it is only marginally significant (*p*=0.09) (Figure 3-4). This indicator does not take into account the frequency of declines across sites, only the summed area of eelgrass.

The second measure of recent change tracks the prevalence of sites with significant decreases in eelgrass area among those sites with significant changes. For every year except one, the number of sites with declines has outnumbered those with increases (Figure 3-5). This indicator does not take into account the amount of eelgrass at sites, only the numbers of sites in categories of loss and gain and no change. It suggests that the pattern of eelgrass losses over the last decade has been characterized by declines at smaller beds.

The results from the two indicators are distinct. The area indicator shows no evidence of decline (Figure 3-4) while the prevalence of site declines indicator (Figure 3-5) suggests that on average there is a greater frequency of site decline than of increase in eelgrass area. Taken together, these two indicators suggest that the distribution of eelgrass is changing, with losses occurring at smaller beds.

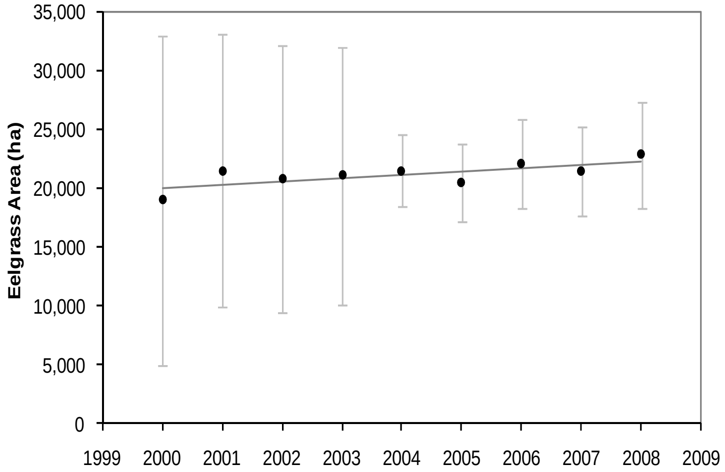

Figure 3-4. Total area of eelgrass in greater Puget Sound as estimated by DNR for 2000-2008. The slightly increasing trend is not significant when judged by the common significance threshold of α=0.05, but it is significant when judged by the threshold of α =0.1 (*p*=0.09). The line shown represents the estimated trend. It is calculated using a weighted regression to account for the sharp gain in precision in 2004. The error bars are 95% confidence intervals on the annual estimates.

Figure 3-5. Numbers of sites with significant annual increases and decreases in eelgrass area as measured by DNR (Gaeckle et al. 2009).

These findings suggest that the two metrics (eelgrass area and prevalence of sites with declines) provide unique information and when considered together provide a more complete characterization of eelgrass status and trends. If the system were truly stable, then we would expect on average that the number of sites with eelgrass losses would be balanced by sites with eelgrass gains. This is not reflected in the data and the results therefore conflict with the stability in the soundwide area metric. Two possible explanations for this conflict are considered, each of which highlights the value of using the two metrics together.

1. The biogeographical range of eelgrass in greater Puget Sound is contracting with no net change in eelgrass area.
2. There is a real net loss of eelgrass area, but the loss is small enough so that it cannot be detected with the existing precision of the soundwide area metric.

3.2 Documented Site Changes

Additional information on site-level change in Puget Sound eelgrass is included from two sources – the historical analysis of Thom and Hallum (1990) and DNR’s Submerged Vegetation Monitoring Project (SVMP).

3.2.1 Historical

Thom and Hallum (1990) completed the most extensive review to date of historical information on eelgrass abundance. In their review, they considered the following data sources:

- Eelgrass annotations on early hydrographic charts from the 1800s.
- WDFW herring spawn survey data collected since 1975.
- Coastal Zone Atlas (Youngman 1978, 1979, 1980) and the original mylar maps used in its production.
- Aerial color infrared photos collected by DNR.
- Dive surveys of 107 sites conducted by Ron Phillips in 1962-63 (Phillips 1972).

Thom and Hallum (1990) were unable to produce overall Puget Sound eelgrass estimates from these sources. They did report estimates for selected areas (Table 3-2). They estimate from an early chart of Padilla Bay that 598 ha of eelgrass were present in 1887. More recent estimates reflect roughly a 4-6 fold increase in eelgrass over this period in which Skagit drainage to Padilla was eliminated (Table 3-3, p. 34), although they note that the accuracy is questionable. They compared an 1855 chart of Bellingham Bay to existing locations of dredging and fill, and found that a discrete bed of 48 ha was reduced to 34 ha – a loss of 30 percent. They noted that there was no evidence to suggest measurable change in eelgrass in other areas of Bellingham Bay.

DNR completed more recent monitoring of a portion of Bellingham Bay in 2008 under an interagency agreement with the City of Bellingham. The same bed for which Thom and Hallum (1990) had estimated a 30 percent loss of eelgrass between 1855 and ~1990, the DNR survey found a reduction in the size of the bed to 4 ha. This represents a loss of 92 percent relative to the 1855 abundance (Gaeckle 2009).

In contrast, the DNR survey mapped a separate area in Bellingham Bay with 12 ha of eelgrass that had not been documented in 1855. This may represent a net gain in eelgrass, but this is highly uncertain due to the limitations of the hydrographic surveys of the 1800s for use in eelgrass mapping.

Thom and Hallum (1990) also documented the loss of an eelgrass meadow in the Snohomish River delta in the vicinity of Everett that was 62 ha. It was also lost to filling and dredging. They estimate an overall minimum of 15 percent loss of eelgrass in the Snohomish delta occurred over the last 100 years.

Anecdotal information reported by Thom and Hallum (1990) indicated eelgrass loss at two additional locations. An eelgrass bed at Duwamish Head in Elliott Bay has been declining since the 1960s according to observations by Ron Phillips. In addition, eelgrass along the northwest shore of Vashon Island has declined substantially over the last 40 years according to the observations of a commercial fisherman.

3.2.2 Contemporary

DNR's Submerged Vegetation Monitoring Project (SVMP) measures eelgrass area annually at a sample of sites. In this section, monitoring results over the last decade are evaluated as a sample of sites that provide a direct measure of year-to-year change in site-scale eelgrass area. In Figure 3-5 (p. 28), the number of sites with eelgrass declines is consistently greater than the number with increases. In this section, that discrepancy is examined on the basis of total area of observed losses, rather than the frequency of losses.

Table 3-2. Summary of information on site-level changes in eelgrass.

Location	Scope	Time interval	Evidence	Source
Bellingham Bay	1 bed	1855 → 1990	48 ha → 34 ha	Thom & Hallum (1990)
		1990 → 2008	34 ha → 4 ha	DNR monitoring, Gaeckle 2009
Padilla Bay	Bay	1877 → 1989	600 ha → 2900 ha	Thom & Hallum (1990); Bulthuis (1995)
Snohomish Delta	1 bed	Late 1800s → 1990	Loss of 62 ha	Thom & Hallum (1990)
	Delta	100 years	≥ 15% loss	Thom & Hallum (1990)
Elliott Bay	1 bed	1960s → 1990	Anecdotal obs. of loss	Ron Phillips as cited by Thom & Hallum (1990)
Vashon Island	1 bed	40 year interval prior to 1990	Anecdotal obs. of loss	Commercial fisherman as cited by Thom & Hallum (1990)

Each year, the change in eelgrass area can be calculated for each site that was measured in two consecutive years (the list of such sites varies partially each year). Figure 3-6 shows the sum of each year's site gains and losses and net change in eelgrass area for those sites that had statistically significant change. The net change is variable from year to year both in sign (+/-) and in magnitude. The 2003-2004 interval had a particularly large gain of 617 ha, but the uncertainty associated with this value was large. This gain was dominated by a measured gain at one large site – Padilla Bay. The more modest net loss in 2006-2007 (-204 ha) was dominated by a loss measured in southern Samish Bay (flats12).

The results in Figure 3-6 illustrate that the magnitude of areal losses actually measured by the SVMP is on the order of hundreds of hectares but with substantial uncertainty as represented by the error bars. This magnitude of loss is low enough so that it would not be captured by the soundwide eelgrass area metric, which has error bars on the order of thousands of hectares (Figure 3-4, p. 27).

This net annual site change analysis reflected in Figure 3-6 is limited in some respects. First, these results only represent the sample measured for each annual time step. A simple extrapolation to the larger Puget Sound population would be biased. The reason for this is not simple, but it is a consequence of the sites coming from different strata, or groupings, of all the sites in the study area.

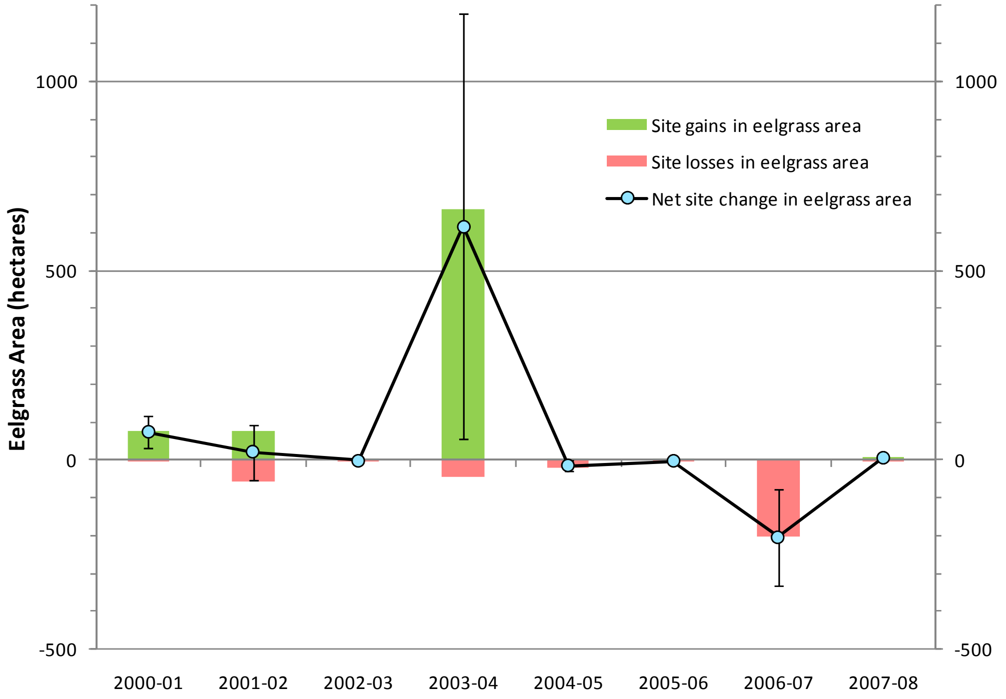

Figure 3-6. The sums of site gains and losses in eelgrass area and the net change for the sample of sites whose eelgrass area was measured in each of two consecutive years over 2000-2008. The error bars on the net change values are 95 percent confidence intervals that represent the total measurement error for each sample. Where error bars are not visible, the interval was smaller than the size of the data point symbol.

Furthermore, some level of natural variability is expected from year to year, and it is not necessarily desirable to attempt to manage the system at this fine temporal scale. Also, by only focusing on site changes that are statistically significant, other changes that may be real, but do not rise above the noise of measurement error, are not considered.

These latter limitations can be addressed by examining multi-year trends rather than annual change. Out of 34 sites with at least four years of data in the 2000-2008 dataset, 11 sites had significant trends (Gaeckle et al. 2009). Most of these trends were negative (8 out of 11), but when the mean annual rate of change implied by the trends is considered there is no net rate of change in area over the sample of 34 sites as a whole (Figure 3-7). An explicit uncertainty analysis was not conducted, but the sum of mean annual rates of gains is almost identical to the sum of mean annual rates of losses. In this case, the rates of losses were dominated by a declining trend in the Snohomish Delta (flats26), and the rates of gains were dominated by an increasing trend in northern Samish Bay (flats11).

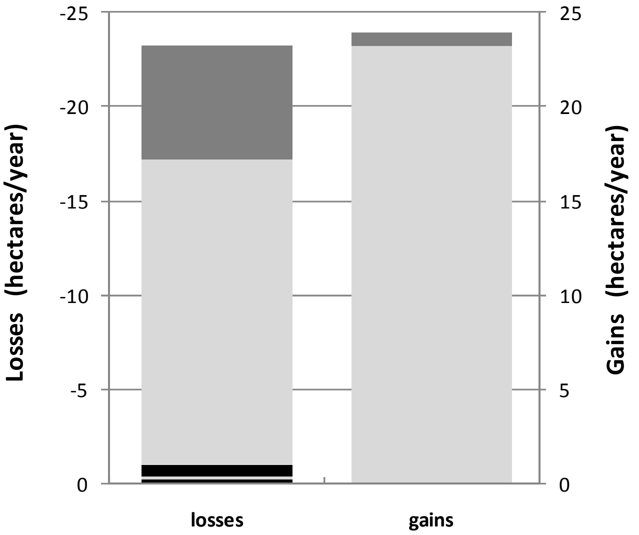

Figure 3-7. Annual rates of site gains and losses in eelgrass area inferred from statistically significant multi-year trends. Shading of the columns indicates contributions from individual sites to the total. These results summarize significant trends at 11 sites out of 34 with four or more years of data that were tested for trends (Gaeckle et al. 2009).

The site trend results summarized in Figure 3-7 echo the results seen with soundwide trends. In the site trend results, there is a prevalence of declining trends (8 of 11 sites with significant trends) among sites with significant trends but the total area implied by the declining trends is balanced by increasing trends, i.e., there is a signal seen on a frequency basis but not on an areal basis. The soundwide site change results (Figure 3-5, p. 28) also reflect a signal on a frequency basis (number of sites with annual declines) but not on an areal basis (Figure 3-4, p. 27). This is the major impetus in the recommendations for considering a second metric to track soundwide abundance – a prevalence of site decline metric in addition to the soundwide eelgrass area metric.

3.3 Potential for Large Site Changes Associated with Altered River Hydrology

Three specific cases are presented where alterations of river hydrology may be linked to changes in site eelgrass abundance. Two of these cases pertain to historical changes (Skagit and Nooksack Rivers) and one pertains to potential future changes (Elwha River). This is not a comprehensive assessment of the effects of river alterations on eelgrass, but rather a brief review of three specific cases thought to be particularly relevant.

3.3.1 Skagit River

Historically, the Skagit River delta has encompassed outlets to Padilla and Samish Bays in addition to Skagit Bay (Figure 3-8). It is thought that in the geologic past the river's primary outlet was to Samish Bay and, more recently, directly to Padilla Bay (Collins 1998). At the time of the earliest mapping in the area (1870s), there was still substantial drainage from the Avon Bend to Padilla Bay through a series of wetlands

(Collins 1998). Records available starting in the late 1800s indicate that floodwaters drained to all three bays during large floods (Collins 1998).

Much of the early flooding and associated drainage was associated with log jams. In the 1870s, drainage patterns in the delta were affected in particular by a large jam near Mount Vernon. This log jam appears to have existed for at least a century, was described as 30 feet deep, consisted of logs generally 3-8 feet in diameter and the surface supported living trees 2-3 feet in diameter (Collins 1998). This log jam was removed by European settlers in 1878-1879, which resulted in greater drainage into Skagit Bay. There has since been considerable effort spent clearing snags that might start new jams (Collins 1998).

Diking has also modified drainage by further containing flow in the main Skagit River channel and designated distributaries with outlets to Skagit Bay. The first dike was built in 1863 (Collins 1998). It is not known if there are contemporary estimates of drainage to Padilla and Skagit Bays. Presumably, there is now no drainage to these bays or it is negligibly small except perhaps under extreme flood conditions.

Thom and Hallum (1990) hypothesized that the elimination of Skagit drainage to Padilla Bay has led to a dramatic increase in Padilla Bay eelgrass due to more optimal salinities. They estimate from an early chart of the bay that 598 ha of eelgrass were present in 1887. More recent estimates reflect roughly a 4-6 fold increase in eelgrass over the period in which Skagit drainage to Padilla was eliminated (Table 3-3). Presumably the effect on Skagit Bay eelgrass would have been less dramatic since this was already the primary outlet for the Skagit River and there was therefore a pre-existing high level of freshwater influence. Recent DNR SVMP estimates suggest there is currently 1,270 ± 100 ha of eelgrass[4] in Skagit Bay – much less than Padilla Bay even though Skagit is the larger bay.

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[4] This overall estimate of Skagit Bay eelgrass was derived from SVMP data for sub-units within Skagit Bay – flats19 (2007 estimate), flats20 (2008), flats21 (2006), flats70 (2008) flats71 (2006).

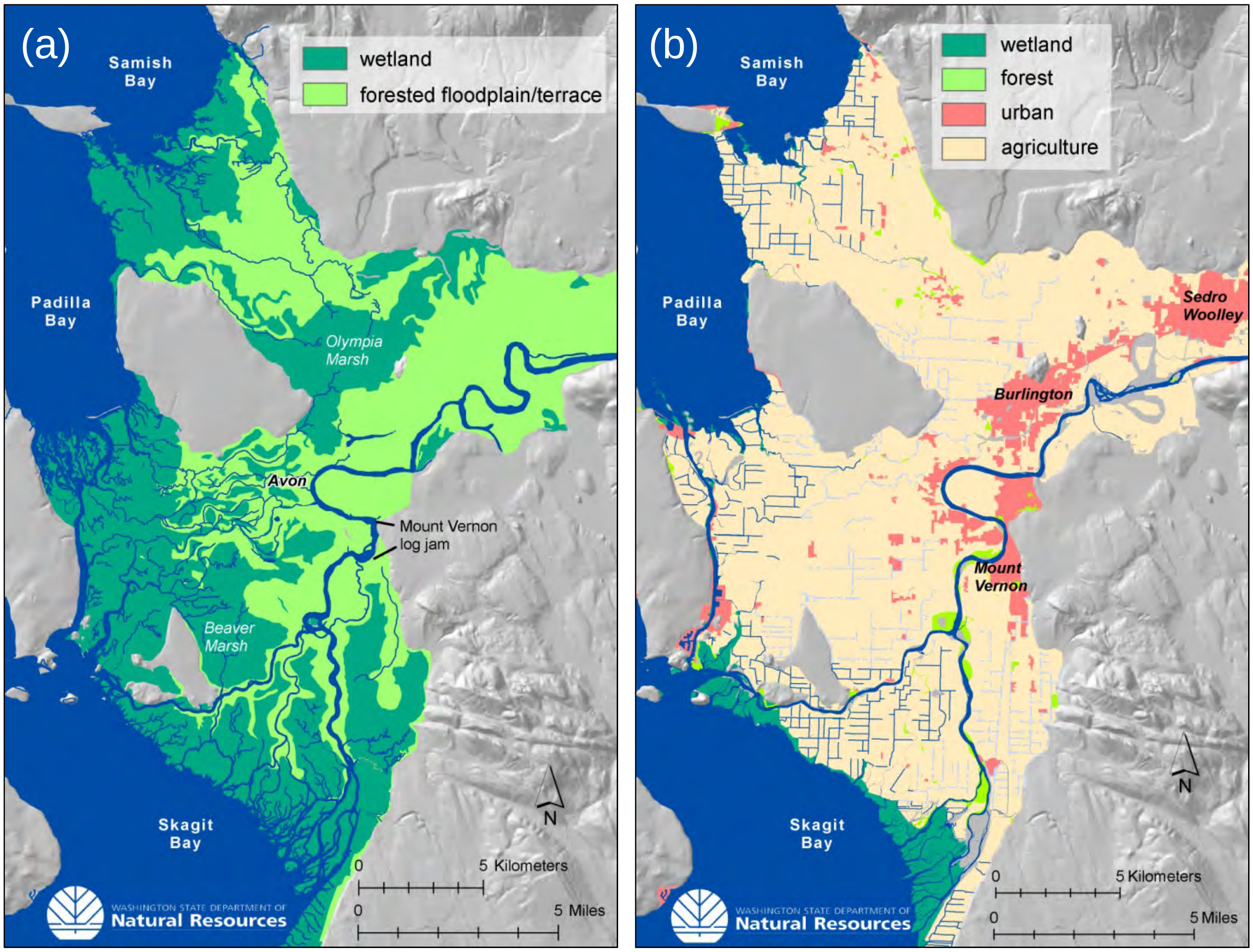

Figure 3-8. The Skagit River delta (a) under historical conditions prior to ditching and diking that began in the 1860s and (b) under recent (~2000) conditions. Eelgrass distribution is not shown. While Skagit Bay was historically the primary outlet for the Skagit River, there was also hydrologic connectivity with Padilla and Samish Bays that has been eliminated. Based on the work of the University of Washington Puget Sound River History Project. These figures are modeled after figures in Collins et al. (2003) based on data produced by Collins and Sheikh (2005). The topography depicted is that of Finlayson et al. (2000).

Table 3-3. Contemporary estimates of eelgrass area in Padilla Bay. The 95% confidence intervals are included for the DNR estimates (Submerged Vegetation Monitoring Project).

Padilla Bay Eelgrass Area Estimate	Year	Source
2,900 ha	1989	Bulthuis (1995)
2,820 ± 404 ha	2003	Dowty et al. (2005) – low DNR (SVMP) estimate
3,440 ± 321 ha	2008	Gaeckle et al. (2009) – high DNR (SVMP) estimate

The Padilla Bay eelgrass bed is currently one of the largest on the west coast of North America (Bulthuis 1995). The Samish Bay eelgrass bed is the second largest in greater Puget Sound at 2,170 ± 170 ha[5] and may also have benefited from alteration of the Skagit River. Together these two eelgrass beds account for over 25 percent of the

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[5] This overall estimate of Samish Bay eelgrass was derived from 2008 SVMP data for flats11 and flats12.

eelgrass area in greater Puget Sound (Gaeckle et al. 2009). While the hypothesis of Thom and Hallum (1990) is still open to question, the evidence suggests the possibility that alteration of the Skagit River may have been the single greatest factor influencing eelgrass area in greater Puget Sound in recorded history.

Future alterations to the Skagit River delta are possible that could have important implications for eelgrass abundance in the area. Such alterations could be associated with either habitat restoration efforts or flood control. Dean et al. (1991) identified priority areas for restoration in the Skagit delta that included areas at the southern end of Padilla Bay and the eastern side of the Swinomish Channel. It does not seem likely that the restoration opportunities identified by Dean et al. (1991) would lead to markedly greater Skagit drainage to southern Padilla Bay or the Swinomish Channel, but this possibility cannot be totally discounted.

Collins et al. (2003) propose elements of a restoration strategy that couple river and forest restoration and highlight the opportunities for restoration in the Skagit delta. They emphasize the need to restore processes that would reinstate the role of large woody debris and the occurrence of river avulsions. While Collins et al. (2003) do not explicitly mention the restoration of historical drainage into Padilla and Samish Bays, that possibility could be inferred from their proposed strategy.

Flood control along the Skagit River has long been an important issue due to frequent flooding that affects communities and agriculture. An analysis of stream gauge data shows that the Skagit River reached flood stage every 1.5 years on average between 1900 and 1999 (Kunzler 2010). Various versions of an ‘Avon Bypass’ have been proposed over the years to alleviate flooding in the delta. The basic idea is to build a bypass or diversion channel running from near the Avon Bend on the Skagit River to either the Swinomish Channel just south of Padilla Bay or into Padilla Bay directly. This was first proposed in 1922 and most recently in 2001 (Kunzler 2005). The Avon Bypass is not currently under consideration, in large part due to the large economic burden associated with the local cost-share that would be required for construction. The potential implications for Padilla Bay eelgrass, however, are obvious and the Department of Ecology had expressed concern about this potential impact (Kunzler 2005). A comprehensive review that evaluated the potential effects of the Avon Bypass on eelgrass in Padilla Bay was inconclusive (Miller et al. 2004).

3.3.2 Nooksack River

The recent history of the Nooksack River is unique but resembles the case of the Skagit River in several key aspects. The outlet of the Nooksack also shifted between adjacent bays in the period of recorded history. The shift involved changes to log jams and the subsequent building of structures to constrain the river flow.

Some of the key documents describing the history of the Nooksack were not available for this review (Deardorff 1992, Wahl 2001), but Collins (2008) and Higgins (2002) include these sources in their reviews.

An early survey map showed that the Nooksack drained almost entirely into Lummi Bay in the 1850s with negligible drainage to Bellingham Bay (Figure 3-9)(Collins 2008). The lower reach draining into Lummi Bay is known as the Lummi River, or sometimes the Red River. Higgins (2002) states that earlier Spanish maps from the 1790s show no connection at all to Bellingham Bay.

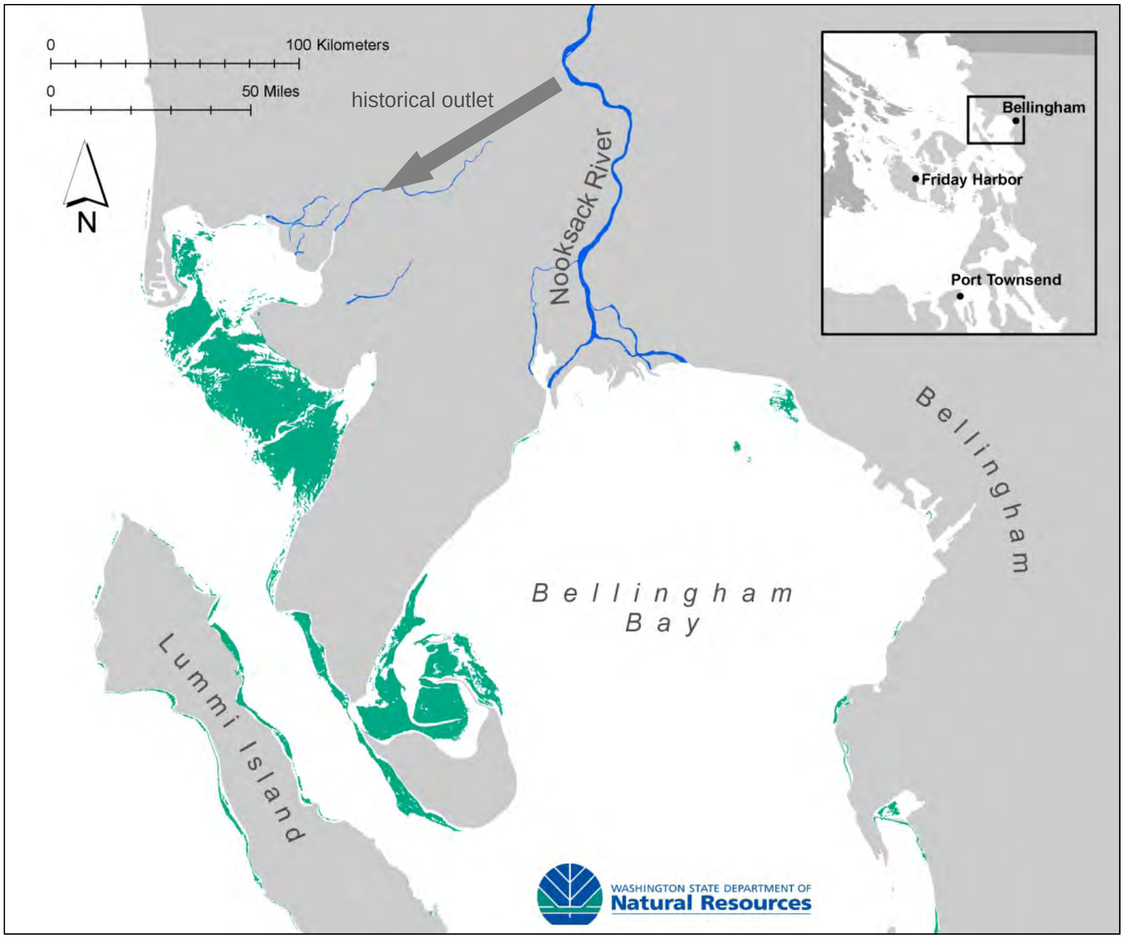


Figure 3-9. The present outlet of the Nooksack River into Bellingham Bay. The arrow indicates the historical outlet into Lummi Bay. The green areas indicate eelgrass beds as classified by DNR using 1995 multispectral imagery (Berry and Ritter 1997).

The exact cause and timing of the shift to Bellingham Bay is not clear, but the change occurred approximately in the 1860s. It appears to have involved some combination of a natural river avulsion associated with flooding (Wahl 2001 cited by Higgins 2002), a new log jam that blocked off the Lummi River outlet (Collins 2008, Collins et al. 2003), and the clearing of a long-standing log jam (the “Portage Jam”) on the lower Nooksack River (Wahl 2001 cited by Collins 2008). There appeared to be further clearing of log jams on the lower Nooksack to allow navigation between upriver timber sources and the City of Bellingham (Bellingham Herald 2008).

The clearing of the outlet to Bellingham Bay released a large volume of sediment to the bay and rapid infilling of the Nooksack Delta. A bathymetric analysis estimated elevation changes of approximately 20 feet in some areas of Bellingham Bay near the mouth of the river (Higgins 2002). In response to this infilling, the Washington State Harbor Line Commission petitioned the Corps of Engineers to redivert the river back to Lummi Bay. The petition was unsuccessful.

Lummi Bay is analogous to Padilla Bay in that historical freshwater inputs have been eliminated and the bay currently supports expansive eelgrass beds. Lummi Bay was found to have approximately 630 ha of eelgrass beds in 1995 (Figure 3-9; Berry and Ritter 1997). A key difference in these two cases is that Skagit Bay received freshwater inputs throughout the historical record, while Bellingham Bay did not. This suggests the possibility that while the Skagit diversion led to a large net increase in eelgrass area (large gain in Padilla Bay, little or no change in Skagit Bay), the Nooksack diversion may have resulted in a large shift of eelgrass distribution (loss in Bellingham Bay, gain in Lummi Bay) with little net change in the system. This is speculative, but it is reasonable to assume that Bellingham Bay supported eelgrass before the large sediment inputs from the Nooksack diversion, and there was no evidence to the contrary seen as part of this review.

3.3.3 Elwha River

The Elwha River dam removal is scheduled to begin in 2011, and it will include the removal of two dams – the Elwha dam and the Glines Canyon dam. It will be the largest dam removal project in the U.S. to date (National Park Service 2010). This planned alteration of the Elwha River is considered here because it represents perhaps the largest restoration effort within the Puget Sound basin, and it is anticipated that one component of the project will be restoration of the marine nearshore.

Norris and Fraser (2007) mapped approximately 31 ha of eelgrass in the vicinity of the mouth of the Elwha River (Figure 3-10), but found that understory kelp was the dominant vegetation in the nearshore. (Norris et al. 2007, Norris and Fraser 2009). It is anticipated that after dam removal, significant quantities of fine sediments will be released into the nearshore. This is expected to lead to a shift in nearshore vegetation as the nearshore substrate becomes less rocky (preferred by kelp) and more sandy (preferred by eelgrass) (U.S. Department of the Interior 1996).

It is not possible with the available information to produce robust quantitative estimates of the potential for eelgrass expansion following dam removal. It is possible to produce an “order-of-magnitude” approximation – essentially an educated guess – to serve as a high value of potential expansion. Consider that the current distribution of eelgrass occupies roughly 25 percent of the shoreline from the western edge of Freshwater Bay to the end of Ediz Hook. If expansion led to complete occupation of the shoreline, this would be a four-fold increase. But perhaps the anticipated delivery of sediment could expand the zone of substrate (sediment) in shallow water. This would effectively push the -20-foot contour away from the shoreline and increase the potential eelgrass habitat.

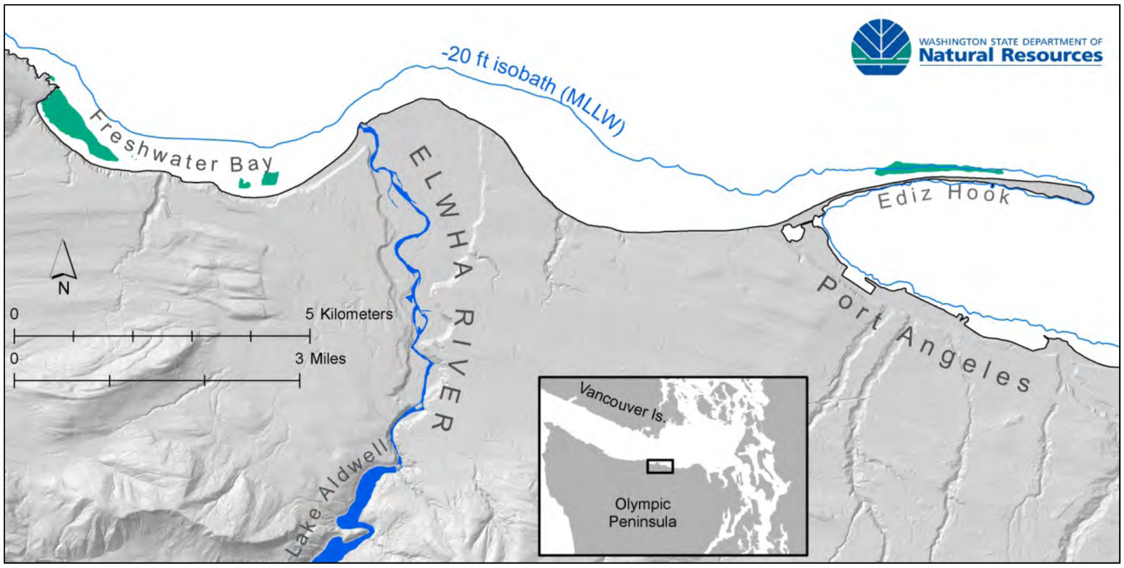


Figure 3-10. The 2006 distribution of eelgrass (shown in green) in the vicinity of the mouth of the Elwha River. The eelgrass beds were redrawn from Norris et al. (2007).

If the magnitude of this effect was in the range of negligible up to doubling the potential habitat, then when combined with the potential to vegetate unoccupied shoreline, a first order estimate of potential expansion would be ~100 ha. Of course, this simple estimate is highly uncertain and should be considered nothing more than an order-of-magnitude guess. The estimate could possibly be refined by consideration of detailed environmental parameters (e.g., exposure) and results of sediment transport studies following dam removal. However, this simple estimate does allow for the magnitude of potential eelgrass expansion to be compared to the magnitude of eelgrass area and change from other sites.

3.4 Summary

Several key points emerge from the information gathered on changes in eelgrass in greater Puget Sound:

1. There are no reliable soundwide estimates of historical or potential eelgrass area for greater Puget Sound. Existing estimates are summarized in Figure 3-11. There has been no change in this regard since Thom and Hallum published their report in 1990. However, additional review of existing estimates was conducted that further supports this assessment.
    a. Phillips’ methodology produces an estimate of potential eelgrass area of Puget Sound proper that appears to have been incorrectly cited as an estimate of actual abundance. The method considers only depth as a constraint and ignores other well-documented factors that limit distribution – e.g., sediment characteristics, temperature, salinity, wave energy – and should therefore be considered an upper bound on potential eelgrass area.

   b. The values Phillips reports (46,600 ha; 44,900 ha; 50,600 ha) are inconsistent with the underlying bathymetric analysis (29,400 ha). Phillips' estimates grossly overestimate the upper bound of potential eelgrass area as implied in the stated methodology. Therefore, the actual values that Phillips reports should not be used.
   c. The value of eelgrass area reported in the Coastal Zone Atlas narratives (50,600 ha) does not match the mapped eelgrass area in the Atlas folios as digitized in the Puget Sound Environmental Atlas (10,900 ha). The mapped eelgrass areas have well-documented limitations and are not reliable estimates of total eelgrass area.
   d. The work of Guerry, Davies and colleagues is still developing. Their estimates of historical and potential eelgrass area should be used with caution until their methodology is finalized and fully documented and reviewed.
2. The evidence from the contemporary monitoring record suggests that more sites have declining eelgrass than have increasing eelgrass (Figure 3-5, p. 28). But the majority of sites, by a wide margin, show no significant change in eelgrass area, suggesting this is a minor effect relative to the size of the overall population of sites. In addition, no change in overall eelgrass area has been detected at the soundwide scale (Figure 3-4, p. 7) or in the sample of sites measured (Figure 3-7, p. 32). This suggests that any system-wide decline may take the form of a contraction of distribution with no discernable change in overall eelgrass area in greater Puget Sound. This also suggests the value of using the two metrics in tandem.
3. The information on historical change at the site level is very sparse, and it is impossible to assess the magnitude of bias. The following conclusions are therefore speculative.
   a. Documented site-level declines in eelgrass have been more frequent than increases since the mid-1800s (Table 3-2).
   b. There appears to have been a large increase in area of eelgrass in Padilla Bay (and possibly Samish Bay) associated with alterations to drainage in the Skagit River delta. This is based on a comparison of an estimate of 600 ha in 1877 (Thom and Hallum 1990) to contemporary estimates of approximately 3,000 ha (Table 3-3, p. 34).

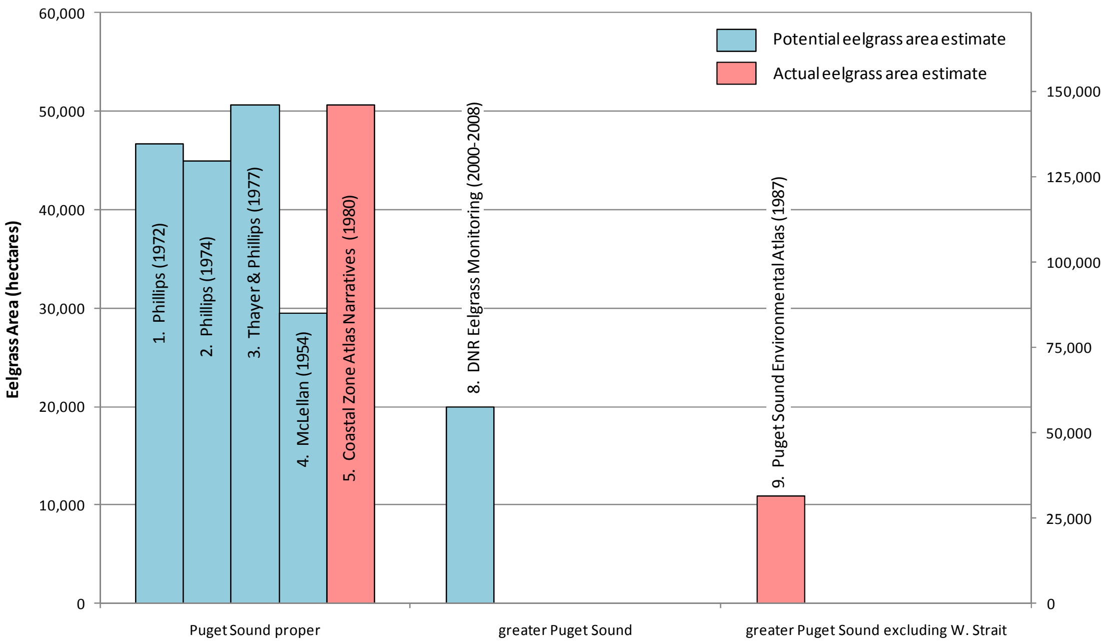


Figure 3-11. Summary of estimates of potential and actual eelgrass area grouped by geographic scope of the estimates – Puget Sound proper, greater Puget Sound, and greater Puget Sound with the western Strait of Juan de Fuca excluded. Notes for each estimate appear below.

Figure Notes:

1. Potential eelgrass area from Phillips (1972). Presented as the area that "could support eelgrass". This value apparently reflects a calculation error (compare to #4).
2. Potential eelgrass area from Phillips (1974). Presented as the area that "eelgrass grows over". This value apparently reflects a calculation error (compare to #4).
3. Potential eelgrass area from Thayer and Phillips (1977). Presented as the area "covered by eelgrass". It is not clear why this estimate diverges from #1 and #2, but it presumably reflects the same error as these estimates (compare to #4).
4. Potential eelgrass area from this report – based on the method of Phillips (1972, 1974) but with input values drawn directly from McLellan (1954).
5. Actual eelgrass abundance from the Coastal Zone Atlas Narratives (Albright et al. 1980). Origin of estimate not reported but matches exactly the potential eelgrass estimate published by Thayer and Phillips (1977) three years earlier (125,000 ac). Geographic scope of estimate is presumably Puget Sound proper. This is likely an example of a rough potential area estimate being misrepresented as an actual eelgrass area estimate.
6. Potential eelgrass area from Davies et al. (in prep.) as cited in Guerry et al. (in press). This estimate should be used with caution as the work is in progress and methods are being refined.
7. Historical eelgrass abundance from Guerry et al. (in press). The methods used to derive this value have not yet been documented and therefore cannot yet be reviewed.
8. Actual eelgrass abundance based on DNR's active annual monitoring (2000-2008) through the Submerged Vegetation Monitoring Project (SVMP) (Gaeckle et al. 2009).
9. Actual eelgrass abundance derived from the digital eelgrass data layer in the Puget Sound Environmental Atlas (Evans-Hamilton, Inc. and D.R. Systems, Inc. 1987), which was based on the Coastal Zone Atlas of Washington (Youngmann 1978, 1979, 1980) (the map folios, not the narratives), but with the western Strait of Juan de Fuca excluded. This estimate should be considered low because of well-documented limitations in the eelgrass mapping in the Coastal Zone Atlas.

3.5 Future Work

Historical estimates are valuable for target setting as evidenced in the case studies (Chapter 2). There are opportunities to further assess past changes in Puget Sound eelgrass that were outside the scope of this report. The following tasks should be considered for future work. This work would expand the available information and help assess and, if necessary, refine the eelgrass targets selected for greater Puget Sound.

1. *Analysis of historical aerial photos*.
   This approach is commonly used in other estuaries to estimate historical seagrass distribution. There would likely be unique challenges in Puget Sound due to the relatively deep-growing eelgrass. However, historical photographs are known to exist for this area and they should be evaluated for the feasibility of a full analysis.
2. *Indirect assessment of historical losses of potential eelgrass habitat*.
   Several existing datasets could be analyzed to assess loss of potential habitat:
   - DNR overwater structures
   - Navigation channels
   - Nearshore fill – Puget Sound Nearshore Ecosystem Restoration Program Change Analysis Geodatabase (Simenstad et al. 2009)
   - Puget Sound Environmental Atlas (1987)
3. *Identification of other existing eelgrass data*.
   It is likely that there is a substantial amount of information on eelgrass distribution commissioned by local jurisdictions and project proponents. Other potential sources of eelgrass distribution data include tribes, local knowledge of shoreline land owners, and other people who use the nearshore environment for recreation and employment. A complete eelgrass data record will rely on connecting with people who have traditional, anecdotal, and professionally documented information on eelgrass in the Puget Sound region.
4. *Sediment core analysis: pollen, seeds, biomarkers*.
   These techniques have been used successfully elsewhere and on a limited basis within greater Puget Sound (Rosenbauer 2006). They should be assessed for broader application.

4 Comparison of Eelgrass Indicators and Metrics for Puget Sound

The total area of eelgrass is the existing eelgrass metric for greater Puget Sound. It has been included in reports by the Puget Sound Partnership (2010) and earlier by the Puget Sound Action Team (2007a, 2005, 2002). Numeric area values of the indicator are generated annually by DNR's eelgrass monitoring program, the Submerged Vegetation Monitoring Project (SVMP) (Gaeckle et al. 2009, 2008, 2007; Reeves et al. 2006; Dowty et al. 2005; Berry et al. 2003).

The existing eelgrass area metric has been used as a means to track the status and trends of eelgrass in the region. It has not been used directly to assess the effectiveness of natural resource management policies or to track progress toward explicit management goals. Currently, a target for eelgrass area in greater Puget Sound has not been set. As a target is developed, it is important to assess the strengths and weaknesses of alternative methods to ensure that the best metric is selected as the basis for target setting. The purpose of this chapter is to:

- Compare the existing eelgrass area metric to the prevalence of site decline metric, another measure of long term eelgrass status.
- Discuss other potential indicators that would complement the eelgrass abundance indicator by more directly measuring management effectiveness in protecting and sustaining eelgrass.

The maximum depth of eelgrass beds has been suggested as a good indicator of eelgrass condition (Krause-Jensen et al. 2005), but depth results from the SVMP reflect high variability across sites (Berry et al. 2003) that create a challenge for application as a regional indicator. At this time, a maximum depth indicator has not been developed for the greater Puget Sound region and maximum depth is not addressed in this chapter.

4.1 Soundwide Eelgrass Area Compared to Prevalence of Sites with Decline

There is an apparent inconsistency between the two soundwide eelgrass metrics presented in Chapter 3.3. The soundwide eelgrass area metric (Figure 3-4, p. 27) shows no evidence of decline while the prevalence of sites with decline metric (Figure 3-5, p. 28) suggests that there is a greater occurrence of site-level eelgrass decline than of increase in eelgrass area.

One possible explanation for the inconsistency lies in the highly aggregated distribution of eelgrass in the region. Based on SVMP monitoring results (Gaeckle et al. 2007), roughly 25 percent of the total eelgrass area in greater Puget Sound is found in only two locations – Padilla Bay and Samish Bay. No significant trend in eelgrass area has been detected in Padilla Bay, but the northern portion of Samish Bay has had an increasing trend over 2001-2008 of approximately +2 percent per year (Gaeckle et al. 2009, p. 21). This suggests the possibility that the two large eelgrass beds in the region may be anchoring the soundwide area indicator, thereby making it insensitive to losses at a potentially large number of sites that contain relatively miniscule eelgrass beds. It is critical to examine this possibility because, depending on local circumstances, small eelgrass beds could be very important in providing ecosystem functions across large segments of shoreline in greater Puget Sound.

Another possible explanation for the inconsistency has to do with limited precision of the soundwide eelgrass area indicator. Figure 4-1 shows the sum of significant annual site gains and losses in eelgrass area when Padilla Bay is withheld (Samish Bay did not have significant annual changes). When Padilla is withheld, the sample results are more indicative of decline, but also it is clear that the magnitude of the measured declines estimated is small (200-300 ha) relative to the extrapolated area tracked by the soundwide indicator (20,000 ha).

This comparison is limited because it is comparing areas derived from a sample to an extrapolated area estimate over the entire study area. Further work is needed to develop a more rigorous statistical framework to interpret prevalence of decline in the sample results and to extrapolate the probability of site decline over the study area. Until this work is completed, the prevalence of decline indicator as presented here provides a useful companion indicator to the soundwide area indicator.

Further work is also needed to better understand the effect of the large eelgrass beds in Padilla and Samish Bays on the soundwide area indicator. This could be addressed to some extent by further analysis of existing SVMP data, but would best be addressed through modeling studies. Recently an eelgrass population model was constructed to support modeling studies such as this (Dowty 2010).

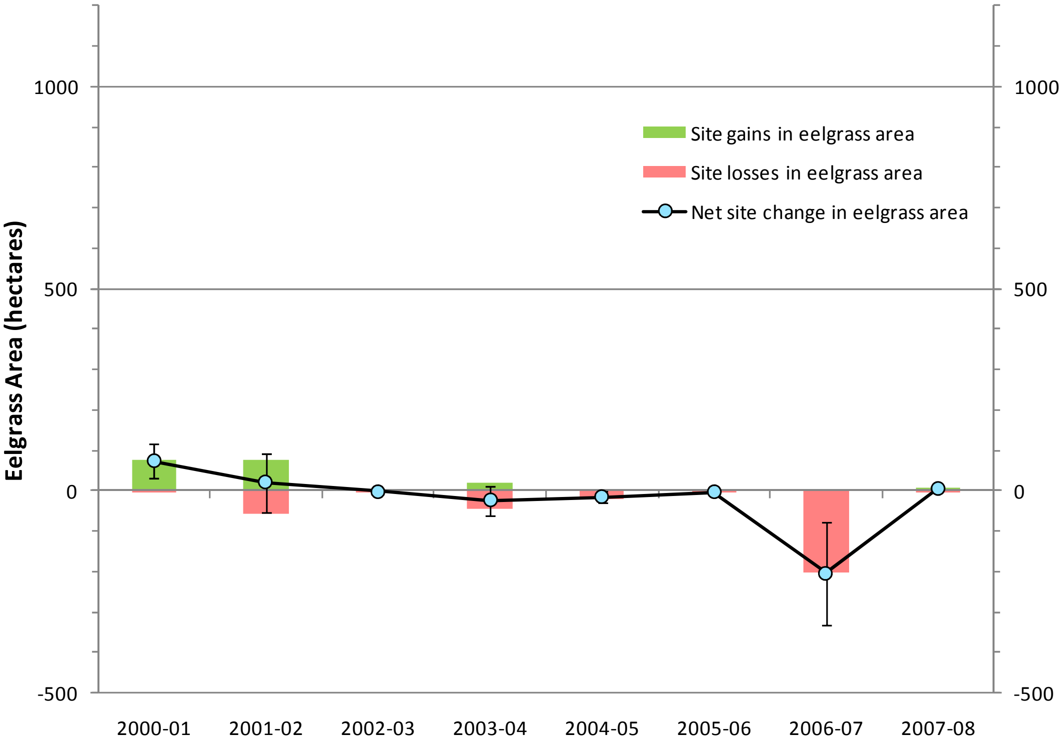


Figure 4-1. The sums of site gains and losses and net change in eelgrass area when Padilla Bay is removed from the sample. These results only represents the sample of sites whose eelgrass area was measured in each of two consecutive years over 2000-2008. The error bars on the net change values are 95% confidence intervals that represent the total measurement error for each sample. Compare to Figure 3-6 (p. 31) with Padilla Bay included.

4.2 Indicators of Management Effectiveness in Eelgrass Protection and Restoration

The eelgrass abundance indicator provides a long-term, integrative measure of habitat condition in response to multiple stressors. In this way, it fulfills the status-and-trends portion of comprehensive monitoring, as defined by the Washington Comprehensive Monitoring Plan (Monitoring Oversight Committee 2002). However, broad status-and-trends indicators such as this one are not generally sensitive measures of the effectiveness of particular management actions over shorter timeframes. Additional measures that assess management effectiveness are important for evaluating progress and will be an integral part of the Partnership's performance management system and the Governor's Government Management, Accountability and Performance (GMAP) program. The Washington Comprehensive Monitoring Plan describes these additional components of monitoring to include: compliance monitoring, project effectiveness monitoring, and validation monitoring. None of these components is measured in a coordinated fashion by existing programs with respect to eelgrass.

In this section, we discuss indicators of management effectiveness that could be monitored to assess the success of efforts to protect and restore eelgrass, respectively.

The themes of protection and restoration are adopted from the Partnership legislation. It is important to acknowledge that these indicators are recommended as concepts to be considered during development of comprehensive eelgrass monitoring by the Partnership or another appropriate group.

4.2.1 Eelgrass Protection Indicator

Habitat protection is widely recognized to be substantially less expensive and more successful than habitat restoration (Fonseca et al. 1998, Orth et al. 2006). For this reason, an indicator of management effectiveness in protecting eelgrass habitat would be valuable in evaluating management success toward the Partnership's goal of healthy, functioning habitats. One potential metric of eelgrass protection is the proportion of permits that avoid impacts to eelgrass, as compared to the number of permits that minimize eelgrass impacts or rely on compensatory mitigation. In Washington State, two established programs are primary candidates for providing information to track the number of projects that potentially affect eelgrass: WDFW Hydraulic Permit Approval permits, and DNR use agreements for activities on state-owned aquatic lands. Additional site management programs could also be considered that protect habitat, such as marine protected areas. Shoreline substantial development permits could also be utilized.

In addition to site-specific measures of eelgrass protection from direct impact, other measures could consider protection of environmental characteristics that are critical to eelgrass survival. High priority candidates include water quality, physical characteristics, and nearshore processes. Many of these measures may be tracked in conjunction with other aspects of performance management, and the data could be used to inform eelgrass management and target-setting.

4.2.2 Area of Eelgrass Restoration

An indicator that tracks the area of eelgrass restored has been used elsewhere (e.g., Chesapeake Bay) to evaluate the success of efforts to restore degraded habitats. In Chesapeake Bay, an active restoration program transplants SAV into unvegetated areas. Its restoration target is 400 ha (1000 ac). The indicator of restored area is partly a measure of program implementation (how many acres have been planted) and partly a measure of effectiveness (how many planted acres have been successfully established and survived). One benefit of this indicator is that it is expected to have a faster response time than soundwide area and is more subject to management influence. However, to be meaningful, it would have to be coupled with either a centralized eelgrass restoration program or a coordinated effectiveness monitoring program that assesses existing restoration projects.

In addition to direct measures of eelgrass planting, restoration activities that improve physical environmental conditions or restore nearshore processes could also facilitate eelgrass expansion. Some of these activities are likely to be measured in the context of water quality improvement and nearshore ecosystem restoration. They could provide additional insight into eelgrass recovery.

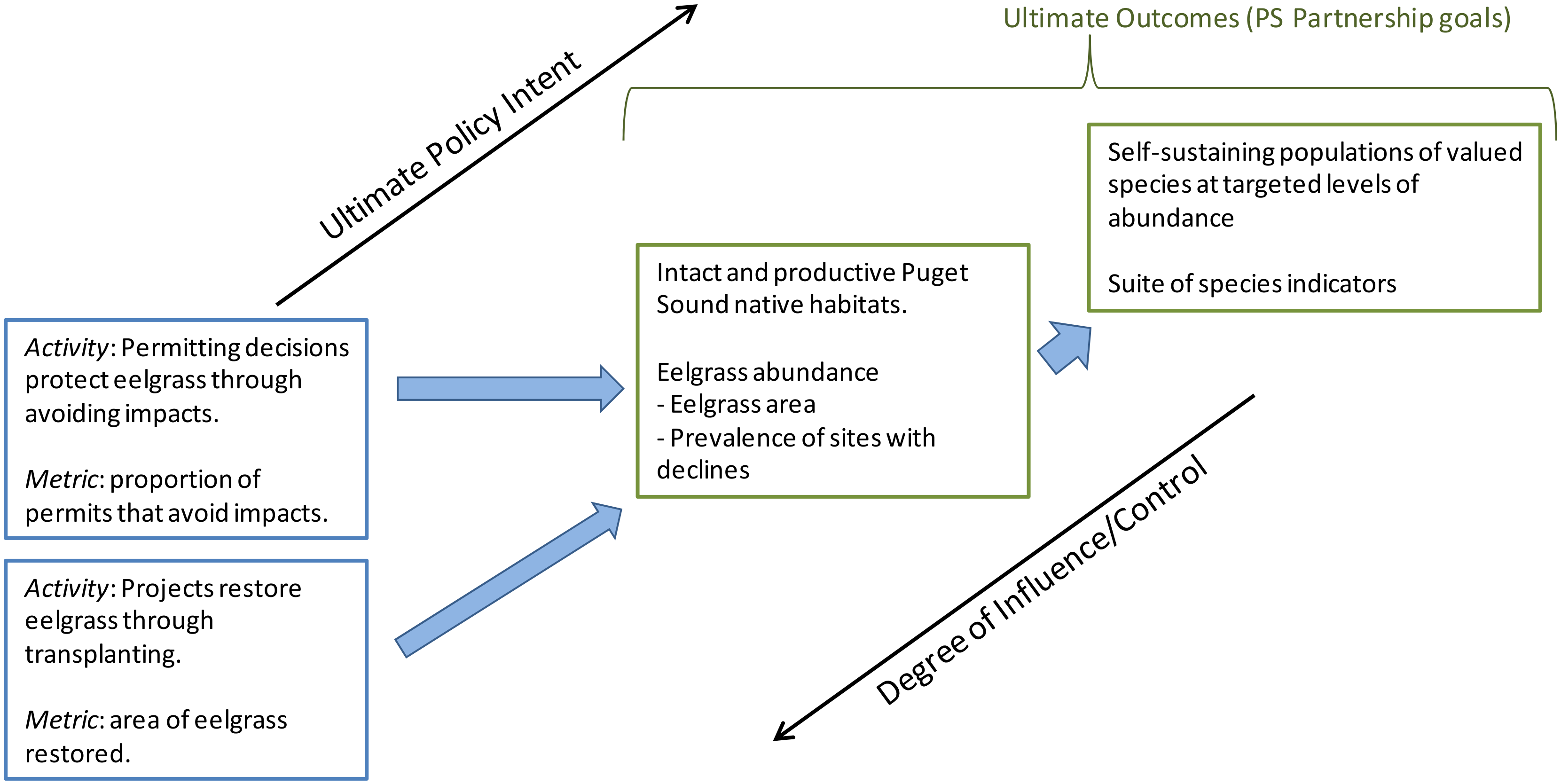
4.3 Linkage of Indicators to a Results Chain

It is useful to place the indicators considered above in the framework of a results chain. Results chains are also a central part of the framework for the performance management system being developed by the Puget Sound Partnership (Neuman et al. 2009). The concept of a results chain was first widely recognized in the region when Governor Gregoire initiated the Government Management, Accountability and Performance (GMAP) program in 2005 (http://www.accountability.wa.gov). The program's intent is to improve government performance through a data-driven approach and increased accountability. Results chains are a key component of GMAP, although they are known as logic models in the GMAP framework. The purpose of the results chain is to illustrate the relationship between specific activities and broader strategic priorities. It also summarizes the theory, explaining how an organization can influence outcomes (Willet 2009).

Figure 4-2 places the two eelgrass abundance metrics (soundwide area and prevalence of sites with declines) and eelgrass restoration and protection indicators in the context of a results chain.

The ultimate outcomes are defined by the Partnership's overall goals related to eelgrass: healthy habitats, species, and food webs. These outcomes are, in turn, dependent on the attributes of the nearshore system and their status. The area of eelgrass is one measure of this status.

Several activities lie at the bottom of the results chain, including direct protection of eelgrass and restoration of eelgrass. The indicators of eelgrass restoration and protection are intermediate outcomes.



Activity: Permitting decisions protect eelgrass through avoiding impacts.

Metric: proportion of permits that avoid impacts.

Activity: Projects restore eelgrass through transplanting.

Metric: area of eelgrass restored.

Intact and productive Puget Sound native habitats.

Eelgrass abundance
- Eelgrass area
- Prevalence of sites with declines

Self-sustaining populations of valued species at targeted levels of abundance

Suite of species indicators

Figure 4-2. A simplified results chain that links some potential Partnership activities to desired intermediate (the lower left) and ultimate eelgrass outcomes (the upper right) discussed in this report. Thick arrows indicate influence or cause-effect relationships. Proximity to the ultimate policy intent increases to the upper right, but the degree of influence by an agency or organization increases to the lower left.

4.4 Summary

Table 4-1 summarizes the eelgrass indicators discussed.

Table 4-1. Summary of eelgrass indicators and metrics

	Eelgrass Restoration Indicator	Eelgrass Protection Indicator	Eelgrass Abundance Indicator	
	Metric: Area of eelgrass restored	Metric: Proportion of permits avoiding impacts	Metric: Eelgrass area	Metric: Prevalence of sites with declines
Description	Area of eelgrass restored through individual projects. Could include direct restoration and/or natural recovery following restoration of physical processes. Could track initial restoration effort or ultimate success.	Proportion of permits that avoid direct impacts to eelgrass. Candidates include HPA permits, DNR use authorizations and Shoreline substantial development.	Area of eelgrass throughout greater Puget Sound and sub-regions.	Ratio of eelgrass increasing/decreasing at individual sites throughout greater Puget Sound and sub-regions.
Type of outcome	Intermediate outcome (responsive to management actions over short time frames)	Intermediate outcome.	Ultimate Outcome (low degree of control and response time)	Ultimate Outcome (low degree of control and response time)
Data Source	Does not exist currently. Various agencies monitor other aspects of restoration projects, including total area of tidally influenced wetlands that are restored.	Data exists in permitting records at regulatory agencies and DNR. Data is not compiled.	DNR SVMP	DNR SVMP
Target Setting Considerations	Target could be based on considering documented losses. Currently, data is limited. Work needed to compile and analyze past records.	Coordination across agencies required.	Historical data is insufficient to develop a target based on historical conditions. Our ability to determine historical area is low with current resources.	Data record begins in 2000.

5

Alternative Strategies to Guide Indicator, Metric and Target Selection

The conceptual question underlying the adoption of an eelgrass target is "how much eelgrass is needed for a healthy Puget Sound?" The scope of this question spans both ecosystem science and environmental policy. Inherent in the term "healthy" is a judgment that some ecosystem states are more optimal than other states. Science considerations alone cannot generate the environmental goals that would help define the optimal state.

We must also consider that the "state" of Puget Sound is complex and multi-dimensional. There is competitive tension between some components of the system. For example, the persistence of some eelgrass beds may compete with water-dependent economic activities or the development of public access infrastructure. These are activities which themselves might support the long-term health of Puget Sound through the cultivation of strong interest groups. Also, tactical considerations may suggest different ways to balance these tensions as compared to an approach that considers longer-term strategic issues only. These issues clearly fall in the policy arena.

This section discusses five alternative strategies to be considered in science-policy discussion to guide the selection of eelgrass indicators, metrics, and numeric targets. A single strategy could be adopted or multiple strategies could be combined. These strategies are discussed in terms of the strength of the underlying rationale, their overall readiness for implementation, and management implications. While these five alternatives are not comprehensive, they represent a broad range of approaches and encompass the approaches adopted by the other estuaries reviewed in the case studies of seagrass target selection (Chapter 2).

The five strategies presented in this chapter are intended as options to be considered in a policy deliberation. They reflect three conceptual approaches to the question of optimal levels of eelgrass:

1. Past conditions are optimal.
2. Current conditions are optimal.

3. We (policy makers and scientists) can determine optimal conditions through analysis. This analysis would be based on our understanding of the social-ecological systems of the Puget Sound basin.

Given the differences between the strategies presented in terms of readiness for implementation, it may be desirable to adopt a phased approach that transitions from a strategy that can be implemented immediately to one that requires further development. Whatever strategy is adopted for setting an eelgrass target, it will be imperative to stipulate a periodic review of the feasibility and effectiveness of the target and allow for revision of the target based on these reviews and new scientific information as it becomes available.

5.1 Return to historical soundwide levels

Indicator: Soundwide eelgrass abundance
Metric: Soundwide eelgrass area

5.1.1 Rationale

A goal to return to historical conditions presumes that current conditions represent a significant departure from an earlier state. Typically, this change is attributed to human influences. The rationale for such a goal rests on the judgment that historical conditions represent an optimal state, typically thought to be a state of negligible human influence.

The idealization of historical conditions into a static optimal state is simplistic. Eelgrass beds, like all ecosystem components, are dynamic. A strategy to return to historical conditions, then, rests on the implicit assumption that the magnitude of the difference between current and historical conditions is much greater than the magnitude of historical natural variability.

5.1.2 Readiness for Implementation

A Puget Sound eelgrass target based on historical soundwide eelgrass area is not feasible in the near-term. This is due to the incomplete historical record for Puget Sound as a whole, and consequently the considerable uncertainty that current eelgrass conditions reflect a significant, overall long-term decline (See Chapter 3). There are historical records for particular sites, but these represent a very limited, haphazard selection that does not support estimates of overall historical conditions. There is currently no systematic measurement of overall historical conditions that is comparable to the current monitoring program and that could provide a reference point.

In the medium-term (1-3 years depending on available resources), efforts to further reconstruct the historical record could prove useful. There are several avenues of investigation (Section 3.5, p. 41) that could potentially produce historical information with enough detail to guide selection of a Puget Sound eelgrass target. Any effort to reconstruct historical abundance should be paired with an effort to inventory areas that are no longer viable eelgrass habitat due to physical alterations (e.g., dredged navigation channels, overwater structures, shoreline modifications associated with ports and urban shorelines). These areas would be subtracted from the historical abundance to generate a realistic target following the approach in other estuaries (see Chapter 2).

The existing DNR annual eelgrass monitoring project could immediately serve the monitoring needs for this strategy. The precision associated with the soundwide eelgrass area indicator supports the ability to detect a 20 percent change in area over any 10-year interval. Precision, and detection capability, could be improved with enhancements to the underlying monitoring program. The target would be achieved when current indicator values could not be statistically distinguished from the historical target.

5.1.3 Management Implications

This strategy could conceivably require more protective management practices than would be required under a no net loss strategy (Section 5.3). This would be the case if current eelgrass abundance reflects a substantial decline relative to historical conditions and restorable habitat is available.

5.2 Restore sites of documented losses

Indicator: Eelgrass restoration
Metric: Area of eelgrass restoration

This strategy would focus on losses of eelgrass that have been documented at the site scale. It would rely on comparisons of historical to contemporary observations which would be opportunistic, rather than systematic, because of the nature of the availability of historical observations. Documentation of eelgrass losses could also be derived from changes within the contemporary monitoring record. Source information could be both anecdotal and quantitative although all anecdotal observations may have to be translated to quantitative estimates depending on the nature of the eelgrass target adopted.

5.2.1 Rationale

This strategy is based on the presumption that stressors on Puget Sound eelgrass have increased with population growth in the basin, and this has led to eelgrass decline relative to earlier, more optimal, conditions. Furthermore, the existing documentation of site losses provides the basis for immediately setting an eelgrass target, while more systematic assessments of past change are developed over time.

5.2.2 Readiness for Implementation

This strategy could be implemented in the short-term upon the resolution of a few issues related to the actual target. In particular:

- Treatment of qualitative documentation would have to be determined. Are these cases translated to quantitative estimates, or ignored for the purposes of developing a numeric target?

- What measure of decline would be used for the contemporary DNR monitoring record? Losses associated with significant 5-year declining trends may be the best approach because these results indicate that the losses are persistent and not associated with interannual variability. Another approach would be to rely on annual change estimates, but these would be more variable and less reliable as the basis for a target.
- Some approach would be necessary to deal with sites with eelgrass losses that are no longer considered viable eelgrass habitat.

While the restoration target can be specified, some level of restoration effort will be necessary to ensure a reasonable expectation of meeting the target. If a restoration program is to be developed, significant resources will be necessary. The first step in site restoration would be an assessment of habitat viability for eelgrass survival. Potential restoration sites could be evaluated with either pilot transplants or the measurement of physical parameters and the modeling of eelgrass viability (Short et al. 2002). The latter approach would require a basic understanding of stressors that are acting at specific sites. In most cases, this would be a research question that would require resources and time. A conservative estimate of restoration cost is US $100,000 per acre (RKK Engineers 2001). A comparison of transplant methods in Australia found the cost to restore seagrass varies from US $500,000 to US $5,000,000 per acre (Walker 2003). Another review found transplant costs varying between US $15,000 to $200,000 in 1998 dollars (Fonseca et al. 1998).

5.2.3 Management Implications

The main management implication for this strategy would be the need for a restoration program or restoration tracking mechanism. Each site to be restored would be assessed (by pilot transplants or environmental monitoring) and, if viable, restored by eelgrass transplants. Important issues to be addressed by a restoration program would include the acquisition of eelgrass plants for transplanting and guidance for cases where the potential restoration site is on private tidelands. Also, monitoring would be needed to assess long-term success (transplant survival).

5.3 No net loss

5.3.1 Background

The no net loss policy is most prominent in the context of wetland regulation in the U.S. It was first formalized in federal statute in 1990 (Robertson 2000). The implementation of this policy is closely associated with compensatory mitigation of wetland losses through the creation of new wetlands or enhancement of existing wetlands.

In 2001, the National Research Council concluded that the goal of no net loss of wetlands was not being achieved. The main reasons identified included poor compliance, poor quality assurance applied to monitoring data, and the failure to adopt a landscape-level approach in permitting (National Research Council 2001, Harper and Quigley 2005).

The Washington Department of Fish and Wildlife (WDFW) already has a no net loss policy for eelgrass in the state (Fresh 1994), which is recognized by WDFW as a habitat of special concern (WAC 220-110-250). The no net loss policy is implemented on a project basis under WDFW authority to manage Hydraulic Project Approval (HPA) (RCW 77.55.021). The statute stipulates that WDFW must accommodate off-site mitigation for habitat loss (RCW 70.55.241).

The Washington State Department of Ecology has a no net loss policy for shoreline ecological function (WAC 173-26-186 [8][b]) under its authority in implementing the Shoreline Management Act (RCW 90.58). This policy is applied on a planning basis to the shoreline master programs developed by local governments. The policy is also applied on a project basis as each permitted development must not cause a net loss of ecological function when mitigation is considered (WAC 173-26-186 [8][b][i]). Ecology also recognizes eelgrass specifically as critical habitat (WAC 173-26-221 [2][c][iii][A]).

In addition to the examples already discussed, no net loss policies have been applied to fish habitat in Canada (Harper and Quigley 2005) and native land cover in Australia (Gibbons and Lindenmayer 2007).

Robertson (2000) discusses important principles that are implicit in no net loss policies. The first principle is that no net loss advances the idea of a resource as a uniform commodity. A given acre of wetland, for example, is completely interchangeable with any other acre of wetland. This leads to the second main principle that the spatial-specificity of ecological function is ignored. Important linkages between a given instance of a resource (a wetland, or an eelgrass bed) and the surrounding watershed or nearshore system are not considered. This leads to tension between the spatial-specificity of ecological function and commodity abstraction (Robertson 2000).

5.3.2 Rationale

In a no net loss strategy, the goal is to maintain current conditions. The underlying rationale, then, is that current conditions are thought to be optimal as judged solely on ecological grounds, or when economic and political constraints are superimposed on ecological considerations.

5.3.3 Readiness for Implementation

In concept, a no net loss strategy could be implemented immediately as a soundwide performance measure. The DNR soundwide eelgrass area metric could serve as the basis for measuring performance. The precision associated with this indicator supports the ability to detect a 20 percent change in overall eelgrass area over any 10-year interval. Precision, and detection capability, could be improved with enhancements to the underlying monitoring program. The target would be achieved by the absence of evidence of decline in the eelgrass area indicator.

An alternative, or companion, implementation of no net loss could be based on compliance monitoring at the project level. This would require multi-year monitoring at project and mitigation sites to assess compliance of projects with no net loss. In this case, the target would be achieved by the absence of evidence of decline in eelgrass area based on the compliance monitoring results.

5.3.4 Management Implications

The primary management implications would be in the management practices that would be needed to support no net loss. Under a scenario where disturbance to eelgrass is completely prohibited, an explicit operational definition of 'disturbance' would be necessary. For example, while removal of eelgrass and complete shading that quickly leads to mortality are clearly forms of disturbance, lower levels of shading may affect long-term viability of eelgrass to varying degrees. This presents a continuum of disturbance which would require clear operational guidelines to assess the presence of disturbance within specific project designs.

The statutory directive to provide public benefit by fostering water-dependent uses (RCW 79.105.030) lends support to providing some mechanism for mitigation for projects that are judged to provide important public benefit but for which impacts to eelgrass are unavoidable. A policy decision would have to be made on whether mitigation is allowed and, if mitigation is accommodated, operational guidelines would have to be developed.

5.4 Increase eelgrass abundance because it is known to be valuable habitat

This strategy would lead to a numeric target of soundwide eelgrass area that represented an increase in area relative to current conditions.

5.4.1 Rationale

The rationale underlying this strategy is that eelgrass provides valuable ecosystem functions and an increase in these functions will contribute to the recovery of Puget Sound. Note that this rationale may be invoked regardless of whether there is an identified need to recover eelgrass itself, based, for example, on documented losses.

5.4.2 Readiness for Implementation

This strategy could be implemented immediately with the selection of a suitable numeric target of soundwide eelgrass area. This target would represent an increase relative to the current estimates from the DNR monitoring program.

Strategies to achieve the target would have to be developed, such as project best management practices, stormwater management practices, and wastewater treatment standards.

5.4.3 Management Implications

This strategy risks unintended consequences associated with habitat conversion to support eelgrass expansion. If expansion is to be pursued even in the absence of evidence of past declines, then there is potential that other habitat types would have to be converted to eelgrass beds.

5.5 Ensure we have enough eelgrass to provide essential ecosystem goods and services.

5.5.1 Background

Natural resources, also referred to as natural capital, provide significant economic and environmental goods and services that contribute to the livelihoods, food, security, and safety of people throughout the world (Conservation International 2008). The sustainable management of natural resources is critical to human health and well-being for generations to come. Past management strategies have largely focused on integral parts of the system separately and have not assessed how humans affect the system or how humans benefit from the goods and services of the natural system.

Lately, there has been a concerted effort to manage marine and estuarine ecosystems on a large-scale, comprehensive basis that incorporates the interactions of all system components and includes humans as factors that not only benefit from the goods and services of the natural system but play an integral role in the system (Levin et al. 2009, Fortes 2010). As a result, tools have been developed to increase our understanding and management of marine and estuarine ecosystems. Examples of these include ecosystem-based management (EBM)(Levin et al. 2009), valued ecosystem components (VECs)(Leschine and Petersen 2007), and social-ecological systems (SES)(Fortes 2010) models. The challenge of integrating the diversity and complexity of system components (e.g., natural resources combined with local and regional policy, economics, and human behavior) has lead to the development of integrated ecosystem assessments (IEAs) (Levin et al. 2009, Millennium Ecosystem Assessment 2010). Integrated ecosystem assessments are scientifically based syntheses that quantitatively evaluate the biological, chemical, ecological, physical, socioeconomic, and human response of ecosystem management over temporal and spatial scales (Murawski and Menashes 2007, Levin et al. 2009).

Research has demonstrated the significance of seagrass to ecosystem processes that provide a vital link connecting upland and other marine habitats (Heck et al. 2008). Eelgrass is considered an important natural resource in Puget Sound. Some of the services eelgrass provides include: shoreline stabilization (erosion control, sediment trapping); oxygen production; nutrient and carbon sequestration and export; maintenance of biodiversity; forage, shelter, and nursery areas for estuarine organisms; scientific research; and tourism. In addition, there have been a number of projects demonstrating the ecological functions that eelgrass provides for Pacific herring (Phillips 1984), migratory salmon (Simenstad et al. 1988, Simenstad 1994), and coastal birds and waterfowl (Wilson and Atkinson 1995, Ganter 2000) within Puget Sound.

One approach to determine the goods and services eelgrass provides to Puget Sound is to quantify the interconnectedness and dependency of ecosystem components to eelgrass. Another approach would be to determine the economic value of the goods and services provided by eelgrass within the system. Some work has been completed that captures the significant role of eelgrass in the Puget Sound (Simenstad et al. 1979, Phillips 1984), but none quantify its level of importance nor the amount of eelgrass that is necessary to support these goods and services. A study has been completed that attempts to demonstrate the economic value of the services eelgrass provides to the Puget Sound ecosystem (Batker et al. 2008), but it only captures one component of eelgrass services (nutrient cycling) and does not address how much eelgrass is needed to support nutrient cycling in Puget Sound. Although there are challenges associated with estimating ecosystem services provided by natural capital, benefits include developing establishment of a baseline for additional research, identification of data gaps, and instigation of further investigations and discussions (Costanza et al. 1997, Batker et al. 2008).

5.5.2 Rationale

Eelgrass is natural capital, a resource that provides essential goods and services to the Puget Sound system. The loss or replacement of natural capital by built capital is far more expensive than promoting a system of self-perpetuating natural capital (Costanza et al. 1997, Batker et al. 2008).

The identification of an eelgrass target necessary to provide essential ecosystem goods and services will be challenging, but the effort will establish a thorough quantitative understanding of eelgrass, its interconnectedness throughout the system, and provide insight on the abundance needed to support a sustainable and healthy Puget Sound.

5.5.3 Readiness for Implementation

This strategy is currently an area of active research and is not ready for implementation. An effort to conduct an IEA for Puget Sound is currently underway (Levin et al. 2009).

To date, there has been one effort to identify the value of eelgrass goods and services in Puget Sound (Batker et al. 2008). This study identified 4 general and 17 specific categories of services for the eelgrass ecosystem. These included: biodiversity; Provisioning Services – food; Regulating Services – shoreline stabilization/erosion control, storm protection, human disease control, waste processing, carbon sequestration; Supporting services – nutrient cycling, habitat, primary productivity; Cultural – spiritual, scientific and educational. Of these services, the authors provided a monetary value for only nutrient cycling. This assessment of the goods and services related to nutrient cycling that eelgrass provides is limited and supports a need for more thorough investigations.

Although there have been additional site-specific investigations throughout Puget Sound that highlight the importance of eelgrass, there is limited information on the quantity of eelgrass that is necessary to provide the goods and services needed by the system. There are currently too many data gaps and a limited understanding of the numerous linkages between eelgrass and other resources in Puget Sound.

Implementation of an eelgrass goods and services model would be challenging at this point; however, the process of developing these models would be valuable. Evaluation of the complex and interconnected goods and services that eelgrass provides in Puget Sound will establish a range of values for the amount of eelgrass necessary to support ecosystem processes (Batker et al. 2008). In most cases, the assessment will underestimate the true importance of the resource in terms of the goods and services it provides or underestimate the abundance of the resource needed in the ecosystem, but the process does establish a baseline and identifies data gaps for further research (Costanza et al. 1997, Batker et al. 2008).

5.5.4 Management Implications

A challenge of implementing management strategies to achieve an eelgrass target based on goods and services would be the delay between adopted policies and the complex response in the ecosystem. The effects of the management changes to the system may be insignificant, delayed over a large temporal scale, or confounded by other factors present but not considered.

A substantial continued commitment to research would be necessary to expand on the current NOAA IEA effort (Levin et al. 2009) and develop it to a point that directly informs the selection of eelgrass targets.

6 Recommended Strategies

Ideally, the process of indicator and metric development and refinement spans multiple years to ensure that a robust suite is chosen, along with associated targets. However, the Partnership requires a more rapid development cycle. Therefore, refinement of the indicators, metrics, and targets must be structured into future iterations. In order to meet both short-term and longer-term needs, we recommend a phased approach for developing and refining eelgrass indicators and targets:

- Phase I proposes an indicator and metric and provides guidance for setting a target based on current monitoring data and existing research into historical trends. This phase meets the Partnership's immediate indicator identification needs.
- Phase II describes high-priority indicator development tasks that are fundamental to comprehensive eelgrass monitoring, and beyond the scope of existing data and indicators.
- Future phases are outlined that are not currently planned or funded.

6.1 Phase 1 Indicator

In Phase I, we recommend adopting the existing soundwide status and trends indicator of eelgrass abundance, with an associated metric of area (below). Due to limited historical information, we do not believe it is possible to set a rigorous target at this time. Therefore, we suggest taking a 'reference direction' approach to target setting (Levin et al. 2010), which defines a direction of change from the current baseline but does not include specific numeric targets for future conditions (i.e., positive trend, negative trend, stable). We also consider several alternate targets to address the Partnership's stated need to develop a quantitative target in the short-term.

Indicator: **Eelgrass abundance** (using data from DNR's monitoring program).

Metric A: Eelgrass area

Description: Total areal extent of eelgrass. It is important to note that at current funding levels the DNR eelgrass monitoring program is designed to detect a 20 percent change over 10 years (Berry et al. 2003). If more precise tracking of trends in area are needed, sampling effort may need to be increased.

Target: Stable or increasing trend in soundwide eelgrass area between 2010 and 2020. Progress toward this target could be evaluated with the 10-year trend analysis as conducted by the DNR SVMP (Berry et al. 2002, Dowty 2005).

Alternate targets:

- Select an areal target based on existing estimates of historical or potential area. This alternative is not recommended because the existing historical estimates are either not substantiated (Albright et al. 1980) or have known limitations (Evans-Hamilton, Inc. and D.R. Systems, Inc. 1987). Depth-based estimates of potential area can be used as an upper reference point but cannot serve themselves as realistic targets since critical environmental factors are neglected (e.g., Phillips' approach for Puget Sound proper, Section 3.1.1. p. 20).
- Select an areal or trend target based on reference to results seen in other estuaries (Table 2-2, p. 16). Gains in the areal extent of submerged aquatic vegetation have been as high as 86 percent (over 30 years) in Chesapeake Bay. While this and the other cases presented serve as useful reference points, these results should be used cautiously because these cases are distinct ecologically from greater Puget Sound. The examples in Table 2-2 represent cases where losses have been closely linked with excessive nutrient inputs and aggressive management actions targeted anthropogenic nutrient inputs.
- Base a target on maintaining current gains and restoring known losses at sites.

The recommended target includes 'stable' as well as 'increasing trend' because there is no evidence of a decrease in soundwide area from historical levels.

No other indicators are recommended for immediate adoption because no other existing programs conduct status and trends, compliance, effectiveness, or validation monitoring for eelgrass in a coordinated fashion across greater Puget Sound.

6.2 Phase II Indicator Activities

Phase II identifies activities that are considered fundamental to meeting Partnership needs for comprehensive monitoring of eelgrass.

Substantial new program development is necessary in the areas of compliance monitoring, project effectiveness monitoring, and validation monitoring. Indicators that capture intermediate outcomes related to eelgrass could be developed by the Partnership as part of its coordinated regional ecosystem monitoring program (Puget Sound Partnership 2009) or by another appropriate group. Information on intermediate outcomes will be needed by the Partnership to provide direct, short-term feedback on the Action Agenda strategies, and to link to long-term results measured by the status-and-trends indicator. While an in-depth consideration of intermediate indicators is beyond the scope of this report, some examples are discussed in Chapter 4.

With respect to DNR's existing status and trends indicator, we propose refinements to Phase I indicator. These activities are planned and funded within DNR's carryforward budget.

First, we propose adding a second metric to DNR's indicator:

Metric B: Prevalence of sites with declines

Description: This measure is the ratio of the number of sites with significant decline in eelgrass area to the number of sites with a change (positive or negative) in eelgrass area. It characterizes change in the ability of Puget Sound shorelines to support eelgrass.

Target: The prevalence of sites with declines is less than or equal to 50 percent. Further development would be necessary for this target to be implemented. The timeframe for evaluation of prevalence would need to be specified. Chesapeake Bay uses the best year within the most recent three years for evaluating progress toward the target (Section 2.1, p. 8). Alternatively, five-year site trends could be used (see Figure 3-7, p. 32).

If the Partnership identifies a need for a single measure of eelgrass health for executive-level reports, the eelgrass area and prevalence of decline metrics could be combined into a single index for reporting purposes. This would have the benefit of simplifying the presentation of results but could produce a less intuitive measure.

Second, DNR plans on completing the following tasks to improve and expand the status-and-trend indicator and metrics:

1. Complete analytical studies that are needed to assess eelgrass area and prevalence of site declines metrics at the sub-basin scale. These studies would ensure sampling intensity is sufficient to support sub-region metrics. Current monitoring provides information at the sub-region scale at five-year intervals. The analysis would assess whether the results are sufficiently robust and develop options for enhancements to the monitoring, if needed. The outcome of this activity will be a specific proposal for new sub-basin metrics.
2. Further develop the underlying framework for the prevalence of sites with declines metric. Because this metric was discovered to be important in the course of

evaluating monitoring results, it has not yet been developed with the same statistical rigor as the soundwide eelgrass area metric. The outcome of this activity would be a proposal for technical revisions to this metric.

3. Assess the potential limitations in the soundwide eelgrass area metric associated with a highly aggregated population (e.g., approximately 25 percent of all eelgrass in greater Puget Sound is in just two bays – Padilla and Samish). This modeling study would apply a new eelgrass population model for the region constructed by DNR. The outcome of this activity would likely be a proposal to refine the soundwide eelgrass area metric.

These priorities could be re-assessed based on future guidance from the Partnership on the structure of indicators and the approach for assessing performance assessment over time. For example, some programs such as Florida Bay adopt a threshold approach to define the condition (e.g., good, fair, poor). Many programs define sub-basins and reporting intervals.

6.3 Future Phases

In addition to work identified in Phases I and II, we summarize four broad areas of need for future work that were identified during preparation of this report. These tasks could be undertaken by many groups and might be best addressed through multi-institutional collaboration. To our knowledge, they are not currently funded.

1. **Increase understanding of historical distribution through collecting historical information on eelgrass abundance and distribution at individual sites.** Results could be used to set eelgrass targets, as well as to improve management decision-making. Information at the scale of sub-basins could be used to drive restoration and protection strategies within sub-areas of greater Puget Sound.
2. **Define ranges for quantitative targets.** Targets would be based on a combination of new information on historical abundance and expert knowledge.
3. **Determine eelgrass requirements to support ecosystem services, and redesign metrics and targets based on Integrated Ecosystem Assessment (IEA).** This approach would most directly address the ecosystem goals of the Partnership, and it is compatible with the Science Panel strategic direction of using IEA. Substantial effort would be needed for this project.
4. **Assess eelgrass stressors and integrate into the management framework.** A major initiative is needed to identify and prioritize historical and current stressors. This work would inform the Partnership's protection and restoration priorities, and ensure the efficacy of management activities.

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