Appendix J
Technical Memorandum: Operational Definition of an Eelgrass *(Zostera marina)* Bed

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Appendix J. Technical Memorandum: Operational Definition of an Eelgrass *(Zostera marina)* Bed

Introduction

Proposed habitat conservation measures aimed at minimizing or avoiding impacts to eelgrass (*Zostera marina*) are currently being discussed among representatives of Washington's shellfish aquaculture industry and management and aquatics program staff of the Washington State Department of Natural Resources (Washington DNR). Questions have emerged from these discussions regarding what constitutes an edge of eelgrass bed: What minimum presence of eelgrass shoots comprise the edge of a bed? Are groups of non-contiguous eelgrass presence considered the edge of one larger bed, or are they treated as independent bed edges? Is there a minimum time during which observable shoots must persist in an area to be considered a bed? The answers to these questions will have direct effects on activities that are constrained because of their proximity to eelgrass beds.

In an effort to address these questions, a technical workgroup was convened with the goal of establishing criteria for defining an eelgrass bed. Workgroup participants included scientists and technical representatives from the Washington DNR Aquatics program, U.S. Fish and Wildlife Service, NOAA Fisheries, University of Washington, Northwest Indian Fisheries Commission, Point-No-Point Treaty Council, Squaxin Island Tribe, and shellfish aquaculture industry. This technical memorandum summarizes the information discussed at the meetings, reviews analyses of available data, proposes criteria for defining an eelgrass bed, and recommends metrics that should be considered when developing conservation measures with the intent to minimize and avoid impacts to eelgrass beds.

Goal

The overall goal is to determine the criteria for an operational definition of the minimum presence of eelgrass necessary to be considered a bed edge. The definition must be sufficient for site-level application for the sustainable management of eelgrass. It must allow for repeatable delineation of the beds, so that any impacts from activities authorized by Washington DNR in marine tidelands can be avoided or minimized with the application of appropriate conservation measures.

Objectives and constraints

- The eelgrass edge criteria must be applicable at the project or site scale (on the order of 0.1–10 acres). This definition must be precise enough to provide a basis for siting of projects on state-owned aquatic land parcels where eelgrass is present.
- Experienced environmental scientists must be able to apply the criteria using common survey methods and equipment.
- While a definition based on ecological principles is preferable, in the absence of conclusive scientific evidence, an operational definition based on best available scientific information will suffice, so long as it is understood that this will be adaptively managed as information is gathered through implementation and monitoring.

Background

Currently used or proposed criteria for eelgrass presence and bed edge

In response to the accumulation of scientific evidence demonstrating the importance of eelgrass to nearshore ecological function, entities tasked with sustainable stewardship of coastal habitats are striving to maintain and restore eelgrass (Orth et al., 2006; Phillips, 1984; Thom et al., 2008). This challenge requires the ability to delineate beds and to measure current status and change in the edge over time. Table 1 summarizes various eelgrass bed and edge criteria and identifies the agency or entity that has implemented or proposed each. Some of these definitions are proposed based on local empirical data; others are based on knowledge of a specific ecological function of the eelgrass (e.g. fish refugia). Some were developed for research or resource management purposes, while others were developed for regulatory implementation.

Table 1. Existing criteria for defining eelgrass presence and bed edge.

Implementation agency, entity, rule, or policy	**Contiguous bed and bed edge criteria**
Washington DNR Habitat Stewardship—Eelgrass Surveying Criteria	Contiguous separation distance ≤ 1 m. Minimum shoot density 3 shoots/m^2.
Washington DNR Submerged Vegetation Monitoring Program	Any eelgrass presence within a 1-m^2 area along the length of a video transect that is continuously sampled at approximately 1-m intervals until no presence is detected. A single shoot within a 0.1-m^2 grab sample.
U.S. Army Corps of Engineers Regional General Permit-6	An area of tidal substrate supporting eelgrass covering a minimum of 25% of the substrate.
Tampa Bay Estuary Program—Proposed Definition	A *seagrass bed* is ≥ 10% cover within a 10–30-m long transect line. The *zone of eelgrass occurrence* is defined as 1 shoot/m^2 for at least 10 m along a line transect (Virnstein *et al.*, 1998).
Alaska Sea Grant	A *persistent patch* of eelgrass from qualitative observations requires ≥ 50 shoots/m^2 (Wyllie-Echeverria & Thom, 1994).
Massachusetts Division of Marine Fisheries	The *edge of the bed* is defined as having two points: 1) the distance to the end of the continuous meadow and 2) the distance to the last shoot (Evans & Leschen, 2010).
Seagrass Net	To be considered within the same bed, any eelgrass present within a 1-m^2 quadrat must be within ≤ 1 m distance of a nearby eelgrass presence. The edge or transition area is indicated by the distance of the furthest eelgrass shoot that is beyond this 1-m contiguous bed from a fixed point along a fixed transect. Eelgrass shoot counts (within 0.0625 m^2) and percent cover (in 0.25 m^2) is estimated in 12 randomly pre-selected quadrats along a 50-m transect (Short *et al.*, 2006).
Seagrass Watch	A single shoot within a 1-m^2 quadrat along a 50-m long transect constitutes presence. Both shoot counts and an estimate of percent cover are recorded (McKenzie *et al.*, 2003).
Ospar Commission	A *seagrass meadow* is defined as an area of at least 2 x 2 m covered in seagrass. If < 10 m exists between patches, they are considered of the same meadow. If a distance > 10 m exists between patches, they are of separate meadows (MARBIPP, 2006).

Scientific literature relevant to the definition of minimum eelgrass presence

When developing a scientifically based definition of the minimum eelgrass presence needed to constitute an edge, the following points should be considered.

- In many areas, eelgrass occurs as a compound grouping of non-contiguous areas. (Fonseca & Bell, 1998). A separation distance criterion must be established to determine how to group these non-contiguous areas.
- The minimum detectable quantity of eelgrass depends on the sampling method used, but most site-scale sampling methods are able to detect eelgrass to the individual shoot. A minimum threshold that constitutes an accepted eelgrass presence (e.g. single shoot, area of specified shoot density, or percent cover) must be defined.
- Eelgrass morphological structure consists of above-ground shoots as well as below-ground rhizomes. The below-ground portion of the plant is often of larger dimension and mass than the visible, above-ground portion.
- Eelgrass presence affects the scope of habitat provision (benthic invertebrates, fish, or birds) (Hirst & Atrill, 2008).
- Eelgrass presence parameters (area and density) affect the ability of eelgrass to stabilize sediment and trap suspended particulates (Koch, 2001).
- Eelgrass biomass, area, and density affect the level of primary productivity and the contribution of the eelgrass to the detrital food web.
- Persistence of the vegetated area is another issue: A minimum eelgrass presence may be needed for an eelgrass unit to remain present year after year. Interannual cross- and long-shore variability of seagrass bed edges has been documented (Frederiksen et al., 2004; Marbà & Duarte, 1995; Grette Associates, 2005, 2008, 2009).
- Resilience of the vegetated area is a factor: A minimum residual eelgrass presence or density may be required to re-establish an area after it has experienced a disturbance (natural or anthropogenic).
- Distances between eelgrass shoots affect seed dispersal and successful gene flow.

These considerations relating to eelgrass attributes are important in understanding the ecological function of an eelgrass bed. Scientific studies with specific metrics regarding ecological attributes and functions of eelgrass beds are summarized below. This information was reviewed and discussed in the workgroup meetings when the participants considered the development of criteria for determining the minimum size, density, and persistence of an eelgrass bed edge.

Habitat

- Fonseca *et al.* (1998) observed that eelgrass present in areas as small as 1–2 m^2 had greater numbers of fish, shrimp, and crab than adjacent unvegetated areas.
- A study comparing benthic infaunal biodiversity of *Zostera* vegetated patches (ranging in size from 0.24 m^2 to 17 m^2) and unvegetated intertidal substrate areas found that all *Zostera* patches supported a higher level of biodiversity than bare sand, and neither the patch size nor mean shoot density had any impact on the level of diversity (Hirst & Attrill, 2008).

- In the United Kingdom, Eelgrass fragmentation was examined for its role in benthic infauna community composition by comparing infaunal communities in a continuous 2.3 ha meadow to the composition of patches 6–9 m^2 (Frost *et al.*, 1999). Communities differed as a result of small changes in species abundance, but not in diversity; however, polychaetes generally associated with unvegetated habitats (such as *Magelona mirabilis*) were found to be more common in the fragmented bed than in continuous beds.
- Neither patch size, nor location of sampling within patches (edge or central) exerted as much influence on the infaunal community as sediment composition (Frost *et al.*, 1999). Total abundance did not differ between patch sizes in univariate analyses. Multivariate analyses, on the other hand, showed that the species that contributed most to the difference in assemblage composition between patches were more abundant at the edge. In particular, the nematodes *Capitella capitata* and *Spio filicornis*—species tolerant of random disturbance (stochastic events)—were more abundant in samples collected at the edge of beds than in samples collected from the interior of the beds.
- An examination of fish and amphipod abundance across seagrass areas (*Halodule wrightii*) ranging from 5 to 93 m^2 in size suggested no consistent relationship between faunal abundance and patch size (Bell *et al.*, 2001).
- Based on a study of varying eelgrass densities (140 to 660 shoots/m^2), no significant differences in the number of fishes sampled were detected between eelgrass plots (Wyllie-Echeverria *et al.*, 2002, as cited in Blackmon *et al.*, 2006).
- It has been shown that throughout the Puget Sound, eelgrass habitat is used by juvenile salmonids, but no indication of how this habitat is used based on the density and structure of the eelgrass beds has been provided (Blackmon *et al.*, 2006).
- Epibenthic faunal abundance was closely related to eelgrass presence and shoot development when unvegetated, transplanted, recently seed-colonized, and mature eelgrass habitats in North Carolina were compared (Fonseca *et al.*, 1990).
- Blue crab survival in the Chesapeake Bay was found to vary with the size and complexity of eelgrass patches (Hovel & Lipcius, 2001, as cited in Blackmon *et al.*, 2006). Juvenile blue crab density decreased as patch size increased, and greater habitat fragmentation improved blue crab survival, because the fragmentation resulted in an increase in seagrass edge habitat. Crab density was significantly lower, however, in isolated patches separated by large areas of unvegetated habitats.
- In a New Zealand study, seagrass patch variables (patch size, percent cover, and biomass) explained only 3–4 percent of the variation in benthic community, while landscape variables (fractal geometry, patch isolation) and wave exposure explained 62.5 percent of the variation in faunal abundance data (Turner *et al.*, 1999).

Sediment characteristics

- Both above and below ground, eelgrass structure contributes to sediment stabilization: Above-ground shoots have the capacity to reduce water flow, which lowers the velocity of the flow on the sediment substrate, thus reducing the amount of sediment that can be entrained and transported (Fonseca el al., 2006).
- Eelgrass acts as a sediment sink, with above-ground shoots trapping sediment and particulates from the water column and below-ground rhizomes and roots anchoring sediment. This can result in sediment accretion that changes the bathymetry, causing mounding in areas around seagrass (Walker, 1999).

- The capacity of eelgrass to accrete sediment increases with increasing patch size. The magnitude of slowing current velocity and accreting sediment is based on the density of the eelgrass shoots, hydrodynamic conditions of the area, and depth of the water column above the plants (Koch, 2001). Changes in physical conditions trap nutrients and stabilize habitats that are necessary for seagrass growth and recruitment. Elimination of newly developed small patches will slow or entirely inhibit the development of larger, more extensive patches (Kendrick et al., 2005).
- Patches as small as 0.3 m and 1.0 m along the axis of current flow were capable of significantly reducing the velocity of the current relative to bare mud-flat habitat (Fonseca & Koehl, 2006). Eelgrass has been shown to attenuate 43 percent of wave energy in a 1-m long vegetated transect (Fonseca & Cahalan, 1992).
- A significant difference in median grain size and sorting coefficient was observed when contiguous and fragmented eelgrass areas were compared, and median grain size was found to be the variable that best explains multivariate community patterns (Frost et al., 1999).

Primary productivity/contribution to food web

Seagrasses can act as short-term sinks for refractory carbon: 1–2 years for above-ground biomass and 4–6 years for below-ground biomass (Mateo, 2006). Eelgrass has the capacity to survive and maintain actively growing perennial populations even in its northern-most limit. It does this by storing excess carbohydrates in the rhizomes during the dark winter. There is, therefore, important ecological function being provided by below-ground structure that may be laterally distant from the visible above-ground shoots (Duarte et al., 2002).

Persistence

In plots established outside a continuous vegetated meadow, patch mortality was observed to decrease as the size (area) and age of the patch increased, and only patches with more than 32 shoots survived. The critical minimum patch area required for survivorship varied seasonally (Olesen & Sand-Jensen, 1994).

Fonseca and Bell (1998) found that eelgrass areas with less than 50-percent cover were less stable than those with greater percent cover.

Resilience

Compared with seedlings, surviving adult plants and small patches may contribute considerably to recolonization of a dieback area, as these plants have faster elongation and branching rates and a lower mortality rate than seedlings (Greve et al., 2005).

Reproduction

There are differences in the relative importance of sexual and clonal portions of eelgrass life history that must be considered when attempting to set management standards for protection and maintenance of genetic structure (Table 2).

Seed Dispersal Distance and Transport Time

- Ninety-five percent of pollination occurs within 15 m of the source. Eighty-three percent of seeds are dispersed within 5 m of the source and 100 percent within 50 m (Ruckelshaus, 1996).
- Pollen is viable for only 7–48 hours (de Cock, 1980; Cox et al., 1992).
- Once buried in sediment, seeds of eelgrass can remain dormant for one to two months (Moore et al., 1993).
- Reproductive shoots carrying maturing seeds can be carried by currents or consumed by water fowl and transported long distances (kilometers).
- Germination rates range between 5 and 20 percent, with 80 percent of the seedling's germination within a 5-m diameter of the source (Orth et al., 1994). Germination rates were found to depend not on seed-density, but on patch size (Orth et al., 2003).

Genetic Neighborhood

- In a study of genetic diversity and patch size, with patches ranging from 0.25 m^2 to 440 m^2, Ruckelshaus (1996) found that genetic diversity was inversely related to patch size. Genetic diversity tended to be higher in intertidal areas that had smaller patch sizes and were more prone to disturbance.
- Ruckelshaus (1994) found that a distance of four meters around a plant was adequate to genetically separate individual plants.

Table 2. Summary table: Values of eelgrass metrics associated with ecological attributes from the review of literature.

Ecological attribute	Eelgrass metric	Value
Benthic Habitat	Minimum area of eelgrass presence that affects habitat value	1–2 m^2 (Fonseca *et al.*, 1998) 0.24 m^2 (Hirst & Attrill, 2008)
Sediment Stability	Minimum area of eelgrass to significantly reduce current velocity	0.3 m^2 (Fonseca & Koehl, 2006)
Seed Dispersal	Seed dispersal distance	5 m (Ruckelshaus, 1996)
Genetic Diversity	Distance at which plants can be genetically distinguished	4 m (Ruckelshaus, 1994)
Vegetative Reproduction	Mean rhizome growth rate	26 cm/yr (Marbà & Duarte, 1998; Sintes *et al.*, 2006)
Persistence	Minimum eelgrass density associated with persistence	> 32 shoots per patch area (Olesen & Sand-Jensen, 1994)

Ecological attribute	Eelgrass metric	Value
	Eelgrass cover associated with greater persistence	> 50% cover (Fonseca & Bell, 1998)

Summary of available data relevant to the definition of eelgrass edge

Existing eelgrass data available to the staff of Washington DNR were evaluated to see if any patterns in eelgrass density, patchiness, or persistence emerged, or if perhaps there was any indication that further investigation of these data might be useful in developing eelgrass bed criteria. The four data sources described below include the Dumas Bay SeagrassNet site, the Submerged Vegetation Monitoring Program density grab samples, mitigation monitoring data from a Maury Island site, and plant morphology data from the Washington DNR stressor project.

Dumas Bay SeagrassNet site

SeagrassNet is a worldwide ecological monitoring program that documents the status of seagrass resources. The program began in 2001 in the western Pacific and now includes 115 sites in 32 countries. It has a global monitoring protocol and web-based data reporting system. A SeagrassNet site was established in Dumas Bay in Washington's Puget Sound in May of 2008. SeagrassNet sampling protocol requires that three fixed transects be established in an area of seagrass presence that is representative of or typical for the area. The fixed transects run along the shore, parallel to the beach. Transect A is located approximately one meter into the contiguous eelgrass from the shoreward edge. Transect C is one meter into the contiguous eelgrass from the waterward edge. Transect B runs through the center of the contiguous eelgrass (Figure 1).

Contiguous is defined as any eelgrass shoot that is within one meter or less of another eelgrass shoot. Furthest shoot data were compiled and analyzed from the Dumas Bay SeagrassNet site. The furthest (last, terminal) shoot is measured from three points (0, 25, and 50 m) perpendicular from the shallow (transect A) shoreward and deep (transect C) seaward transects (Figure 1a). The distance to the edge of the area of contiguous eelgrass (where the space between shoots is equal to or less than one meter) is also measured from these points. Data is collected quarterly.

Figure 1. Illustrates SeagrassNet transect placement, measurement to bed edge, and furthest shoot distance.

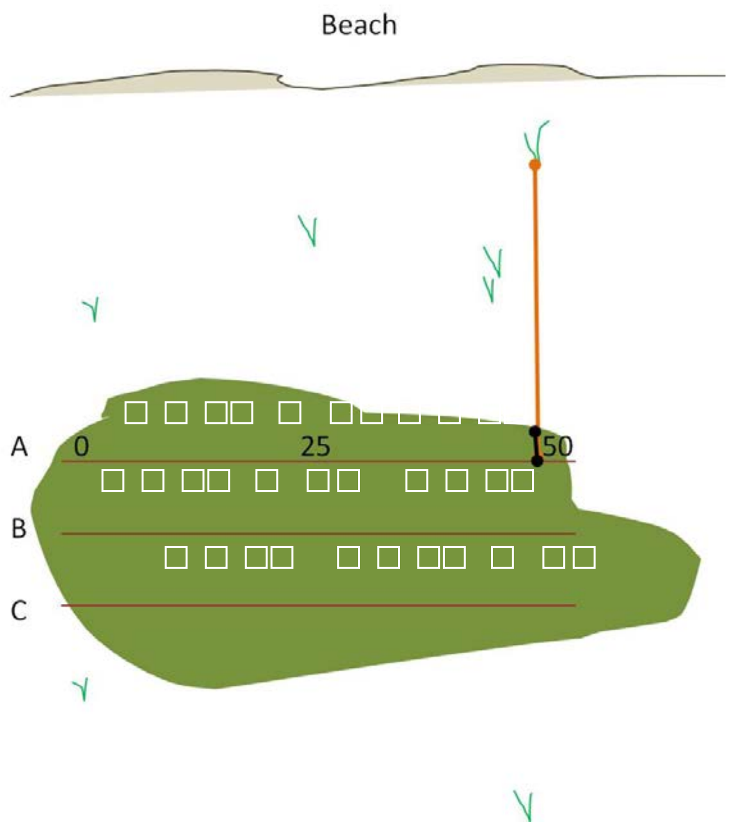
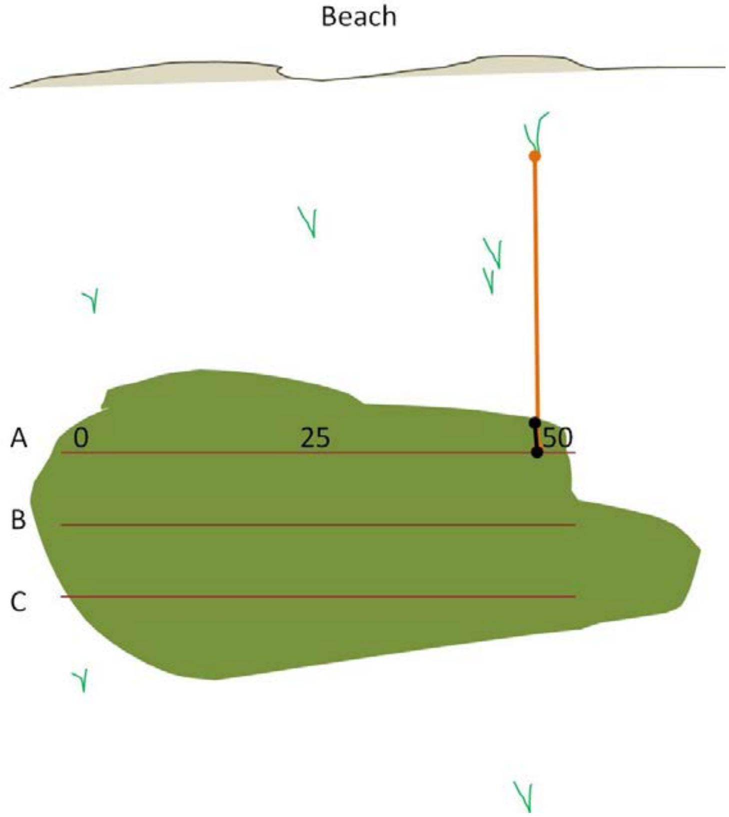


Figure 1a. Schematic of SeagrassNet site and distance to edge of bed (black line) and furthest shoot distance (orange line). (Diagram not to scale).



From May 2008 through January 2011, thirteen sampling events occurred. There were not enough sample times for the collection of furthest shoot data from the deep transect (transect C) to provide any meaningful information for the analysis. A basic evaluation of the furthest shoot data collected from the shallow transect (transect A) revealed the following:

Furthest shoot distance: Dumas Bay

Sparse, patchy eelgrass along the intertidal edge of larger contiguous eelgrass areas had been observed in the field by many of the workgroup participants. From the discussion, it seems that the size, distance from the contiguous eelgrass, and ephemeral nature of this eelgrass varies considerably. This prompted an examination of the available data to see whether any of these parameters might be quantified. Here, the furthest shoot refers to the single furthest shoot from the central area of the eelgrass.

- Furthest shoots were not present throughout the year; they were only present during the spring and summer sample times.
- When furthest shoots were present, they were located near the places they had been previously detected (the maximum change in furthest shoot distance was 5.3 m).
- The maximum distance of a furthest shoot from the contiguous edge was 8.9 m.
- The change in contiguous edge location over all sampling times (through all seasons) ranged from 0.4 m at the center position to 11.3 m at the left position.

- Net change from the first spring sampling (May 2008) to the most recent spring sampling (April 2010) was much smaller, ranging from 0.1 m at the center position to 1.7 m at the left position.

The results are summarized in Table 3 and Table 4.

Table 3. Furthest shoot distance, Dumas Bay, SeagrassNet site.

	Shallow transect furthest shoot distance (M)				n (# Times furthest shoots present)	n (# Times bed examined for furthest shoot)
	Max	**Min**	**Mean**	**Std dev**		
SeagrassNet Site, Dumas Bay May '08–Jan '11	8.9	1.8	6.6	2.3	7	34

Table 4. Change in edge and furthest shoot location, Dumas Bay, SeagrassNet site.

Position on Transect A	Max seasonal change in edge distance (m)	Max annual change in edge distance	Max change in furthest shoot distance (m)
Center	+0.4	+0.3	+1.5
Left	-11.3	-3.4	-1.7
Right	-6.1	+2.2	+5.3

This analysis provided some insight into the magnitude of changes in the edge and furthest shoot location, as well as the seasonality in the expansion and contraction of the edge and furthest shoot presence at this site. In addition, a pilot investigation of data from Washington DNR's Submerged Vegetation Monitoring Program was conducted to see what might be learned about furthest shoot distance from contiguous bed edge and what comparisons could be made among the different areas of Puget Sound. This preliminary analysis indicated that the furthest shoot distance could not be estimated using the Submerged Vegetation Monitoring Program's data. The program's data did not distinguish between a single blade in a square meter and thousands of shoots per meter. Further analysis of the data was therefore abandoned.

Eelgrass density: Dumas Bay

Eelgrass density and percent cover estimates were conducted at fixed random sites along three 50-m longshore transects at +1, 0, and -1.6 mean lower low water (MLLW) tidal elevations. Seasonal variability is apparent in density and percent cover, with maximum values observed in the spring and summer (data not shown). Interannual variability is also observed. This is apparent from the range in density and the standard errors reported only for the July samplings (the SeagrassNet site is sampled quarterly) of 2008–2011, as documented in Table 5.

Table 5. Shoot density and percent cover at Dumas Bay, SeagrassNet site.

Transect & Elevation (MLLW)	Date	Average Density (shoots/m^2)	SE (n)	Average % Cover	SE (n)
A, +1	July '08	597.3	277.7 (12)	28	12 (12)
A, +1	July '09	292.0	206.7 (12)	16	9 (12)
A, +1	July '10	184.0	97.9 (12)	12	6.8 (12)
A, +1	July '11	109.3	76.8 (12)	8	5 (12)
B, 0	July '08	769.6	175 (12)	46	6.6 (12)
B, 0	July '09	878.7	192.4 (12)	61	7.9 (12)
B, 0	July '10	892.0	135.6 (12)	72	9.7 (12)
B, 0	July '11	841.3	148 (12)	62	9.1 (12)
C, -1.6	July '08	210.7	32 (12)	46	6.2 (12)
C, -1.6	July '09	280.0	33 (12)	38	4.1 (12)
C, -1.6	July '10	186.7	29.6 (12)	28	4.9 (12)
C, -1.6	July '11	130.7	10.9 (12)	26	4.3 (12)

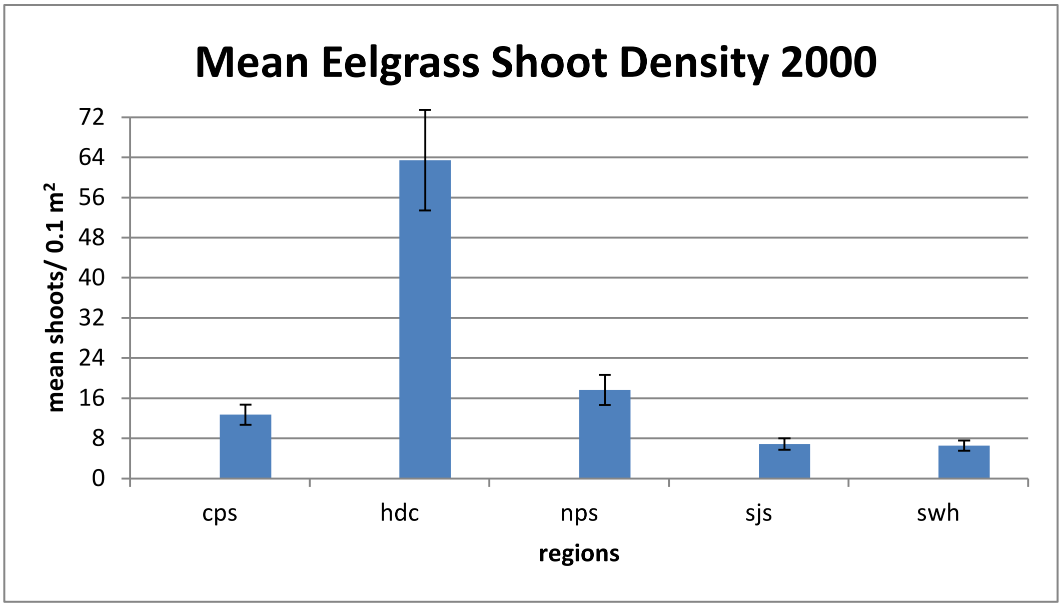
Submerged vegetation monitoring program: eelgrass shoot density

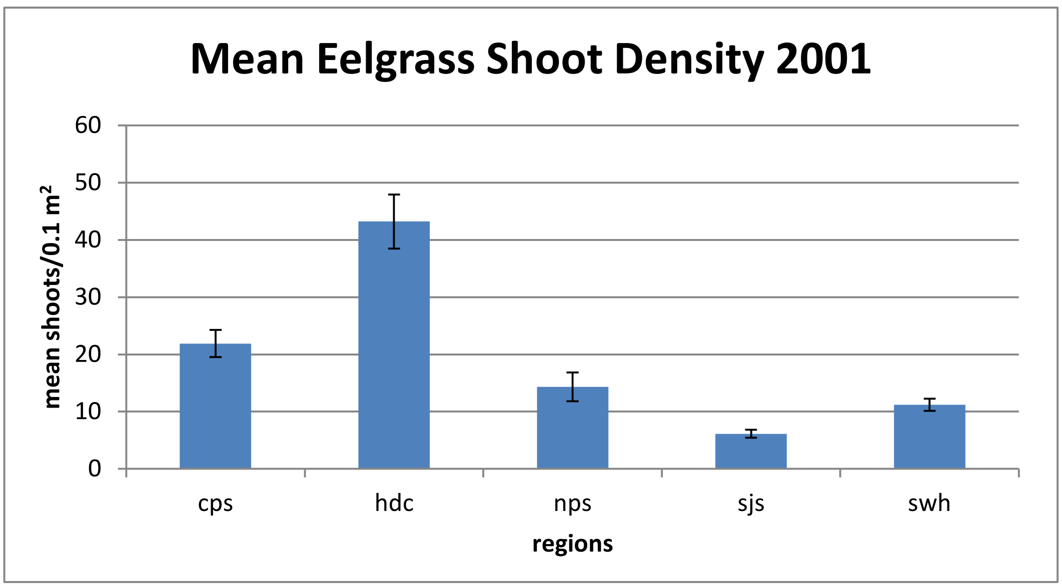
Environmental parameters influencing eelgrass plant structure and eelgrass density have been reported in scientific literature (Boese et al., 2003; Turner et al., 1999). Workgroup participants have also cited field observations of geographic differences in plant structure and density. This encouraged an examination of the available data on eelgrass shoot density, specifically to see if regional differences or variability in eelgrass density over time might be quantified.

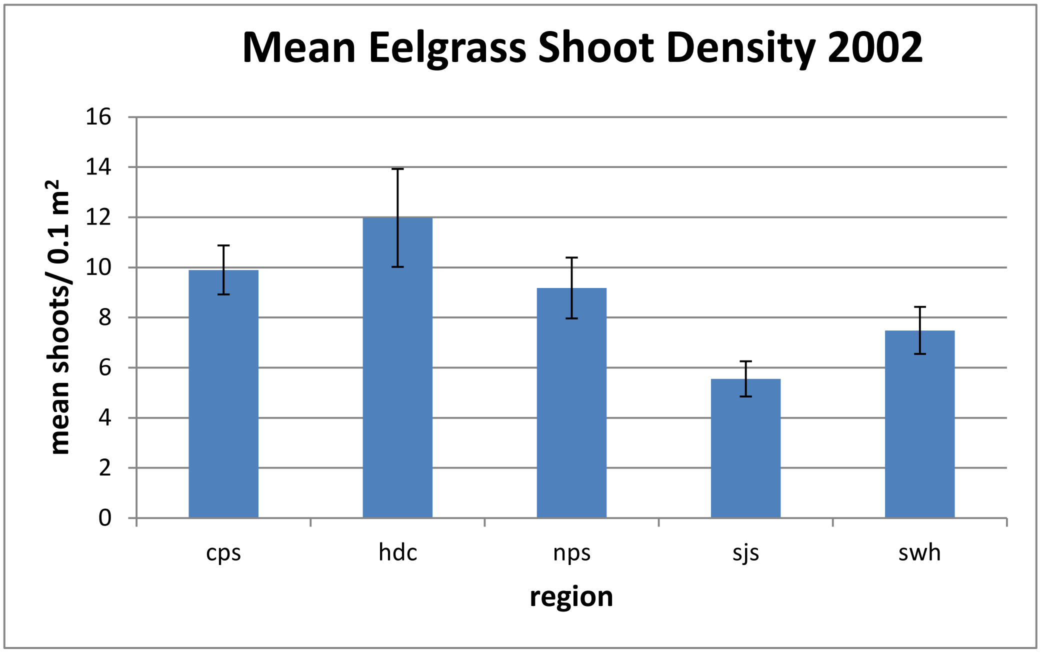
DNR grab sample density counts

Initial sampling for the Submerged Vegetation Monitoring Program included shoot density counts of grab samples collected with a van Veen sampler. An average of 23.9 shoots per sample, with a minimum of 1 shoot per unit area, was reported from 1,020 samples collected during 2000–2003. Sites sampled within each region were not necessarily sampled each year, although some sites were sampled in consecutive years. Sampling did not fall in the same period for each year either. While the absolute density numbers differed each year, visual observation of the data (see plots in Figure 2) does indicate a fairly consistent pattern of relative difference in shoot density among the five regions sampled, with Hood Canal (hdc) having the highest density, Central Puget Sound (cps) and North Puget Sound (nps) competing for second highest, and then South Whidbey (swh) and San Juan Island (sjs) with the lowest density.

Figure 2. Mean eelgrass shoot density from annual grab sampling by region, 2000–2002. Error bars are standard errors of the means.







Mitigation monitoring data: Maury Island

Eelgrass at a proposed project site on Maury Island was monitored intensely in 2005, 2008, and 2009 by the consulting firm Grette Associates LLC. Fixed grids with grid cell size of 1 x 1 m were established to encompass the entire eelgrass area. Dive survey sampling included eelgrass percent cover estimates within each square-meter grid cell, eelgrass density shoot counts within a 0.25 m^2 portion of each grid cell, and delineation of eelgrass presence in each square meter. Eelgrass survey maps from sample years 2005, 2008, and 2009 are reproduced in Figures 3–5 below, with eelgrass presence delineated and the density counts per 0.25 m^2 indicated within each grid cell. Sampling occurred during July for 2005 and 2008, and then in August for 2009. The images are from Northwest Aggregates: Maury Island Gravel Dock Annual Eelgrass Survey Reports, December 19, 2005, September 19, 2008, and December 15, 2009, prepared for Northwest Aggregates by Grette Associates LLC.

Eelgrass density: Maury Island

Close examination of the data from eelgrass monitoring of the north, south, and control patches (Figures 3–5) indicated differences in the stability of the three eelgrass areas. These findings are summarized in Table 6.

Table 6. Eelgrass area and mean density at Maury Island gravel site.

Patch Name	**Year**	**Area (m^2)**	*Net Change in Area (m^2) from '05 to '09*	**Average Density (shoots/m^2)**	*Net Change in Avg. Density (shoots/0.25m^2) from '05 to '09*
North	2005	126		77	
	2008	127		72	
	2009	85	-41	13	-64
South	2005	148		54	
	2008	152		56	
	2009	218	+70	28	-26
Control	2005	261		30	
	2008	256		37	
	2009	265	+4	26	-4

Figure 3. Eelgrass monitoring, Maury Island, north patch, 2005, 2008, 2009 (Grette Associates, 2005, 2008, 2009).

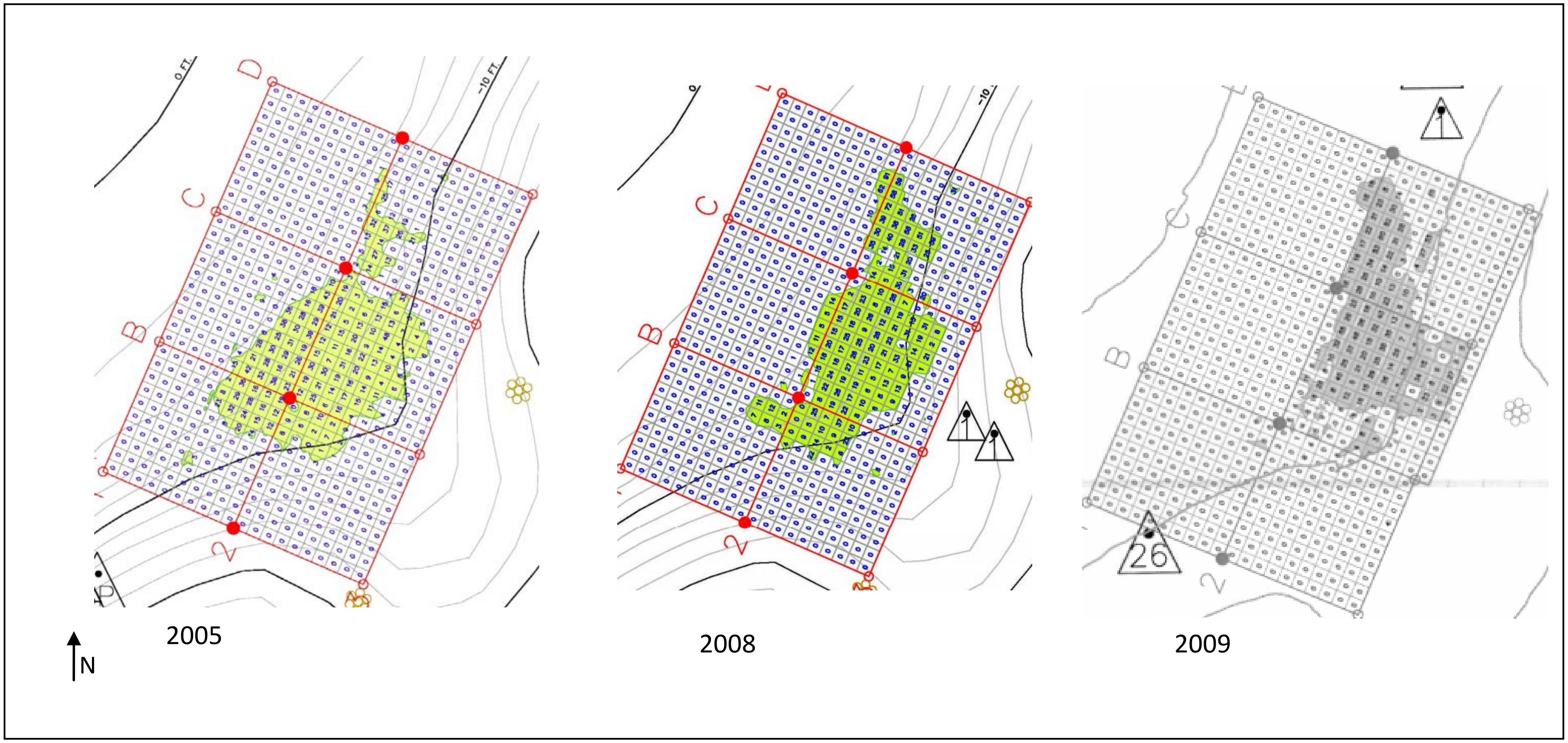
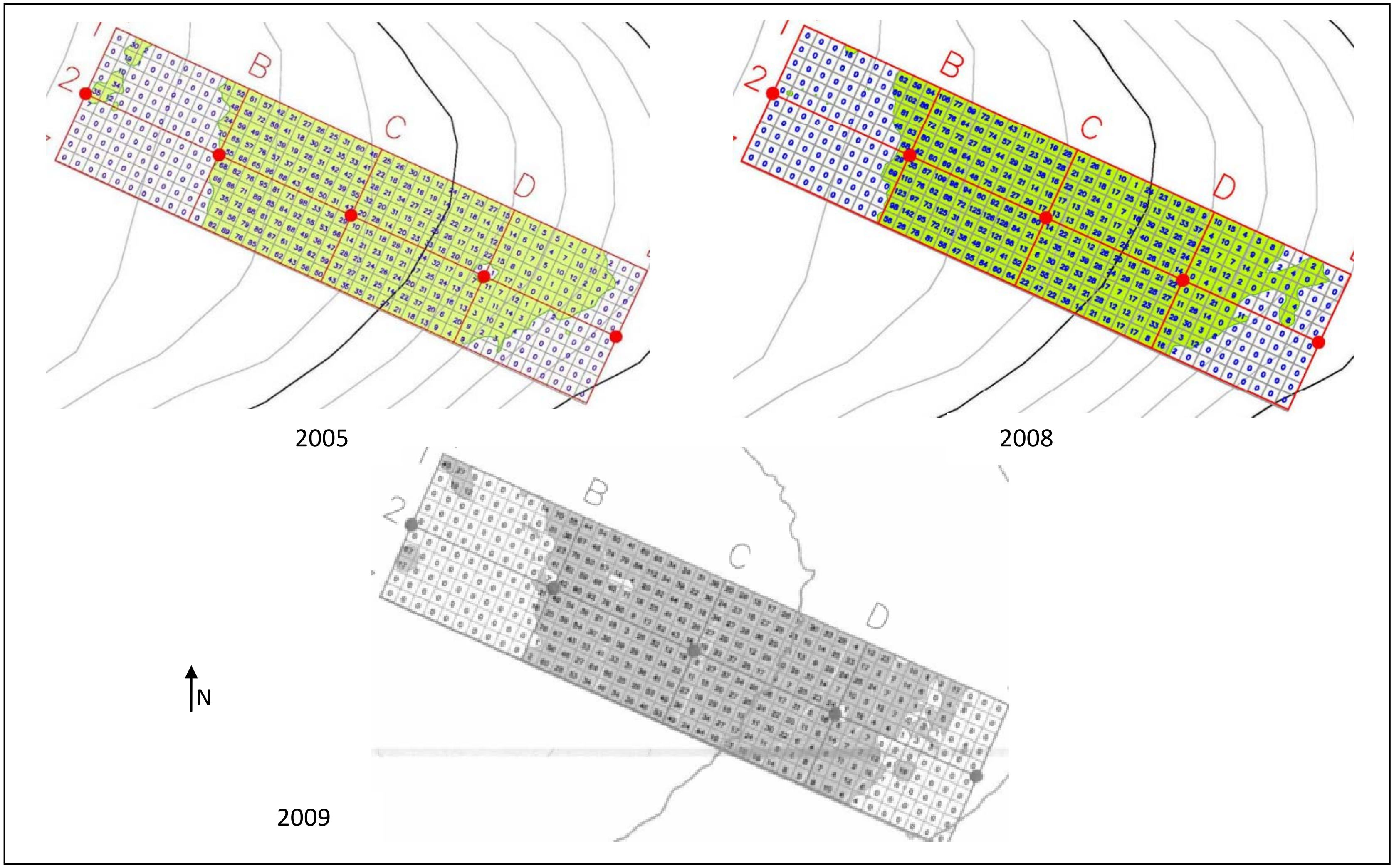


Figure 4. Eelgrass monitoring, Maury Island, south patch, 2005, 2008, and 2009 (Grette Associates, 2005, 2008, 2009).

Figure 5. Eelgrass Monitoring, Maury Island, Control Patch, 2005, 2008, and 2009 (Grette Associates, 2005, 2008, 2009)



The apparent differences in contiguous eelgrass stability that the comparison of the control site to the other two eelgrass areas revealed may be an artifact of differences between the survey limits of the control site and those of the north and south sites: The control site survey was limited to a swath from a larger contiguous area, while the survey extents of the north and south sites contained the entire eelgrass presence in each case, and surveys increased if necessary to capture edge migration. Assessment of the comparison between the north and south sites and relative change for each of these two areas over time is not affected by this survey limitation.

The eelgrass area and average shoot density remained relatively stable at the control site (again, this may be an artifact of the extent of the survey for this site). The eelgrass area increased in the south site and decreased in the north site, while the average shoot density decreased in both north and south patches.

The eelgrass edge of the north site moved approximately two meters east between 2005 and 2008 (spreading out both north and south). The northward edge contracted approximately five meters from 2008 through 2009.

The western eelgrass edge of the south site migrated approximately two meters to the east (filling in the patchier northern portion) from 2005 to 2008. It continued to migrate approximately four more meters eastward between 2008 and 2009.

Migration of the control site edges cannot be accurately assessed, because the monitoring area does not contain the long-shore edges of that eelgrass area. It is apparent that smaller areas of eelgrass along the shoreward edge were ephemeral in size and shape.

Furthest shoot: Maury Island

When looking at the pattern of density in all sites for three years, gradual tapering off of the density toward the shallow edge is never observed. In fact, some of the highest density grid cells are located directly on the shallow edge. The decrease in density is slightly more gradual on the deeper edge, but only one to two meters before complete drop-off.

In the north, south, and control sites, furthest shoots were documented (shoots located beyond a meter distance of the contiguous eelgrass area) off the shallow and deep edges. A furthest shoot was not always present. When present, furthest shoot distances on the shoreward edges ranged from 1.1 m to 8.0 m. The furthest shoot distances on the seaward edges (when present) ranged from 2.1 m to 3.5 m. Table 7 summarizes the furthest shoot distances measured at these sites.

While eelgrass presence did not migrate beyond the location at which a furthest shoot was found (shoreward or seaward), eelgrass did migrate along shore to areas where no eelgrass had been found during the previous sample time.

Table 7. Edge migration and shoot distance in eelgrass patches at Maury Island gravel site.

Patch Name	Year Sampled	Edge Migration: Expansion, +, Contraction, -(m)	Shoreward Furthest Shoot Distance (m)	Seaward Furthest Shoot Distance (m)
North Patch	2005		1.7	_
	2008	+2 east	2.0	2.1
	2009	-5 north		
South Patch	2005		1.1	3.5
	2008	+ 2 east	_	_
	2009	+4 east		
Control Patch	2005		_	_
	2008		8.0	_
	2009		_	_

Eelgrass persistence: Maury Island

Persistence of eelgrass area and density was evaluated in the Maury Island data (Table 8) so that it could be compared with the estimates provided in the literature. Only eelgrass presence that had a maximum area of 2 x 2 m was included in the analysis. Eelgrass that persisted beyond a season was larger in area and had a higher average shoot density compared to eelgrass that did not persist. The area of eelgrass that persisted was at least 0.3 m^2, with minimum density of 3 shoots per 0.25m^2.

Table 8. Minimum area and shoot density for eelgrass persistence at Maury Island gravel site.

Patch Persistence	Shoot Density (shoots/0.25m^2)				Patch Area (m^2)			*n*
	average	*min*	*max*	*SE(n)*	*average*	*min*	*max*	
> 1 season	54.4	***3***	124	2.44	0.9	***0.3***	4.0	*10*
< 1 season	13.7	1	36	0.76	0.6	0.1	1.0	*14*

Plant morphology data: Washington DNR Eelgrass Stressor Project

Plant structure provides important ecological functions. Above-ground shoots can provide three-dimensional structure for fish refugia and for epiphyte and invertebrate attachment. Below-ground structure provides habitat for macroinvertebrate attachment and sediment stabilization. Morphology of the above- and below-ground structure of *Z. marina* differs with environmental factors, as has been documented (Turner et al., 1999; Frederiksen et al., 2004). Plant structure is relevant to the development of bed criteria, because the distance between the plants and the bed edge is influenced by the length of shoots and rhizomes. The results of the analysis of plant morphology data from Washington DNR's eelgrass stressor project are presented below (Table 9).

The average shoot length at four sites (SE = 1.4, n = 180) in Puget Sound was 53.1 cm, with an average maximum shoot length of 89.7 cm (SE = 6.5, n = 45)(Washington DNR unpublished data). Average rhizome length at these sites was 33.3 cm (SE = 2.9, n = 169), with an average maximum rhizome length of 68.4 cm (SE = 4.4, n = 43).

Table 9. Eelgrass morphology metrics.

Ecological Attribute	Eelgrass Metric	Value
Eelgrass Morphology	Shoot length	Average shoot lengths ranged from 53.1 cm to 89.7 cm (Washington DNR unpublished data)
	Rhizome length	Average rhizome length ranged from 33.3 cm to 68.4 cm (Washington DNR unpublished data)

Index of eelgrass densities in Puget Sound and Willapa Bay

Eelgrass densities measured throughout Puget Sound and Willapa Bay are presented in Table 10. In the workshops, it was suggested that when pre-construction eelgrass surveys are conducted for proposed projects, it may be possible to begin developing a spatially explicit index of patch densities for comparison. A preliminary compilation of eelgrass density data is presented in Table 10; the sample size and standard error are indicated when known. These data were largely drawn from scientific publications, but other sources include Washington DNR Aquatics program field surveys, and environmental evaluation reports required for proposed projects on state-owned aquatic lands. These data may be helpful to those who are developing mitigation performance standards and selecting reference sites. These data cannot be used to determine minimum patch size, because they are reported as means (most often with very large variation in the mean) or ranges of densities, with limited or no information on sample size.

Table 10. Compilation of eelgrass densities measured throughout Washington.

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Puget Sound					
Lummi Bay	Apr-May 2007	160.7		20	Yang (2011)
North Samish Bay	Apr-May 2007	157		20	Yang (2011)
South Samish Bay	Apr-May 2007	177.1		20	Yang (2011)
Padilla Bay	Apr-May 2007	207.8		20	Yang (2011)
Similk Bay	Apr-May 2007	78		20	Yang (2011)
Kayak Point	Apr-May 2007	50.7		20	Yang (2011)
North Hood Canal	Apr-May 2007	137.8		20	Yang (2011)
Dabob Bay, Hood Canal	Apr-May 2007	155.9		20	Yang (2011)
Edmonds	Apr-May 2007	89.1		20	Yang (2011)
Carkeek Park	Apr-May 2007	212.2		20	Yang (2011)
Golden Gardens	Apr-May 2007	156.4		20	Yang (2011)
Seabeck, Hood Canal	Apr-May 2007	277.1		20	Yang (2011)
Lynch Cove, Hood Canal	Apr-May 2007	76.2		20	Yang (2011)
Purdy Spit, Car Inlet	Apr-May 2007	260		20	Yang (2011)
Rocky Point, Case Inlet	Apr-07	150		20	Yang (2011)
	May-07	89		20	Yang (2011)
Union, Hood Canal	Apr-May 2007	81.5		20	Yang (2011)
Dumas Bay	Apr-May 2007	141.8		20	Yang (2011)

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Dumas Bay: Washington DNR SeagrassNet Site (-1.6 to +1 MLLW)	Apr-08	464.9	77.5	36	Washington DNR unpublished data
	Jul-08	525.9	87.6	36	DNR unpublished data
	Apr-09	479.5	79.9	36	DNR unpublished data
	Jul-09	483.6	80.6	36	DNR unpublished data
	Apr-10	352.4	58.7	36	DNR unpublished data
	Jul-10	420.9	70.2	36	DNR unpublished data
	Apr-11	392.2	66.4	36	DNR unpublished data
	Jul-11	360.4	60.1	36	DNR unpublished data
Post Point Outfall, Bellingham	2005	22–61			City of Bellingham (2005)
Golden Tides, Bellingham	Jun-06	28–39			Geomatrix (2007)
	Jul-08	29–88			Geomatrix (2008)
Taylor Ave. Dock, Bellingham	Jul-98	42–238		30	Talyor Assoc. (1998)
	2004	49–235			Anchor Env. (2004)
Shannon Pt., Bellingham	2009	5–50			ATSI (2010)

Location (elevation)	Date	Average or Range of Densities (shoots/m^2)	SE	n	Reference
Maury Island Gravel Site (North)	Jul-05	77			Grette Assoc. (2005)
	Jul-08	72			Grette Assoc (2008)
	Aug-09	13			Grette Assoc (2009)
Maury Island Gravel Site (South)	Jul-05	54			Grette Assoc. (2005)
	Jul-08	56			Grette Assoc (2008)
	Aug-09	28			Grette Assoc (2009)
Maury Island Gravel Site (Control)	Jul-05	30			Grette Assoc. (2005)
	Jul-08	37			Grette Assoc (2008)
	Aug-09	26			Grette Assoc (2009)
Willapa Bay					
Oysterville	Apr-May 2007	114.4		20	Yang (2011)
Oysterville (-0.5 to +1.5 MLLW)	Jul-07	290	14	20	Ruesink *et al.* (2010)
Stackpole (-0.5 to +1.5 MLLW)	Jul-07	353	39	20	Ruesink *et al.* (2010)
Stackpole Flats	2007	22.8	5.3	44	Ruesink *et al.* (2010)
Nahcotta (-0.5 to +1.5 MLLW)	Jul-07	69	7	20	Ruesink *et al.* (2010)
Parcel A., Willapa Bay	Apr-May 2007	100.3		20	Yang (2011)
Willapa Bay (7 Locations)	Jul-04	159.5	33.9	7	Ruesink *et al.* (2006)

Summary of relevant findings

- Changes in ecological function were observed where a very small area of eelgrass was present; differences in benthic community diversity were observed when a 0.24 m^2 sized area of eelgrass-vegetated substrate was compared to an unvegetated substrate. An eelgrass area of 0.3m^2 was documented to have increased sediment trapping function when compared with unvegetated bottom.
- A minimum density of 3 shoots per 0.25 m^2 was necessary for an area of eelgrass to persist from one season to the next at a site in Puget Sound.
- With reported rhizome growth of 0.3 m per year and observed average rhizome lengths ranging from 0.3 to 0.7 m, a distance of 1 m would be necessary to ensure that the below-ground biomass of two adjacent shoots are captured when delineating a bed.
- Eelgrass edges at a site in Puget Sound were documented to migrate seasonally and annually. Maximum annual expansion to areas beyond the previously recorded edge was documented at 4 meters, while maximum annual contraction to areas of the previously recorded bed interior was up to 5 meters.
- Edge migration shoreward or seaward was always within the distance defined by the furthest shoot; however, edges also migrate along the shore, where the furthest shoot is not defined.
- Shoots greater than 1 meter from a contiguous eelgrass area have been documented appearing and disappearing seasonally and interannually.

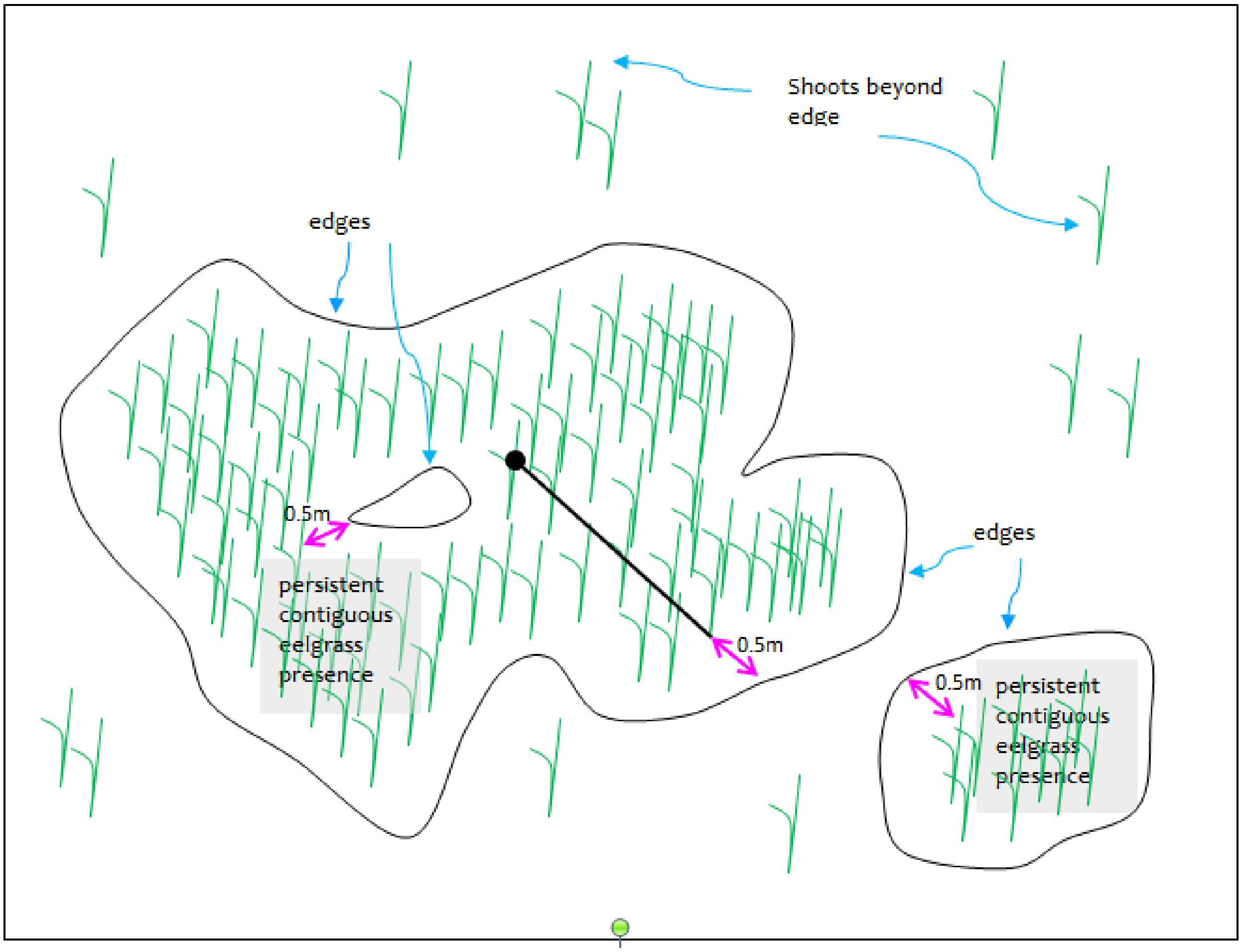
Proposed criteria

The proposed criteria for identifying the minimum eelgrass presence needed to delineate a vegetated edge with demonstrated ecological function are listed in Table 11. The criteria are based on information derived from review of the scientific literature and examination of available field data (from Puget Sound sites). Note that these criteria emerged from the limited data and information available regarding ecological function of *Zostera marina* characteristics and dynamics and are meant to provide an operational definition. Future sampling and further analysis may indicate that an adaptation or refinement of these criteria is necessary. In particular, field data from the estuaries of Washington's outer coast may provide scientific support for establishing separate criteria for those estuaries.

Table 11. Criteria for eelgrass bed edge and beyond.

Terms	Criteria	Bed edge or beyond?	Rationale
Persistent Bed Edge	Begin at a point within the interior of the bed (where ≥ 3 shoots/0.25m^2 within 1 m of adjacent shoots); move along any radial transect. Find the last shoot that is within 1 m of an adjacent shoot along that transect. Continue 0.5 m beyond this shoot: This is the bed edge. Both exterior and interior edges of bed can exist (Figure 6).	Bed edge	• Vegetated areas as small as 0.24 m^2 demonstrated different ecological function from unvegetated substrate. • 3 shoots per 0.25 was the minimum density necessary for an eelgrass patch to persist from one season to the next in Puget Sound. • Observed average rhizome lengths ranged from 0.3 to 0.7 m, and rhizome growth rates of approximately 0.3 m per year have been documented. Observed average shoot lengths ranged from 0.5 to 0.9 m. • Two adjacent shoots would require a minimum distance of 1.0 m to accommodate above- and below-ground parts of the plant. • A distance of 0.5 m beyond the last shoot is needed to accommodate the below-ground rhizome of an edge shoot.
Shoots or Patches	Single shoot or patches < 3 shoots/0.25m that are > 1 m from adjacent shoot	Beyond	• The ecological function of patches below this size and density has not been documented. • Patches below this size and density have been documented as ephemeral.
Ephemeral Shoots and Patches	Shoots or patches that may disappear then reappear from one season or year to the next	Beyond	• The ecological function of shoots and patches with limited temporal consistency has not been documented. • Ephemeral shoots and patches cannot feasibly be monitored for before-after effects analysis.

Figure 6. Schematic depicting two distinct, intact, contiguous eelgrass areas. Edges are 0.5 m beyond the last shoot found within 1 m of an adjacent shoot.



Conservation approaches

The ephemeral nature of eelgrass, particularly the edges of eelgrass presence, has been documented in the scientific literature and by data from Puget Sound and Willapa Bay. It has also been anecdotally observed in the field by shellfish growers and scientists. SeagrassNet protocol acknowledges it by requiring measurement from a fixed transect to the edge and to the furthest shoot. Eelgrass at the edge is less persistent than eelgrass near the center of a contiguous area. This migratory characteristic of eelgrass makes it a challenge to specify protocols for detecting changes effected by a specific activity. It is also a problem for those making management decisions, such as at what distances from the eelgrass it might be appropriate to encourage use and access of the tidelands, while still protecting sustainable eelgrass functions. Table 12 presents some metrics from published literature and the recent data analysis that may be relevant in determining these distances.

Table 12. Metrics relevant for developing buffers.

Relevant ecological attribute	Eelgrass Metric	Value
Potential Migration Zone	Expansion (+) or contraction (-) distance	Maximum documented annual bed expansion of +4 m, and contraction of -5 m (Washington DNR un-published data for two different sites) sampled over 4 year period).
Seed Dispersal	Seed dispersal distance	5 m (Ruckelshaus, 1996)
Genetic Diversity	Distance at which plants can be genetically distinguished	4 m (Ruckelshaus, 1994)

Recommendations

The revised goal described in the introduction of this memo was to determine the criteria for defining an eelgrass bed edge. The definition ". . . must allow for repeatable delineation of the beds, so that any impacts from activities authorized by Washington DNR in marine tidelands can be avoided or minimized with the application of appropriate conservation measures." There was consensus early on among the workshop participants that the purpose of this effort was to apply scientific evidence to distinguish between an intact, persistent, and functioning eelgrass area and spare individual blades of eelgrass, ephemeral eelgrass areas, or potential eelgrass habitat. A comprehensive review of scientific literature and analysis of available data led to the following recommendations:

- Apply the proposed criteria listed in Table 11 to delineate an edge around eelgrass presence. This distinguishes between contiguous eelgrass presence and sparse shoots of eelgrass that may be present at a site, but are not within a contiguous area.

- Consider the values provided in Table 12 as the uncertainty distance around an intact, persistent eelgrass area. It is only through siting activities within this expansion, contraction, and seed dispersal distance that positive or negative changes to eelgrass can be effectively monitored for adaptive management.

Next steps

It was suggested that further examination of the available data might be used to develop some indices of bed characteristics from different areas of the state. Various seagrass attributes (such as shoot density, plant architecture, and colonization rates) have been shown to have a strong relationship to the physical setting of an area (Frederiksen et al., 2004; Robbins & Bell, 1994; Turner et al., 1999). Monitoring interannual variability in shoot density and the edge location in different areas would provide information on how to determine best site uses that do not conflict with sustainable ecological function of eelgrass habitat.

If the intent is to develop the most effective operational definition possible, it will be useful to design initial baseline and adaptive management sampling to evaluate the practicability of the bed criteria and some of the eelgrass metrics listed in Table 2. Data relevant to longshore dynamics of *Zostera marina* are limited (Frederiksen et al., 2004); therefore, Washington DNR's adaptive management monitoring should include baseline sampling designed to explore interannual edge migration in both the cross and longshore.

These proposed edge criteria, delineation methods, and conservation approaches are the outcome of a series of technical workgroup discussions. This information can serve as a starting point for future policy deliberations on developing effective conservation measures that will allow for management of resources, while encouraging sustainable uses on state-owned aquatic lands.

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