Eelgrass Mapping In Crescent Bay, Freshwater Bay, Port Angeles Harbor, and Dungeness Bay June 2009

Prepared by
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Submitted To:
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November 30, 2009

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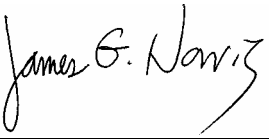

Signature (James G. Norris)

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Introduction

Elwha Dam and Glines Canyon Dam have blocked access to 93% of Elwha River anadromous fish spawning habitat since the early 1900s (NPS 1995). The dams also have limited sediment and woody debris from flowing downstream, thus impacting lower river morphology and the nearshore marine habitats east and west of the river mouth.

In 1992 the United States Congress enacted the Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495) with the goal of fully restoring the Elwha River ecosystem and native anadromous fish populations. The Final Environmental Impact Statement released by the National Park Service in 1995 concluded that removing both dams was the only alternative to meet this goal (NPS 1995).

Six to seven million m^3 of sediment trapped behind the dams will be delivered to the nearshore within five years of dam removal, which is anticipated to be a three year process (Randle et al. 2004). Shaffer et al. (2005) developed a conceptual model for measuring the restoration response of nearshore habitats and fish use to dam removal. The model has two components (Fig. 1):

1. Compare post-dam removal nearshore resource and habitat function to pre-dam removal nearshore resource and habitat function;
2. Compare habitat function within Elwha nearshore to comparable nearshore outside the project area.

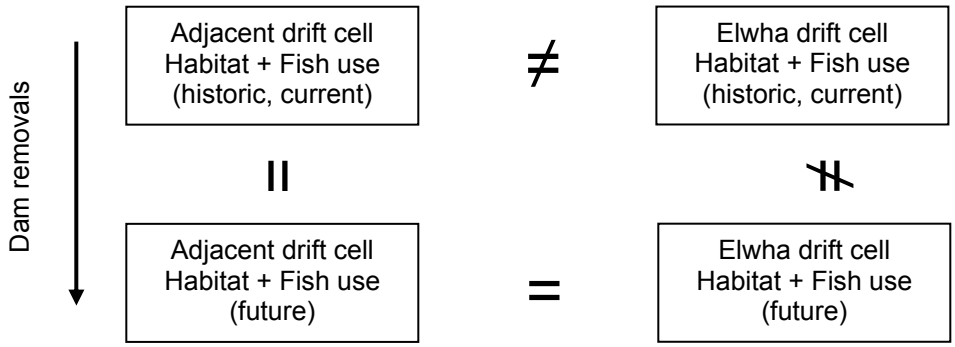

Figure 1. Conceptual model for measuring restoration response to dam removal (from Shaffer et al. 2005).

The primary Elwha drift cell defined by Shaffer et al. (2005) extends from the western edge of Freshwater Bay (3.1 nautical miles of shoreline west of the river mouth) to the eastern end of Ediz Hook (7.2 nautical miles of shoreline east of the river mouth). They identified Crescent Bay and the shoreline between Port Angeles and the tip of Dungeness Spit as comparable shoreline outside the primary drift cell.

In June and September 2006 we surveyed eelgrass (*Zostera marina*) along the entire shorelines of the Elwha and adjacent drift cells as shown in Fig. 2 (Norris et al. 2007). Our goal for this project was to survey eelgrass in Crescent Bay, Freshwater Bay, Port Angeles Harbor (tip of Ediz Hook to Morse Creek), and Dungeness Bay.

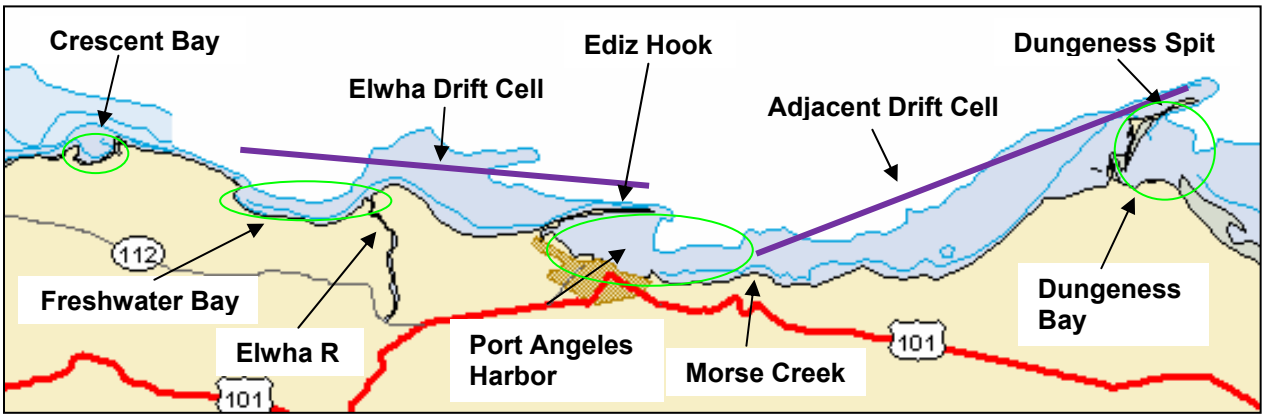

Figure 2. Map of the study areas from the 2006 survey (purple lines) and this survey (shaded green).

Our specific objectives for this survey were to use the Washington State Department of Natural Resources (DNR) Submerged Vegetation Monitoring Project (SVMP) methods to: (1) delineate any eelgrass beds within the study areas; and (2) for each eelgrass bed, estimate five parameters—eelgrass fraction (within a bed boundary, the fraction of the area that has eelgrass), eelgrass area coverage (number of square meters of seabed that has at least one shoot of eelgrass growing on it), patchiness index (the number of eelgrass presence/absence transitions along 100 m of transect length), mean minimum and maximum eelgrass depths (Berry et al. 2003; Dowty et al. 2005). These parameters describe in statistical terms the characteristics of each eelgrass bed and provide a means of comparing a single bed over time or different beds at the same time (see Dowty 2005 for a complete description and discussion of these parameters).

Fig. 3 illustrates the concepts of eelgrass area, eelgrass fraction, and patchiness index. In this figure all three eelgrass beds have the same eelgrass area (i.e., number of square meters of seabed covered with eelgrass, shown in green) within the bed boundary (shown in red). Although eelgrass bed "a" is smaller than beds "b" and "c," the fraction is 100% and the eelgrass area is the same. Beds "b" and "c" have the same eelgrass fraction (about 65%), but bed "c" has a much higher patchiness index.

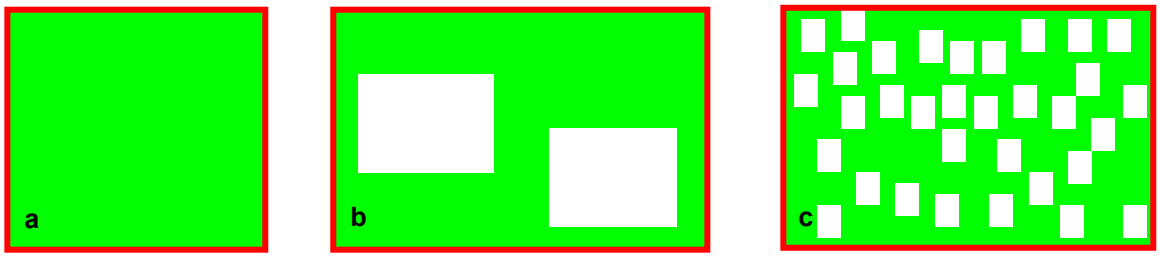

Figure 3. Illustration of eelgrass area coverage, eelgrass fraction, and patchiness.

Fig. 4 illustrates the concepts of mean minimum and maximum eelgrass depths. Each transect running perpendicular to the isobaths has a minimum and maximum eelgrass depth associated with it. If transects within a site are selected randomly, averaging the collection of minimum (or maximum) depth observations provides an estimate of mean minimum (or maximum) eelgrass depth for a site.

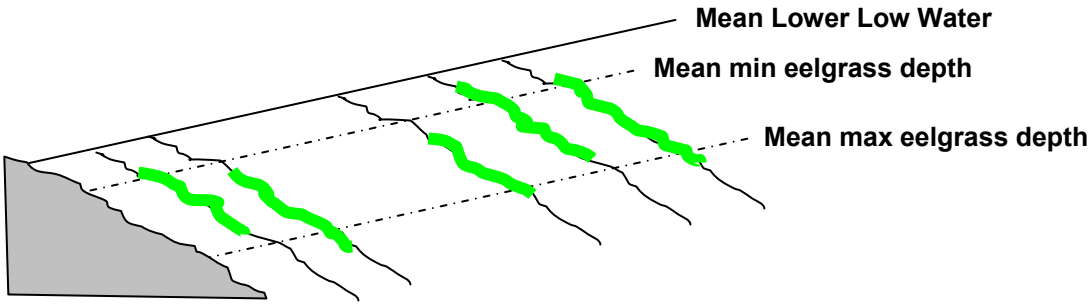

Figure 4. Illustration of mean minimum and maximum eelgrass depths.

Methods

Personnel

We conducted the survey between June 1 and 10, 2009. On all survey days Ian Fraser and Frank Converse served as chief scientist and skipper, respectively.

Site Description

We defined the survey areas to be the DNR SVMP "fringe" sites in Crescent Bay, Freshwater Bay, and Port Angeles Harbor. A fringe site is defined to be a 1000 m length of shoreline as measured along the -20 ft isobath. Crescent Bay, Freshwater Bay, and Port Angeles Harbor contained 2, 7, and 14 fringe sites respectively. For Dungeness Bay we used the two DNR SVMP "flats" sites plus two fringe sites. Flats sites include shallow embayments, tide flats and river deltas.

Sampling Plan

Our two primary goals were to: (1) delineate any eelgrass beds as accurately as possible, given the available field survey time (10 days); and (2) for each eelgrass bed, estimate five parameters using DNR SVMP methods. To satisfy the first goal we could place transects systematically to accurately delineate the eelgrass beds. However, to satisfy the second goal we were required to place transects randomly and oriented perpendicular to the shoreline to satisfy SVMP statistical considerations.

Our sampling plan for each fringe site was to conduct at least 10 randomly selected transects and add non-random transects as needed to more accurately delineate any eelgrass beds. In some cases where no eelgrass was found on the first six or seven randomly selected transects, no further transects were conducted. At the inner flats site in Dungeness Bay (flats50) we used a grid sampling pattern (i.e., non-random) due to its irregular shape and our desire to get an accurate map of the eelgrass distribution. At the outer flats site (flats49) we used 18 random tracks and two non-random tracks. Table 1 lists the number of random and non-random tracks at each site.

Table 1. The number of random, non-random, and total transects conducted at each site.

Area	Site Code	Random	Non-Random	Total	Eelgrass Present
Crescent Bay	sjs2740	9	4	13	Yes
	sjs2741	14	4	18	Yes
	Total	23	8	31	
Freshwater Bay	sjs2727	6	0	6	No
	sjs2728	10	0	10	No
	sjs2729	15	0	15	Yes
	sjs2730	10	0	10	Yes
	sjs2731	11	0	11	Yes
	sjs2732	10	0	10	Yes
	sjs2733	13	1	14	Yes
	Total	75	1	76	
Port Angeles Harbor	sjs2700	10	0	10	No
	sjs2701	10	2	12	Yes
	sjs2702	7	0	7	No
	sjs2703	7	2	9	Yes
	sjs2704	7	0	7	Yes
	sjs2705	16	3	19	Yes
	sjs2706	6	0	6	No
	sjs2707	10	0	10	No
	sjs2708	10	0	10	No
	sjs2709	10	0	10	No
	sjs2710	10	0	10	No
	sjs2711	13	0	13	Yes
	sjs2712	14	1	15	Yes
	sjs2713	13	2	15	Yes
	Total	143	10	153	
Dungeness Bay	sjs2674	10	1	11	Yes
	sjs2675	10	1	11	No
	flats49	18	2	20	Yes
	flats50	0	25	25	Yes
	Total	38	29	67	
	Total	279	48	327	

Survey Equipment and Methods

Vessel

We conducted sampling aboard the 36-ft *R/V Brendan D II* (Fig. 5). We acquired position data using a sub-meter differential global positioning system (DGPS) with the antenna located at the tip of the A-frame used to deploy the camera towfish. Differential corrections were received from the United States Coast Guard public DGPS network using the NAD 83 datum.

A laptop computer running Hypack Max hydrographic survey software stored position data, depth data from one echosounder (Garmin), and user-supplied transect information onto its hard drive. Position data were stored in both latitude/longitude and State Plane coordinates (Washington North, US Survey Feet). All data were updated at 1 s intervals. Table 2 lists all the equipment used during this survey.

Figure 5. The *R/V Brendan D II*.

Table 2. Survey equipment used onboard the *R/V Brendan D II* during the 2009 Elwha nearshore underwater videographic survey.

Item	Manufacturer/Model
Differential GPS	Trimble AgGPS 132 (sub-meter accuracy)
Depth Sounders	BioSonics DE4000 system (including Dell laptop computer with Submerged Aquatic Vegetation software) Garmin FishFinder 250
Underwater Cameras (2)	SplashCam Deep Blue Pro Color (Ocean Systems, Inc.)
Lasers	Deep Sea Power & Light
Underwater Light	Deep Sea Power & Light RiteLite (500 watt)
Navigation Software	Hypack Max
Video Overlay Controller	Intuitive Circuits TimeFrame
DVD Recorder	Sony RDR-GX7
Digital VideoTape Recorder	Sony digital tape deck GVD800

Video Data

We obtained underwater video images using an underwater camera mounted in a down-looking orientation on a weighted towfish. Two parallel red lasers mounted 10 cm apart created two red dots in the video images as a scaling reference. We mounted a second forward looking underwater camera on the towfish to give the winch operator a better view of the seabed. We deployed the towfish directly off the stern of the vessel using the A-frame and winch. Video monitors located in both the pilothouse and the work deck assisted the helmsman and winch operator control the speed and vertical position of the towfish. The weight of the towfish kept the camera positioned directly beneath the DGPS antenna, thus

ensuring that the position data accurately reflected the geographic location of the camera. A video overlay controller integrated DGPS data (date, time) and user supplied transect information (transect number and site code) into the video signal. We stored video images directly onto a Sony Digital8 videotape and onto a DVD-R disk.

Depth Data

Our primary depth sounder was a BioSonics DE4000 system. The advantage of this system is its ability to accurately measure distance between the transducer and the seabed, even when the seabed is covered with dense vegetation (e.g., eelgrass and/or macroalgae). Other depth sounders often measure distance only to the top of the vegetation canopy. The BioSonics system does not produce depth readings in real time. Instead, it records on a laptop computer all of the returning raw signals in separate files for individual transects. During post-processing, individual transect files are combined into larger files and processed through EcoSAV software (part of the BioSonics system). The output is a single text file with time, depth, and position data. These data are then merged with the tide correction data to give corrected depths.

Our backup depth sounder was a Garmin FishFinder 250. Although this echosounder provided real-time estimates of depth (which were recorded by the Hypack Max program), it often estimated depth only to the top of the vegetation canopy rather than to the seabed.

For both echosounders, we mounted the portable transducers on poles attached to the starboard (Garmin) and port (BioSonics) corners of the transom. Since the DGPS antenna was mounted along the centerline of the vessel, each transducer was offset 1.5 m from the DGPS antenna. During analysis, we ignored this slight offset and assumed that depth readings from both depth sounders were taken at the location of the DGPS antenna.

Field Sampling Procedures

At the start of each transect the skipper backed the vessel close to the shoreline and the winch operator lowered the camera to just above the seabed. Visual references were noted and all video recorders and data loggers were started. As the vessel moved along the transect the winch operator viewed live video on a monitor and raised and lowered the camera towfish to follow the seabed contour (Fig. 6). The field of view changed with the height above the bottom. The vessel speed was held as constant as possible (about 1 m/sec). In addition to driving the vessel, the skipper watched a video monitor and used a real-time "clicker" to record preliminary eelgrass observations (i.e., clicker on/off when eelgrass was present/absent on the monitor). The preliminary observations were used to select non-random transects to better delineate eelgrass bed boundaries. However, these observations often included drifting (i.e., non-rooted) plants and do not distinguish between eelgrass and surfgrass (*Phyllospadix* spp.). At the end of the transect, we stopped the recorders, retrieved the camera towfish, and moved the vessel to the next sampling position. We maintained field notes for each transect (Appendices A through D). To verify species identification we occasionally collected specimens using a van Veen grab sampler or by dragging a small Danforth style anchor (Fig. 7).

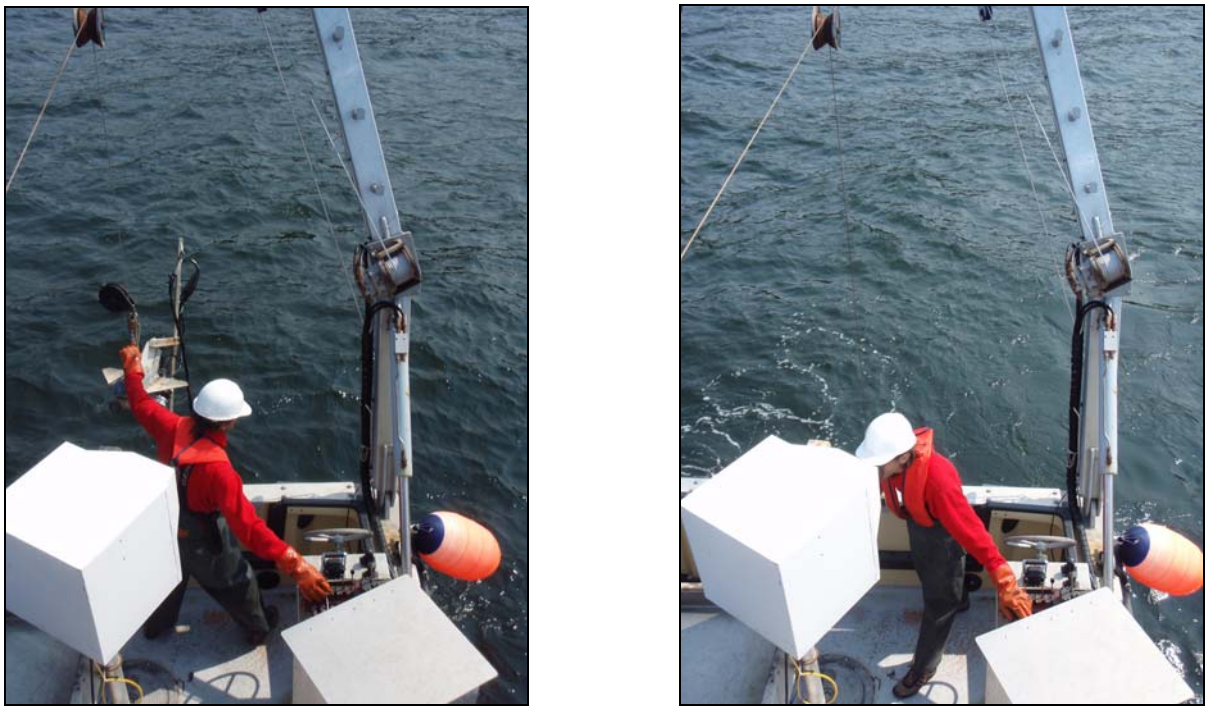

Figure 6. Launching the camera towfish and "flying" the towfish during a transect.

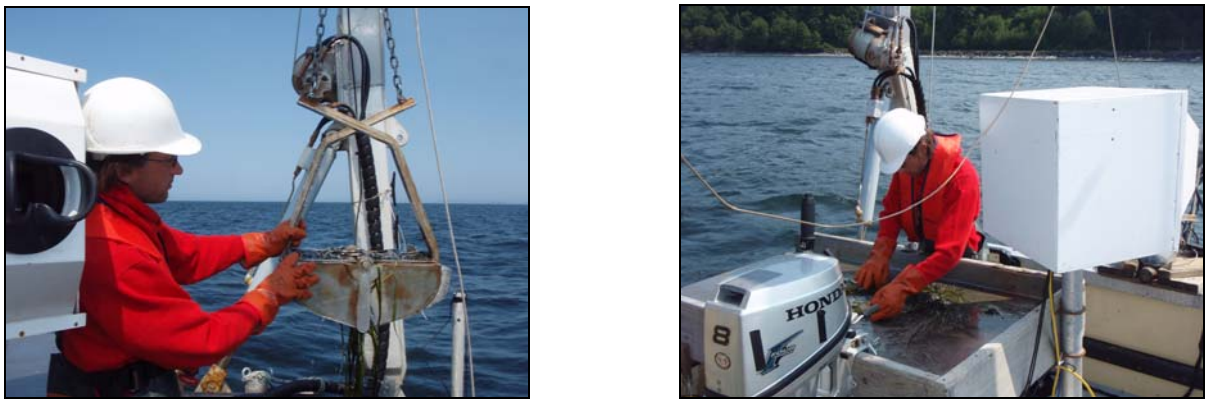

Figure 7. Collecting specimens with a van Veen grab sampler for identification.

Underwater Video Data Post-Processing

Data stored on the laptop computer were downloaded and organized into spreadsheet files including blank columns for video code, eelgrass code, and other seabed attribute codes. To provide consistency with the DNR SVMP we hired their staff to review videotapes to assign video codes (0 = cannot view the seabed; 1 = seabed in view) and attribute codes for eelgrass and surfgrass presence (0 = absent; 1 = present).

Tide Heights

We used the BioSonics echosounder to gather bathymetry data. Raw depths collected from the echosounder measure the distance between the seabed and the transducer. We applied three factors to correct these depths to the MLLW vertical datum:

- transducer offset (i.e., distance between the transducer and the water surface);

- predicted tidal height (i.e., predicted distance between the surface and MLLW);
- tide prediction error (i.e., predicted tidal height minus the observed tidal height at a reference station).

Corrected depth equals depth below the transducer plus the transducer offset minus the predicted tidal height plus the tide prediction error. We measured the transducer offsets directly each day. To get predicted tide heights we used the computer program Tides and Currents Pro 3.0 (Nobletec Corporation). Table 3 gives the specific stations used for each site (when two stations are given the predictions were averaged).

Table 3. Tide prediction station data for each study area.

Study Area	Sites	Tide Station ID(s)	Tide Station Location
Crescent Bay	sjs2740 to sjs2741	0979 (Crescent Bay)	48 10.00 N; 123 44.00 W
Freshwater Bay	sjs2727 to sjs2733	0979 (Crescent Bay) 0982 (Ediz Hook)	48 10.00 N; 123 44.00 W 48 08.40 N; 123 24.80 W
Port Angeles Harbor (south)	sjs2700 to sjs2708	0981 (Port Angeles)	48 07.50 N; 123 26.40 W
Port Angeles Harbor (north)	sjs2709 to sjs2713	0982 (Ediz Hook)	48 08.40 N; 123 24.80 W
Dungeness	Flats49, Flats50, and sjs2674 to sjs2675	0983 (Dungeness)	48 10.00 N; 123 07.00 W

We computed tide prediction errors by comparing the computer program predicted tide heights for the Port Townsend reference station (station ID 0995; 48.90 N, 122 45.00 W) with actual observed tide heights published by the National Oceanic and Atmospheric Administration on their web site (http://tidesandcurrents.noaa.gov).

We merged all data (using DGPS time as the common field) into a single database file and screened each data field for gross errors. We created maps in Hypack Max, ArcGIS Map, and AutoCad to illustrate the locations of tracks and eelgrass observations. We estimated eelgrass parameters using DNR SVMP methods, as described in the next section.

Parameter Estimation

Eelgrass Fraction and Area Coverage

For individual fringe sites, we estimated the total eelgrass area coverage at each fringe site using methods described in Norris et al. (1997) and Dowty (2005). After video tape post-processing, we plotted the positions of all eelgrass observations in AutoCAD and drew polygons around the eelgrass beds. We calculated the area (A) of each polygon using AutoCAD tools. At sites that had been surveyed previously (Crescent Bay and Freshwater Bay) we used the same polygons as in previous analyses.

At the western edge of site sjs2741 in Crescent Bay our physical sampling indicated the presence of the surfgrass *Phyllospadix serrulatus*, sometimes mixed with *Z. marina*. This

species is very difficult to distinguish from *Z. marina* on video footage alone, and this is the first survey at this site in which the video tape reviewers attempted to distinguish the two during video tape post-processing. To make our analyses consistent with previous years, we combined the *P. serrulatus* and *Z. marina* observations into a single "eelgrass" category.

For each straight-line transect, we computed (using proprietary software) the length of the transect passing through the eelgrass polygon and the lengths associated with eelgrass presence. Table 4 lists the notation and formulae for estimating eelgrass area coverage at a single site.

Table 4. Notation and formulae for estimating eelgrass area coverage at a single site.

Parameter	Estimation formula	Definition
n		Number of transects passing through the sample polygon.
A		Area within the sample polygon. This value is determined after the sample polygon is drawn using AutoCAD or ArcGIS or some other analytical means.
l_i		Length of track i that has eelgrass.
L_i		Length of track i within the sample polygon.
$\hat{\rho}$	$\frac{\sum_i l_i}{\sum_i L_i}$	Estimated eelgrass fraction (i.e., fraction of sample area A that has eelgrass).
$Var(\hat{\rho})$	$\frac{1-f}{n \cdot \bar{L}^2} \frac{\sum_i l_i^2 - 2\hat{\rho}\sum_i L_i l_i + \hat{\rho}^2 \sum_i L_i^2}{n-1}$	Estimated variance of $\hat{\rho}$.
$\hat{E}$	$\hat{\rho}A$	Estimated area of eelgrass within sample polygon.
$Var(\hat{E})$	$A^2 Var(\hat{\rho})$	Estimated variance of $\hat{E}$.
CI	$CI = \hat{E} \pm 1.28\sqrt{Var(\hat{E})}$	Approximate 80% confidence interval around $\hat{E}$ assuming a normal distribution.

When a single eelgrass bed spanned two or more fringe sites, we computed the total bed area as the sum of the individual fringe site areas and the associated variance as the sum of the variances. Let B = bed index and h = fringe site index. Then

$$\hat{E}_B = \sum_h \hat{E}_h \text{ and } Var(\hat{E}_B) = \sum_h Var(\hat{E}_h).$$

We estimated the eelgrass fraction for the total bed as:

$$\hat{\rho}_B = \frac{\sum \hat{E}_h}{\sum A_h}.$$

Since each video observation also has an associated depth observation, it is possible to estimate the amount of eelgrass within any given depth zone (see Table 5 for the notation and formulae). For depth zone estimates we used 1 ft wide depth zones centered around whole numbers (e.g., the -2 ft depth zone ranged from -1.50 ft to -2.49 ft).

Table 5. Notation and formulae for estimating eelgrass fraction and eelgrass area coverage within a given depth zone.

Parameter	Estimation formula	Definition
n_d		Number of transects passing through both the sample polygon and depth zone *d*.
A_d	$\frac{\sum_i L_{i,d}}{\sum_i L_i} \cdot A$	Estimated area inside the sample polygon and inside depth zone *d*. This area is unknown unless known isobaths are available.
$l_{i,d}$		Length of track *i* that has eelgrass within depth zone *d*.
$L_{i,d}$		Length of track *i* within the sample polygon and within depth zone *d*.
$\hat{\rho}_d$	$\frac{\sum_i l_{i,d}}{\sum_i L_{i,d}}$	Estimated eelgrass fraction (i.e., fraction of area within depth zone *d* that has eelgrass).
$Var(\hat{\rho}_d)$	$\frac{1-f}{n_d \cdot \bar{L}_d^{\,2}} \frac{\sum_i l_{i,d}^{\,2} - 2\hat{\rho}_d \sum_i L_{i,d} l_{i,d} + \hat{\rho}_d^{\,2} \sum_i L_{i,d}^{\,2}}{n_d - 1}$	Estimated variance of $\hat{\rho}_d$.
$\hat{E}_d$	$\hat{\rho}_d \hat{A}_d = \frac{\sum_i l_{i,d}}{\sum_i L_{i,d}} \cdot \frac{\sum_i L_{i,d}}{\sum_i L_i} \cdot A = \frac{\sum_i l_{i,d}}{\sum_i L_i} \cdot A$	Estimated amount of eelgrass located within the sample polygon and depth zone *d*. Note that both components of this parameter are estimated.

Mean Minimum and Maximum Eelgrass Depths

Minimum and maximum eelgrass depths refer to the shallow- and deepwater boundaries of eelgrass growth. Consider a straight-line transect oriented perpendicular to the isobaths (i.e., running shallow to deep) and passing through an eelgrass bed. If one records the depths at which eelgrass is observed at regular intervals along the transect, there will be both a minimum and a maximum depth observation. If measurements are taken along many such transects, one will have a collection of minimum and maximum depth measurements. Our

parameters of interest are the averages of these collections of minimum and maximum depth measurements. We used depths from BioSonics echosounder to estimate these parameters.

When a single bed spanned two or more fringe sites, we estimated bed depth parameters using formulae for stratified random sampling (treating each fringe site as a separate stratum within the bed). Thus, we computed the mean minimum (maximum) eelgrass depth as the weighted mean of the individual fringe sites, where the weights were determined from the number of random transects within each site. Let B = bed index and h = fringe site index. Then

$$\hat{\bar{D}}_B = \sum_h W_h \hat{\bar{D}}_h$$

where $\hat{\bar{D}}_h$ = estimated mean minimum (or maximum) eelgrass depth at site h and

$$W_h = \frac{n_h}{\sum_h n_h}$$

(n_h = number of depth observations at site h). We estimated the bed variance as:

$$Var_B = \sum_h \frac{W_h^2 \cdot Var_h}{n_h} .$$

Confidence intervals were estimated using:

$$\hat{\bar{D}}_B \pm t \cdot \sqrt{Var}_B$$

where the t-statistic effective degrees of freedom was computed as

$$n_e = \frac{\left(\sum Var_h\right)^2}{\sum \frac{Var_h^2}{n_h - 1}} .$$

Patchiness Index

Patchiness index was computed as the number of patch/gap transitions per 100 m of straight-line transect length. A gap was defined to be a transect section at least 1 m long with no eelgrass. For a bed composed of multiple sites we computed patchiness index as the weighted average with the weights being the estimated eelgrass areal extent for individual sites:

$$PI_B = \sum_h W_h PI_h \text{ where } W_h = \frac{\hat{E}_h}{\sum_h \hat{E}_h} .$$

Results

In Crescent Bay and Freshwater Bay we observed eelgrass in the same locations as in previous surveys. In the areas not previously surveyed we observed eelgrass beds in the following locations:

- the inner eastern portion of Ediz Hook;
- just east of the Port Angeles City Pier (Feiro Marine Life Center);
- the eastern tip of Dungeness Spit;
- outer Dungeness Bay;
- inner Dungeness Bay.

We did not observe any eelgrass in the industrialized western part of Port Angeles harbor. Much of the seabed in this area was covered with wood waste. East of the old Rayonier Mill we observed a few rooted eelgrass plants in two sites (sjs2701 and sjs2703), but no significant bed formations. Table 6 summarizes the statistics for all observed eelgrass beds, and Tables 11 and 12 in appendix E provide detailed results for individual sites where eelgrass was observed. The following sections provide more detailed results for each study area.

Table 6. Summary statistics for eelgrass beds surveyed by this project.

Bed	DNR SVMP Sites	Eelgrass Area (ha)	Patch Index	Eelgrass Fraction	Mean Max Depth (ft)	Mean Min Depth (ft)
West Crescent Bay	W sjs2741	10.3	7.4	49%	-21.3	-3.1
East Crescent Bay	E sjs2741 sjs2740	2.6	6.5	10%	-28.8	-19.9
West Freshwater Bay	sjs2731 sjs2732 sjs2733	23.9	12.0	55%	-20.8	-3.2
East Freshwater Bay	sjs2729 sjs2730	1.5	8.8	14%	-21.8	-12.5
Inner Ediz Hook	sjs2711 sjs2712 sjs2713	2.6	1.85	45%	-15.6	-2.1
Port Angeles Harbor	sjs2705	1.8	9.0	57%	-4.7	-1.6
Dungeness Spit	sjs2675	0.3	2.8	7%	-22.0	-19.6
Outer Dungeness Bay	flats49	74.8	5.7	23%	-23.1	-0.6
Inner Dungeness Bay	flats50	72.3	2.5	22%	-7.7	-0.8

Crescent Bay

Crescent Bay contains two DNR fringe sites—sjs2740 and sjs2741. The DNR SVMP surveyed sjs2741 from 2000 to 2005. In our report for the 2006 survey we re-analyzed the 2005 data for site sjs2741 by breaking it into western and eastern portions to illustrate the dramatic difference in eelgrass depth distribution within the site. In the eastern portion of the site, which is less protected from dominant westerly wind and wave energy, the grass does not grow as shallow as in the western end and is more patchily distributed. This distribution

pattern was very similar to that observed in Freshwater Bay during the 2006 survey for the Clallam County Marine Resources Committee.

Fig. 8 shows the track locations and eelgrass observations for the current survey, which also included site sjs2740. Note that the eastern portion of sjs2740 was dominated by a rocky reef and did not contain any eelgrass. To compare our current findings with those of the 2006 survey, we divided site sjs2741 into the same east and west components we used in 2006. Although the summary statistics show some minor differences between the two surveys (Table 7), none of the differences are statistically significant. The depth profiles are also very similar between years, but very different between the east and west sites (Fig. 9). Note that in Table 6 we combined east sjs2741 with sjs2740 to define the "East Crescent Bay" bed.

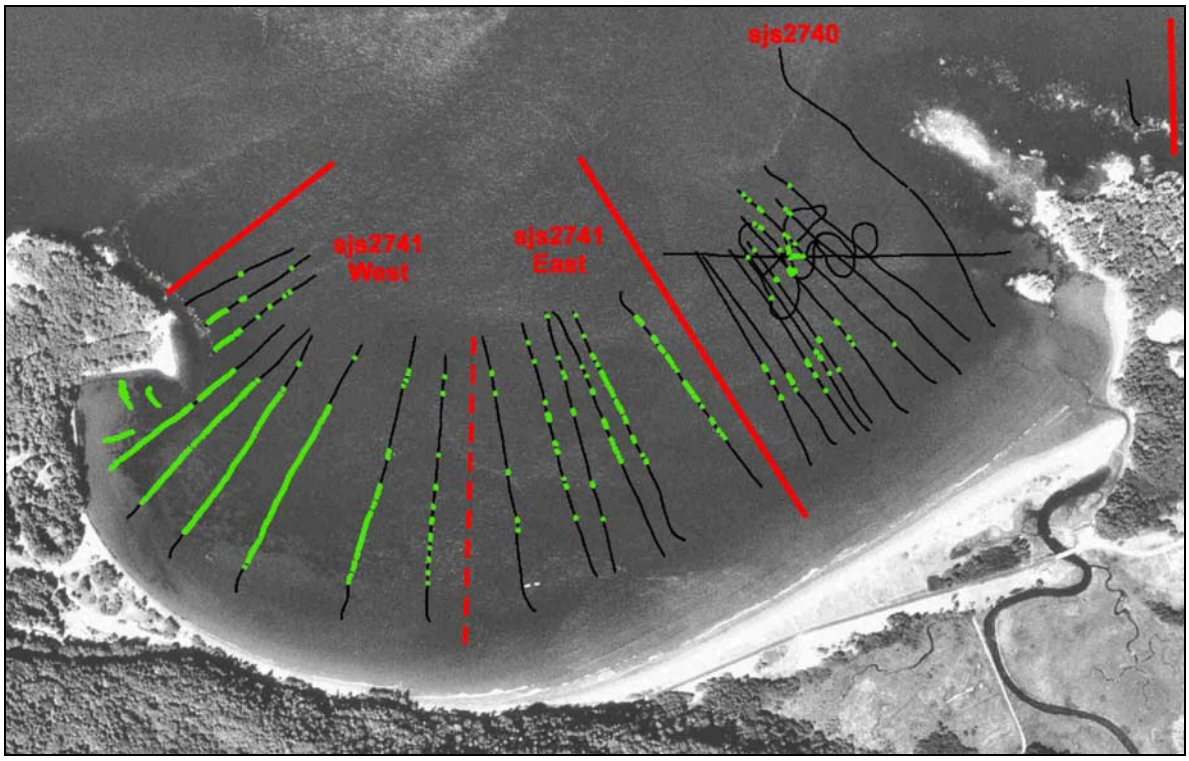

Figure 8. Transect locations (black) and eelgrass observations (green) in Crescent Bay.

Table 7. Summary statistics by survey year for the west and east portions of site sjs2741.

Site and Survey Date	Eelgrass Area (ha)	Patchiness Index	Eelgrass Fraction	Mean Maximum Depth (ft)	Mean Minimum Depth (ft)
sjs2741 West 2005 *	12.8	4.36	61%	-25.4	-4.0
sjs2741 West 2009	10.3	7.43	49%	-21.3	-3.1
sjs2741 East 2005 *	2.3	5.31	14%	-26.6	-16.1
sjs2741 East 2009	2.2	7.27	14%	-28.5	-18.5

* From DNR SVMP

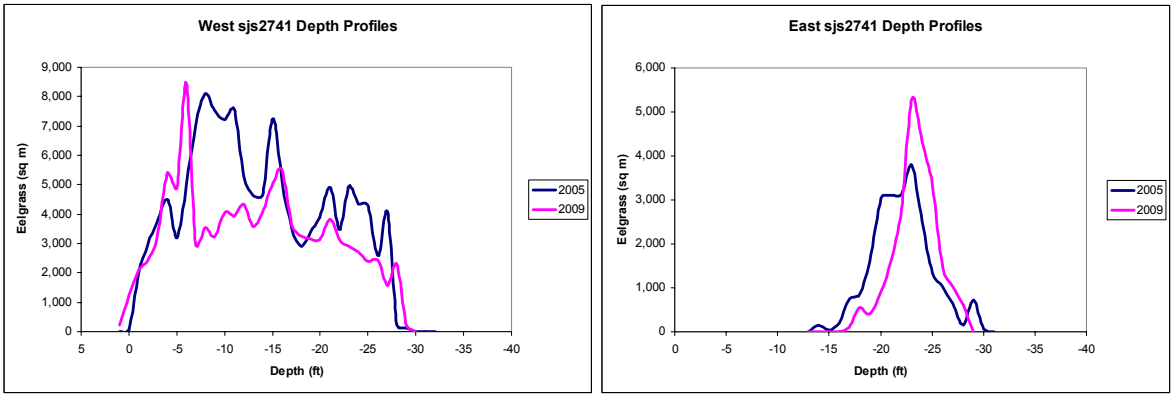

Figure 9. Depth profiles by survey year for the western and eastern portions of site sjs2741.

Freshwater Bay

The eelgrass distribution in Freshwater Bay was very similar to that observed during the June 2006 survey (Fig. 10). Most of the eelgrass was located in the protected western third of the bay (west bed). A smaller bed of grass was located about 0.8 nm west of the Elwha River mouth (east bed). No eelgrass was observed near the Elwha River mouth. The summary statistics (Table 8) and depth profiles (Fig. 11) for both the west and east beds are nearly identical to those from the 2006 survey.

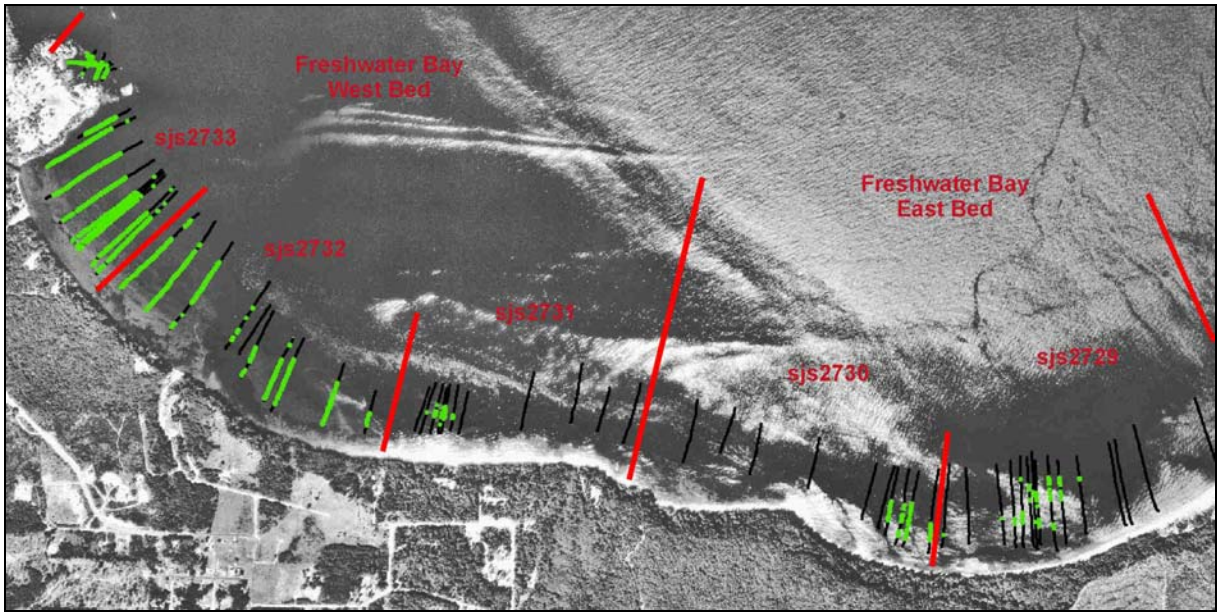

Figure 10. Transect locations (black) and eelgrass observations (green) in Freshwater Bay.

Table 8. Summary statistics by survey year for the west and east beds in Freshwater Bay.

Site and Survey Date	Eelgrass Area (ha)	Patchiness Index	Eelgrass Fraction	Mean Max Depth (ft)	Mean Min Depth (ft)
Freshwater Bay West 2006	21.6	8.6	52%	-19.9	-3.7
Freshwater Bay West 2009	23.8	12.0	55%	-20.8	-3.2
Freshwater Bay East 2006	1.6	8.3	15% *	-21.5	-13.0
Freshwater Bay East 2009	1.5	8.8	14%	-21.8	-12.5

* The Final Report for the 2006 survey misreported this eelgrass fraction as 26%.

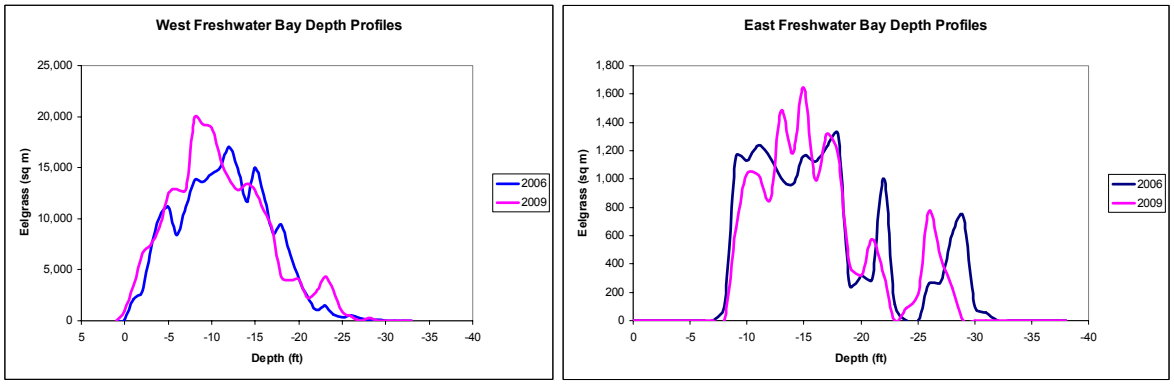

Figure 11. Depth profiles by survey year for the west and east eelgrass beds in Freshwater Bay.

Port Angeles Harbor

We found no eelgrass in the western half of Port Angeles Harbor (sites sjs2706 to sjs2710). Much of this shoreline is industrialized, and a large percentage of the seabed was covered with wood waste.

We observed only two prominent eelgrass beds in rest of the Port Angeles Harbor area. The first was a narrow band of eelgrass along the southern edge of Ediz Hook from just west of the lighthouse to approximately 330 m west of the Pilot Station (Fig.12). Eelgrass in this bed was concentrated in shallower water than the outer bed surveyed in 2006 (Fig. 13).

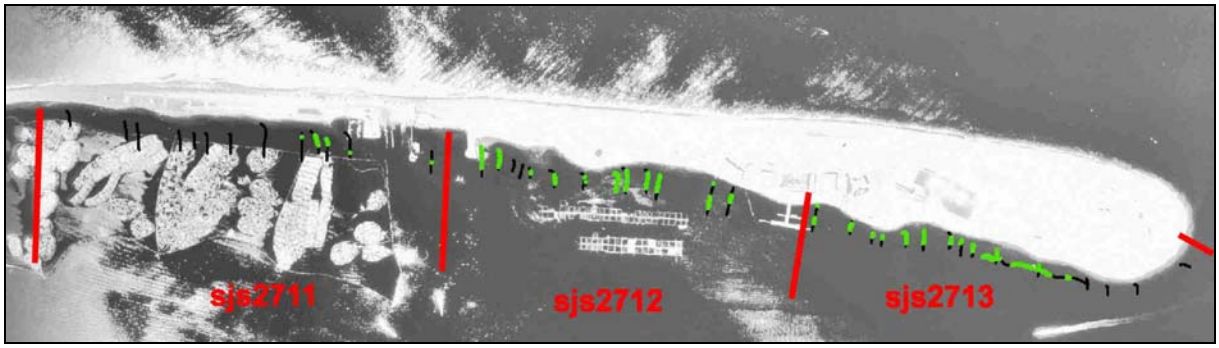

Figure 12. Transect locations (black) and eelgrass observations (green) in the inner portion of Ediz Hook.

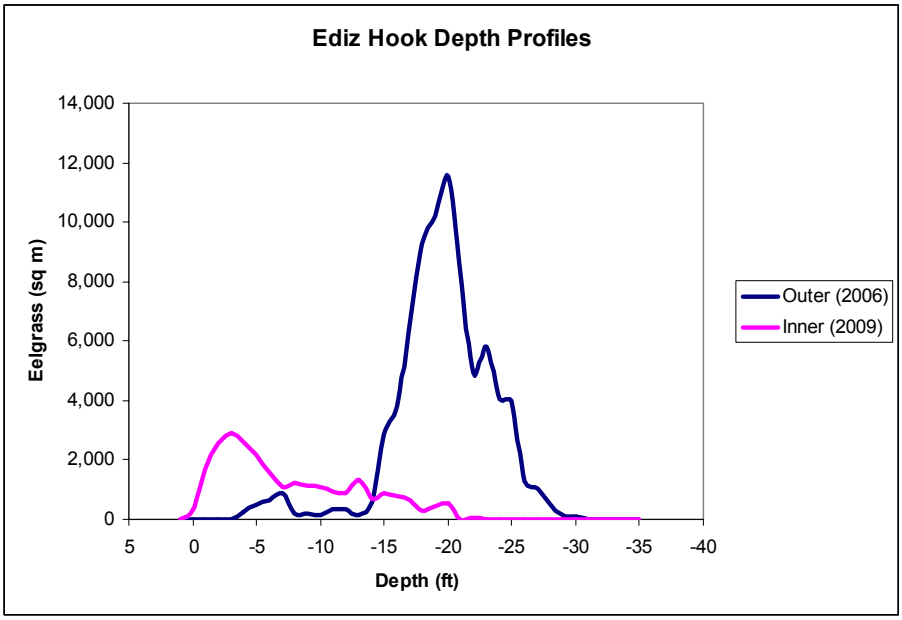

Figure 13. Eelgrass depth profiles for the outside bed surveyed in 2006 and the inside bed surveyed in 2009.

The second eelgrass bed was another narrow band of eelgrass extending east approximately 520 m from the Port Angeles City Pier (Fig. 14). This bed lies almost entirely within site sjs2705, but extends approximately 55 m into site sjs2704 (only the westernmost transect in site sjs2704 passed through the bed). Most of the eelgrass in this bed was concentrated between -1 ft and -5 ft (Fig. 15). Site sjs2703 had a few eelgrass plants and sjs2701 had a small patch of eelgrass.

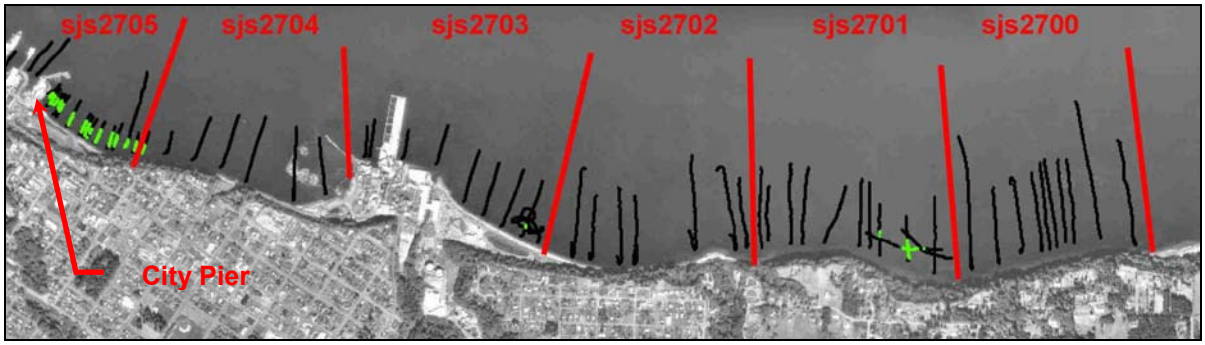

Figure 14. Transect locations (black) and eelgrass observations (green) east of the Port Angeles City Pier.

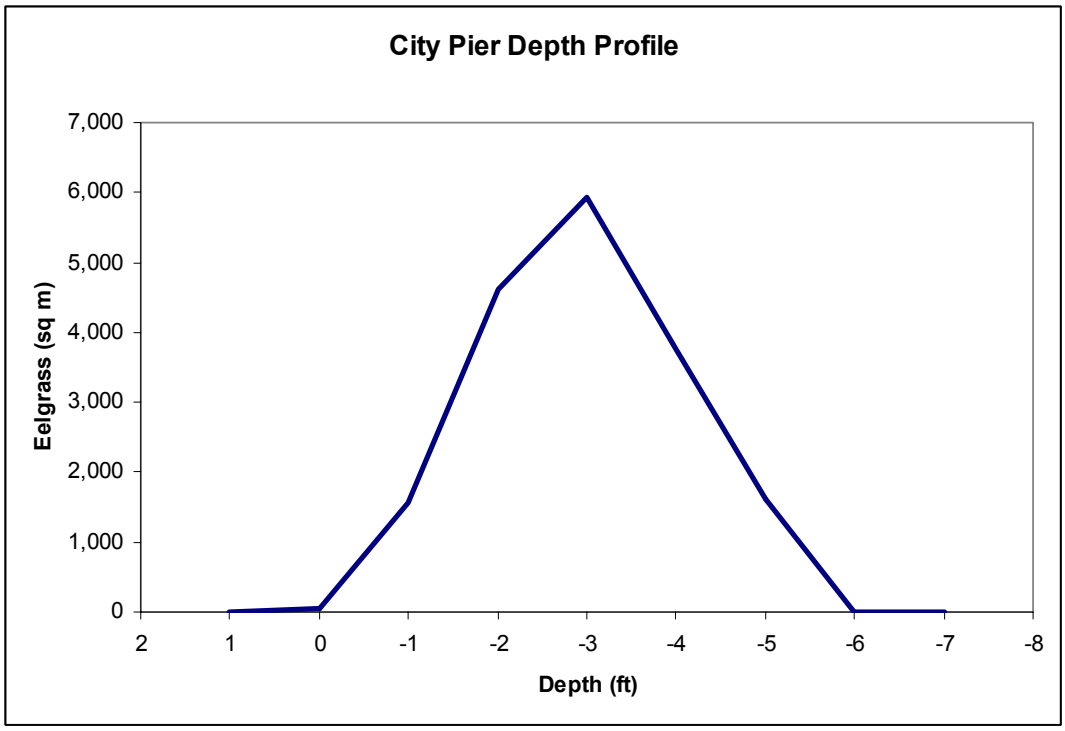

Figure 15. Eelgrass depth profile for the bed (sjs2705) just east of the Port Angeles City Pier.

Dungeness Bay

We observed a small patch of eelgrass at the tip of Dungeness Spit, but no eelgrass along the inner 1700 m of the spit (Fig. 16). Eelgrass at this location was concentrated in a very narrow depth range of -21 ft to -22 ft (Fig. 17).

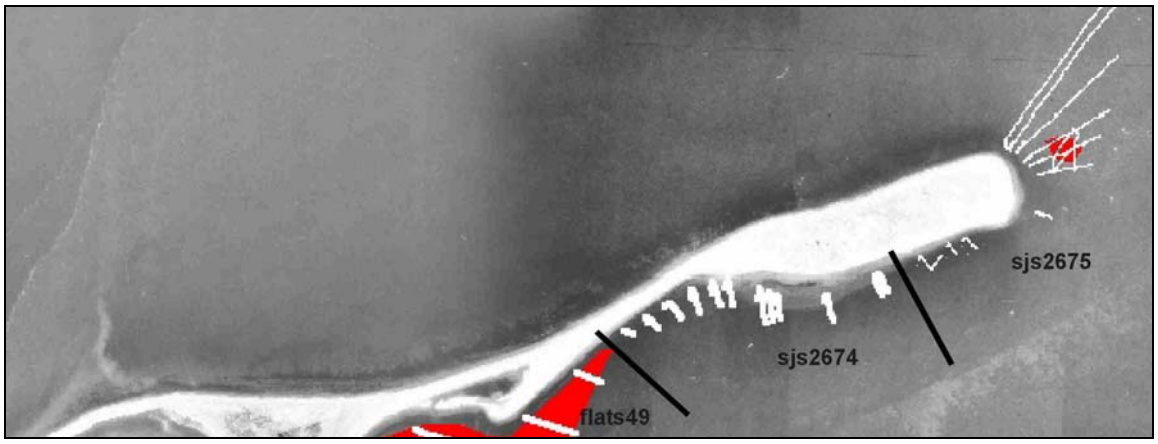

Figure 16. Track lines (white) and eelgrass beds (red) observed around the tip of Dungeness Spit.

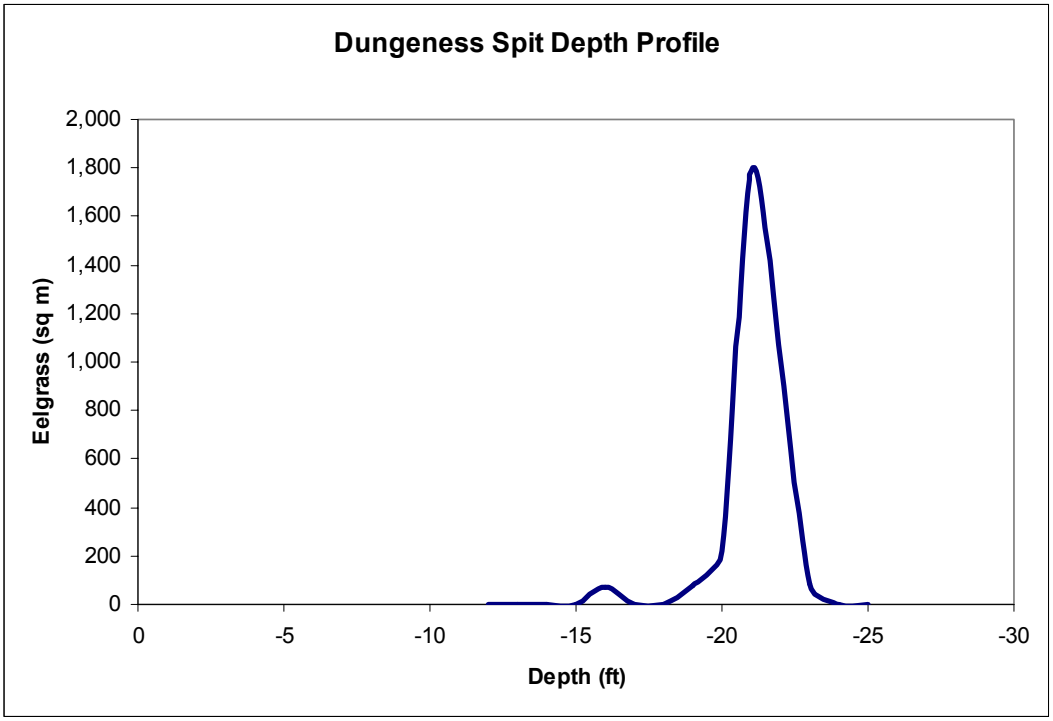

Figure 17. Eelgrass depth profile for the small bed at the tip of Dungeness Spit (sjs2675).

The outside flats site (flats49) had patchy eelgrass throughout (Fig. 18). Eelgrass in the inner flats site (flats50) was located mostly in the northern half of the site, although we also observed a very narrow band of eelgrass along the southeastern shore and widely scattered individual plants in the southwestern portion of the site (Fig. 18).

The summary statistics for these two sites (Table 9) are quite similar, except for the mean maximum eelgrass depths (-23.1 ft in the outer bay compared with -7.7 ft for the inner bay). Eelgrass in the inner bay was concentrated in a narrow depth range between -1 ft and -4 ft (Fig. 19).

Table 9. Summary statistics for the inner (flats50) and outer (flats49) sections of Dungeness Bay surveyed in 2009.

Site	Eelgrass Area (ha)	Patchiness Index	Eelgrass Fraction	Mean Max Depth (ft)	Mean Min Depth (ft)
Flats49 (outer bay)	74.8	5.72	23%	-23.1	-0.6
Flats50 (inner bay)	72.3	2.51	22%	-7.7	-0.8

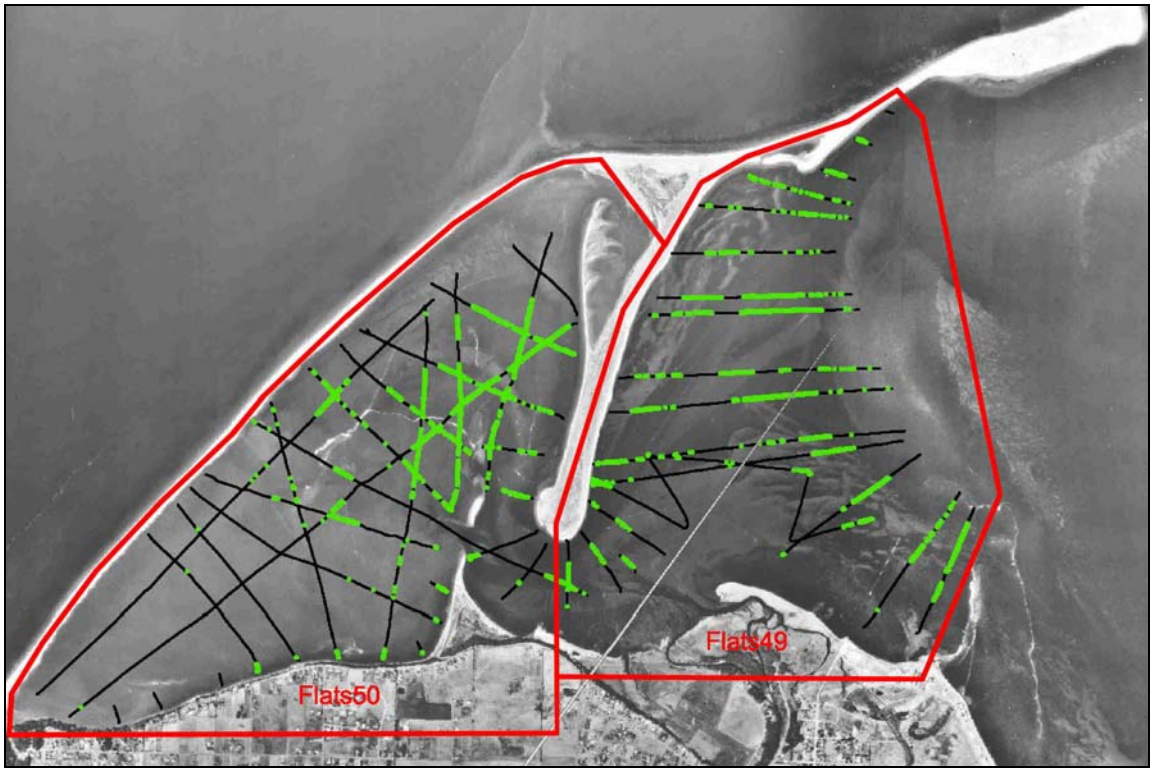

Figure 18. Transect locations (black) and eelgrass observations (green) in Dungeness Bay.

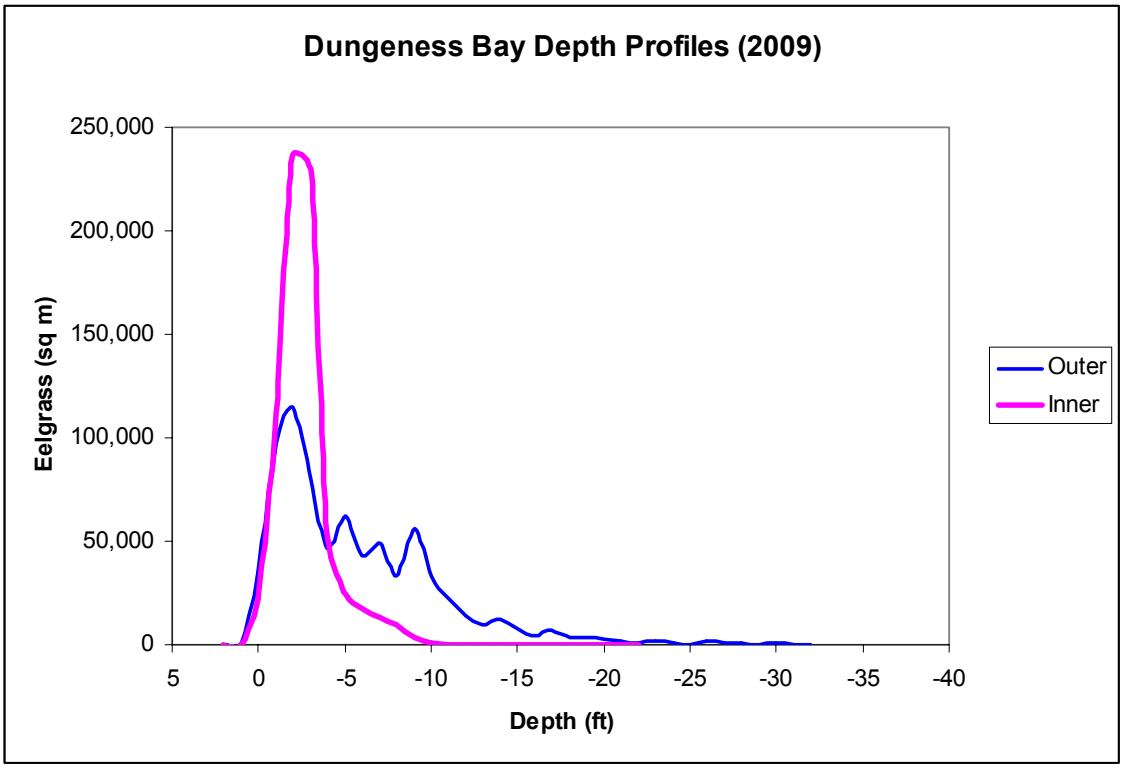

Figure 19. Eelgrass depth profiles for the inner (flats49) and outer (flats50) portions of Dungeness Bay.

Discussion

With the completion of this work we have now surveyed nearly the entire shoreline between Crescent Bay and Dungeness Bay (Fig. 20). The only section not surveyed is the rocky shoreline between Crescent and Freshwater Bays, an area that appears to be dominated by canopy forming kelp with low probability of eelgrass presence. For perspective, we have included the large Jamestown eelgrass bed in Fig. 20 which has been surveyed by the DNR SVMP every year since 2000. The average estimated Jamestown eelgrass area from 2000 to 2007 was 468 ha (Fig. 21), about twice the area of all beds between Crescent Bay and Dungeness Bay combined.

Our results indicate that the beds in Crescent and Freshwater Bays were relatively unchanged over the past three to five years with respect to both location and statistical description. For site sjs2741 in western Crescent Bay the DNR SVMP also observed no significant change in the long-term trend analysis from 2000 to 2005, although they did note some significant changes between adjacent years (Fig. 21; Berry et al. 2003, Dowty et al. 2005, Gaeckle et al. 2007). Their results from 2003 to 2004 are particularly interesting. All four sites surveyed along the Strait of Juan de Fuca had significant increases from 2003 to 2004—Pysht River (sjs2775), Crescent Bay (sjs2741), Jamestown (core003), and Protection Island (sjs0989). This suggests the possibility of a common factor affecting eelgrass beds throughout an area that extends well beyond the Elwha and adjacent drift cells. Thom et al. (in prep) show that climate-forced variations in water temperature, mean sea level, and desiccation stress may drive annual variations in eelgrass density and growth rate. Thus, when examining the effects of Elwha dam removals on eelgrass beds, researchers must also consider the possible effects of more broad-scale environmental forcing factors.

Eelgrass beds within our study region fall into three broad categories (Fig. 22; Table 10): (1) large depth range; (2) narrow, deep depth range; and (3) narrow, shallow depth range. The first category includes western portions of Crescent and Freshwater Bays, inner Ediz Hook, and outer Dungeness Bay. The average depth range for these sites is from -2.0 ft at the shallow edge to -22.2 ft at the deep edge. These sites are protected from dominant westerly winds, are open to the south or east, and have relatively steep slope that extends into depths below -45 ft.

Beds in the narrow, deep depth range category include east Crescent Bay, east Freshwater Bay, outer Ediz Hook, Dungeness Bluffs, and Dungeness Spit. The average maximum eelgrass depth at these sites (-23.2 ft) is nearly the same as for the large depth range category (-22.2 ft), but the average minimum eelgrass depth is much deeper (-14.0 ft vs -2.0 ft). These sites are exposed to dominant westerly winds and have slopes that extend into depths below -45 ft. During both our 2006 and 2009 surveys in these areas we noted very poor visibility along the shoreline due to suspended sediment during and shortly following high wind events. It is likely that both lower light availability and physical disturbance from higher wave energy combine to prevent eelgrass from growing in shallow water at these sites.

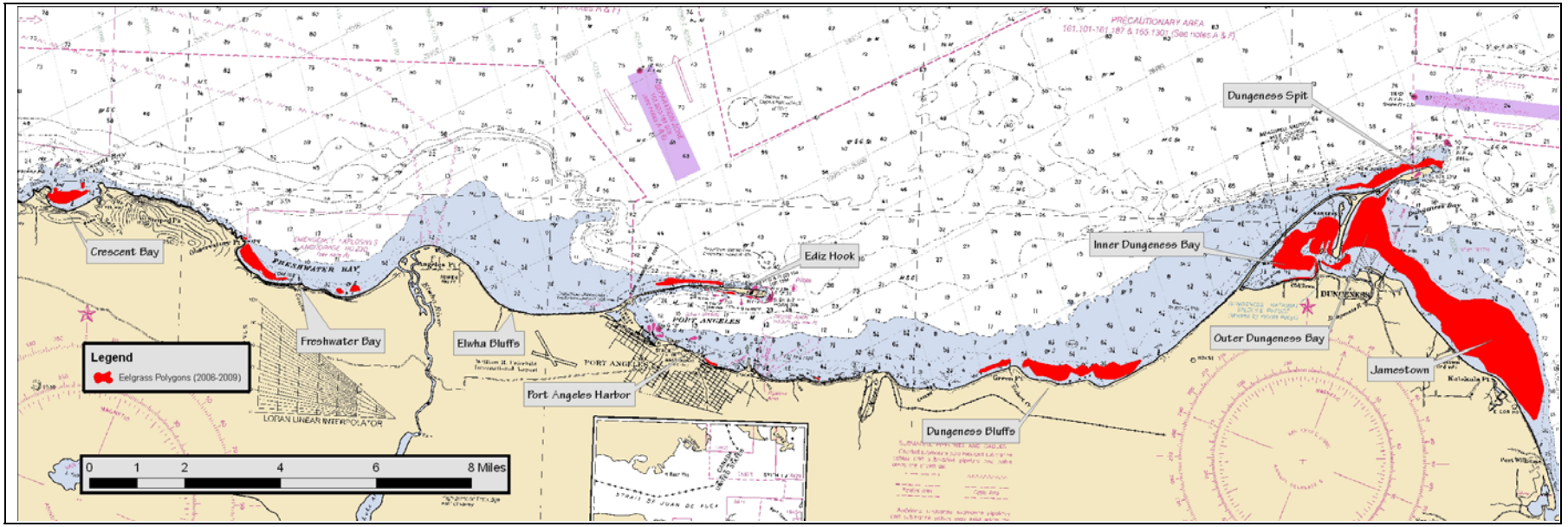

Figure 20. Eelgrass beds (red) observed during the 2006 and 2009 Clallam County MRC surveys and the Jamestown eelgrass bed surveyed by the DNR SVMP from 2000 to 2009.

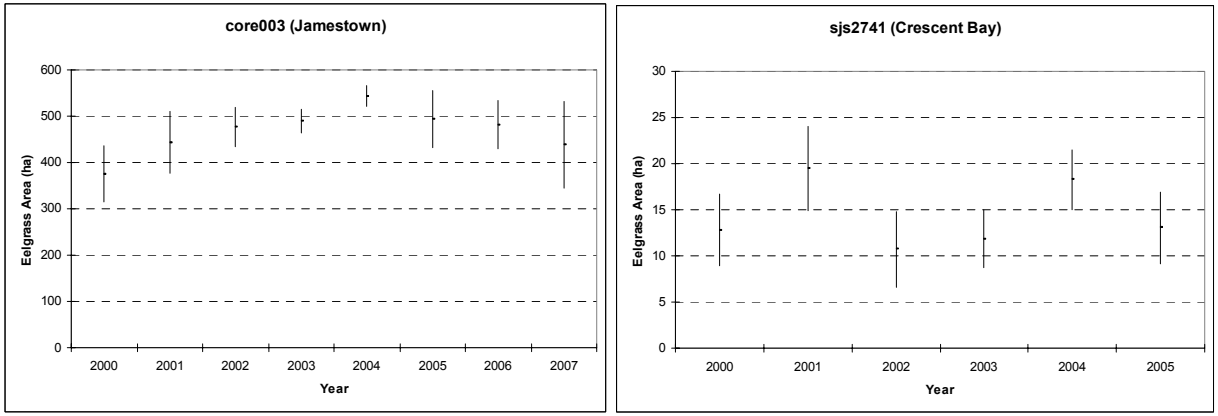

Figure 21. DNR SVMP eelgrass coverage estimates (w/ 80% conf intervals) for sites core003 (Jamestown) and sjs2741 (Crescent Bay).

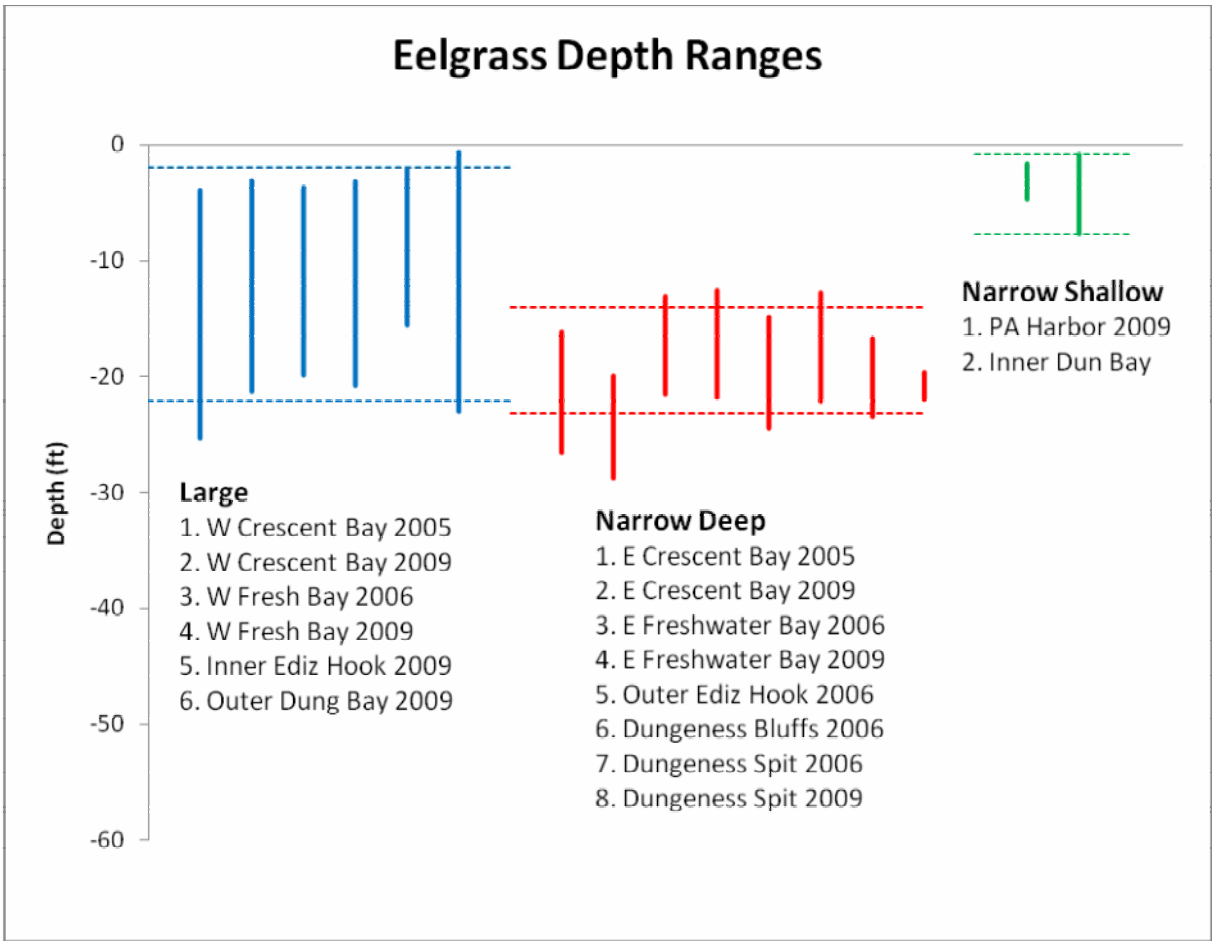

Figure 22. Eelgrass depth ranges (mean minimum depth to mean maximum depth) for all major eelgrass beds and years surveyed.

Table 10. Weighted average characteristics (weights are bed eelgrass areas) of three eelgrass bed types.

Bed type	Patchiness Index	Eelgrass Fraction	Mean Max Depth (ft)	Mean Min Depth (ft)
Large depth range	7.1	.38	-22.2	-2.0
Narrow, deep depth range	7.7	.20	-23.2	-14.0
Narrow, shallow depth range	2.7	.23	-7.7	-0.8

Only two beds are in the narrow, shallow depth range category—the bed along the south shore of Port Angeles Harbor and the bed in inner Dungeness Bay. The average depth range is -0.8 ft to -7.7 ft. Both of these areas are protected from westerly winds, so we speculate that some other factors prevent eelgrass from growing much deeper than -7.7 ft. As noted in the results section, the southwestern portion of inner Dungeness Bay had very poor visibility.

On both the 2006 and 2009 surveys we frequently observed the surfgrass *P. scouleri* in shallow areas. This species is relatively easy to distinguish from *Z. marina* on video footage,

and we recommend that future underwater videographic surveys continue to separate these two species. We observed *P. serrulatus* occasionally in deeper areas and often mixed with *Z. marina*. Since this species is much more difficult to distinguish from *Z. marina*, we recommend that future underwater videographic surveys in this area do not separate these two species for analysis purposes. However, it is still recommended to continue the collection of specimen samples to verify that all species are still present after the dams are removed.

We did not post-process this survey's video footage for algae or fish presence/absence. However, our field notes and analyses from the 2006 survey make it clear that algae is the dominant vegetative feature of the shoreline between Crescent Bay and Dungeness Bay, and that this habitat appears to be important for juvenile fish species, especially Pacific sandlance (*Ammodytes hexapterus*). We recommend that the video footage collected during 2006 and 2009 be post-processed again to describe in more detail the algal community. This community is quite complex, and DNR staff are currently developing an effective post-processing methodology (T. Mumford, pers. comm.). Of immediate interest is the possible expansion of *Ulva* in the Dungeness Bay and Jamestown areas (A. Shaffer, pers. comm.). No further field work would be necessary, and the labor intensive post-processing might make a good project for properly trained MRC volunteers or Peninsula College students.

Acknowledgments

We greatly appreciate the especially thorough review of this report by Jeff Gaeckle of the Washington State Department of Natural Resources. We also thank Anne Shaffer and Tom Mumford for their helpful comments and Ron Thom for kindly sharing his relevant "in-prep" manuscript. The Northwest Straits Commission and the Clallam County Marine Resources Committee funded this project. Cathy Lear provided administrative assistance.

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Appendix A

Crescent Bay
Field Notes

Site	Date	Track	Time	Comment
sjs2740	6/3/2009	1	0740	W. edge of site. Mostly bare sand. *Dendraster* (sand dollars) @ start. Patches of eelgrass.
		2	0759	E. of 1, pretty similar. Eelgrass in occasional patches 15-25 feet.
		3	0813	E. of 2, less eelgrass.
		4	0820	Deep to shallow. East of 3, one patch deeper ~27 feet.
		5	0831	A few solitary eelgrass shoots ~40 feet. Growing there or drift?
		6	0842	Deep-->shallow, starting on kelp rocks-->creek mouth. Just a couple of ZM shoots.
		7	0853	Out nearly parallel across tip of point. No grass. Dig-8 tape maybe ran out.
		8	0915	Out from between island & point. A small ZM bed ~28 feet. I think the deeper shoots (~35 feet) were drift.
		9	0936	On outside of point. Steep and rocky w/thick bull kelp. No video, BS only.
		10	0948	Non-random. Meander around outer ZM bed. Saw 1 tuft of surfgrass. Also some drift ZM.
		11	1013	Non-random between 1 & 2.
		12	1024	Non-random between 4 & 5.
		13	1036	Non-random between 5 & 6. Drift shoots in mid 30s.
sjs2741	6/3/2009	1	1050	D-->S, eelgrass in patches 29-18 feet. *Dendraster* higher.
		2	1100	S-->D, pretty consistent w/prev. years. Saw some surfgrass & drift near deep end.
		3	1109	D-->S.
		4	1120	S-->D. Maybe a bit more grass than in prev. years.
		5	1130	D-->S Between 3 & 4. Less grass on this track. A few rooted shoots 30+ ft.
		6	1140	Sparse patches of eelgrass.
		7	1152	Similar
		8	1207	Eelgrass growing shallower & denser toward protected west corner. More algae too.
		9	1221	Trend continues. Big school of sandlance.
		10	1235	Lots of green algae back in the corner. Some surfgrass (*serrulatus*) mixed in w/the browns?
		11	1250	Skimmed rocky point. Grass shallow here, but got min depth.
		12	1301	Non-random. Min depth only track.
		13	1305	Non-random. Min depth only track.
		14	1309	Non-random. Min depth only track.
		15	1313	Outside of point. Started @ kelp. Some plants pretty deep.
		16	1320	Similar to 15.
		17	1327	Similar to 16, but less grass.
		18	1336	Non-random track between 7 & 8.
				Samples: *Phyllospadix serrulatus* only in samples near the point. ZM and *serrulatus* mixed w/kelp (track 10, etc).

Appendix B

Freshwater Bay
Field Notes

Site	Date	Track	Time	Comment
sjs2727	6/2/2009	1	1042	E. end of site, to the east of Elwha mouth. Loaded with kelp. High current.
		2	1055	Sand and gravel bottom covered with lots of kelp.
		3	1107	Moving West. Similar track. Reds under the kelps further out. Went over a 6' boulder.
		4	1118	In front of eastern most Elwha mouth fork. Less *Nereocystis*.
		5	1130	Out of river mouth. Bare, then plenty of kelp and later reds underneath.
		6	1143	E. edge of W. mouth branch. Similar to other tracks.
sjs2728	6/4/2009	1	1058	Just W. of Elwha mouth. Lots of big browns. Reds scattered under later.
		2	1108	Moving West. Same stuff.
		3	1117	Moving West. Much more bare sand after the step down. Browns and reds pick up near end.
		4	1126	Mixed browns to ~13 ft. then mostly bare sand w/patches of browns.
		5	1136	Balls of dead seagrass near start? Algae?
		6	1145	I think the balls at the start are mixed dead stuff.
		7	1154	Lots of bare sand. More algae and tube worms near end.
		8	1202	What were those little things we drifted over (they're on a bunch of the tracks)? Abandoned holdfasts?
		9	1211	Not much different on this track.
		10	1219	W. edge of site.
sjs2729	6/2/2009	1	1207	Mostly bare sand. Diatoms starting ~15 ft, brown in low density ~23 ft, increasing with depth.
		2	1217	Bare sand-->juv. Sandlance @ 15 ft-->*Pterygophera* ~20 ft w/other small critters. One tuft of surfgrass (*scouleri*) at ~32 feet.
		3	1227	*Pterygophera* w/surfgrass ~10 ft. Surfgrass doesn't go out very far. Other browns later.
		4	1238	Pretty much the same as track 3.
		5	1248	Big jump to the west. Kelp throughout. Surfgrass (*scouleri*) from start to ~20 ft. Eelgrass @~14 ft, then again 21-29 feet. 1 tuft of surfgrass around 30 ft.
		6	1259	Similar to 5. Surfgrass from start-->15 ft, eelgrass ~16 feet, then ~25 feet. Kelps throughout. 1 tuft surfgrass ~30 feet.
		7	1310	Surfgrass to 15 feet. Eelgrass 24-30 ft. Very sparse at deeper depths. There sure are a lot of juvenile fish of various sizes amongst the kelp.
		8	1321	More eelgrass in shallower depths here (~17 ft). An ~50 x 20 foot bed of *Macrocystis* at 48N08.185',123W35.337'.
		9	1331	Eelgrass only from 15-20 ft here.
		10	1342	Only a little eelgrass ~14 feet.
		11	1400	Extra random track. I didn't see any eelgrass on this one. Between 9 & 10.
		12	1409	Extra random track. A few eelgrass plants ~18 feet, ~14:11, look to right side. Between 9 & 11.

Site	Date	Track	Time	Comment
		13	1418	Extra random track. Eelgrass in patches 14--24 feet. Between 5 & 6.
		14	1427	Extra random track. Just East of track 5. Eelgrass @20-30 feet in patches.
		15	1436	Extra random track. Between 4&5. Just a little eelgrass, not all that much surfgrass either.
sjs2730	6/2/2009	1	1457	Surfgrass & *Pterygophera* then eelgrass ~12 feet, then kelps.
		2	1506	Eelgrass from 11-20 feet
		3	1514	Very similar to track 2.
		4	1523	Another one pretty much the same.
		5	1531	I didn't see any eelgrass--lots of kelps w/surfgrass (*scouleri*)
		6	1538	Similar to Track 5. Increasing bull kelp.
		7	1545	More bull kelp. Very little surfgrass.
		8	1552	Similar to Track 7. 1 stalk of *Pterygophera* encased in something ~15:55
		9	1559	Couldn't get in very shallow. Stopped by big bull kelp.
		10	1606	Got to surfgrass at the beginning. Lots of kelp.
sjs2731	6/2/2009	1	1625	Lots of *Pterygophera* w/other brown kelps. Saw some surfgrass off camera at start. *Macrocystis* near us at start too.
		2	1633	Similar to Track 1—more bull kelp at start.
		3	1639	More of the same.
		4	1648	Surfgrass and lots of kelps.
		5	1656	Surfgrass and kelps. Inside the bull kelp band @ W end of site.
		6	1704	Surfgrass then eelgrass then surfgrass.
		7	1710	Similar to 6, but some tufts of surfgrass in the eelgrass zone.
		8	1716	Same kind of deal.
		9	1723	Just a touch of eelgrass on this one.
		10	1730	I don't think I saw any eelgrass on this one. W edge of site.
		11	1736	More like track 8.
sjs2732	6/3/2009	1	1442	Patchy grass throughout W. end of site. Mixed algae. A few plants shallower, but stopped by rocks.
		2	1453	Similarly, couldn't get the shallowest few patches because of rocks.
		3	1505	Grass doesn't go out as far--gets rocky w/lots of browns earlier.
		4	1516	More kelp, less grass.
		5	1525	No grass on this one.
		6	1532	Some grass on first half of track. A few patches of surf/eelgrass shallower than we got amongst the rocks.
		7	1541	More grass on this one. I think we got the shallow edge.
		8	1549	Similar to 7. Confirmed surfgrass (*scouleri*) shallower than we started.
		9	1559	Eelgrass inside kelp band. Occasional *Pterygophera*.
		10	1606	Similar, but shorter track before kelp band.

Site	Date	Track	Time	Comment
sjs2733	6/4/2009	1	1251	Eastern edge of little bed tucked in kelp off point of W. end of site.
		2	1256	Non-random. W-->E across bed. Lots of sandlance @ start.
		3	1301	Backed in to sandy nook. Lots of seagrass mixed w/kelps.
		4	1308	Backed to SE edge of bed & went north.
		5	1313	Through NW part of bed. Video says "track 4". My samples from this bed were all eelgrass mixed with the kelps.
		6	1332	Main bed W. end of Freshwater Bay. Eelgrass mixed w/browns and greens. Big school of little fish on sounder after the end of track. 5 m thick.
		7	1339	Lots of green algae & ZM is heavily epiphytized at shallow end.
		8	1352	Grass sparse & patchy @ shallow end-->becomes pretty thick.
		9	1405	Similar to 8. Started next to the big rock.
		10	1418	Grass might go out a little further than 2006.
		11	1431	The sparse grass patches @ the shallow edge sure get shallow. Not nearly so much algae or epiphytes in the shallows down near this end of the site.
		12	1445	There really are a lot of greens along with the eelgrass--just not shallow.
		13	1457	Grass seems pretty consistent w/2006 survey.
		14	1509	Didn't write any notes.

Appendix C

Port Angeles Harbor
Field Notes

Site	Date	Track	Time	Comment
sjs2700	6/4/2009	1	1716	Surfgrass (*scouleri*) in tufts at start--thick kelps (& other browns) throughout.
		2	1729	What a kelp forest!
		3	1742	Just completely solid brown algae throughout.
		4	1752	I'm not sure I ever saw the bottom on this track.
		5	1802	Middle of the site. Solid brown algae cover.
		6	1813	On this track or one of the next two there was one eelgrass tuft on the meter plus thick browns--I have a hard time believing it was growing there.
		7	1823	Lots of the fuzzy *desmerestia*.
		8	1832	Barely missed a rock on that one. <1 ft of clearance.
		9	1842	More of the same.
		10	1851	Some surfgrass @ the start.
sjs2701	6/4/2009	1	1915	More bare sand at this site. Early, sparse mixed algae. Later, thick kelps.
		2	1925	Stopped by big rocks, but we may have gotten the shallow edge. Quite a bit of eelgrass here.
		3	1933	Only a little eelgrass ~15 feet. More kelp. Clicker on too long.
		4	1941	Only saw 1 ZM plant. 15' rock in 20' water near end of track.
		5	1951	No grass. Lots of browns.
	6/9/2009	6	1549	Thick brown algae. Juv. Sandlance through much of track. No grass--clicker error.
		7	1600	Much like track 1. Bigger school of something on BS after we pulled up camera.
		8	1609	Lots of fuzzy *desmerestia* & other browns. Not as many fish.
		9	1621	More sandlance again.
		10	1631	Like all the other tracks today.
		11	1641	Non-random. Parallel to shore through grass area--must recover first 1/2 of track from secondary logging source.
		12	1649	Non-random. Again, but missed most of the grass this time.
sjs2702	6/9/2009	1	1707	Some bare sand at beginning, but no grass otherwise, thick brown alga.
		2	1717	Again, more bare sand, but no grass. Still lots of brown after start.
		3	1728	No grass. A lot more green aglae. Bare sand near start. Boulders near end.
		4	1740	A bit steeper slope on West 1/2 of site. Lots of mixed alga.
		5	1750	Same as 4.
		6	1759	Thick mixed algae through most of track.
		7	1808	W. end of site. Same stuff.

Site	Date	Track	Time	Comment
sjs2703	6/9/2009	1	1825	A few patches of eelgrass @~10 ft, then thick mixed algae.
		2	1833	Similar, but no grass.
		3	1840	Non-random track to fill in a gap. Similar to track 2.
		4	1848	More bare sand, but still a lot of mixed algae.
		5	1856	Cobbles @ start, then more of the same.
		6	1903	Just East of pier. Steeper, and loaded with algae.
		7	1910	Just W. of pier. Loads of algae. Starts pretty deep @ riprap (~10 ft).
		8	1918	Just @. Of Track 7. Same stuff.
		9	1927	Non-random. Meandering around area where we saw eelgrass on track 1. We couldn't find any this time.
sjs2704	6/9/2009	1	1950	In old log booming area. Lots of mixed algae. No eelgrass. Bad vis.
		2	1958	W. end of old log booming area. Loads of algae--bad vis.
		3	2007	Middle of site, lots of algae--no eelgrass, but light level is too low now & water isn't clear enough to use lamp well. That's it for the night.
	6/10/2009	4	1607	Rocky @ start w/thick mixed algae throughout.
		5	1617	Similar, but more sand at start. No ZM.
		6	1625	Near West end of site. Same as previous tracks.
		7	1632	Right on W. boundary. Grass here.
sjs2705	6/10/2009	1	1508	Between old pier & Coho pier. Murky w/brown algae.
		2	1514	Between Coho & Victoria Express. Murky w/mixed algae.
		3	1520	Between Downriggers & city dock. Thick mixed algae. Not quite as murky.
		4	1527	Just W. of city dock. Similar to 3. Lots of interesting reds toward deep end.
		5	1534	Beach inside city dock. Eelgrass w/algae in shallows. Must return @ higher tide.
		6	1539	Non-random. East of 5--couldn't quite get back of bed at this tide.
		7	1546	Grass in shallow @ East end of site. Will come back in a while.
		8	1649	Starts in rocks, then to eelgrass with mixed algae.
		9	1653	Starts in front of small footbridge. Eelgrass 5 ft-->9 ft.
		10	1658	W. of small footbridge--similar to 9.
		11	1703	No rocks @ start. Less algae. Grass similar.
		12	1708	Similar to 11.
		13	1712	E. end of larger footbridge. Same as above.
		14	1717	Middle of larger footbridge. Some rocks @ start. Otherwise similar.
		15	1722	Non-random--filling in gap.
		16	1727	At start of sandy beach in front of Red Lion.
		17	1731	Close to 16. Pretty much the same.
		18	1736	Middle of small sandy Red Lion beach.
		19	1741	Non-random. Starts at riprap-pier intersection to define edge of eelgrass bed.
sjs2706	6/10/2009	1	1435	E. of Polar dock. Steep to deep. A bit murky w/algae.
		2	1440	BS only. Deep. Just E of 1.
		3	1446	Between log boom and creek mouth. Sandy plateau then quickly down to 20s depth. Some algae--murky.
		4	1451	Backing up to riprap wall. Sand w/some brown algae. Murky.
		5	1456	Just W. of pier. More brown algae.
		6	1502	Just E. of pier. Thick brown algae. Murky.

Site	Date	Track	Time	Comment
sjs2707	6/1/2009	1	1613	Near W. end of marina. Lots of green algae w/some browns.
		2	1618	Near marina entrance. Drops quickly w/lots of logs.
		3	1622	Between marina entrance and log booming area. Steep with not much algae.
		4	1628	E. of current log booming area. Steep w/wood waste--not much algae.
		5	1633	Maybe more algae. Some fish near a log/piling.
		6	1636	Near a log ramp. Scattered greens and browns, then drops quickly.
		7	1639	Near last (E) log ramp. More algae. Did Frank see ZM blade at the end? I didn't.
		8	1642	Shallow corner. Some juv. Fish--Sandlance?
		9	1644	A tire near the start.
		10	1647	Steep. No grass.
sjs2708	6/1/2009	1	1024	East of pier, W. of boat ramp. Lots of *ulva*, no eelgrass.
		2	1029	W. of pier. Similar to 1, but steeper slope. Greens with scattered brown algae.
		3	1033	W. of log boom. Greens w/scattered browns--no eelgrass.
		4	1038	Between 2 & 3. Lots of ulva.
		5	1044	Dense greens w/mixed brown. W. of log boom.
		6	1050	E. of old pier, W. of log boom. More of the same.
		7	1056	Between Piers E. of Mill. Maybe more browns. Drops off quickly.
		8	1102	More gentle slope. More gravely inshore. More browns. Lots of wood waste--just south of mill.
		9	1110	No video--BioSonics only. Off face of mill dock. Starts at 30 feet.
		10	1112	As above. Starts at 35 feet. North of 9.
sjs2709	6/1/2009	1	1124	NE of mill. Fine sediment bottom w/mixed scattered algae.
		2	1130	Working NE. Steep slope--dense greens with scattered brown. Juv. Sandlance?
		3	1134	Similar to track 2.
		4	1137	As above.
		5	1144	Long(er) plateau @ ~14 ft. Lots of wood waste. Still some juv. Sandlance(?).
		6	1149	No Plateau. Lots of wood waste. Similar to other tracks.
		7	1153	Not as steep. More brown aglae.
		8	1158	Similar. A few more fish.
		9	1203	As above.
		10	1210	A large cloud of something small near the end. Larval fish or *mysids*?
sjs2710	6/1/2009	1	1232	Very steep w/lots of green algae and some brown. Large cloud of small critters near the end of track.
		2	1236	As above.
		3	1240	Not quite as steep, but still fairly steep.
		4	1245	Similar. Slope gentle at first then becomes steeper. *Mysids*?
		5	1250	Maybe a little less algae, but still a lot.
		6	1253	More of the same.
		7	1257	Again.
		8	1300	Same.
		9	1205	More *mysids* (?)
		10	1308	Similar.

Site	Date	Track	Time	Comment
sjs2711	6/1/2009	1	1319	Steep w/lots of *ulva* and scattered browns. Wood waste.
		2	1323	Similar w/lots of logs at deep end.
		3	1326	More *Sargassum* than we've seen today. Lots of sizable fish @ end of track.
		4	1329	Similar to 1 & 2.
		5	1333	As above.
		6	1335	As above.
		7	1339	As above.
		8	1343	Similar, but little eelgrass patch here in about 6.5 ft water.
		9	1350	Eelgrass from ~5-7 feet. Just W. of old boat ramp.
		10	1357	A few eelgrass plants between start of track (log boom) and 16 feet. Just east of pilot station.
	6/10/2009	11	1804	Between 7 & 8--no grass. Mixed algae & pretty steep.
		12	1811	Between 8 & 9--good strip of eelgrass.
		13	1815	Just caught edge of bed (E. of 9). Process BS for grass on the way in.
sjs2712	6/1/2009	1	1415	Lots of eelgrass from 3 ft to 18 ft.
		2	1420	No eelgrass. Steeper and coarser.
		3	1425	One tuft of eelgrass amongst mixed green and brown algae.
		4	1428	Aborted--couldn't get to the shallow edge of the eelgrass at this tide.
		5	1432	Lots of eelgrass out to 17 ft. Started right at min grass depth.
		6	1437	Odd hole/gully near shore. Eelgrass mostly offshore of that.
		7	1442	Offshore hump not as pronounced, but that's where the eelgrass is.
		8	1449	Right in Coast Guard marina. Fell out of site to East (sjs2713), but there's grass in the marina.
	6/10/2009	9	1824	Between 1 & 2. Just got inside edge.
		10	1828	Between 2 & 3. Good grass fringe on steep slope.
		11	1831	Near 3. Lots of grass on BS on the way in (process for positions), only a bit on the way out.
		12	1835	Non-random. Re-do of track 4 to get inside edge.
		13	1838	Next to 12.
		14	1843	Between 13 & 5. Same stuff.
		15	1850	E. of 2. Grass on way out here.
		16	1853	W. of 2. Grass on way in, only 1 plant on way out. Use BioSonics to get those positions.
sjs2713	6/1/2009	1	1500	Tattered kelp and algae, then a narrow band of eelgrass on a steep slope.
		2	1502	Started at shallow edge of ZM. Rock stopped us from getting shallower.
		3	1506	Just got shallow edge of ZM. Steep slope, but grass over wide depth range.
		4	1510	Got shallow edge, but it went shallower nearby.
		5	1514	Got shallower than ZM.
		6	1518	Two individual plants we couldn't get, but we got most of the bed.
		7	1522	No grass as we got closer to the end of the spit.
		8	1525	Very steep sand w/cobbles and kelps.
		9	1528	Some green algae in there too.
		10	1531	Near end of spit. Steep gravel with kelp.
		11	1538	Non-random. Zig-zag to find eastern extent of eelgrass bed.
		12	1547	Non-random track between 6 and 7 to look at bed shape.
	6/10/2009	13	1903	E. side of CG breakwater.
		14	1908	Between 2 & 3. Right at shallow edge.
		15	1911	Between 3 & 4. Grass not as shallow on this one.

Appendix D

Dungeness Bay
Field Notes

Site	Date	Track	Time	Comment
sjs2674	6/8/2009	1	1501	Steep slope w/algae, but no eelgrass.
		2	1505	Similar to track1, working east.
		3	1509	Less algae at the top & 1 eelgrass plant seen on slope.
		4	1513	Lots of drift junk at this elbow--didn't see any eelgrass.
		5	1517	Plateau, then steep slope w/one step. Mostly bare sand.
		6	1522	Similar to 5, but more drift junk here. 1 obviously drift eelgrass plant.
		7	1527	Similar to the last two tracks.
		8	1532	Plateau, then downslope. Mostly bare sand.
		9	1537	Much like 8
		10	1541	Same stuff.
		11	1549	Non-random track between 2&3. Similar to 2. Large school of Juv. Fish 40-50 ft down.
sjs2675	6/8/2009	1	1610	Steep mostly bare slope. Sandlance at start.
		2	1612	Steep slightly less bare sand slope.
		3	1615	Similar to 2.
		4	1620	Near end of spit. Very steep.
		5	1625	Lots of kelps off the end of the spit on a plateau ~8m.
		6	1633	Similar to 5, but seagrass on plateau w/kelp.
		7	1641	Less seagrass w/the kelp on this one.
		8	1650	More plateau, but I didn't see any grass. Big school of sandlance (?) near start.
		9	1701	Longest point of plateau. Didn't see any grass.
		10	1717	Like Track 9, but I saw seagrass (*Zm* or *Ps*?). 5 eagles feasting on some corpse on beach.
		11	1734	Non-random. Meander through grass bed. Samples taken were ZM only.

Site	Date	Track	Time	Comment
flats49	6/6/2009	1	2008	Non-random. Lost GPS before we hit the grass.
		2	2018	Non-random. Meandering around Old Town point.
	6/7/2009	3	1521	Steep slope w/algae & a large school of Juv. Fish (~9 m depth). North end of site.
		4	1526	Eelgrass from 3-6.5m w/plenty of epiphytes and lots of juv. Sandlance.
		5	1532	Similar eelgrass distribution (a bit deeper) lots of greens and browns before and after.
		6	1538	Started at secondary spit tip. Grass patchy throughout. Quite a bit of drift eelgrass mixed in w/alga deeper. Was any rooted? A couple appeared healthy @ ~40ft, but we did have much wind recently.
		7	1602	Patchy grass throughout. I'll guess the ZM beyond ~8m is drift, but it's awfully hard to tell.
		8	1625	Almost no veg in main Dung. Bay drain channel outlet. Got a good look at ZM root on some of the deeper plants (drift). Also suspicious that the deeper ZM ONLY co-occurs w/brown algae--never in sand gaps.
		9	1650	Very similar to 8, but more eelgrass in the 20s depths.
		10	1715	Pretty much same as 9.
		11	1743	Patchy grass throughout.
		12	1815	There was a pretty long stretch of solid grass on this one.
		13	1850	A little less grass on this one, and grass doesn't go as deep.
		14	1928	Most of this track (the middle) is bare sand.
	6/8/2009	15	1821	Eelgrass through most of track to ~22 ft. Lots of *Ulva* @ start. S. end of site.
		16	1842	Start just S. of old pier. Less eelgrass and a few deeper plants, but similar to 14.
		17	1908	Off Old Town point. Similar to 16, but without the deeper plants.
		18	1935	From Graveyard Spit toward mouth of Dungeness River--no grass on the delta.
		19	1948	More eelgrass to the West.
		20	1958	W. boundary of site. No eelgrass @ tip of Graveyard Spit. Plenty on S. side of entrance channel.

Site	Date	Track	Time	Comment
flats50	6/5/2009	1	1501	W-->E toward Cline Spit across hole. Thick greens w/patches of ZM. Some browns in hole.
		2	1528	From end of 1 to the north.
		3	1556	From end of 2 (D. Spit) East to Graveyard Spit. Near sight marker.
		4	1615	From near end of 3 NW to D. Spit. Video says "track 3". No grass.
		5	1627	From near end of 4 South to Cline Spit island. DVD runs out.
		6	1705	Between Cline Spit & Graveyard spit across channel.
		7	1716	Graveyard spit--> Cline Spit, south of 6.
		8	1726	Tip of Graveyard to base of Cline. Stopped right at grass edge.
		9	1745	Between Tracks 1 & 3. Graveyard to Dung. Video says "Track 8"
		10	1809	Aborted
		11	1813	Between 1 & 9 ending near top of Cline Spit.
		12	1840	N-->S Parallel to Cline Spit. Only occasional plants on south 1/2 of track and water gets murkier and murkier as we go south until almost zero vis near south end, until we go up the slope and find a little fringing eelgrass.
		13	1923	Across back of bay. Very murky. ZM fringe on S. shore. Occasional plants along track.
		14	1946	From N. of 13 end to near Cline Spit house--not quite so murky. More grass.
		15	2025	Near mouth of site. Video says "track 14"
	6/6/2009	16	1512	From NE corner to SW corner. South part of bay is very murky w/near zero visibility.
		17	1614	Across south part of bay--murky. I didn't see any eelgrass.
		18	1633	A bit north of yesterday's southernmost track. Occasional plants & a little band on S. Shore.
		19	1654	N. of 18. Occasional patches. In and out of total murk.
		20	1725	Parallel to D. Spit relatively close to it. No ZM on south 1/2 of track.
		21	1819	Short track off south shore near head of bay--no ZM. Some *enteromorpha* near start.
		22	1826	Short track of south shore, near docks marked on chart. No ZM. *Enteromorpha* & other greens @ start, then a couple of browns.
		23	1837	Short track off shore near SE corner. A bit of ZM.
		24	1843	Short track north of boat ramp. Good band of ZM.
		25	1851	Just north of boat ramps (s. of 23) across bay. No ZM on 2nd half of track.
		26	1921	Starts on D. Spit shore heading toward Cline Spit. We expected to stop at Cline Spit, but found a low spot/channel out and ran the track all the way to the site boundary.

Appendix E

Table 11. Summary of eelgrass area coverage, eelgrass fraction, and patchiness index statistics by site.

Site	Bed	Date	Number of Transects	Eelgrass Fraction	Areal Extent (ha)	Variance	CV	80% Lower Limit	80% Upper Limit	Patchiness Index
2741	West Crescent Bay	6/3/2009	8	0.4875	10.2925	3.2037	0.1739	8.0014	12.5835	7.43
2741	East Crescent Bay	6/3/2009	6	0.1389	2.2486	0.5406	0.3200	1.3075	3.1898	7.27
2740	East Crescent Bay	6/3/2009	7	0.0300	0.3159	0.0053	0.2314	0.2223	0.4094	1.34
	Bed Estimates		13	0.0960	2.5645	0.5459	0.2881	1.6188	3.5102	6.54
2731	West Freshwater Bay	6/2/2009	6	0.2116	0.1440	0.0010	0.2194	0.1035	0.1844	7.54
2732	West Freshwater Bay	6/3/2009	10	0.4762	12.4369	3.0994	0.1416	10.1834	14.6903	10.35
2733	West Freshwater Bay	6/4/2009	14	0.6727	11.2893	0.1274	0.0316	10.8325	11.7462	13.78
	Bed Estimates		30	0.5477	23.8702	3.2278	0.0753	21.5705	26.1699	11.96
2729	East Freshwater Bay	6/2/2009	10	0.0629	0.4917	0.0175	0.2693	0.3222	0.6613	3.86
2730	East Freshwater Bay	6/2/2009	4	0.3532	0.9772	0.0200	0.1449	0.7959	1.1584	11.27
	Bed Estimates		14	0.1388	1.4689	0.0375	0.1318	1.2210	1.7168	8.79
2711	Inner Ediz Hook	6/1&9/2009	5	0.1813	0.1818	0.0105	0.5644	0.0505	0.3132	0.98
2712	Inner Ediz Hook	6/1&10/2009	13	0.5109	1.4656	0.0593	0.1662	1.1539	1.7774	1.67
2713	Inner Ediz Hook	6/1&10/2009	10	0.5109	0.9528	0.0283	0.1764	0.7375	1.1680	2.3
	Bed Estimates		28	0.4532	2.6002	0.0981	0.1205	2.1993	3.0011	1.85
2703	South PA Harbor	6/9/2009	1	NA	trace	NA	NA	NA	NA	NA
2704	South PA Harbor	6/9&10/2009	1	NA	0.1147	NA	NA	NA	NA	NA
2705	South PA Harbor	6/10/2009	11	0.5716	1.7521	0.0139	0.0674	1.6010	1.9033	8.95
2701	South PA Harbor	6/9/2009	3	0.2987	0.6351	0.1139	0.5312	0.2031	1.0670	3.2
2675	Dungeness Spit	6/8/2009	5	0.0650	0.3249	0.0683	0.8042	0.0000	0.6594	2.83
Flats49	Outer Bay	6/7&8/2009	17	0.2338	74.8275	103.0600	0.1357	61.8332	87.8219	5.72
Flats50	Inner Bay	6/5&5/2009	19	0.2215	72.3103	234.3020	0.2117	52.7174	91.9031	2.51

Table 12. Summary of minimum and maximum depth statistics by site.

		Minimum Eelgrass Depth						Maximum Eelgrass Depth					
Site	Bed	n	Absolute Depth (ft)	Mean Depth (ft)	SE	95% Lower Limit	95% Upper Limit	n	Absolute Depth (ft)	Mean Depth (ft)	SE	95% Lower Limit	95% Upper Limit
2741	West Crescent Bay	9	1.2	-3.1	1.6	-6.7	0.5	8	-32.4	-21.3	1.4	-31.6	-25.1
2741	East Crescent Bay	6	-16.6	-18.5	0.6	-20.1	-16.9	6	-30.5	-28.5	0.7	-30.4	-26.7
2740	East Crescent Bay	6	-17.7	-21.3	2.8	-28.5	-14.1	7	-40.8	-29.1	2.8	-35.9	-22.2
	Bed Estimates		-16.6	-19.9		-23.6	-16.2		-40.8	-28.8		-32.6	-25.1
2729	East Freshwater Bay	8	-10.5	-14.1	1.2	-17.0	-11.2	8	-28.4	-24.3	1.6	-28.1	-20.5
2730	East Freshwater Bay	4	-8.3	-9.4	0.6	-11.3	-7.5	4	-18.5	-16.9	1.2	-20.9	-12.9
	Bed Estimates		-8.3	-12.5		-14.4	-10.6		-28.4	-21.8		-24.4	-19.3
2731	West Freshwater Bay	4	-7.6	-8.6	0.5	-10.2	-7.0	4	-12.3	-10.9	0.7	-13.0	-8.9
2732	West Freshwater Bay	9	-0.6	-3.8	0.8	-5.7	-1.8	9	-27.5	-18.7	1.8	-22.9	-14.6
2733	West Freshwater Bay	8	0.8	0.3	0.2	-0.2	0.8	14	-30.7	-25.0	1.1	-27.4	-22.5
	Bed Estimates		0.8	-3.2		-4.0	-2.4		-30.7	-20.8		-22.6	-19.1
2701	South PA Harbor	2	-5.9	-8.4	2.5	0.0	23.1	2	-12.4	-12.0	0.3	-16.5	-7.7
2703	South PA Harbor	1	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA
2704	South PA Harbor	1	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA
2705	South PA Harbor	11	-0.9	-1.6	0.2	-2.0	-1.2	13	-5.3	-4.7	0.1	-5.0	-4.4
2711	Inner Ediz Hook	3	-1.8	-2.6	0.5	-4.8	-0.4	4	-17.8	-11.4	2.8	-20.2	-2.5
2712	Inner Ediz Hook	7	-0.4	-1.4	0.4	-2.5	-0.3	10	-19.4	-14.4	1.5	-17.8	-11.1
2713	Inner Ediz Hook	9	0.3	-2.4	0.5	-3.5	-1.2	9	-22.2	-18.7	0.9	-20.8	-16.6
	Bed Estimate		0.3	-2.1		-2.7	-1.4		-22.2	-15.6		-17.6	-13.6
2675	Dungeness Spit	5	-16.3	-19.6	0.9	-22.0	-17.2	5	-22.8	-22.0	0.3	-22.8	-21.2
Flats49	Outer Bay	17	1.9	-0.6	0.6	-1.9	0.6	14	-30.5	-23.1	1.6	-26.4	-19.7
Flats50	Inner Bay	21	0.7	-0.8	0.2	-1.1	-0.4	10	-10.3	-7.7	0.9	-9.8	-5.7