FINAL REPORT

Eelgrass Mapping Along The Elwha Nearshore

June and September 2006

by

James G. Norris and Ian E. Fraser

Submitted To:

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June 18, 2007

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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 of the dams, 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).

Approximately 10 million cubic yards of sediment trapped behind the dams will be delivered to the nearshore within five years of dam removal, which is anticipated to be a two year process. 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.

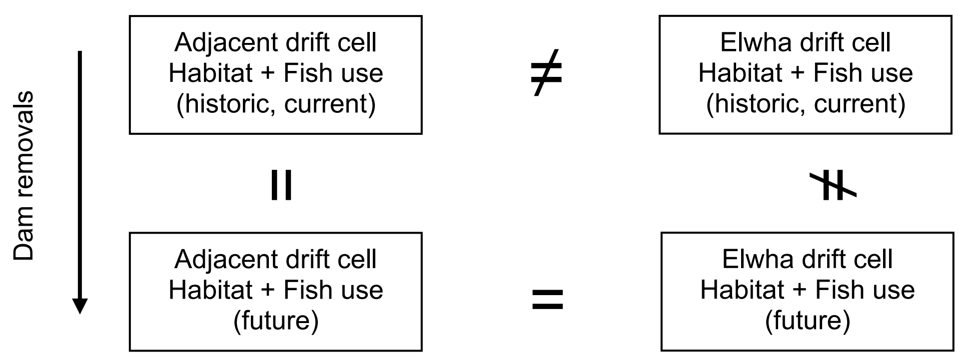

Figure 1. Conceptual model for measuring restoration response to dam removal (from Shaffer et al. 2005).

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

There are four general geomorphic habitat types within the Elwha drift cell and the comparable shoreline: (1) the protected western portions of Crescent and Freshwater Bays; (2) the less protected eastern portions of Crescent and Freshwater Bays which are exposed to strong westerly winds in spring and summer; (3) the Elwha Bluffs and Dungeness Bluffs which have relatively gentle bathymetry gradients; and (4) Ediz hook and Dungeness Spit which have relatively steep bathymetry gradients. Eelgrass (*Zostera marina*) beds are a critical component of nearshore habitats. Our goal for this project was to document the current status of eelgrass resources within the Elwha drift cell and the comparable shoreline (Fig. 2).

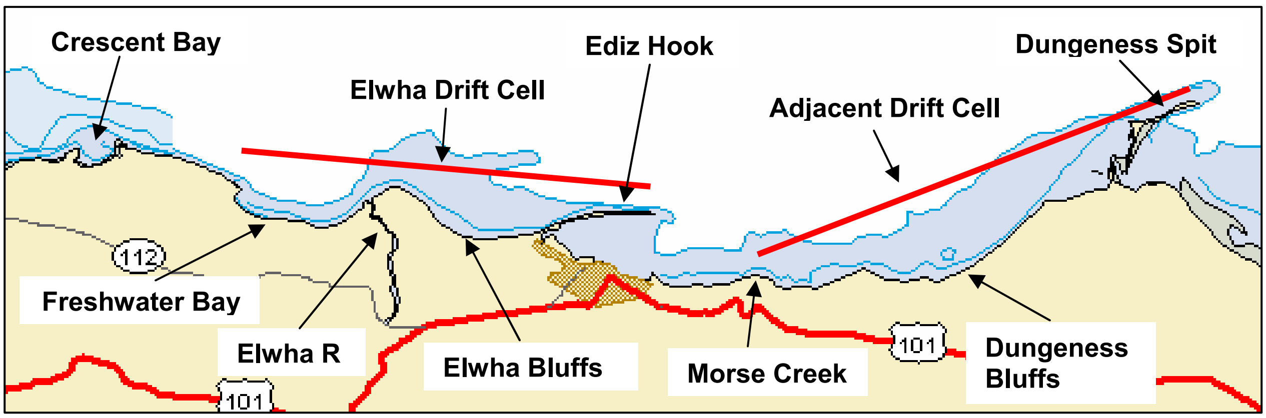

Figure 2. Map of the study areas.

The Washington State Department of Natural Resources (DNR) Submerged Vegetation Monitoring Project (SVMP) surveyed Crescent Bay in 2005, so we did not include it in this survey. Our specific objectives for this survey were to: (1) delineate any eelgrass beds within the Elwha and adjacent drift cells; and (2) for each eelgrass bed, estimate five parameters using DNR SVMP methods—basal 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), eelgrass fraction (within a bed boundary, the fraction of the area that has eelgrass), 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 basal area coverage, eelgrass fraction, and patchiness index. In this figure all three eelgrass beds have the same basal area coverage (i.e., number of square meters of seabed covered with eelgrass, shown in green) within the bed boundary (shown in red). The eelgrass fraction in bed “a” is 100%. Beds “b” and “c” have the same eelgrass fraction (about 65%), but bed “c” has a much higher patchiness index.

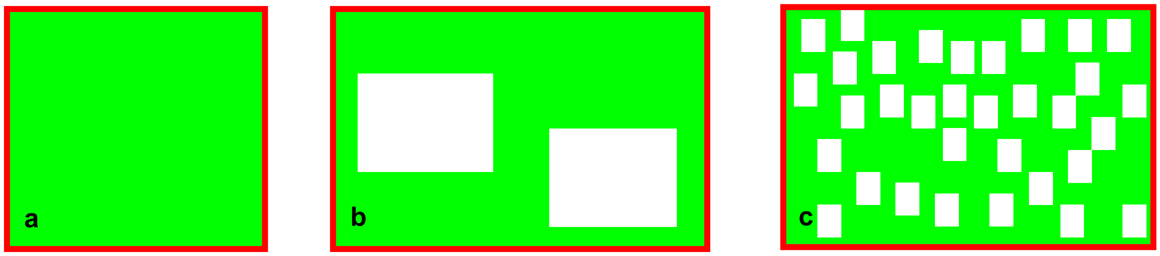

Figure 3. Illustration of basal area coverage, eelgrass fraction, and patchiness.

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.

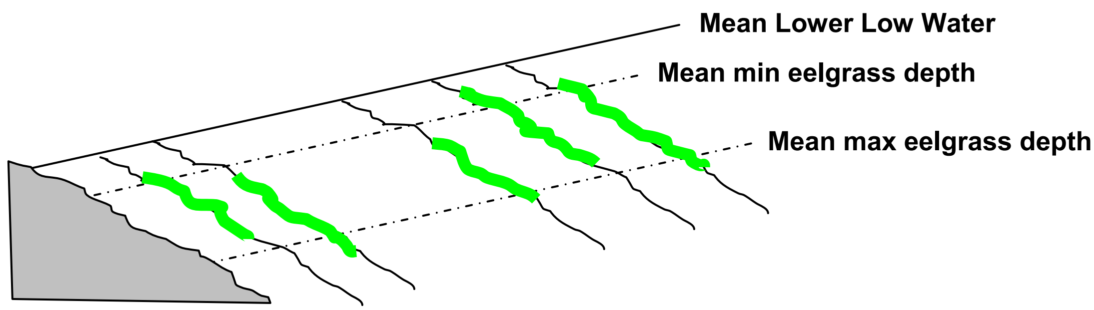

Figure 4. Illustration of mean minimum and maximum eelgrass depths.

Methods

Personnel

We conducted the Elwha drift cell survey between June 5 and 13, 2006 and the Morse Creek to Dungeness Spit survey between September 13 and 27, 2006. On all survey days Ian Fraser and Lou Schwartz served as chief scientist and skipper, respectively. Jim Norris participated in the first two days of the survey (June 5 and 6, 2006).

Site Description

We defined the survey areas to be the Elwha and adjacent drift cells as depicted in Fig. 2 and out to a depth of -35 ft Mean Lower Low Water (MLLW). We chose -35 ft because that is the deepest we have observed eelgrass in Puget Sound and the Strait of Juan de Fuca. The Elwha and adjacent drift cells contain 20 and 24 “fringe” sites, respectively, as designated in the DNR SVMP (Fig. 5). A fringe site is defined to be a 1000 m length of shoreline as measured along the -20 ft isobath.

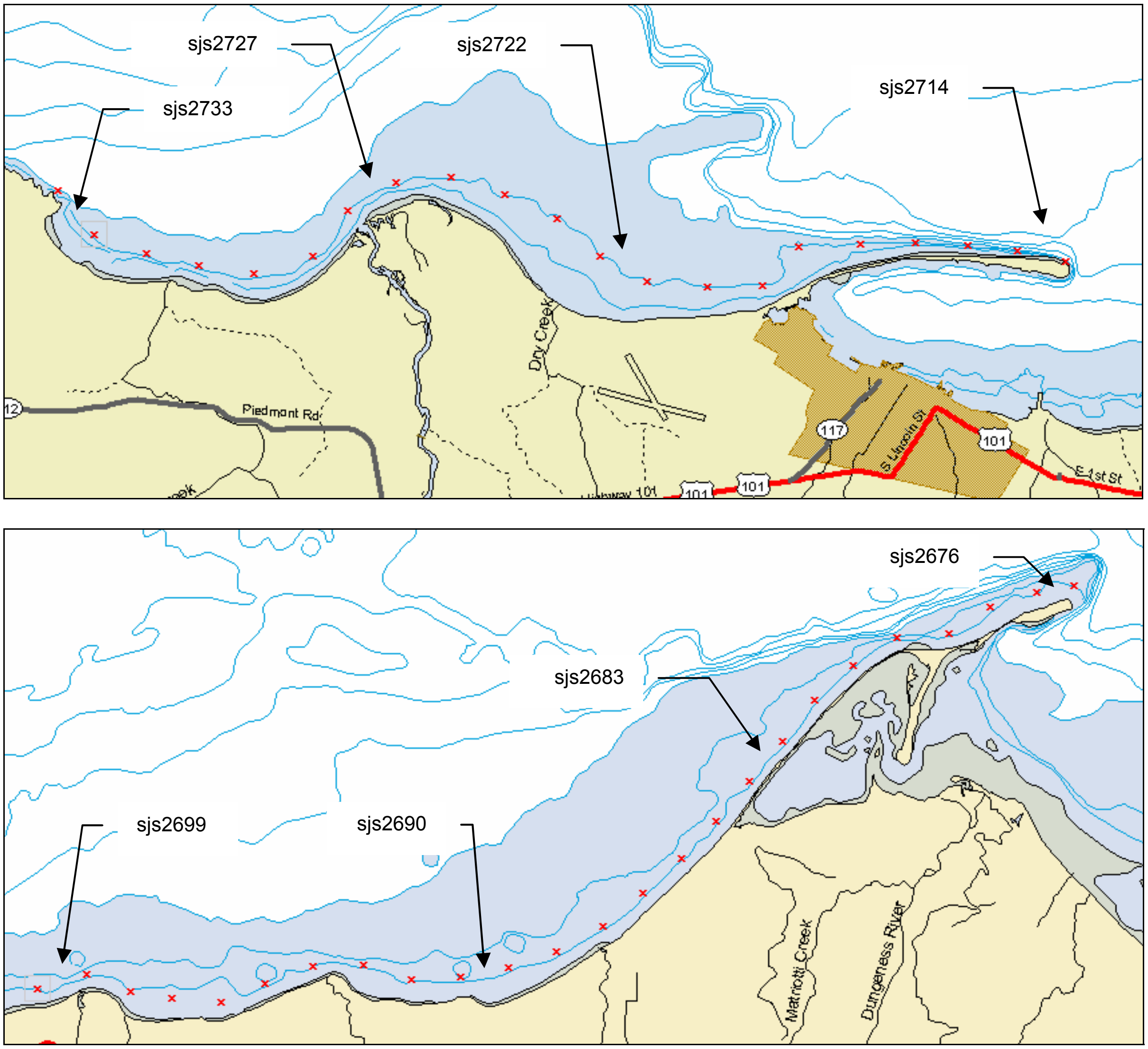

Figure 5. Maps of the survey areas showing boundaries of the DNR SVMP fringe sites (red x's).

Sampling Plan

Our two primary goals were to: (1) delineate any eelgrass beds as accurately as possible, given the field survey time available (seven days for each drift cell); 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.

Within each drift cell, our sampling plan called for spending between two to four hours for each initial site visit, which would take six field days. One field day was allocated to follow-up site visits to increase the number of random transects through previously observed eelgrass beds or to add additional non-random transects to better delineate eelgrass bed boundaries. For each initial site visit we randomly selected 11 transects (this is the minimum number of random transects the SVMP uses) and started surveying with the eastern- or western-most transect at that site. If eelgrass was observed on any of the first few transects or it appeared that all 11 transects could be completed within the allotted time, we continued surveying all 11 random transects and added non-random transects when the distance between random transects was greater than 75 m (e.g., sites sjs2714 through sjs2719 and sjs2729 through sjs2733).

If eelgrass was not observed on any of the first few transects and it appeared that all 11 transects could not be completed within the allotted time, we surveyed only four or five of the randomly selected transects such that the surveyed transects were about 200 m apart. Sites sjs2720 through sjs2726 (the area between the base of Ediz Hook and Angeles Point) were in this category. For the two sites around the Elwha River mouth (sjs2727 and sjs2728) we did some random transects and added non-random transects both perpendicular to and parallel to the shoreline to produce a grid sampling pattern. Thick canopy forming kelp prevented us from conducting random transects at four sites just west of Green Point (sjs2695 through sjs2698). At these sites we maneuvered the vessel into gaps in the kelp, dropped the camera, and meandered through whatever opening was available. Table 1 shows the number of random and non-random transects conducted at each site.

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

Elwha Drift Cell					Adjacent Drift Cell			
Site	Random	Non-Random	Total		Site	Random	Non-Random	Total
sjs2714	11	3	14		sjs2676	11	1	12
sjs2715	11	5	16		sjs2677	10	0	10
sjs2716	11	3	14		sjs2678	3	0	3
sjs2717	11	2	13		sjs2679	11	0	11
sjs2718	9	3	12		sjs2680	10	1	11
sjs2719	10	0	10		sjs2681	6	0	6
sjs2720	5	0	5		sjs2682	7	0	7
sjs2721	5	0	5		sjs2683	7	0	7
sjs2722	4	0	4		sjs2684	9	0	9
sjs2723	4	0	4		sjs2685	7	0	7
sjs2724	4	0	4		sjs2686	6	0	6
sjs2725	5	0	5		sjs2687	5	1	6
sjs2726	5	0	5		sjs2688	5	1	6
sjs2727	5	6	11		sjs2689	12	0	12
sjs2728	11	3	14		sjs2690	10	0	10
sjs2729	14	5	19		sjs2691	10	0	10
sjs2730	10	1	11		sjs2692	11	0	11
sjs2731	9	1	10		sjs2693	9	0	9
sjs2732	14	2	16		sjs2694	11	0	11
sjs2733	9	10	19		sjs2695	0	3	3
Total	167	44	211		sjs2696	0	4	4
					sjs2697	0	4	4
					sjs2698	0	5	5
					sjs2699	12	0	12
					Total	172	20	192

Survey Equipment and Methods

Vessel

We conducted sampling aboard the 36-ft *R/V Brendan D II* (Fig. 6). 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 6. The *R/V Brendan D II*.

Table 2. Survey equipment used onboard the *R/V Brendan D II* during the 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 DVR-TRV310 Digital8 Camcorder

Video Data

We obtained underwater video images using an underwater camera mounted in a down-looking orientation on a heavy 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 were combined into larger files and processed through EcoSAV software (part of the BioSonics system). The output was a single text file with time, depth, and position data. These data were then merged with the tide correction data (see sub-section below) 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 raised and lowered the camera towfish to follow the seabed contour. The field of view changed with the height above the bottom. The vessel speed was held as constant as possible (about 1 m/sec). 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 and B).

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. We reviewed videotapes in the laboratory to assign video codes (0 = cannot view the seabed; 1 = seabed in view) and attribute codes for eelgrass (0 = absent; 1 = present). Within the Elwha drift cell we also coded (0 = absent; 1 = present) for surfgrass (*Phyllospadix* sp), macroalgae, and juvenile fish.

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 at each fringe site we computed a weighted average of the predicted tide heights (using the computer program Tides and Currents Pro 3.0; Nobletec Corporation) for the two closest tide prediction stations, where the weights were inversely proportional to the distances from the fringe site to the two tide stations. We used the following prediction stations: Crescent Bay (station ID 0979; 48 10.00 N, 123 44.00 W); Port Angeles at Ediz Hook (station ID 0982; 48 08.40 N, 123 24.80 W); and Dungeness (Station ID 0983; 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 1049; 47 36.20 N, 122 20.20 W) with actual observed tide heights published by the National Oceanic and Atmospheric Administration on their web site (http://www.co-ops.nos.noaa.gov/data_res.html).

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

Parameter Estimation

Eelgrass Fraction and Basal Area Coverage

For individual fringe sites, we estimated the total basal area coverage of eelgrass 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.

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. Table 3 lists the notation and formulae for estimating basal area coverage at a single site.

Table 3. Notation and formulae for estimating basal 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).
$Var(\hat{\rho})$	$\frac{1-f}{n \cdot \overline{L}^2} \frac{\sum_i l_i^2 - 2\hat{\rho}\sum_i L_i l_i + \hat{\rho}^2 \sum_i L_i^2}{n-1}$	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 the weighted mean of eelgrass fractions of individual fringe sites, where the weights were determined from the estimated eelgrass areas:

$$\hat{\rho}_B = \sum_h W_h \hat{\rho}_h \text{ where } W_h = \frac{\hat{E}_h}{\sum_h \hat{E}_h}.$$

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 4 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 4. Notation and formulae for estimating eelgrass fraction and basal 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

Maximum and minimum 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 at regular intervals along the transect the depths at which eelgrass is observed along this transect, there will be both a maximum and a minimum depth observation. If measurements are taken along many such transects, one will have a collection of maximum and minimum depth measurements. Our parameters of interest are the averages of these collections of maximum and minimum depth measurements. We used depths from BioSonics echosounder to estimate these parameters.

When a single bed spanned two or more fringe sites, 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 (maximum) eelgrass depth at site *h* and

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

(n_h = number of random transects at site h). We estimated the variance as the weighted average of the individual site variances using the same weighting factors.

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.

Fish Density Analysis

During the survey in the Elwha drift cell we observed large schools of juvenile fish, most of which appear to be Pacific sand lance (*Ammodytes hexapterus*) (Shaffer and Pentilla, pers. obs). Although our survey was not designed to estimate fish distribution and abundance, we decided to analyze the BioSonics acoustic data (using the BioSonics *Visual Analyzer 4* program) to estimate fish densities within the region we did survey. These results could be useful in designing future forage fish abundance surveys.

We estimated fish densities (fish per square meter of surface area) using echo integration over 10 second intervals along each transect on which we observed fish. To avoid including surface noise and signals from understory kelp, we eliminated signals within 1 m of the surface and the seabed. Fig. 7 shows a sample echograph with a large school of fish at the deep end of the transect (note: the red line indicates the seabed; the wave pattern of the seabed is due to surface waves—the boat going up and down—and does not represent sand waves).

We used a target strength value of -70.33 dB, as determined for 4.0 cm long fish from the relationship given in Thomas et al. (2002). A histogram of the resulting densities indicated a log distribution (some very high densities and many very low densities), which we divided into three categories—low (< 220 fish/m^2), medium (880 – 7,500 fish/m^2), and high (> 7,500 fish/m^2). We converted density in fish/m^2 to fish/m^3 by dividing fish/m^2 by the average depth of the associated transect segment. We plotted these three categories on a map and manually created polygons representing the locations of each density category.

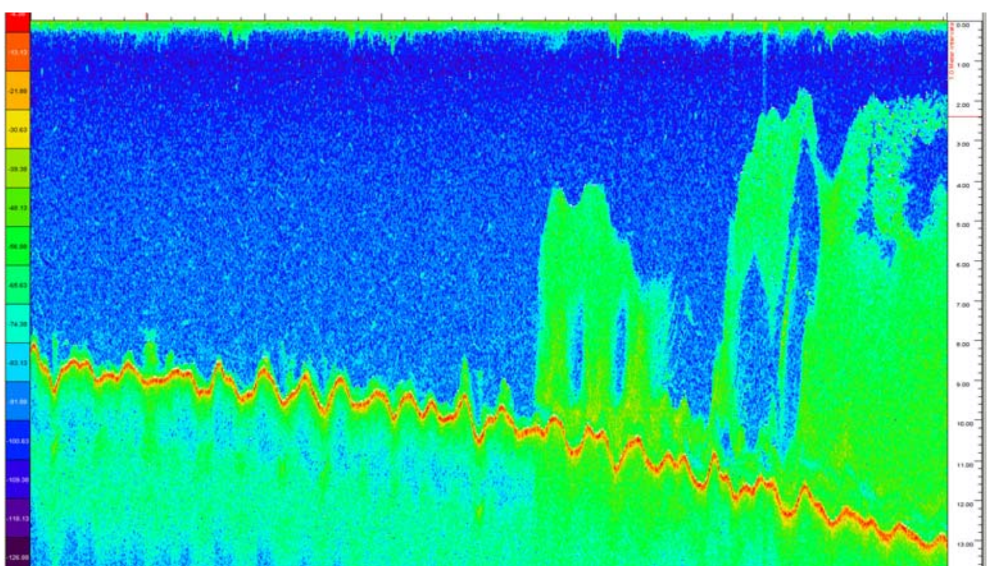

Figure 7. Sample echograph from the BioSonics DE4000 system.

Results

Eelgrass

We conducted a total of 403 transects, 211 in the Elwha drift cell and 192 in the adjacent drift cell. On many transects we extended sampling beyond -35 ft to a depth of -45 ft. On September 13 and 14 leftover turbulence and associated suspended sediment from a strong westerly wind event made visibility so poor we could only survey one site. Visibility was worse nearest the shore.

During the current survey we observed three eelgrass beds in the Elwha drift cell and two in the adjacent drift cell (Table 5; Fig. 8). We did not observe any eelgrass in the Elwha Bluffs area. Bed size varied between 1.6 ha (East Freshwater Bay) and 29.8 ha (Dungeness Bluffs). Patchiness indices were lower in the Crescent Bay beds (4.4 and 5.3) than other beds (7.3 to 8.6). Eelgrass fractions in the western portions of Crescent and Freshwater Bays (61% and 52%) were higher than other beds (14% to 26%). Mean maximum eelgrass depths were similar for all beds (-19.9 ft to -26.6 ft) (Fig. 9a). Mean minimum eelgrass depths in the western portions of Crescent and Freshwater Bays (-3.8 ft and -4.0 ft) were shallower than other areas (-13.0 ft to -17.4 ft) (Fig. 9b). The protected west portions of Crescent and Freshwater Bays had eelgrass growing as shallow as -0.4 ft and +0.4 ft. The deepest observed eelgrass was at -32.7 ft in site sjs2679 (Dungeness Spit). Tables 6 and 7 in Appendix C summarize parameter statistics for individual sites.

Table 5. Summary statistics for five eelgrass beds surveyed by this project and the east and west portions of the Crescent Bay bed surveyed during the 2005 DNR SVMP.

Bed	Basal Area Coverage (ha)	Patchiness Index	Eelgrass Fraction	Mean Maximum Depth (ft)	Mean Minimum Depth (ft)
* West Freshwater Bay	21.6	8.6	52%	-19.9	-3.8
West Crescent Bay	12.8	4.4	61%	-25.4	-4.0
* East Freshwater Bay	1.6	8.3	26%	-21.5	-13.0
East Crescent Bay	2.3	5.3	14%	-26.6	-16.1
* Elwha Bluffs			No eelgrass observed		
Dungeness Bluffs	29.8	7.9	19%	-22.3	-12.2
* Ediz Hook	7.9	8.1	23%	-24.5	-14.8
Dungeness Spit	11.3	7.3	22%	-23.5	-17.4

* Regions within the primary Elwha drift cell.

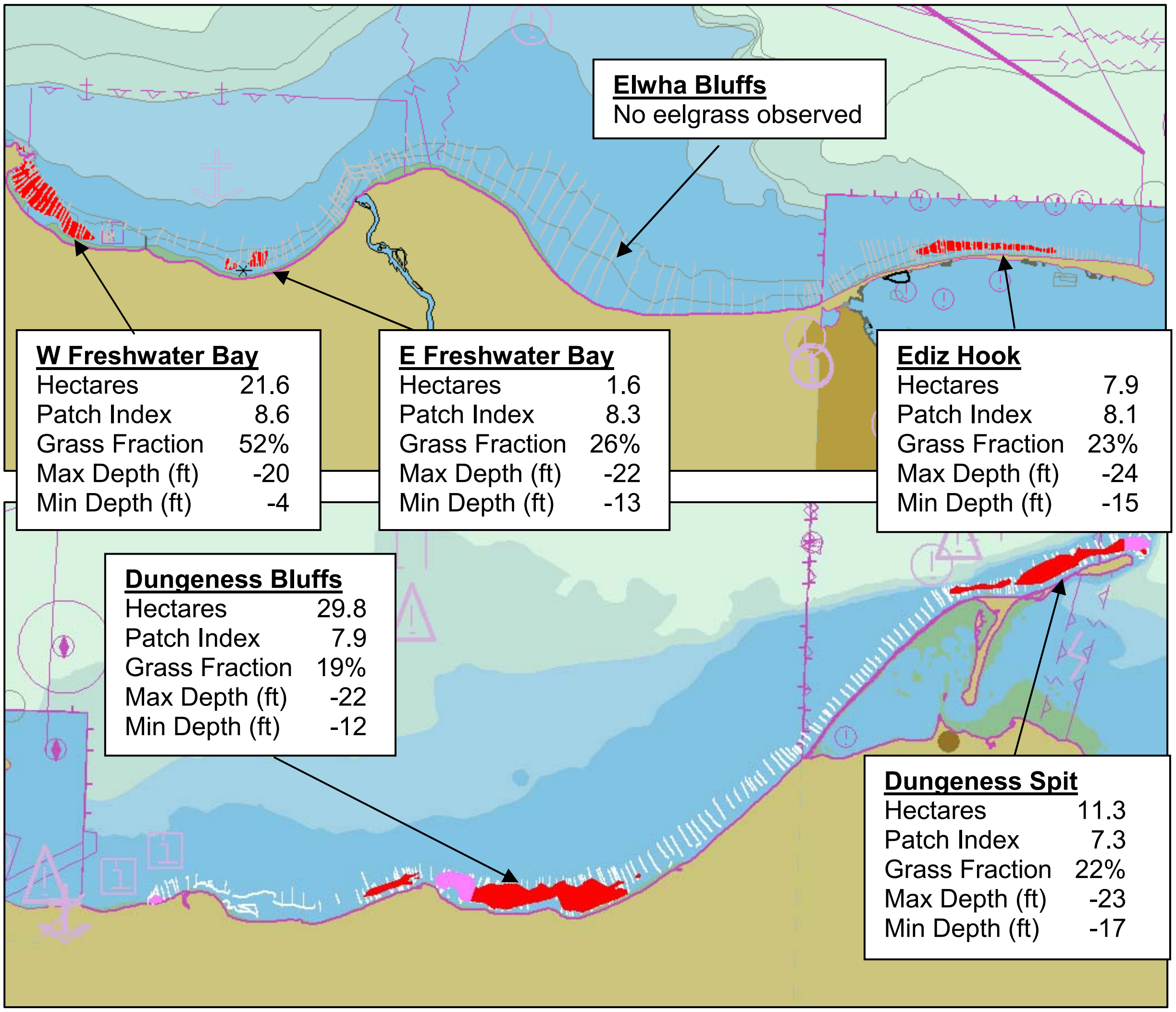

Figure 8. Eelgrass beds (shown in red and magenta) observed in the Elwha and adjacent drift cells.

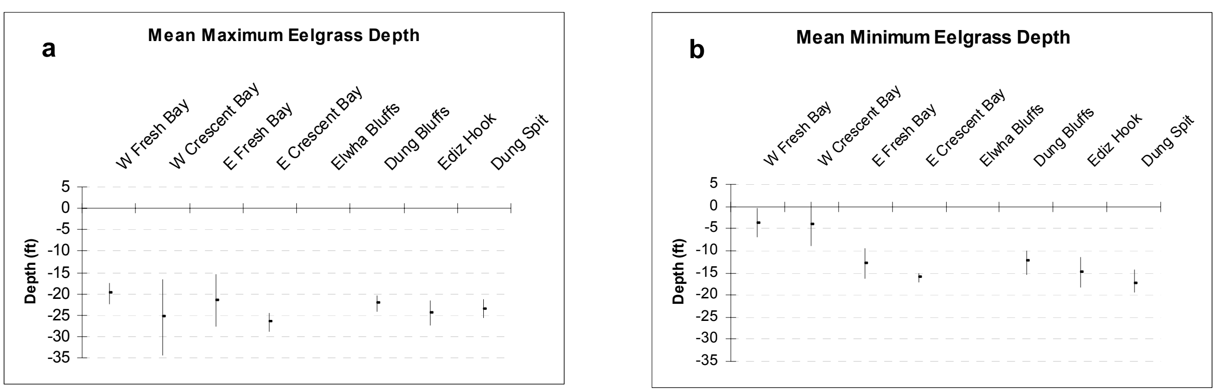

Figure 9. Estimated mean maximum (a) and minimum (b) eelgrass depths and 95% confidence intervals.

In some cases it was difficult to distinguish between eelgrass and surfgrass on the video footage. In general, we used leaf width and shoot pattern as the primary defining characteristics—surfgrass has narrower leaves and shorter distance between root nodes. Surfgrass was mixed throughout the Ediz Hook eelgrass bed (Fig. 10). In this figure, individual eelgrass observations are shown as red dots. The red hatched polygon shows the boundaries of the eelgrass observations. Surfgrass observations are shown as green dots. On several occasions while surveying the Ediz Hook eelgrass bed we attempted to collect seagrass specimens (using a small Danforth anchor) to ground-truth our identification of eelgrass and surfgrass. Unfortunately, we did not collect a single specimen because the anchor immediately choked with macro algae on every deployment.

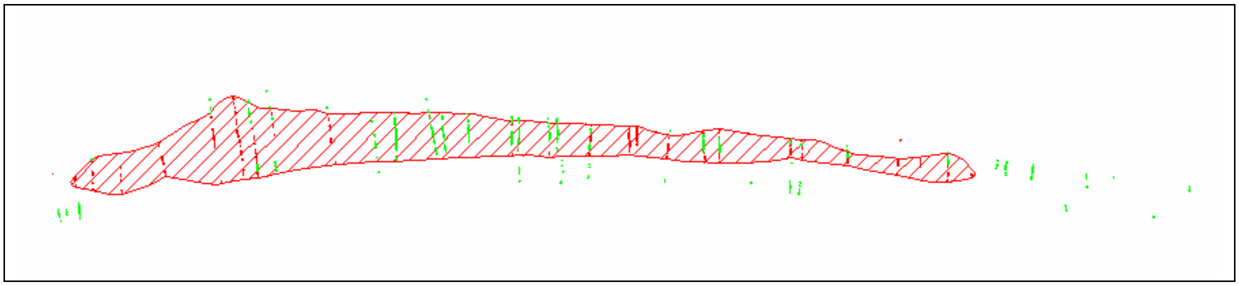

Figure 10. Detail map of the eelgrass (red) and surfgrass (green) observations along the north shore of Ediz Hook.

The west Freshwater Bay eelgrass bed spanned a broad depth range at its west end (-0.6 ft to -21.4 ft), but narrowed at its east end (-11.3 ft to -12.1 ft). The nearshore edge became deeper and the offshore edge became shallower from west to east (Fig. 11). The Crescent Bay eelgrass bed showed a similar pattern for the nearshore edge, but the deepwater edge did not become shallower toward the east (Fig. 12).

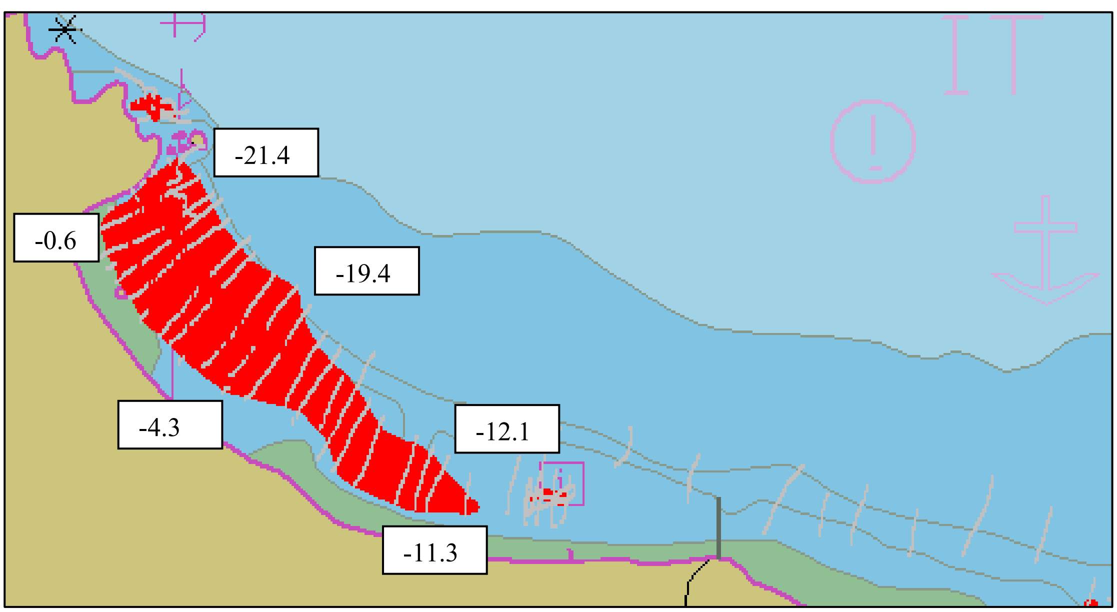

Figure 11. Detail map of the west Freshwater Bay eelgrass bed.

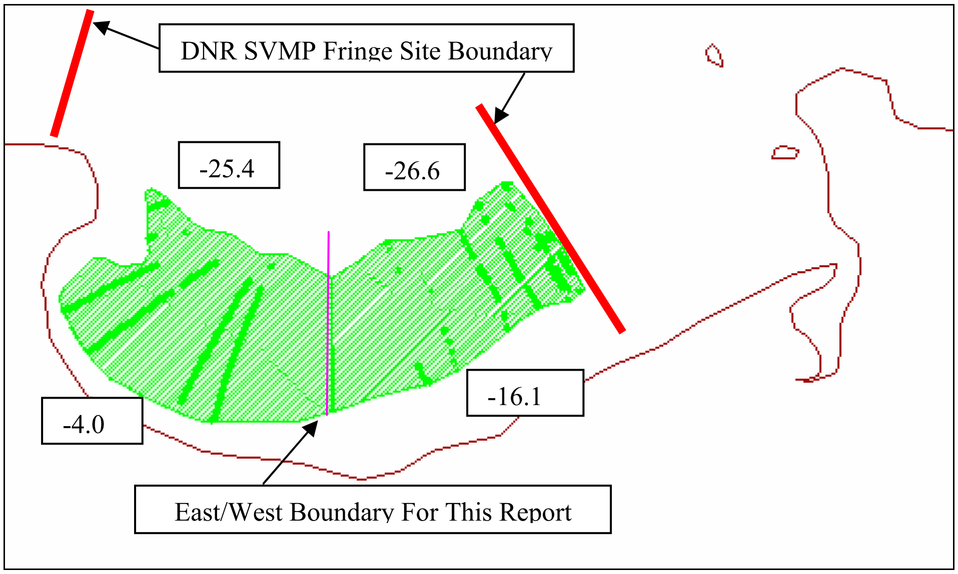

Figure 12. Detail map of the Crescent Bay eelgrass bed.

Fig. 13 shows the eelgrass distribution by depth for comparable eelgrass beds within and outside the Elwha drift cell. The Ediz Hook and Dungeness Spit beds had very similar distributions, with most eelgrass concentrated between -15 ft and -23 ft. Eelgrass in east Freshwater Bay was concentrated between -9 ft and -18 ft, whereas eelgrass in east Crescent Bay was concentrated between -18 ft and -25 ft. Eelgrass in west Freshwater Bay and west Crescent Bay beds spanned a broad depth range, with more eelgrass between -1 ft and -10 ft than the other beds.

Macro Algae

Within the Elwha drift cell we observed macro algae virtually everywhere, including the deep end of our transects. Broad-leafed brown algae dominated, but some red and green algae also were observed. Because we observed significant understory kelp at -45 ft, we can conclude that the photic zone extends at least to this depth, and most likely beyond. Further surveys are needed to determine the deep-water extent of the vegetation. Assuming understory kelp beds are present throughout the nearshore we estimate understory kelp beds to encompass a minimum of 763 ha in the Elwha drift cell.

Fish Densities

We observed fish all along Ediz Hook, with the highest densities along the western deepwater edge of the eelgrass bed (Fig. 14). Lower densities were observed in Freshwater Bay and around Angeles Point. We often observed fish at the deepwater end of our transects (e.g., Fig. 7).

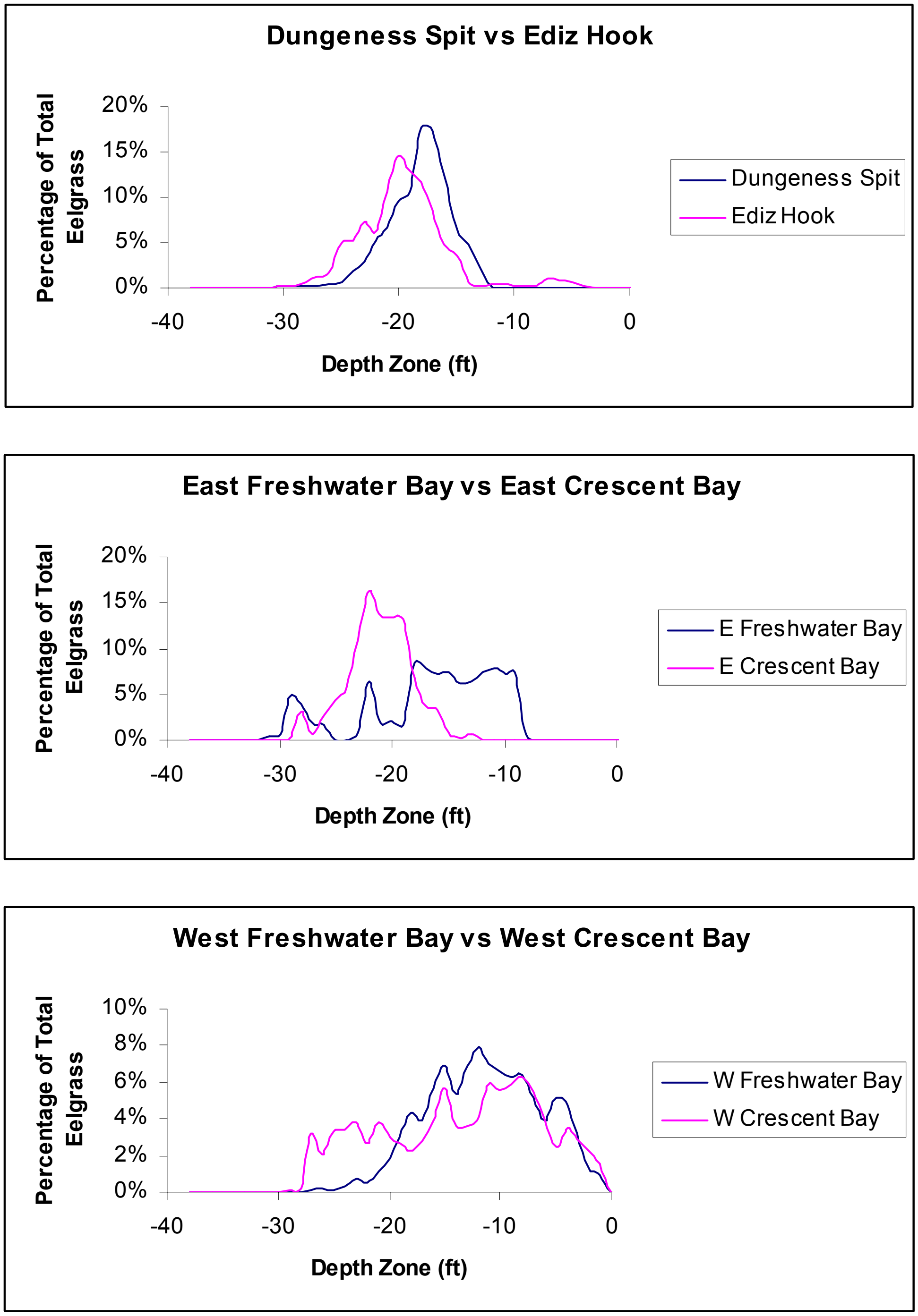

Figure 13. Eelgrass distributions by depth zone for comparable sites within and outside the Elwha drift cell.

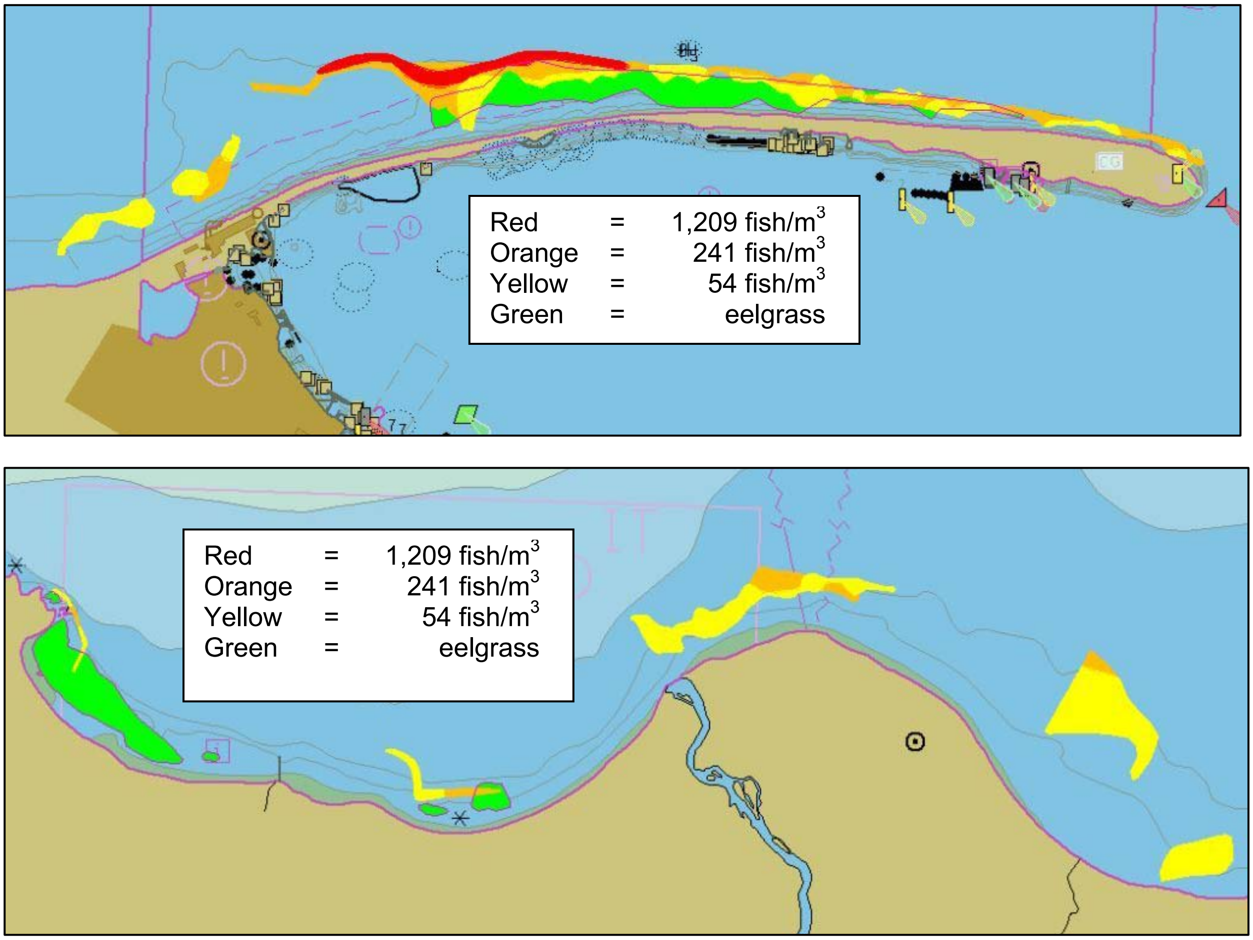

Figure 14. Estimated fish densities in the Elwha drift cell.

Discussion

Eelgrass beds in Crescent Bay and the west end of Freshwater Bay also were noted in the Coastal Zone Atlas (Albright et al. 1980), Washington Department of Fisheries surveys from 1975-1989 (Thom and Hallum 1990), and the 1995 DNR ShoreZone Survey (Berry and Ritter 1997). The beds along Ediz Hook and Dungeness Spit were shown as much smaller beds in the Coastal Zone Atlas, but were not shown at all in the DNR ShoreZone Survey. The Dungeness Bluffs bed (the largest bed we observed) was shown as a very small bed in the DNR ShoreZone survey. One reason previous surveys did not identify the full extent of the Ediz Hook, Dungeness Spit, and Dungeness Bluffs beds is that these beds have relatively deep minimum eelgrass depths—they do not start until -12 ft to -17 ft below MLLW and are not visible at low tide.

Within our study area the protected western portions of Crescent and Freshwater Bays appear to offer the best conditions for eelgrass growth. The beds in these regions have higher eelgrass fractions and extend shoreward into the intertidal zone. It is likely that the shoreline in other areas is subject to high wave energy from strong westerly winds during spring and summer which prevents eelgrass from growing shallower than about -13 ft. Our observations on September 13 and 14 that visibility is poorest nearest the shore following a strong wind event suggest that lower light availability might be a contributing factor. Both Crescent and Freshwater Bays are excellent sites for further study of wave energy effects on eelgrass beds.

In three of the four geomorphic habitat types eelgrass parameters were very similar in both the Elwha drift cell and comparable shoreline regions. This suggests similar current eelgrass growing conditions within these habitat types. Two possible explanations for this observation are: (1) within these three habitat types, sediment flow from the Elwha River does not have a significant impact on eelgrass growing conditions; or (2) dam construction caused these habitat types within the Elwha drift cell to become more similar to those outside the drift cell (e.g., the comparable shoreline outside the Elwha drift cell does not have any major rivers emptying into the Strait of Juan de Fuca).

In the fourth geomorphic habitat type, we found a large eelgrass bed in the Dungeness Bluffs area, but no eelgrass in the Elwha Bluffs area. Again, two possible explanations are: (1) sediment flow from the Elwha River does not have a significant impact on this habitat type, and there was no eelgrass in the Elwha Bluffs region prior to dam construction; or (2) eelgrass did grow in this region prior to dam construction, but died out as sediment starvation gradually created a harder substrate that favored macro algae over eelgrass. Washington Department of Natural Resources has documented a significant increase in overstory kelp coverage in this area of the Elwha nearshore over the last 100 years (Berry, pers com), which is consistent with, and attributed to, sediment starvation in this area. Shoreline armoring along the Elwha Bluffs combined with dams in river are the dominant limiting factors disrupting sediment processes in this area, and as a result likely impacting current eelgrass growing conditions.

Unfortunately, there are no pre-dam construction eelgrass surveys to help answer these questions. Perhaps tribal oral history can shed some light on the historic distribution of eelgrass. Eelgrass monitoring following dam removal will be needed to understand the effects of the Elwha River on nearby eelgrass beds.

Our findings indicate that understory kelp is the dominant vegetative feature of the Elwha drift cell. It is also characterized by high variability (Shaffer 2000). Unfortunately, detailed analysis of understory kelp beds is outside the scope of this study. However, since understory kelp may be impacted by increased sediment deposition, more detailed research on this habitat's extent and importance for fish use in the Elwha nearshore is a top priority for future funding and research. The archived video footage from this survey could be post-processed to determine species composition.

Our fish density analysis must be used with caution, because we did not capture any live specimens to confirm species composition and fish size. Nevertheless, our observations on Pacific sand lance are consistent with Shaffer (2004), who noted that Pacific sand lance are found in very high numbers in the nearshore during spring and summer months, and tend to favor deeper habitats than juvenile salmon (*Onchorynchus* sp) and surf smelt (*Hyponasus pretiosus*). Juvenile and post-larval surf smelt are being found in very high numbers throughout nearshore areas during the current 2007 Elwha nearshore study season (Shaffer, unpublished data). Further study defining forage fish use, including species composition, of understory kelp beds, is recommended.

This study provided a number of intriguing insights into the Elwha nearshore. Multiple years of sampling are needed to accurately define macro vegetation areal extent, composition, and fish use in this area of the Strait, which is defined by high interannual and geographic variability. The work is of high priority—with it we will provide keys to optimizing the restoration opportunities associated with a watershed restoration event of national scale.

Acknowledgments

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Appendix A

Clallam County Marine Resources Committee
Eelgrass Mapping Along The Elwha Nearshore
Field Notes—June 5 to June 13, 2006

Site	Date	Track	Time	Comment
sjs2714	6/5/06	1	1008	No grass. No Dig8 video. Lots of large brown algae. Lots of juv fish (candlefish?). DVD goes long. HyPack also goes long.
		2	1012	No grass. More kelp.
		3	1020	No grass. Still lots of kelp with cobble at start.
		4	1024	No grass. More of same. Stop once to clear towfish.
		5	1028	No grass. Cobble then kelp. Some fish at deep end.
		6	1032	No grass. Same as #5. Some very small fish (juv candlefish?).
		7	1036	More of same.
		8	1040	More of same. HyPack records this as track 7.
		9	1044	More of same.
		10	1048	More of same.
		11	1053	Less kelp; more softer-looking sediment. End of random tracks.
				Start 3 more fill-in tracks (ie non-random).
		12	1058	Similar to #11. This track just east of 11.
		13	1103	Just east of #12.
		14	1110	About 1.5 min extra footage of data at start. More kelp here again. Tracks 11, 12, and 13 had less kelp and more soft bottom.
sjs2715	6/5/06	1	1121	Random track. Some kelp, but lots of soft-looking sediment.
		2	1126	Random track. May have been one clump of eelgrass (or surfgrass). Mostly soft sediment with very little kelp.
		3	1131	Start of 3 non-random tracks. More soft sediment, but no grass observed.
		4	1136	Non-random. Several more possible eelgrass observations—pretty deep (30 ft).
		5	1142	Non-random. Some surfgrass near start. Toggled "on" on HyPack.
		6	1148	Start random tracks again. No grass. Lots of kelp again.
		7	1153	Random. Possible eelgrass clump at deep end (about 30 ft).
		8	1203	Random. Several possible clumps—some look like eelgrass and some like surfgrass.
		9	1209	Random. Looks like surfgrass at shallow end.
		10	1215	Non-random. Lots of potential clumps of grass. Hard to tell if its eelgrass or surfgrass.
		11	1220	Random. More possible grass at same depth range as #10. It is mixed with kelp.
		12	1227	Random. Same as #11.
		13	1233	Random. A few more clumps—looks like eelgrass.
		14	1238	Random. First grass observation looks like eelgrass, deepest observation looks like surfgrass.
		15	1244	Non-random. All possible observations look like eelgrass.
		16	1250	Random. More eelgrass here.
sjs2716	6/5/06	1	1334	False clicks at first part. Both eelgrass and surfgrass at deep end.
		2	1340	Surfgrass at start (some clicked). Deeper observations look like both eelgrass and surfgrass.
		3	1347	Surfgrass at start (no clicking). Eelgrass at deep end (may have some surfgrass).

Site	Date	Track	Time	Comment
		4	1355	Same as #3.
		5	1403	Same as #3.
		6	1411	Same, but doesn't look like surfgrass.
		7	1418	Same.
		8	1425	Surfgrass at start (a few errant clicks). Eelgrass at deep end, may have some surfgrass.
		9	1433	At deep end, eelgrass (may be with surfgrass).
		10	1441	Surfgrass at start (some clicking). Eelgrass at deep end, with possible surfgrass.
		11	1449	No surfgrass or eelgrass at shallow end. Eelgrass at deep end.
				Start 3 non-random tracks.
		12	1457	Between #7 and #8. Small amount of surfgrass (?) at start, then eelgrass at deep end.
		13	1506	Between #5 and #6. No grass at shallow end. Eelgrass at deep end.
		14	1515	Between #3 and #4. Small amount of surfgrass at start (a few errant clicks). No eelgrass at deep end.
sjs2717	6/13/06	1	1745	Lots of kelp. Several patches of eelgrass. Didn't notice any surfgrass. Some fish toward end of track.
		2	1756	Non-random. Eelgrass patches pretty consistent with previous track.
		3	1805	Somewhat more eelgrass.
		4	1806	Still more eelgrass, then a lot of surfgrass deeper out to 37 ft. Lots of fish at end of track. Ratfish!
		5	1827	More eelgrass, less surfgrass. Transition at 31 ft. Lots of fish at deep end.
		6	1838	Eelgrass with surfgrass mixed early and transitioning to surfgrass later.
		7	1849	Surfgrass, then eelgrass, then surfgrass. Not much eelgrass.
		8	1900	Non-random. Patches of eelgrass and maybe some surfgrass.
		9	1909	Surfgrass mixed with kelp. Maybe a bit of eelgrass. Ratfish!
		10	1918	Surfgrass mixed with kelp. Any eelgrass? Ratfish!
		11	1926	Surfgrass mixed with kelp and a couple of eelgrass patches with kelp toward deep end.
		12	1234	Seagrass mixed with kelp. Surfgrass mostly of all?
		13	1942	Same as previous track.
				Note: Tried to snag some grass again. Only got kelp.
sjs2718	6/13/06	1	1518	Big groundswell and strong flood make visibility poor at start. No eelgrass. Lots of understory kelp on a sand/gravel bottom. A couple of schools of fish.
		2	1532	Same sort of track. Didn't notice any fish.
		3	1547	Saw fish school. Maybe two shoots of eelgrass @ 3:50:27/8.
		4	1602	Similar to 3, but didn't see any eelgrass.
		5	1615	No eelgrass. Hit fish school at end.
		6	1627	No so many fish.
		7	1640	Non-random. No grass. Didn't notice any fish.
		8	1651	No grass. Lots of fish at deep end—they continue out.
		9	1703	Same.
		10	1715	A bunch of surfgrass at shallow end, and eelgrass out deeper.
		11	1727	Non-random. Surfgrass at start. Maybe one eelgrass shoot later.
		12	1734	Non-random. Deep to shallow. Maybe a few eelgrass shoots. Surfgrass at end.

Site	Date	Track	Time	Comment
sjs2719	6/6/06	1	1045	Sand with some rocks and spots of kelp. Becomes more coarse with kelp at 28 ft.
		2	1050	Similar, but less kelp. Fish school toward end of track.
		3	1109	Similar. Lots of fish early.
		4	1120	Similar. A couple of good schools of fish.
		5	1130	Similar.
		6	1143	Bare sand to 25 ft, then some kelp becoming dense at 30 ft.
		7	1151	Similar to #6. A bit more kelp.
		8	1200	More kelp and lots of fish.
		9	1210	Bare sand to 25 ft, then adding gravel and kelp. Lots of fish.
		10	1222	Similar. Took it out further. Dig8 runs out.
				No eelgrass. No surfgrass.
sjs2720	6/7/06	1	0939	Sand with some kelp, becoming coarser with more kelp.
		2	0950	Similar. Denser kelp starting at 30 ft.
		3	0959	Same as #2.
		4	1008	Similar, but dense kelp starting a bit shallower.
		5	1025	Similar. Large school of fish. Go through mill outfall near end.
sjs2721	6/7/06	1	0810	Mostly bare sand with some stones and kelp; becoming more coarse with more kelp, but not as dense as to the west.
		2	0825	Similar to #1, but much more kelp.
		3	0845	Bare sand becomes mixed sand and gravel with kelp at 15 ft.
		4	0900	Same—accidental clicker a couple of times at start.
		5	0915	Similar, but gravel and kelp start at 24 ft.
sjs2722	6/6/06	1	0620	Sand to gravel. Surfgrass at start (clicker on too long). Kelp throughout. Some fish schools.
		2	0653	Similar to track 1.
		3	0720	Similar, but gets deeper quicker. Also, more fish now.
		4	0740	Similar, but no surfgrass. Clicker accidentally on at end.
sjs2723	6/6/06	1	1137	Lots of kelp to about 20 ft, then understory kelp over coarse sand and shell hash. Huge schools of juv fish.
		2	1214	Same as #1, except fewer fish on deep half. No grass.
		3	1249	Clumps of surfgrass at start (no clicks). No other grass—just understory kelp. Only a few fish schools.
		4	1319	A few clumps of surfgrass at start. Wind has increased steadily—now about 20W with 1-2 ft lump. Same as #3.
sjs2724	6/12/06	1	0937	Mixed kelp on gravel bottom. Swift current. Kelp from start to shore.
		2	1008	Same.
		3	1030	Same.
		4	1053	Same.
sjs2725	6/9/06	1	1133	Sandy bottom quickly becomes coarser. Kelp throughout. Current slacking, but still strong.
		2	1147	Similar to previous.
		3	1203	Similar. Ended a little early because we were towing too much kelp.
		4	1218	A bit of surfgrass at the start. Then lots of kelp.
		5	1234	No surfgrass. Lots of kelp.

Site	Date	Track	Time	Comment
sjs2726	6/9/06	1	0958	Lots of kelp and lots of little fish. Strong current.
		2	1012	Good kelp watching.
		3	1025	No shortage of kelp.
		4	1037	Lots of kelp. Lots of debris flying by in current.
		5	1050	Tough conditions. Patch of grass (surfgrass probably) right at start.
sjs2727	6/6/06	1	0913	No grass. Starts at river mouth. Some kelp, but not as much as E and W of mouth. Large schools of juv fish (salmon, sandlance, herring???).
		2	0928	Lots of kelp at the start. Kelp along entire transect. Several schools of juv fish.
		3	0941	Lots of kelp throughout. No grass.
		4	0954	Thick canopy kelp at start, then changes to understory kelp for rest of track. Several schools of juv fish at deep end.
		5	1010	Starts at deep edge of canopy kelp (about 20 ft). Understory kelp, but no eelgrass.
				Start 3 non-random tracks. We decided to use systematic sampling for the last 3 tracks (since no eelgrass is anticipated).
		6	1020	Non-random. Same as #5.
		7	1032	Non-random. Same as #5.
		8	1047	Non-random. Starts close to beach in the canopy kelp. Understory kelp after about 26 ft. Dig8 tape stops at about 1054.
	6/12/06	9	1122	Non-random. Parallel to isobaths. Kelp on gravel. Ratfish!
		10	1137	Non-random. Parallel to isobaths. Kelp on gravel.
		11	1152	Non-random. Parallel to isobaths. Kelp on gravel.
sjs2728	6/6/06	1	0657	No Dig8 tape. Soft sediment throughout, but no grass. A few kelp plants at the deep end.
		2	0710	No Dig8 tape. Same as #1.
		3	0719	Soft sediment throughout. Some kelp at deep end. All of first 3 tracks seem to have small tubes sticking up.
		4	0730	Same as #3.
		5	0744	Same as #3.
		6	0754	Dramatic change. Lots of kelp on shallow half of this track, interspersed with bare soft sediment. Less kelp as we got deeper.
				Note: Geoduck dive boats are anchoring up just beyond the deep ends of tracks 5 and 6. We couldn't go as deep as we wanted to.
		7	0803	Thick kelp to about -20 ft, then bare soft sediment. A few sea pens starting about -30 ft. Geoduck divers made a test dive and then moved west.
		8	0816	Same as #7. Kept camera at kelp canopy top on first half. Had to clear once.
		9	0834	New DVD. Same as #7 and #8.
		10	0843	Same.
		11	0852	This track starts directly at the river mouth. Not much canopy kelp. Large schools of juv fish (salmon, herring, sand lance???). Dig8 tape may end early.
	6/12/06	12	1220	Non-random. Parallel to isobaths. Kelp on gravel with sand. Labeled "Track 11" on tape. More sand to west. Some sea pens.
		13	1236	Non-random. Parallel to isobaths. Similar to previous. A bit shallower. A bit more kelp.
		14	1245	Non-random. Parallel to isobaths. Shallower. Coarse gravel with kelp.
sjs2729	6/9/06	1	0752	In kelp gap. Only a bit of grass.

Site	Date	Track	Time	Comment
		2	0759	Inner kelp thicker, outer kelp thinner. No grass.
		3	0812	Non-random. Meandering in another kelp gap. A patch of surfgrass and a few patches of eelgrass.
		4	0820	Surfgrass mixed with kelp at start, then eelgrass patches and 1 eelgrass patch much deeper (about 25 ft) than the rest.
		5	0829	Surfgrass with kelp at start, then patches of eelgrass (maybe another patch of surfgrass). More eelgrass on the deeper end of this track.
		6	0839	Surfgrass and kelp at shallow end. No eelgrass until deeper area, but less than on track 5.
		7	0849	Non-random. Between #5 and #6. Surfgrass at shallow end. Most grass yet at deep end.
		8	0900	No grass. Bare sand at shallow end. Kelp out deeper.
		9	0909	Non-random. Between #6 and #8. Surfgrass (?? Didn't get a good look) with kelp at start. A bit of eelgrass deeper (maybe a surfgrass patch out there too?).
		10	0918	Non-random. East of #8. One clump of surfgrass out deep. Maybe uprooted.
		11	0927	Bare sand at start. No grass.
		12	0935	One plant way out deep (about 36 ft).
	6/12/06	13	1310	Mostly sand w/kelp spots. No grass.
		14	1320	Same.
		15	1330	Surfgrass at shallow end. Eelgrass out deeper.
		16	1339	Same. Surfgrass and eelgrass don't overlap, but come close.
		17	1347	Meander at west end of bed. One patch of grass (eel or surf??) on top of a boulder.
		18	1358	Surfgrass mixed with kelp.
		19	1403	Eelgrass in kelp gap, then surfgrass with kelp.
sjs2730	6/9/06	1	0637	Kelp-o-Rama!
		2	0646	Kelp all the way. When we tried to turn light on, it fried everything. No track 1 and 2 on DVD.
		3	0700	Thick kelp to the beach and out to 30+ ft.
		4	0709	An abundance of kelp. Lots of little fish again today.
		5	0718	Gap between kelp bed and shore. Many patches of eelgrass and maybe one patch of surfgrass.
		6	0730	Meander through kelp gap. Plenty of eelgrass and maybe a patch or two of surfgrass.
	6/12/06	7	1420	Surfgrass with kelp, then eelgrass in kelp gap.
		8	1425	Same, but with some surfgrass later too.
		9	1431	Eelgrass mixed with kelp. No surfgrass.
		10	1436	Surfgrass and eelgrass mixed with kelp.
		11	1441	Surfgrass with kelp. No eelgrass.
sjs2731	6/8/06	1	0759	Kelp city! Short kelp looked a lot like eelgrass near start.
		2	0808	More kelp.
		3	0820	Kelp, kelp, kelp!
		4	0828	Deep to shallow. Lots of kelp.
		5	0834	Deep to shallow. Some surfgrass and eelgrass inside main kelp bed.
		6	0900	Labeled track 5. Meander in kelp gap. Mixed patches of kelp, surfgrass, and eelgrass.
	6/12/06	7	1459	Surfgrass mixed with kelp. Mislabeled "sjs2730". Maybe an eelgrass patch.
		8	1505	Surfgrass mixed with kelp. Eelgrass later. Maybe another surfgrass patch?

Site	Date	Track	Time	Comment
		9	1511	Surfgrass mixed with kelp, then surfgrass, kelp, and a little eelgrass later.
		10	1517	We think just surfgrass mixed with kelp.
sjs2732	6/8/06	1	0923	A few patches of surfgrass and maybe eelgrass mixed with kelp.
		2	0935	Lots of eelgrass inside main kelp bed.
		3	0942	Non-random. Between #1 and #2. A bit of eelgrass.
		4	0950	Similar to #2. Kelp problem with engine water intake. [At end of day had to dive under boat to remove a kelp bulb that had lodged in the through-hull intake!]
		5	1013	Similar to #4.
		6	1022	Abort.
		7	1029	Near continuous patches of grass from shore to kelp bed.
		8	1040	Similar to #7, but with a kelp gap.
		9	1048	All kelp.
		10	1057	Patches of eelgrass mixed with kelp.
		11	1108	More continuous (eelgrass) with patches on ends.
		12	1122	More continuous; more grass.
		13	1132	More grass.
	6/12/06	14	1532	Patchy eelgrass.
		15	1544	Surfgrass (?) at start, mixed with thick kelp. A few little eelgrass patches further out.
		16	1629	Min edge track. No DVD.
		17	1632	Same. No DVD.
sjs2733	6/8/06	1	0637	Mostly rocky kelpy bottom. Grass in front of pocket beach. Beach clicker on late.
		2	0649	Non-random. Out from pocket beach. Not all the way in. Kelp and eelgrass mixed. NW end of grass bed.
		3	0659	Out from ?? pocket beach. South end of grass bed. We got shallow edge.
		4	0708	Non-random. Meander through grass.
		5	0720	Along edge of kelp bed next to reef. Grass mixed with kelp.
		6	0728	Non-random. Zig-zag along deep edge at west end of bay.
		7	0738	Non-random. Mixed grass and algae. Need more water for inner edge.
		8	1210	Probably still not getting shallowest patches. Lots of grass.
		9	1228	Similar to #8. Possibly some un-rooted plants toward deep end.
		10	1245	May have gotten shallowest patches on that one.
		11	1300	One plant out deeper than the rest at about 34 ft.
		12	1315	Similar to #11. Didn’t see any stray deep plants.
		13	1330	Similar, but with a couple of stray deeper plants. Visibility went to crap at about 35 ft.
	6/12/06	14	1603	Min edge track.
		15	1607	Same.
		16	1611	Min/north edge track.
		17	1614	North edge track.
		18	1617	Same.
		19	1620	Same.

Appendix B

Clallam County Marine Resources Committee
Eelgrass Mapping Along The Elwha Nearshore
Field Notes—September 13 to 26, 2006

Site	Date	Track	Time	Comment
sjs2676	9/19/06	1	1125	Starting at tip of spit. Steep with gravel and kelp. Shoreline on chart not accurate.
		2	1132	Just a bit north. Not as steep. Patches of eelgrass in about 20 ft. More variety of algae.
		3	1140	Non-random. Meander to define south extent of eelgrass. Strong current.
		4	1157	NW of #2. A few small patches of eelgrass. BIG current.
		5	1208	Long track out broad flat area to about 20 ft. A couple patches of grass.
		6	1225	Drift with current across broad flat at ends of spit. Maybe some plants?
		7	1238	West of #5. A few patches of eelgrass. Why no surfgrass?
		8	1253	West of #7. Much more grass. Dig 8 tape runs out. No eelgrass at that end of track.
		9	1306	New Dig 8 tape. West of #8. Still more continuous grass. Not as deep as further east eelgrass.
		10	1319	Between #8 and #9. As expected.
		11	1333	West of #9. Similar.
		12	1346	West end of site. Somewhat less grass.
sjs2677	9/19/06	1	1403	East end of site. Just a few small patches of eelgrass.
		2	1414	Surfgrass near shore, then patches of eelgrass. Understory kelp throughout.
		3	1425	Surfgrass mixing to eelgrass. Understory kelp throughout.
		4	1435	Similar to #3. Maybe no mixed zone.
		5	1445	Somewhat less surfgrass.
		6	1456	Just a little surfgrass. Then more eelgrass than previous tracks.
		7	1506	Less eelgrass than Track 6. Similar surfgrass.
		8	1518	Less surfgrass. Less eelgrass.
		9	1529	No surfgrass. Lots more eelgrass.
		10	1542	Eelgrass patchy. Consistent with DNR sjs2678.
sjs2768	9/14/06		1010	Visibility slightly better, but can’t see more than a few inches, and even then, it’s just a vague shape right before collision. Can’t use this track. Will return later.
	9/27/06	1	1150	Eelgrass (and surfgrass) in distribution consistent with 2003 DNR survey.
		2	1202	Surfgrass then eelgrass. Consistent with DNR 2003.
		3	1215	Consistent with DNR 2003.
sjs2679	9/19/06	1	1559	Surfgrass shallow near shore. No eelgrass. Some kelp.
		2	1608	Right on east edge of site. One small patch of eelgrass.
		3	1617	Surfgrass shallow. Kelp deeper. Maybe one eelgrass plan deep.
		4	1627	Less surfgrass, more kelp. A few eelgrass plants deep.
		5	1637	More kelp. Maybe an eelgrass plant or two deep.
		6	1647	More eelgrass. Not quite so deep.
		7	1657	Less kelp. More eelgrass.

Site	Date	Track	Time	Comment
		8	1706	A little less eelgrass. Mostly about 25 ft.
		9	1714	Missed surfgrass at start this time. Maybe more eelgrass.
		10	1722	Less of shallow surfgrass. Similar deep eelgrass.
		11	1730	
sjs2680	9/27/06	1	1001	Bare sand becoming kelpy. No grass.
		2	1012	More understory kelp earlier. Still no grass.
		3	1022	One seagrass (eelgrass or surfgrass?) pretty shallow.
		4	1032	I didn't see any seagrass. Lou says maybe. Visibility limited.
		5	1042	No seagrass. Some thick kelp.
		6	1052	Surfgrass shallow and eelgrass deeper. Kelp in between.
		7	1100	Non-random. Between #5 and #6 to define edge of eelgrass bed.
		8	1108	Surfgrass and maybe a patch of eelgrass shallow. Increasing eelgrass deep.
		9	1117	Surfgrass shallow. Decreased eelgrass deeper.
		10	1125	Didn't see surfgrass this time. Deep grass spottier.
		11	1132	Surfgrass shallow. Eelgrass deep.
sjs2681	9/14/06		0945	Still no visibility. Can't see anything until we hit it. Move around corner of where spit turns west.
	9/16/06	1	1718	Less kelp.
		2	1728	Less kelp. Particularly poor visibility near shore.
		3	1737	A little better visibility. Otherwise similar.
		4	1747	One uprooted eelgrass plant floats by.
		5	1756	Better visibility. More of same. Lots of kelp.
		6	1805	Less kelp again. Still no grass.
sjs2682	9/16/06	1	1609	Moderate visibility. Sand with some gravel and stones. Some kelp.
		2	1617	More stones, but quite similar.
		3	1625	More kelp.
		4	1634	More of same.
		5	1644	More kelp.
		6	1655	Less kelp. Visibility a bit worse.
		7	1704	More kelp again. Visibility getting worse with setting sun.
sjs2683	9/16/06	1	1505	Some kelp throughout. No eelgrass or surfgrass. Visibility better.
		2	1511	Stones near shore then sand. Kelp throughout.
		3	1520	As above.
		4	1528	As above.
		5	1538	As above.
		6	1548	As above. Kelp getting a bit more sparse.
		7	1557	More of the same.
sjs2684	9/16/06	2	1350	Visibility gets better further from shore. Some kelp. No grass.
		3	1400	Similar to the previous track.
		4	1407	Even the deeper kelp looks pretty beaten.
		5	1415	Kelp thick here.
		6	1424	Kelp thins out a bit again.
		7	1435	Similar to #6, but a couple of tufts of surfgrass mixed in with kelp.
		8	1443	No surfgrass seen on this one. More stones as we get further north.
		9	1453	
sjs2685	9/20/06	1	1057	Marginal visibility. Improves away from shore. Some kelp. No grass.

Site	Date	Track	Time	Comment
		2	1106	Much like the first. Slightly more kelp.
		3	1116	Visibility a bit worse. Rockier bottom.
		4	1127	Sandier. Saw a couple of detached seagrass blades float by.
		5	1138	Starting outside thick kelp bed. Still kelpy. Lotsa monster tube worms.
		6	1148	Similar to #5. Thick kelp out deeper.
		7	1157	As above.
				Note: “Kelp” on this site refers to bull kelp and walking stick kelp.
sjs2686	9/20/06	1	1209	Starting outside thick kelp. Continuous kelp. No grass.
		2	1217	As above.
		3	1227	Loads of kelp.
		4	1238	Pretty much the same.
		5	1248	As above.
		6	1258	Much the same. Lots of kelp.
				Note: “Kelp” on this site refers to bull kelp and walking stick kelp.
sjs2687	9/20/06	1	1328	Sand near shore becomes more gravely offshore. Kelp throughout.
		2	1340	Starting outside of thick kelp. Much like the first track.
		3	1354	Starting a bit shallower. Similar.
		4	1408	Meander inside kelp band. More kelp.
		5	1414	Starting outside kelp bed. Kelpy throughout.
		6	1425	As above. Kelp slightly less dense.
				Note: “Kelp” on this site refers to bull kelp and walking stick kelp.
sjs2688	9/20/06	1	1441	Kelp throughout.
		2	1454	Starts outside thick kelp.
		3	1506	Meander behind kelp bed at MacDonald Creek. Some seagrass. Sampled and confirmed surfgrass.
		4	1517	Starts outside kelp band. Kelp throughout.
		5	1528	Able to start shallower. Ran into probable surfgrass, but visibility very poor near shore.
		6	1542	Starts outside thick kelp.
				Note: “Kelp” on this site refers to bull kelp and walking stick kelp.
sjs2689	9/20/06	1	1606	Starting at west end of site. Many patches of eelgrass out to about 20 ft. Then some eelgrass mixed with kelp at about 25 ft.
		2	1631	Just west of #1. Similar, but slightly more grass.
		3	1650	East of #1. Kelp mixes in earlier and no deeper patches of grass.
		4	1710	East of #3. Grass not quite as deep. Dig 8 tape runs out at end.
		5	1728	East of #4. Much less grass.
		6	1741	East of #5. Even less grass.
	9/21/06	7	1055	Useless—no visibility.
	9/25/06	8	1126	Pretty good visibility. Eelgrass out to about 15 ft, then a little mixed with kelp at about 20 ft.
		9	1143	A little grass at about 12 to 15 ft and a little mixed with kelp at about 20 ft. Increasing kelp.
		10	1159	New Dig 8 tape. Maybe one or two eelgrass plants. Abutting kelp bed to the east.
		11	1212	No grass. Starting outside thick kelp.
		12	1224	East side of site. Starting outside kelp bed. A little grass mixed with kelp at about 20 ft.
sjs2690	9/25/06	1	1245	East side of site. Many patches at about 10 to 20 ft. No deeper eelgrass.

Site	Date	Track	Time	Comment
		2	1303	Patch of surfgrass at start mixed with kelp. Similar to #1, but outlying patches mixed with kelp to about 28 ft.
		3	1321	Much like #2, but no surfgrass and more outer eelgrass, though not quite as deep.
		4	1340	Less grass on both ends.
		5	1358	Less inshore grass.
		6	1416	New Dig 8 tape. Surfgrass less than 10 ft; eelgrass greater than 10 ft. A little more grass than #5.
		7	1433	Much like #7. Surfgrass shallow, eelgrass deeper. More grass than #6.
		8	1450	New DVD. Thick kelp to the west. Surfgrass shallow, then much more eelgrass deeper.
		9	1505	Starts just outside thick kelp. Just a couple patches of eelgrass.
		10	1520	Similar to #9, but somewhat more grass.
sjs2691	9/25/06	1	1541	Starts outside kelp band. Lots of eelgrass. Up and over kelp shoal near end of track.
		2	1555	Muck like #1, but no shoal. Lots of kelp and tube worms mixed with eelgrass.
		3	1608	Significantly less grass and less kelp, too.
		4	1620	Surfgrass shallow (was there an eelgrass plant there too?); eelgrass deeper.
		5	1634	A little surfgrass at start. A bit more eelgrass out about 25 ft.
		6	1649	Patches of eelgrass starting about 15 ft, then much more at 25 ft to about 30 ft. Grey whale active here today.
		7	1705	Much more eelgrass on shallow end. A bit more on deeper end.
		8	1721	New Dig 8 tape. More continuous grass patches, but not quite as far as deep end.
		9	1738	Eelgrass, then thick kelp, then mixed grass and kelp.
		10	1755	Some grass at shallow end. Similar to #9. Only a little grass after kelp band.
sjs2692	9/26/06	1	0933	East end of old DNR site. Many patches of eelgrass from about 10 to 25 ft. Some areas of thick kelp. Many ratfish.
		2	0948	Less kelp, more eelgrass. Big changes in both since DNR survey.
		3	1003	Much grass mixed with understory kelp. Once kelp peters out (about 23 ft), no more eelgrass either.
		4	1017	Starting outside kelp bed. Much like #3.
		5	1030	Less grass than #4 or #3. Much of the Bull Kelp we pull up has holdfast on tube worms!
		6	1045	Decreasing eelgrass as we move west.
		7	1058	A bit murky at start, then a few individual plants. No patches. Dig 8 tape runs out.
		8	1114	New Dig 8 tape. As above.
		9	1128	A few isolated plants.
		10	1144	Maybe a couple of plants?
		11	1155	Surfgrass inshore of thick kelp.
sjs2693	9/13/06	1	1130	Useless. Swell had water so turbid we could not see a thing. Surfgrass at start. Bouncing up and down. Crashing into things. Catching kelp. Can't survey here now.
		2		
	9/26/06	3	1224	Less surfgrass at start. Several adrift eelgrass plant caught. Any rooted?
		4	1234	Maybe 1 or 2 rooted eelgrass plants. Maybe none.

Site	Date	Track	Time	Comment
		5	1245	Several plants caught on algae tufts. A rooted plant or two.
		6	1254	I don't think any of that eelgrass was rooted.
		7	1301	Siltier close to creek mouth. Many tubeworms.
		8	1308	Significant quantity of grass in kelp gap mixed with kelp.
		9	1317	No grass seen. Much kelp.
		10	1325	Grass in kelp gap and fringes of kelp bed.
		11	1336	Just a bit of grass at edge of kelp bed.
sjs2694	9/26/06	1	1352	Patches of eelgrass mixed with understory kelp out to about 25 ft.
		2	1402	Increasing eelgrass; out a bit deeper.
		3	1413	Less eelgrass, but in a more concentrated area. Still mixed with understory kelp.
		4	1425	Less grass, over the same area.
		5	1434	Slightly decreasing eelgrass; increased kelp.
		6	1446	A bit more eelgrass now. Kelp is similar quantity.
		7	1455	Less grass in a similar distribution—further west.
		8	1506	A bit more grass over slightly smaller area.
		9	1514	Pretty much the same. Kelp is borderline problematic at this site.
		10	1523	West edge of site. One healthy looking eelgrass plant in the kelp. Rooted??
		11	1531	Between #9 and #10. Some grass. Took it out much farther—no grass there. Dig 8 runs out.
sjs2695	9/26/06	1	1556	No eelgrass—consistent with DNR surveys.
		2	1605	Starting outside thick kelp. No grass.
		3	1613	Between inner and outer thick kelp. Kelp still pretty thick. No grass. Consistent with DNR surveys.
sjs2696	9/26/06	1	1622	Running along edge of very thick kelp. No video. Took a little Dig 8 video (no overlay) of kelp bed.
		2	1630	Starting outside thick kelp. Substrate gravel and rock when visible. Still quite kelpy.
		3	1637	Pretty much the same as #2.
		4	1647	Much the same.
sjs2697	9/13/06	1	1152	BioSonics only. Kelp perimeter. Thick, thick kelp bed.
		2	1203	Meander between inner and outer kelp bands. Sparse kelp. Some visibility at start. Bad visibility as we get shallower.
		3	1218	Among outside edge of inner kelp band. Bad visibility. No grass seen or suspected on BioSonics.
	9/26/06	1	1702	Meander in kelp gap. No grass.
sjs2698	9/13/06	1	1233	BioSonics only. Meander along outer kelp perimeter. Kelpy. No gap inshore of kelp for us to navigate.
	9/26/06	2	1720	Meander I kelp gap east of point. No grass.
		3	1729	Outside thick kelp. More kelp. Rocky/gravel substrate.
		4	1737	Kelp gap. Kelpy.
		5	1744	West end of site. Kelp!
sjs2699	9/13/06	1	1250	Some visibility. An assortment of kelp and algaes.
		2	1300	Kelp quickly gives way to sand with assorted algae.
		3	1309	Mostly kelp with some other algae.
		4	1317	More kelp and more gravel substrate.
		5	1328	Near beginning of train bulkheading. A few tips of seagrass plants at start, but not enough to get species.

Site	Date	Track	Time	Comment
		6	1340	One eelgrass plant.
		7	1350	One or two eelgrass plants.
		8	1358	No eelgrass seen.
		9	1408	One eelgrass patch.
		10	1415	No grass seen.
		11	1423	No grass. Along kelp edge at west end of site.
		12	1431	Did I see a seagrass plant? 14:35:49…14:35:10

Appendix C

Table 6. Summary of basal area coverage, eelgrass fraction, and patchiness index statistics.

Site	Bed	Date	Number of Transects	Eelgrass Fraction	Areal Extent (ha)	Variance	CV	80% Lower Limit	80% Upper Limit	Patchiness Index
2731	W Freshwater Bay	6/12/06	5	0.0896	0.0610	0.0011	0.5462	0.0184	0.1036	3.89
2732	W Freshwater Bay	6/12/06	12	0.4276	11.1696	2.4102	0.1390	9.1825	13.1568	7.99
2733	W Freshwater Bay	6/12/06	9	0.6196	10.3977	0.3383	0.0559	9.6532	11.1422	9.23
	Bed Estimates			0.5189	21.6283	2.7496	0.0767	19.5058	23.7508	8.57
2741	W Crescent Bay	9/13/05	4	0.6082	12.8405	0.4417	0.0518	11.9898	13.6912	4.36
2729	E Freshwater Bay	6/12/06	7	0.0704	0.5502	0.0459	0.3895	0.2759	0.8245	2.55
2730	E Freshwater Bay	6/12/06	5	0.3652	1.0105	0.0244	0.1546	0.8105	1.2105	11.35
	Bed Estimates			0.2613	1.5607	0.0703	0.1699	1.2212	1.9002	8.25
2741	E Crescent Bay	9/13/05	7	0.1438	2.3115	0.3831	0.2678	1.5193	3.1037	5.31
2689	Dungeness Bluffs	9/25/06	11	0.1389	4.1004	0.8655	0.2269	2.9097	5.2912	5.30
2690	Dungeness Bluffs	9/25/06	10	0.1676	7.4048	1.8085	0.1816	5.6835	9.1262	10.36
2691	Dungeness Bluffs	9/25/06	10	0.2629	10.2858	1.6153	0.1236	8.6590	11.9126	8.49
2692	Dungeness Bluffs	9/26/06	10	0.1156	4.6680	1.4013	0.2536	3.1528	6.1832	5.65
2693	Dungeness Bluffs	9/26/06	7	0.0471	0.4758	0.0701	0.5564	0.1369	0.8147	2.41
2694	Dungeness Bluffs	9/26/06	11	0.2272	2.8158	0.1389	0.1323	2.3388	3.2927	7.72
	Bed Estimates			0.1921	29.7506	5.8994	0.0816	26.6416	32.8596	7.90
2715	Ediz Hook	6/5/06	10	0.1210	0.6526	0.0433	0.3190	0.3861	0.9191	4.94
2716	Ediz Hook	6/5/06	11	0.2561	3.5051	0.1206	0.0991	3.0606	3.9496	7.35
2717	Ediz Hook	6/5/06	11	0.2316	3.6946	0.1905	0.1181	3.1359	4.2533	9.38
2718	Ediz Hook	6/5/06	3	0.1081	0.0390	0.0006	0.6228	0.0080	0.0700	5.66
	Bed Estimates			0.2327	7.8913	0.3550	0.0755	7.1286	8.6540	8.09
2676	Dungeness Spit	9/19/06	9	0.2002	4.5226	2.2141	0.3290	2.6179	6.4272	5.39
2677	Dungeness Spit	9/19/06	10	0.2216	4.7448	0.8648	0.1960	3.5544	5.9351	8.93
2679	Dungeness Spit	9/19/06	10	0.0856	0.8106	0.0542	0.2871	0.5127	1.1085	4.10
2680	Dungeness Spit	9/27/06	6	0.3303	1.2465	0.0564	0.1905	0.9425	1.5505	10.40
	Bed Estimates			0.2153	11.3245	3.1895	0.1577	9.0385	13.6105	7.33

Table 7. Summary of minimum and maximum depth statistics.

		Minimum Eelgrass Depth						Maximum Eelgrass Depth					
Site	Eelgrass Bed	n	Absolute Depth (ft)	Mean Depth (ft)	Standard Error	95% Lower Limit	95% Upper Limit	n	Absolute Depth (ft)	Mean Depth (ft)	Standard Error	95% Lower Limit	95% Upper Limit
2731	W Fresh Bay	3	-9.1	-11.3	1.2	-16.3	-6.3	3	-13.2	-12.1	0.9	-15.9	-8.4
2732	W Fresh Bay	10	0.2	-4.3	0.9	-6.2	-2.4	10	-24.3	-19.4	1.2	-22.1	-16.7
2733	W Fresh Bay	9	0.4	-0.6	0.2	-1.1	-0.1	19	-28.5	-21.4	0.8	-23.1	-19.8
	Bed Estimates		0.4	-3.8	0.8	-7.0	-0.5		-28.5	-19.9	1.0	-22.4	-17.5
2741	W Crescent Bay	4	-0.4	-4.0	1.5	-8.9	1.0	4.0	-29.2	-25.4	2.8	-34.3	-16.5
2729	E Fresh Bay	7	-10.3	-15.7	1.7	-20.0	-11.4	7	-31.3	-24.5	3.0	-31.8	-17.1
2730	E Fresh Bay	5	-8.3	-9.1	0.5	-10.6	-7.7	5	-19.2	-17.4	1.0	-20.3	-14.5
	Bed Estimates		-8.3	-13.0	1.3	-16.4	-9.5		-31.3	-21.5	2.4	-27.7	-15.4
2741	E Crescent Bay	7	-14.3	-16.1	0.4	-17.1	-15.0	7.0	-29.6	-26.6	0.9	-28.8	-24.5
2689	Dung Bluffs	9	-8.2	-10.4	1.0	-12.6	-8.2	9	-22.6	-19.3	0.7	-21.0	-17.7
2690	Dung Bluffs	10	-7.4	-11.3	1.7	-15.2	-7.4	10	-28.3	-24.1	1.0	-26.2	-21.9
2691	Dung Bluffs	10	-8.2	-12.4	1.4	-15.6	-9.2	10	-28.9	-25.7	0.7	-27.4	-24.1
2692	Dung Bluffs	10	-6.6	-11.0	0.8	-12.9	-9.1	10	-26.0	-21.5	1.1	-24.0	-18.9
2694	Dung Bluffs	11	-16.1	-17.8	0.3	-18.4	-17.2	11	-23.9	-20.4	0.4	-21.3	-19.5
	Bed Estimates		-6.6	-12.2	1.1	-15.4	-10.1		-28.9	-22.2	0.8	-24.1	-20.4
2715	Ediz Hook	8	-6.6	-17.6	2.0	-22.4	-12.8	8	-28.7	-23.3	2.3	-28.8	-17.8
2716	Ediz Hook	11	-3.8	-11.4	1.6	-14.9	-7.7	11	-26.5	-24.8	0.3	-25.4	-24.2
2717	Ediz Hook	11	-12.3	-15.5	0.5	-16.5	-14.5	11	-30.4	-25.8	0.9	-27.8	-23.8
2718	Ediz Hook	2	-18.7	-19.2	0.4	-24.7	-13.6	2	-20.2	-19.9	0.3	-23.7	-16.1
	Bed Estimates		-3.8	-14.8	1.4	-18.2	-11.5		-30.4	-24.5	1.3	-27.5	-21.4
2676	Dung Spit	9	-10.5	-15.1	1.2	-17.7	-12.4	9	-25.8	-20.7	0.8	-22.4	-19.0
2677	Dung Spit	10	-12.4	-14.7	0.6	-16.0	-13.4	10	-26.1	-21.8	0.7	-23.5	-20.1
2679	Dung Spit	9	-16.0	-20.6	1.5	-24.0	-17.1	9	-32.7	-27.8	1.3	-30.7	-24.9
2680	Dung Spit	6	-14.5	-17.0	0.7	-18.8	-15.1	6	-27.1	-23.9	0.7	-25.8	-22.1
	Bed Estimates		-10.5	-17.4	1.1	-19.3	-14.2		-32.7	-23.5	0.9	-25.7	-21.3

Eelgrass Mapping Along The Elwha Nearshore

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Keywords: Elwha, eelgrass, kelp, macro algae, forage fish, sand lance

Abstract

The goal of this project was to gather pre-dam removal nearshore habitat data along the Elwha drift cell (west end of Freshwater Bay to the tip of Ediz Hook) and an adjacent drift cell (mouth of Morse Creek to the tip of Dungeness Spit) by mapping the location of eelgrass (*Zostera marina*) beds and estimating parameters describing each bed (areal extent, patchiness index, eelgrass fraction, mean minimum and maximum eelgrass depths). Our survey methods were identical to those used by the Washington State Department of Natural Resources Submerged Vegetation Monitoring Project. We observed three eelgrass beds within the Elwha drift cell (one along the north shore of Ediz Hook and two in Freshwater Bay) and two beds in the adjacent drift cell (one near Green Point and another along the north edge of Dungeness Spit). The distance between the Elwha River mouth and the nearest eelgrass bed was 0.96 nm. In three of four comparable geomorphic habitat types eelgrass parameters within the Elwha drift cell were very similar to those from regions outside the cell. In the fourth habitat type we observed no eelgrass along the Elwha Bluffs but a large bed along the Dungeness Bluffs. WDNR has documented that the Elwha Bluffs area has experienced significant increase in overstory kelp coverage over the last 100 years. This habitat shift is attributed to larger substrate size resulting from sediment starvation. The dominant feature of the Elwha drift cell was understory kelp and large schools of juvenile Pacific sand lance (*Ammodytes hexapterus*). The project, funded by the Clallam County Marine Resources Committee (MRC), is part of a multi-disciplinary effort to understand and optimize the nearshore restoration associated with the upcoming dam removals.

Introduction

Elwha and Glines Canyon dams 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 of the dams, 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).

Approximately 10 million cubic yards of sediment trapped behind the dams will be delivered to the nearshore within five years of dam removal, which is anticipated to be a two year process. 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.

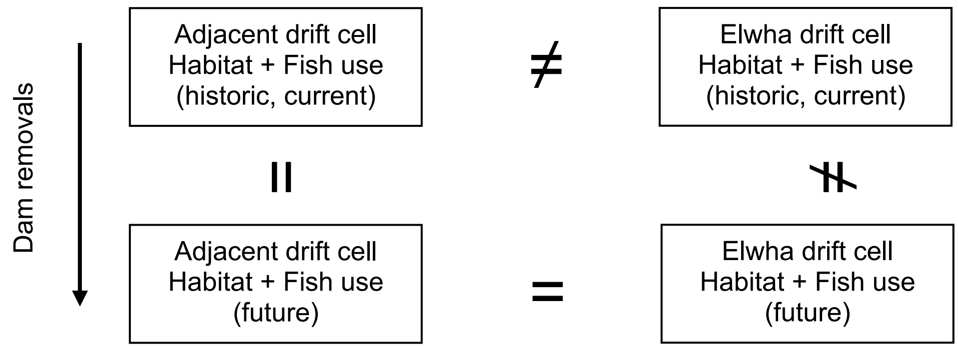


Figure 1. Conceptual model for measuring restoration response to dam removal (from Shaffer et al. 2005).

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

There are four general geomorphic habitat types within the Elwha drift cell and the comparable shoreline: (1) the protected western portions of Crescent and Freshwater Bays; (2) the less protected eastern portions of Crescent and Freshwater Bays which are exposed to strong westerly winds in spring and summer; (3) the Elwha Bluffs and Dungeness Bluffs which have relatively gentle bathymetry gradients; and (4) Ediz hook and Dungeness Spit which have relatively steep bathymetry gradients. Eelgrass (*Zostera marina*) beds are a critical component of nearshore habitats. Our goal for this project was to document the current status of eelgrass resources within the Elwha drift cell and the comparable shoreline (Fig. 2).

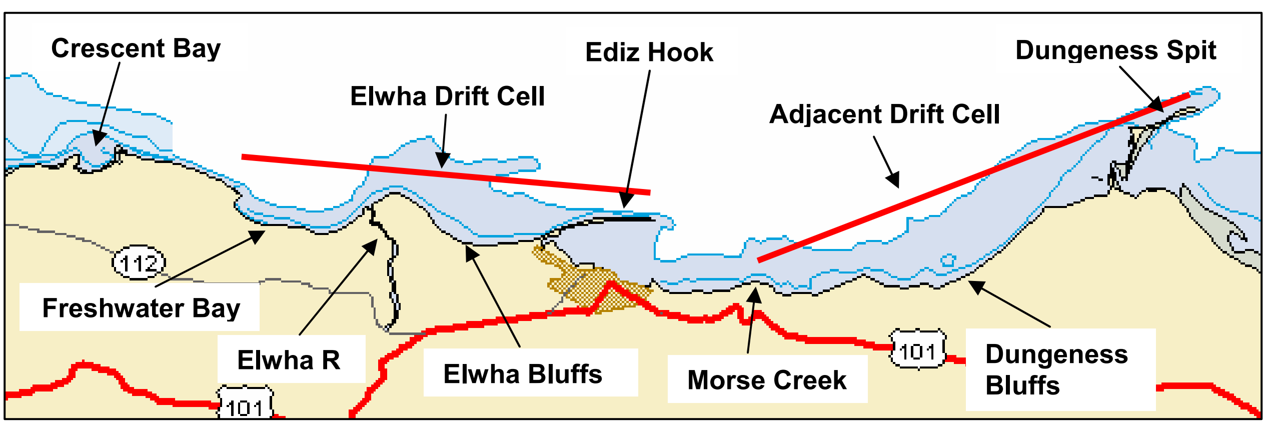


Figure 2. Map of the study areas.

The Washington State Department of Natural Resources (DNR) Submerged Vegetation Monitoring Project (SVMP) surveyed Crescent Bay in 2005, so we did not include it in this survey. Our specific objectives for this survey were to: (1) delineate any eelgrass beds within the two drift cells; and (2) for each eelgrass bed, estimate five parameters using DNR SVMP methods—basal 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), eelgrass fraction (within a bed boundary, the fraction of the area that has eelgrass), 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. Figs. 3 and 4 illustrate the parameter concepts (see Dowty 2005 for a complete description and discussion of these parameters).

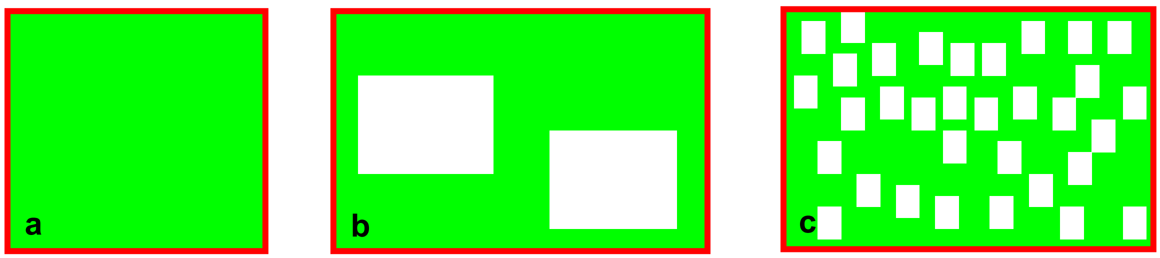


Figure 3. Illustration of basal area coverage, eelgrass fraction, and patchiness index. All three eelgrass beds have the same basal area coverage (i.e., number of square meters of seabed covered with eelgrass, shown in green) within the bed boundary (shown in red). The eelgrass fraction in bed "a" is 100%. Beds "b" and "c" have the same eelgrass fraction (about 65%), but bed "c" has a much higher patchiness index.

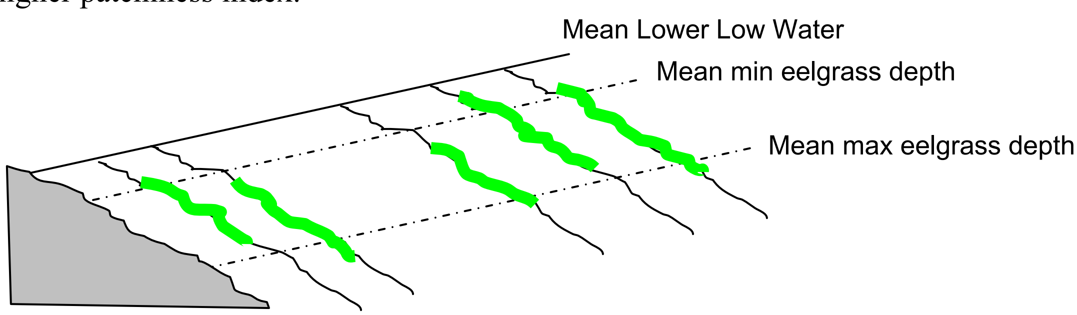


Figure 4. Illustration of mean minimum and maximum eelgrass depths. Each transect running perpendicular to the isobaths has a minimum and maximum eelgrass depth associated with it. If transects within a site are selected randomly, averaging the minimum (or maximum) depth observations provides an estimate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

Methods

Site Description

We defined the survey areas to be the Elwha and adjacent drift cells as depicted in Fig. 2 and out to a depth of -35 ft Mean Lower Low Water (MLLW). We chose -35 ft because that is the deepest we have observed eelgrass in Puget Sound and the Strait of Juan de Fuca. The Elwha drift cell contains 20 “fringe” sites designated in the DNR SVMP (Fig. 5). A fringe site is defined to be a 1000 m length of shoreline as measured along the -20 ft isobath. The adjacent drift cell contains 24 fringe sites.

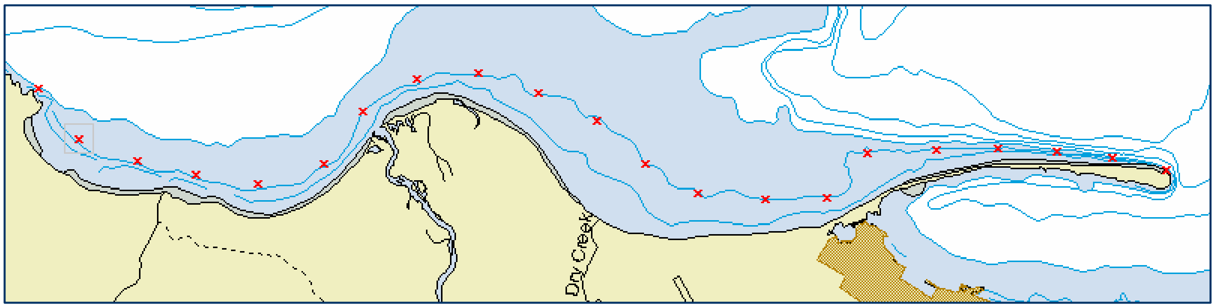


Figure 5. The Elwha drift cell with DNR SVMP fringe site boundaries delineated by red x’s.

Sampling Plan

To delineate eelgrass bed boundaries we could place transects systematically. However, to estimate DNR SVMP parameters we were required to place transects randomly and oriented perpendicular to the shoreline.

We surveyed the Elwha drift cell on seven days between June 5 and 13, 2006 and the adjacent drift cell on seven days between September 13 and 27, 2006. Our sampling plan called for spending between two to four hours for each initial fringe site visit. For each initial site visit we randomly selected 11 transects (this is the minimum number of random transects the SVMP uses) and started surveying with the eastern- or western-most transect at that site. If eelgrass was observed on any of the first few transects or it appeared that all 11 transects could be completed within the allotted time, we continued surveying all 11 random transects and added non-random transects when the distance between random transects was greater than 75 m. If eelgrass was not observed on any of the first few transects and it appeared that all 11 transects could not be completed within the allotted time, we surveyed only four or five of the randomly selected transects such that the surveyed transects were about 200 m apart. For the two sites around the Elwha River mouth we did some random transects and added non-random transects both perpendicular to and parallel to the shoreline to produce a grid sampling pattern.

Underwater Videographic and Hydroacoustic Methods

Our DGPS receiver (Trimble Ag132) provided sub-meter position accuracy with an associated time stamp (updated once per second). The underwater videographic system collected geo-referenced video images by recording track ID code and the time stamp from the DGPS system directly onto the video images. Simultaneously, a data file recorded the DGPS time stamp and position. Our acoustic system (BioSonics 2400 T) stored the data from every ping and associated that data with the time stamp and position data from the DGPS system.

Video tapes were post-processed to assign attribute codes (eelgrass presence/absence) for every position record along a transect. For transects within the Elwha drift cell we also assigned codes for macro algae and fish presence/absence. Acoustic data were post-processed to determine depths below the transducer for each 1 s interval, and these depths were corrected to MLLW by adjusting for transducer offset (depth of transducer below the surface), predicted tide height, and tide prediction error. Finally, all data were merged into a single data file using the DGPS time stamp as the common field.

The 2005 DNR SVMP surveyed a single fringe site within Crescent Bay. We divided the site into east and west components and computed separate parameter estimates for each.

Fish Density Analysis

During the survey in the Elwha drift cell we observed large schools of juvenile fish, most of which appear to be Pacific sand lance (*Ammodytes hexapterus*) (Shaffer and Pentilla, pers. obs). Although our survey was not designed to estimate fish distribution and abundance, we decided to analyze the BioSonics acoustic data (using the BioSonics *Visual Analyzer 4* program) to estimate fish densities within the region we did survey. These results could be useful in designing future forage fish abundance surveys.

We estimated fish densities (fish per square meter of surface area) using echo integration over 10 second intervals along each transect on which we observed fish. To avoid including surface noise and signals from understory kelp, we eliminated signals within 1 m of the surface and the seabed. Fig. 6 shows a sample echograph. We used a target strength value of -70.33 dB, as determined for 4.0 cm long fish from the relationship given in Thomas et al. (2002). A histogram of the resulting densities indicated a log distribution (some very high densities and many very low densities), which we divided into three categories—low (< 220 fish/m^2), medium (880 – 7,500 fish/m^2), and high (> 7,500 fish/m^2). We converted density in fish/m^2 to fish/m^3 by dividing fish/m^2 by the average depth of the associated transect segment. We plotted these three categories on a map and manually created polygons representing the locations of each density category.

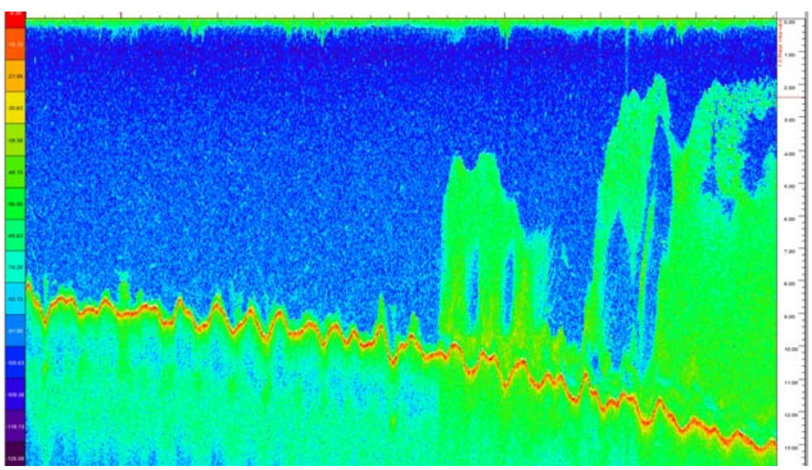


Figure 6. Sample echograph from the BioSonics 2400 T system showing a large school of fish at the deep end of the transect. The red line indicates the seabed. The wave pattern of the seabed is due to surface waves (i.e., the boat going up and down), and do not represent sand waves.

Results

Eelgrass

During the current survey we observed three eelgrass beds in the Elwha drift cell and two in the adjacent drift cell (Fig. 7; Table 1). We did not observe any eelgrass in the Elwha Bluffs area. Bed size varied between 1.6 ha (East Freshwater Bay) and 29.8 ha (Dungeness Bluffs). Patchiness indices were lower in the Crescent Bay beds (4.4 and 5.3) than other beds (7.3 to 8.6). Eelgrass fractions in the western portions of Crescent and Freshwater Bays (61% and 52%) were higher than other beds (14% to 26%). Mean maximum eelgrass depths were similar for all beds (-19.9 ft to -26.6 ft). Mean minimum eelgrass depths in the western portions of Crescent and Freshwater Bays (-3.8 ft and -4.0 ft) were shallower than other areas (-13.0 ft to -17.4 ft). The protected west portions of Crescent and Freshwater Bays had eelgrass growing as shallow as -0.4 ft and +0.4 ft. The deepest observed eelgrass was at -32.7 ft in site sjs2679 (Dungeness Spit).

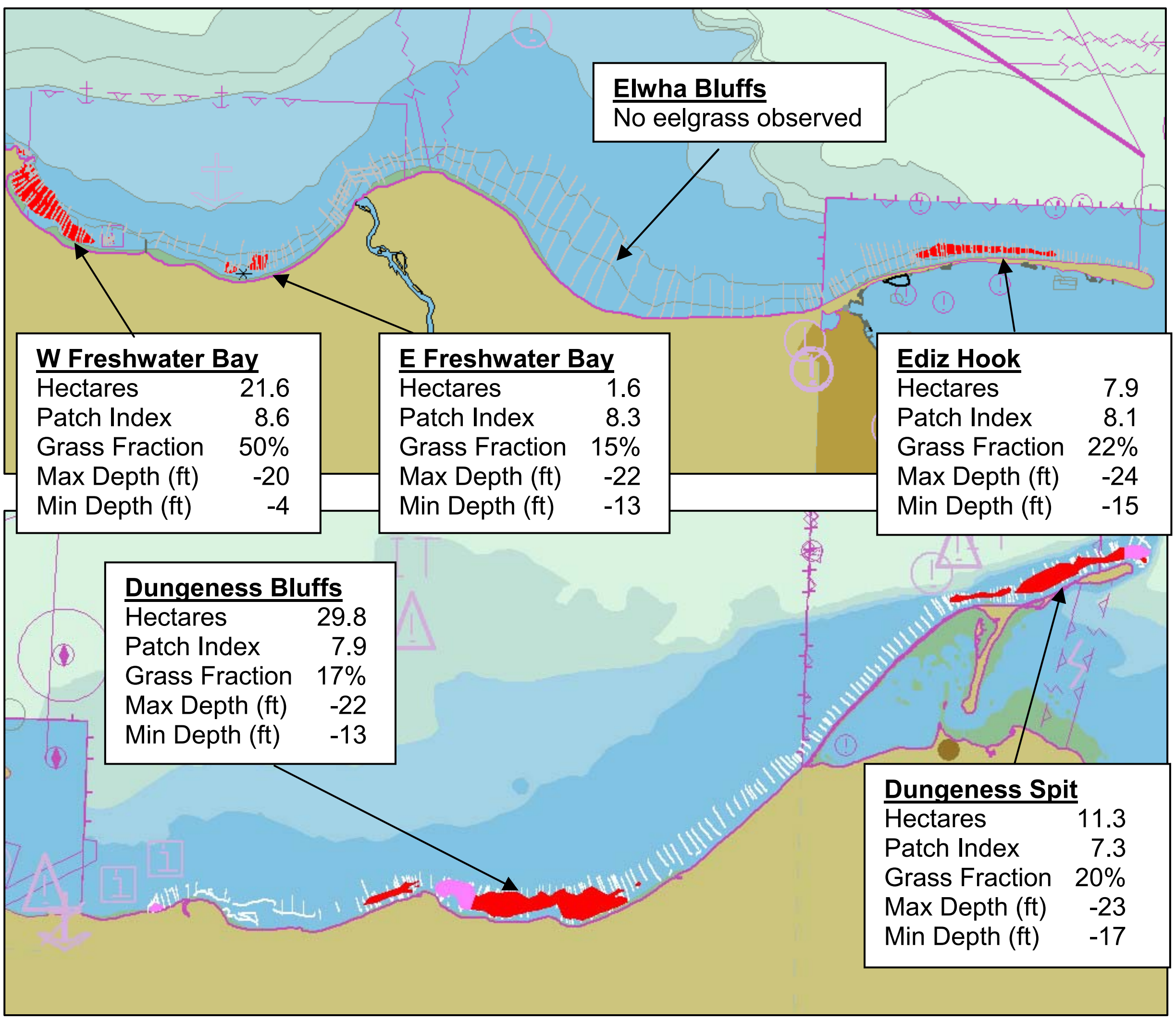


Figure 7. Eelgrass beds (shown in red and magenta) observed in the Elwha and adjacent drift cells. Transects are shown in white.

Table 1. Summary statistics for five eelgrass beds surveyed by this project and the east and west portions of the Crescent Bay bed surveyed during the 2005 DNR SVMP.

Bed	Basal Area Coverage (ha)	Patchiness Index	Eelgrass Fraction	Mean Maximum Depth (ft)	Mean Minimum Depth (ft)
* West Freshwater Bay	21.6	8.6	52%	-19.9	-3.8
West Crescent Bay	12.8	4.4	61%	-25.4	-4.0
* East Freshwater Bay	1.6	8.3	26%	-21.5	-13.0
East Crescent Bay	2.3	5.3	14%	-26.6	-16.1
* Elwha Bluffs	No eelgrass observed				
Dungeness Bluffs	29.8	7.9	19%	-22.3	-12.2
* Ediz Hook	7.9	8.1	23%	-24.5	-14.8
Dungeness Spit	11.3	7.3	22%	-23.5	-17.4

* Regions within the primary Elwha drift cell.

Macro Algae

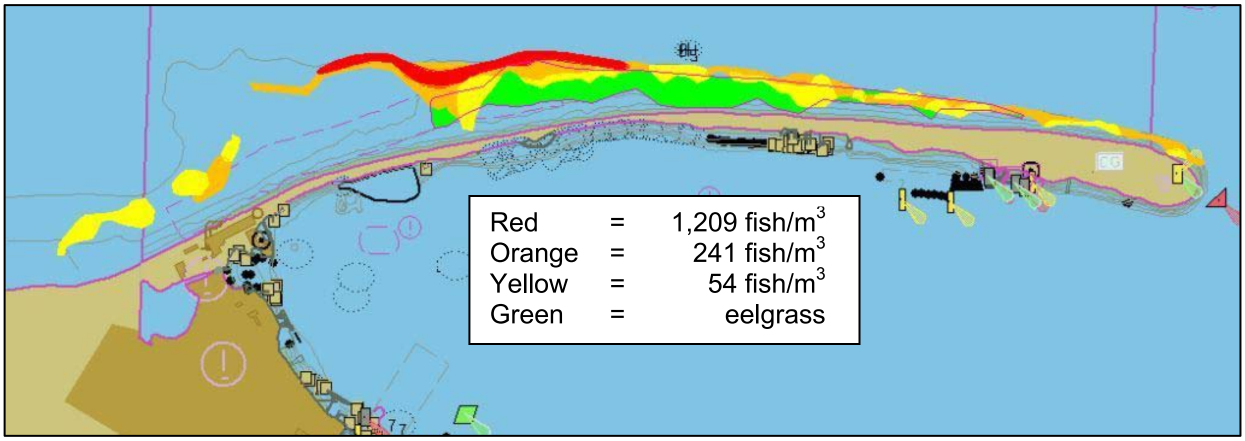
Within the Elwha drift cell we observed macro algae virtually everywhere, including the deep end of our transects. Broad-leafed brown algae dominated, but some red and green algae also were observed. Because we observed significant understory kelp at -45 ft, we can conclude that the photic zone extends at least to this depth, and most likely beyond. Further surveys are needed to determine the deep-water extent of the vegetation. Assuming understory kelp beds are present throughout the nearshore we estimate understory kelp beds to encompass a minimum of 763 ha.

Fish Densities

We observed fish all along Ediz Hook, with the highest densities along the western deepwater edge of the eelgrass bed (Fig. 8). Lower densities were observed in Freshwater Bay and around Angeles Point. We often observed fish at the deepwater end of our transects (e.g., Fig. 6).

Discussion

Eelgrass beds in Crescent Bay and the west end of Freshwater Bay also were noted in the Coastal Zone Atlas (Albright et al. 1980), Washington Department of Fisheries surveys from 1975-1989 (Thom and Hallum 1990), and the 1995 DNR ShoreZone Survey (Berry and Ritter 1997). The beds along Ediz Hook and Dungeness Spit were shown as much smaller beds in the Coastal Zone Atlas, but were not shown at all in the DNR ShoreZone Survey. The Dungeness Bluffs bed (the largest bed we observed) was shown as a very small bed in the DNR ShoreZone survey. One reason previous surveys did not identify the full extent of the Ediz Hook, Dungeness Spit, and Dungeness Bluffs beds is that these beds have relatively deep minimum eelgrass depths—they do not start until -13 ft to -17 ft below MLLW and are not visible at low tide.



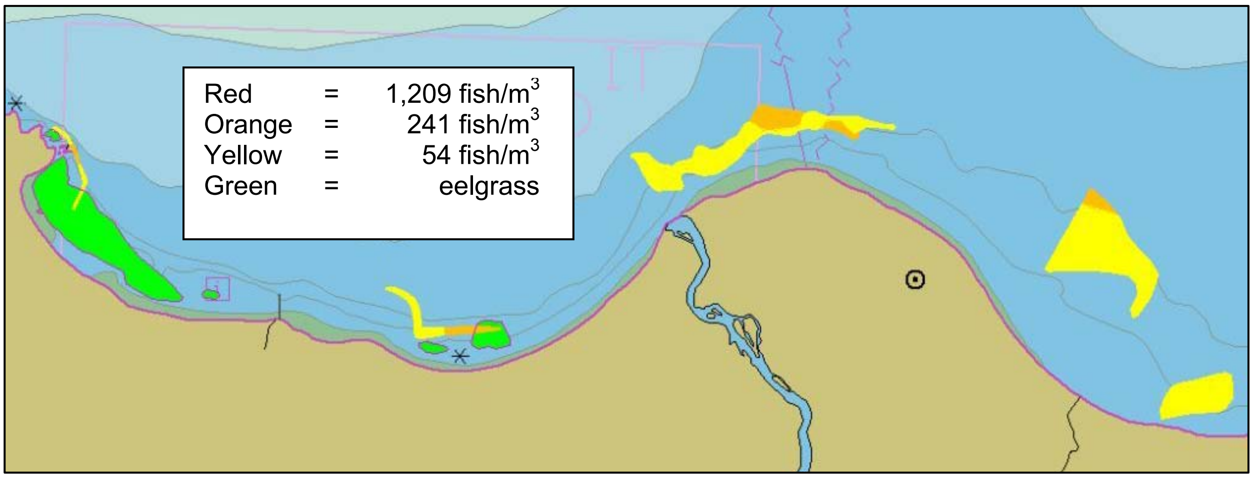


Figure 8. Estimated fish densities in the Elwha drift cell.

Within our study area the protected western portions of Crescent and Freshwater Bays appear to offer the best conditions for eelgrass growth. The beds in these regions have higher eelgrass fractions and extend shoreward into the intertidal zone. It is likely that the remaining shoreline is subject to high wave energy from strong westerly winds during spring and summer which prevent eelgrass from growing shallower than about -13 ft. Both Crescent and Freshwater Bays are excellent sites for further study of wave energy effects on eelgrass beds.

In three of the four geomorphic habitat types eelgrass parameters were very similar in both the Elwha drift cell and comparable shoreline regions. This suggests similar current eelgrass growing conditions within these habitat types. Two possible explanations for this observation are: (1) within these three habitat types, sediment flow from the Elwha River does not have a significant impact on eelgrass growing conditions; or (2) dam construction caused these habitat types within the Elwha drift cell to become more similar to those outside the drift cell. We note that the comparable shoreline outside the Elwha drift cell does not have any major rivers emptying into the Strait of Juan de Fuca.

In the fourth geomorphic habitat type, we found a large eelgrass bed in the Dungeness Bluffs area, but no eelgrass in the Elwha Bluffs area. Again, two possible explanations are: (1) sediment flow from the Elwha River does not have a significant impact on this habitat type, and there was no eelgrass in the Elwha Bluffs region prior to dam construction; or (2) eelgrass did grow in this region prior to dam construction, but died out as sediment starvation gradually created a harder substrate that favored macro algae over eelgrass. Washington Department of Natural Resources has documented a significant increase in overstory kelp coverage in this area of the Elwha nearshore over the last 100 years (Berry, pers com), which is consistent with, and attributed to, sediment starvation in this area. Shoreline armoring along the Elwha Bluffs combined with dams in river are the dominant limiting factors disrupting sediment processes in this area, and as a result likely impacting current eelgrass growing conditions.

Unfortunately, there are no pre-dam construction eelgrass surveys to help answer these questions. Perhaps tribal oral history can shed some light on the historic distribution of eelgrass. Eelgrass monitoring following dam removal will be needed to understand the effects of the Elwha River on nearby eelgrass beds.

Our findings indicate that understory kelp is the dominant vegetative feature of the Elwha drift cell. It is also characterized by high variability (Shaffer 2000). Unfortunately, detailed analysis of understory kelp beds is outside the scope of this study. However, since understory kelp may be impacted by increased sediment deposition, more detailed research on this habitat's extent and importance for fish use in the Elwha nearshore is a top priority for future funding and research. The archived video footage from this survey could be post-processed to determine species composition.

Our fish density analysis must be used with caution, because we did not capture any live specimens to confirm species composition and fish size. Nevertheless, our observations on Pacific sand lance are consistent with Shaffer (2004), who noted that Pacific sand lance are found in very high numbers in the nearshore during spring and summer months, and tend to favor deeper habitats than juvenile salmon (*Onchorynchus* sp) and surf smelt (*Hyponasus pretiosus*). Juvenile and post-larval surf smelt are being found in very high numbers throughout nearshore areas during the current 2007 Elwha nearshore study season (Shaffer, unpublished data). Further study defining forage fish use, including species composition, of understory kelp beds, is recommended.

This study provided a number of intriguing insights into the Elwha nearshore. Multiple years of sampling are needed to accurately define macro vegetation areal extent, composition, and fish use in this area of the Strait, which is defined by high interannual and geographic variability. The work is of high priority—with it we will provide keys to optimizing the restoration opportunities associated with a watershed restoration event of national scale.

Acknowledgments

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