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Changes in Eelgrass Habitat and Faunal Assemblages Associated with Coastal Development in Juneau, Alaska

by
P. M. Harris, A. D. Neff, and S. W. Johnson

U.S. DEPARTMENT OF COMMERCE
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Seaward view of eelgrass (*Zostera marina*) bed at Auke Nu Cove, Alaska, in August 2004 (left) and 2011 (right).

Northern portion of eelgrass bed at Auke Nu Cove, Alaska, in August 2004 (top) and 2011 (bottom).

ABSTRACT

We studied three eelgrass (*Zostera marina*) beds in the City and Borough of Juneau (CBJ), Alaska, to track changes associated with coastal development. These beds were initially sampled as part of a baseline eelgrass inventory from 2004 to 2007. Between 2008 and 2011, beds were remapped and resampled for eelgrass variables (e.g., percent cover, faunal assemblage). Eelgrass area declined at all beds from baseline (2004 to 2007) to post-baseline (2008 to 2011) years. Areal loss of eelgrass was twice as great at the bed with the most recent and intense development (Auke Nu Cove, 61% loss) compared with losses at the previously developed Bay Creek (29%) and undeveloped Bridget Cove (30%) beds. The largest loss of eelgrass at Auke Nu Cove was along the seaward edge of the entire bed and was probably related to increased turbidity. In contrast, the seaward extent of eelgrass at Bay Creek and Bridget Cove remained relatively stable. Differences in eelgrass characteristics between baseline and post-baseline years in developed and undeveloped beds were also apparent. Mean percent eelgrass cover and shoot density declined from baseline to post-baseline years at all beds, but declines at developed beds (42% to 51%) were approximately twice those at the undeveloped bed (23% to 25%). Additionally, biomass declined 45% to 48% at developed beds but increased 17% at the undeveloped bed.

Faunal assemblages changed with eelgrass loss. Coincident with the complete loss of eelgrass at one seine site, mean catch-per-unit-effort of fishes declined from 401 to 140, and the number of fish species declined from 19 to 16. The most sensitive species to eelgrass loss was tubesnout (*Aulorhynchus flavidus*). Seine catch of green sea urchin (*Strongylocentrotus droebachiensis*) increased from baseline to post-baseline years at Auke Nu Cove; urchin grazing likely accounted for some of the observed loss of eelgrass at the cove.

Monitoring of these three eelgrass beds will provide resource managers with useful information to evaluate possible effects of future coastal development upon this important nearshore habitat. Careful consideration of development is especially warranted because eelgrass distribution is limited in the CBJ. We recommend biennial monitoring of these beds that includes, at a minimum, mapping seaward eelgrass boundaries and sampling percent eelgrass cover by tidal elevation. Coincidently, fauna should be sampled with a beach seine to monitor abundance of indicator fish (e.g., tubesnout) and invertebrate (e.g., green sea urchin) species. Seawater temperature and ambient light dataloggers should also be placed at monitored areas.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Few studies in southeastern Alaska have tracked changes in the health of eelgrass (*Zostera marina*) beds over time (Johnson and Thedinga 2005), especially changes associated with coastal development. Eelgrass supports a high abundance and diversity of marine fish and invertebrates (Thayer et al. 1978, Heck and Orth 1980, Johnson and Thedinga 2005, Harris et al. 2008, Johnson et al. 2012), and may be an essential habitat for some species. In Alaska, eelgrass is often used as a spawning substrate by Pacific herring (*Clupea pallasii*) (Blankenbeckler and Larson 1982, Cooney 2007) and provides rearing habitat in spring and summer for many commercial and forage fish species (Murphy et al. 2000, Johnson et al. 2012). Eelgrass also provides other important ecological functions–oxygen production, nutrient recycling, erosion control, and contaminant filtration (Spalding et al. 2003, Waycott et al. 2009).

Eelgrass is the most widely distributed seagrass in Alaska and is often the dominant vegetation in protected, shallow subtidal and lower intertidal areas. Eelgrass occupies approximately 6,000 linear km (20%) of the southeastern Alaska coast (NMFS 2011). In the City and Borough of Juneau (CBJ), Alaska, however, eelgrass is not widely distributed and is present on only about 3% of the shoreline (Harris et al. 2008). Areas with eelgrass in the CBJ are vulnerable to development because their low gradient and protected shorelines facilitate construction of docks and harbors. Anecdotal evidence suggests that the area of some eelgrass beds has declined in the CBJ, but changes near coastal development have not been documented nor compared to beds not subject to developmental pressure. Furthermore, little is known about what ecological variables should be monitored (e.g., bed area, percent cover, faunal assemblages) or what frequency of monitoring is necessary to detect change.

Our study was undertaken to track changes associated with coastal development at three eelgrass beds that were previously sampled as part of a CBJ-wide eelgrass baseline inventory (Harris et al. 2008). The primary objective was to identify changes in eelgrass variables (e.g., bed area, percent cover, and faunal assemblages) in the CBJ. Secondary objectives were to recommend the most practical and sensitive variables to monitor at CBJ eelgrass beds and the frequency of monitoring.

STUDY AREA

Our study focused on three eelgrass beds in the CBJ: Auke Nu Cove, Bay Creek, and Bridget Cove. The Auke Nu Cove and Bay Creek beds are within Auke Bay, which is approximately 35 km southeast of the Bridget Cove bed (Fig. 1), previously referred to as Bridget Cove central (Harris et al. 2008). All three beds are on protected, partially mobile sand and gravel tidal flats (NMFS 2012) dissected by small streams.

Timing and intensity of shoreline development differs among the three study areas. Auke Nu Cove and Bay Creek are developed areas characterized by docks, boat traffic, and urban development, whereas Bridget Cove has no shoreside development (Figs. 2-4). Auke Nu Cove is the study area with the most intensive recent development. When our study began in 2004, approximately 13% of the Auke Nu Cove intertidal area had already been filled by state and private projects (ADOT 1996). Since 2004, an additional 1.73 ha of Auke Nu Cove was filled for construction of a privately owned seafood processing plant and a public commercial loading facility. The seafood processing plant project filled 0.25 ha in 2004, and the loading facility project filled 1.48 ha from 2008 to 2010. The loading facility directly affected 0.06 ha of the eelgrass bed by burial or partial shading from a transfer bridge to the floating dock (Fig. 2). The Bay Creek area was largely developed before the 1970s for private and public docks and marinas and remains a major harbor in the CBJ. Bridget Cove has 7.7 ha of eelgrass in three distinct eelgrass beds (Harris et al. 2008), is surrounded by a CBJ Natural Area Park, and is a popular location for recreational Dungeness crab (*Cancer magister*) harvest and seasonal anchorage for commercial seiners. Since 2003, a small-scale mariculture project has operated at Bridget Cove (Fig. 4).

MATERIALS AND METHODS

Eelgrass Mapping and Sampling

All three eelgrass beds were mapped several times between 2008 and 2011 (Table 1). Beds were mapped using the same methods as the baseline study (2004-2007, Harris et al. 2008). At extreme low tide (usually at or below − 1.0 m relative to mean lower low water, MLLW), a person with a backpack Trimble TSC1® Asset Surveyor GPS (global positioning system) walked the exposed perimeter of the eelgrass bed following the edge of the bed as closely as possible. On foot, eelgrass was mapped in water up to about 1 m deep. Deeper portions of beds were mapped from a small boat by motoring slowly around the bed perimeter while keeping the GPS antenna over the visible edge of the bed. The GPS collected real-time, differentially corrected positions once each second while we circumnavigated the eelgrass beds; accuracy of positions was ± 0.5 m. The GPS data were geo-processed using mapping software; raw data was converted into shapefiles with Trimble Pathfinder software, and shapefiles were managed in ESRI ArcView® 10. Positions of eelgrass patches under the grated transfer bridge at Auke Nu Cove (Fig. 2) were not precisely mapped because GPS reception was erratic; so we estimated size and position of patches with a meter tape.

Eelgrass characteristics were sampled at each bed several times between 2008 and 2010 (Table 1). Eelgrass characteristics (i.e., percent cover, shoot density, biomass, canopy height, and percent flowering shoots) were measured along permanent transects using the same methods as the baseline study (2004-2007, Harris et al. 2008). Transects were perpendicular to the waterline and divided into 0.5 m blocks by tidal elevation. The first tidal block was − 1.0 m to − 0.5 m, the second was − 0.5 m to 0.0 m, and the third was 0.0 m to + 0.5 m. In each block, eelgrass characteristics were measured within at least four randomly placed 0.5 m × 0.5 m quadrats. Percent cover was the percentage of the quadrat covered by eelgrass shoots to the nearest 5% when beds were emergent. Percent-cover reference photos were used to standardize estimates, and two observers often conferred to determine an estimate. Shoot density was determined by counting the number of above-ground stems in a subquadrat (0.25 m × 0.25 m) placed inside the upper left corner of the 0.5 m × 0.5 m quadrat. To estimate biomass, all eelgrass shoots in a randomly selected half of the subquadrat were clipped at the substrate surface and collected. In the laboratory, each eelgrass shoot was rinsed and scraped of sediment and epiphytic flora and fauna, dried at 60° C to a constant weight, and weighed to the nearest 0.01 g. Canopy height was the maximum height in centimeters (cm) of a handful of eelgrass shoots in the quadrat; the bundle was extended to its maximum height without uprooting, and the maximum height of the shortest 80% of the bundle was measured (i.e., the tallest 20% of shoots were ignored).

Percent flowering shoots in each quadrat was determined to get some indication of reproductive capacity. The above eelgrass characteristics are useful indicators to track changes in a bed over time related to natural or anthropogenic disturbances (PIBMC 2002).

Faunal Sampling

Faunal assemblages were sampled several times between 2008 and 2011 (Table 1). Fish and invertebrates were sampled with a beach seine at two sites within Auke Nu Cove (north and south), and one site each at Bay Creek and Bridget Cove (Figs. 2-4). Seine sites were the same as in the baseline study (Harris et al. 2008), with the exception of Auke Nu Cove north. By 2011, eelgrass at Auke Nu Cove had declined along the seaward edge, leaving both seine sites devoid of eelgrass. Consequently, the Auke Nu Cove north site was shifted higher on the beach in 2011 (Fig. 2); the south site, however, was not moved and continued to be seined to observe possible changes in faunal assemblage associated with eelgrass loss. Seining occurred at all sites in 2009, and again at both Auke Nu Cove sites in 2011 (Table 1).

Similar to the baseline study (Harris et al. 2008), two different beach seines were used. At Auke Nu Cove and Bay Creek, fauna were sampled with a 37-m long, non-tapering (1.2-m wide), non-variable mesh (3.2 mm) seine. The seine was set from the bow of a skiff in about 1.0 m of water; two people, each holding opposite ends of the seine, disembarked either side of the skiff and then walked towards the beach pulling the seine onto shore about 18 m apart. At Bridget Cove, fauna were sampled with a variable-mesh, 37-m long seine that tapers from 5-m wide at the center to 1-m wide at the ends. Outer panels are each 10 m of 32-mm stretch mesh, intermediate panels are each 4 m of 6-mm square mesh, and the bunt is 9 m of 3.2-mm square mesh. We set the seine as a round haul by holding one end of the seine on the beach, backing around in a skiff with the other end to the beach, and pulling the seine onto shore; the width of the seine area was about 18 m. Both seines have a lead line and a float line so that the bottom contacts the substrate and the top floats. All seining occurred in daylight and within 2 hours of low tide (range + 1.0 m to − 1.5 m below MLLW).

Fish and invertebrates captured by seine were identified to species where possible, counted, and released on site. Juveniles (< 50 mm length) of some fish species (e.g., pholids, cottids, and hexagrammids) that were difficult to identify to species in the field were recorded as juvenile gunnels, juvenile sculpin, or juvenile greenling. *Myoxocephalus* species (i.e., frog sculpin, *M. stelleri*; great sculpin, *M. polyacanthocephalus*; shorthorn sculpin, *M. scorpius*) were combined into one taxon (*Myoxocephalus* spp., Table 2) to avoid misidentification. Similarly, we combined the northern rock sole (*Lepidopsetta polyxystra*) and southern rock sole (*L. bilineata*) and refer to them collectively as rock sole.

Benthic and epiphytic invertebrates were also observed and identified in eelgrass quadrats (Table 1). In addition, epiphytic invertebrates from eelgrass biomass samples were removed from shoots in the laboratory, identified, pooled by tidal block, dried at 60° C to a constant weight, and weighed to the nearest 0.01 g.

Temperature and Cloud Cover

Sea water temperatures and cloud cover data were obtained for the CBJ area. Temperatures were measured with Hobo® Tidbit™ thermographs at Auke Nu Cove and Bridget Cove (Table 1; Figs. 2 and 4). Because of the close proximity of Auke Nu Cove and Bay Creek, we used temperature data from Auke Nu Cove also for Bay Creek, and hereafter refer to the thermograph in Auke Nu Cove as the Auke Bay thermograph. Thermographs were attached to the midsection of a 1-m polypropylene line; a 10-kg anchor was on one end of the line and a small float on the other end. Temperatures at about − 3.0 m depth relative to MLLW were recorded every 2 hours by two thermographs (one for backup) in each location. Some gaps in data occurred due to loss of thermographs and logistical difficulties. Cloud cover was examined by looking at the number of days that were cloudy (> 80% cloud cover), partly cloudy (40%-70%), or clear (≤ 30%), for the Juneau area from May through September, 2007-2010 (NOAA National Weather Service 2012).

ANALYSIS

Eelgrass

Percent change in area of each eelgrass bed was calculated by comparing the area of each bed mapped in 2011 to that of baseline years. Baseline area was a compilation of mapping that occurred from 2004 to 2007 (Harris et al. 2008).

Interannual differences among all years were examined for each eelgrass characteristic in each bed. Change in percent cover, shoot density, and biomass was calculated. One-way ANOVAs were performed for each characteristic (arcsin sqrt or sqrt transformed), with bed as the independent variable to see whether percent change was related to bed.

Two-way ANOVAs, with either year and tidal block as factors or time period (baseline or post-baseline) and tidal block as factors, were used to analyze eelgrass characteristics at each bed. Analyses of interaction between year and tidal block were not possible due to empty cells, but were possible between time period and tidal block. Percent cover and percent flowering shoots were arcsin-sqrt transformed before analysis, and sqrt transformations were applied to shoot density, biomass, and canopy height values (Appendices 1 and 2). When data could not be normalized, the two factors (year or time period and tidal block) were analyzed separately with one-way ANOVA or Kruskal-Wallis ANOVA on ranks. Significant differences were identified with pairwise comparisons (Holm-Sidak, two-way ANOVA; Tukey Test, one-way ANOVA; and Dunn's ANOVA on ranks) (Appendices 1 and 2).

The frequency of eelgrass sampling and relationships among eelgrass characteristics were examined to refine future monitoring efforts. Three different monitoring scenarios were examined to determine if changes in sampling frequency would detect long-term differences in eelgrass characteristics. Scenarios were 1) annual sampling, comparing baseline years 2004–2007 with post-baseline years 2008-2010, 2) biennial sampling, comparing baseline years 2004 and 2006 with post-baseline years 2008 and 2010, and 3) sampling every 5years, comparing baseline year 2005 with post-baseline year 2010. *T*-tests were used to compare data from scenario 1 to scenarios 2 and 3. Pearson product moment correlation was used to determine relationships among eelgrass characteristics in each bed. Significance in all analyses was accepted at $P \leq 0.05$.

Fauna

Abundance, percent frequency of occurrence (FO), and species richness of fish were determined from our seine catches. Abundance is expressed in absolute numbers (i.e., number of individual fish captured) and catch-per-unit-effort (CPUE; i.e., number of fish captured per seine haul). Frequency of occurrence is calculated as the number of seine hauls in which a species was captured divided by the total number of seine hauls and multiplied by 100. Species richness (total number of fish species captured) was also calculated for each seine site. Individuals identified only to family (e.g., unidentified juvenile sculpin, Cottidae) were counted in the total catch, but were considered as a separate species for species richness calculations only if no other species from the same family was captured at the seine site. Seine haul catches at each site were highly variable and too few to enable robust analysis; only trends in total catch and changes in catch composition are presented.

For invertebrates, biomass and FO comparisons were made between baseline (2004-2007) and post-baseline (2008-2011) years. Biomass data for each time period were transformed (ln) and compared for each bed with a *t*-test. Overall FO for common invertebrate species was calculated within each time period as the number of eelgrass quadrats in which a species was present divided by the number of quadrats and multiplied by 100.

Temperature and Cloud Cover

Monthly mean seawater surface temperatures were calculated to provide an annual temperature profile and to examine the period of optimum temperature for eelgrass growth ($\geq 10^{\circ}$ C, Phillips 1984). Temperatures were available from 2004 to 2010 at Auke Bay and from 2004 to 2006 and from 2009 to 2010 at Bridget Cove (Table 1). Percentage of temperatures $\geq 10^{\circ}$ C at each thermograph location was calculated for each year. Temperatures in July were compared between Auke Bay and Bridget Cove with a Kruskal-Wallis ANOVA on ranks, with year as the independent variable. Significant differences were examined with Dunn's pairwise-multiple comparison procedures. Relationships between mean July temperatures in Auke Bay and Bridget Cove and eelgrass characteristics were examined with Pearson product moment correlation. Correlations of all eelgrass characteristics and July temperatures with percent cloudy days and percent clear days were also considered. Significance in all analyses was accepted at $P \leq 0.05$.

RESULTS

Eelgrass

All eelgrass beds decreased in area between baseline and post-baseline years. Loss of eelgrass was twice as great at Auke Nu Cove (61%) compared with Bay Creek (29%) and Bridget Cove (30%) (Figs. 2-4). The largest loss of eelgrass at Auke Nu Cove was along the seaward edge across the entire bed; this trend became evident in 2009. From 2004 to 2006, eelgrass was present at our seine site at Auke Nu Cove south, but had disappeared by 2009; by 2011, the bare area had increased, and the only remaining eelgrass at the south end of the bed was well above MLLW. Along the eelgrass sampling transect, the depth of the seaward edge was reduced from approximately − 2.4 m in 2004 to − 0.6 m in 2011. Another noticeable change in eelgrass at Auke Nu Cove was under the transfer bridge (Fig. 2). Prior to bridge installation, eelgrass in that portion of the bed was continuous; however, no eelgrass was observed there in 2009, and only about 3 m^2 of patchy and sparse eelgrass was observed in 2011. In contrast, the seaward extent of eelgrass at Bay Creek and Bridget Cove remained stable from 2004 to 2011; loss of eelgrass at these beds was primarily above MLLW and along the perimeter (Figs. 3 and 4).

Within each bed, there were interannual differences in eelgrass characteristics (Fig. 5, Appendix 1). Percent cover and biomass differed significantly ($P \leq 0.003$) among years in all beds. Shoot density differed significantly ($P \leq 0.001$) among years at Auke Nu Cove and Bay Creek, but not at Bridget Cove. Differences in mean canopy height were not significant among years, with the exception of Auke Nu Cove, where mean canopy height was significantly ($P = 0.001$) greater in 2007 than in 2005 or 2008. Percent flowering shoots tended to increase at Auke Nu Cove and Bay Creek and decrease at Bridget Cove.

Differences were observed in percent cover, shoot density, and biomass between baseline and post-baseline years in all beds (Fig. 6, Appendix 2). Mean percent cover and shoot density in all beds declined significantly ($P \leq 0.05$); declines at Auke Nu Cove and Bay Creek (42% to 51%) were approximately twice that of Bridget Cove (23% to 25%). Mean biomass declined significantly ($P < 0.001$) at Auke Nu Cove and Bay Creek (45% to 48%). At Bridget Cove, however, mean biomass increased 17% ($P = 0.51$).

Biomass and canopy height differed significantly among some tidal blocks (Appendix 2). At all beds, mean biomass and canopy height were significantly ($P \leq 0.013$) greater in the lowest tidal block (− 1.0 m to − 0.5 m) than in the highest block (+ 0.5 m to 1.0 m). At Bay Creek and Bridget Cove, mean canopy height in the lowest block was also significantly ($P \leq 0.001$) greater than the middle block (− 0.5 m to 0.0 m). Interaction between time period (baseline or post-baseline years) and tidal block was significant ($P = 0.005$) only with mean biomass in Auke Nu Cove.

Relationships varied among eelgrass characteristics, water temperature, and cloud cover. Correlation coefficients among mean percent eelgrass cover, shoot density, and biomass suggest that moderate to strong positive relationships ($r = 0.579$ to 0.791, $P \leq 0.001$) existed in all beds (Appendix 3). At Auke Nu Cove and Bay Creek, correlations suggest the presence of strong positive relationships ($r = 0.822$ to 0.988, $P \leq 0.045$) between July mean water temperatures (2004-2009) and mean percent cover, shoot density, and biomass. At Bridget Cove, there were no clear trends among eelgrass characteristics and July temperatures.

Differences between sampling frequencies and among relationships of eelgrass characteristics were analyzed in relation to monitoring. Overall, *t*-tests indicated that biennial monitoring is an adequate substitute for annual monitoring. Significant long-term differences in percent cover, shoot density, and biomass suggest that these three characteristics are sensitive indicators of eelgrass health. The moderate to high correlation among percent cover, shoot density, and biomass in all beds suggests that only one of these characteristics need be sampled. Canopy height and percent flowering shoots showed negligible correlations with other eelgrass characteristics and no significant long-term trends.

Fauna

A total of 10,523 fish, representing 38 species, were captured at all seine sites during baseline and post-baseline years (Table 2). Mean overall CPUE was 619 fish (SE = 214) (Table 2). Mean CPUE in post-baseline years (2009 and 2011) at Auke Nu Cove north, Bay Creek, and Bridget Cove sites was similar to or greater than baseline CPUE (Fig. 7). At Auke Nu Cove south, however, mean CPUE in post-baseline years was less than half the baseline CPUE (Fig. 7). The most abundant species (CPUE ≥ 53 fish, FO ≥ 53%) were Pacific herring

(*Clupea pallasii*), tubesnout (*Aulorhynchus flavidus*), threespine stickleback (*Gasterosteus aculeatus*), and crescent gunnel (*Pholis laeta*) (Table 2). These four species comprised 79% of the total overall catch. Other frequently caught species were Pacific staghorn sculpin (*Leptocottus armatus*), *Myoxocephalus* spp., and tubenose poacher (*Pallasina barbata*). Fifteen species were represented by a total catch of < 10 fish (Table 2).

Fish species composition varied between baseline and post-baseline years (Figs. 2-4). In baseline years, crescent gunnel, threespine stickleback, and tubesnout comprised 30% to 95% of catches at all sites. In post-baseline years, these three species again comprised a major portion of catches at Auke Nu Cove north (56%) and Bay Creek (88%), but no tubesnout and only a few threespine stickleback were caught at Auke Nu Cove south, where capelin (*Mallotus villosus*, 41%) and Pacific staghorn sculpin (27%) were dominant (Figs. 2 and 3). The 2009 catch at Bridget Cove was dominated by larval Pacific herring (95%) (Fig. 4).

A total of 15 invertebrate species were captured with a beach seine. In both baseline and post-baseline years, common species included adult crangonid shrimp (*Crangon alaskensis and C. franciscorum angustimana*), juvenile shrimp (Pandalidae), hairy hand hermit crab (*Pagurus hirsutiusculus*), and the false white sea cucumber (*Eupentacta pseudoquinquesemita*). A species that showed a change in abundance between baseline and post-baseline years was the green sea urchin (*Strongylocentrotus droebachiensis*). Urchins were caught in small numbers during baseline years at all sites, but they were more numerous in parts of Auke Nu Cove in post-baseline years; 39 and 84 were captured at Auke Nu Cove south in 2009 and 2011.

Twenty-two invertebrate taxa were observed in eelgrass sample quadrats. The most frequently occurring species was the variegated chink snail (*Lacuna variegata*). The snail's yellow, donut-shaped egg masses on eelgrass shoots were typically more numerous than adults. Overall, snail egg masses or adults were found in 98% of quadrats. Blue mussel (*Mytilus trossulus*) spat and juveniles up to 1 cm in length were also very common (FO = 82%) on shoots and contributed most to invertebrate biomass samples primarily due to the weight of their shells. Juvenile barnacles (*Balanus glandula* and *Semibalanus balanoides*) and juvenile limpets (Lottiidae) were less numerous. Common epibenthic invertebrates in quadrats were the false white sea cucumber (FO = 47%), adult barnacles (FO = 10%), and adult blue mussels (FO = 10%).

Invertebrate biomass samples varied greatly, largely due to conditions affecting blue mussel spat settlement in a bed. Although mean invertebrate biomass at Auke Nu Cove in 2008-2010 was considerably lower than in baseline years, differences were not significant ($P = 0.41$) (Fig. 8).

Temperature and Cloud Cover

Mean monthly seawater temperatures at Auke Bay (Auke Nu Cove thermograph) and Bridget Cove ranged from 2.5° C to 13.8° C (Fig. 9). The coldest temperatures were in February or March, and warmest temperatures were in July or August (Fig. 9). Monthly mean temperatures at the two thermograph sites tracked each other closely in the years they were both monitored; the greatest differences (up to 1.3° C) occurred in summer months. Optimum temperatures for eelgrass growth (10° C to 20° C) occurred 109 to 146 days per year, generally from late-May until mid-September. During this optimum time period, temperatures were ≥ 10° C approximately 80% of the time in most years. In 2008, however, only 55% of the temperatures in the optimum period were ≥ 10° C; consequently, the mean July 2008 sea water temperature (10.5° C) was significantly colder than July temperatures in all other years. In years with cloud cover data (2007-2010), 4% of days were clear, 23% were partly cloudy, and 73% were cloudy during June through August (NOAA National Weather Service 2012). Relationships among eelgrass characteristics and percent cloud cover (2007-2010) were inconsistent at all sites (Appendix 4).

DISCUSSION

Eelgrass

Eelgrass beds are a dynamic coastal habitat with sometimes large annual fluctuations in area and biological characteristics. Annual areal change as high as 50% has been reported in some Oregon eelgrass beds (Risser 2000). Over a 3 year period, changes in eelgrass bed area ranging from − 25% to + 11% were reported in six undisturbed beds in southeastern

Alaska (Johnson and Thedinga 2005). The consistent decline in eelgrass across all three beds in the CBJ is notable because it represents more than annual fluctuation.

Regional factors can contribute to declines in eelgrass over large areas. For example, isostatic rebound due to glacial retreat is causing nearshore areas in northern southeastern Alaska to rise faster than global sea level rise (Larsen et al. 2005). As land rises in relation to sea level, upper intertidal eelgrass is subjected to increasing emersion and desiccation. This may partially explain the roughly 30% decline in area and 25% declines in percent eelgrass cover and shoot density shared by all three CBJ eelgrass beds. Other regional factors such as lower seawater temperatures or reduced ambient light (e.g., persistent cloudy weather) may also affect eelgrass productivity (Short 1975).

Site-specific factors can also lead to declines in eelgrass. The nearly two-fold decline in percent cover and shoot density at Auke Nu Cove and Bay Creek, compared with Bridget Cove, could be due to localized coastal development. The additional 30% areal loss of eelgrass at Auke Nu Cove is likely due to recent development activities in the cove. Deleterious effects of burial and sediment resuspension during and after construction of the loading facility at Auke Nu Cove were anticipated (Miller et al. 2005, Miller 2006), but the cumulative effects of sedimentation and resuspended sediments on eelgrass area may have been underestimated. The year after fill placement at Auke Nu Cove, an additional 6 cm to 8 cm of sediment was observed in several areas of the bed, as judged by the exposed height of PVC pipes that marked the eelgrass sampling transect. Furthermore, sediment composition in the cove appeared to change after completion of the loading facility. Prior to facility construction, sediment in the transfer bridge area ranged from 22% to 48% sand (mean 34% ± 8%) (Miller 2006), and the substrate was firm throughout the bed. In 2010, two years after fill placement, substrate under the transfer bridge, next to the landing craft ramp, and at the seaward end of the eelgrass sampling transect was extremely soft and poorly drained, suggesting deposition of finer materials. By 2011, the seaward extent of eelgrass had retreated at least 25 m horizontally, and the depth limit had been reduced by 1.8 m across the entire bed.

Areal losses of the deepest portions of eelgrass beds often indicate increased turbidity (de Boer 2007). Turbidity reduces the amount of ambient light reaching eelgrass shoots, and because eelgrass depth limits are often determined by light level, reductions in light have the greatest effect on the deepest part of a bed (de Boer 2007). Turbidity related to sediment resuspension by increased vessel traffic in Auke Nu Cove was expected (Miller et al. 2005, Miller 2006), and increased turbidity may explain the unanticipated reduction of the eelgrass depth limit at the cove in post-baseline years. Notably, eelgrass depth limits at Bay Creek and Bridget Cove were stable across baseline and post-baseline years.

Resuspended sediments can contribute to declines in eelgrass productivity (Ralph et al. 2006). Unstable sediments are easily suspended in the water column and can become part of a negative feedback loop in eelgrass beds (de Boer 2007): as turbidity increases, productivity decreases; then shoot density decreases, and more sediment is exposed and subject to resuspension, which further increases turbidity that further reduces eelgrass productivity. When the bottom cover of seagrass declines to 50% or less, sediment resuspension can increase markedly (Moore 1996). At Auke Nu Cove, mean percent cover in post-baseline years declined to 37%, which could have perpetuated the negative feedback loop and further reduced eelgrass productivity.

We are unsure why the large area of eelgrass on the south side of Auke Nu Cove, farthest from the fill, is now bare. Habitat may have been marginal for eelgrass before the fill; compared to the north side, the south is more exposed to wave erosion and characterized by coarser and better drained substrate. Another possible contributing factor to the relatively high loss of eelgrass on the south side is circulation within the cove. A small, counter-clockwise gyre in Auke Nu Cove has been suggested (Malecha and Stone 2003) within the otherwise general clockwise circulation of Auke Bay (Nebert 1990). A counter-clockwise gyre within the cove would increase the likelihood that silt and clay originating from the fill or resuspended from benthic sediments would be carried to the south side of the bed.

Recovery and recruitment of eelgrass at Auke Nu Cove is possible if sediment deposition and resuspension are reduced. Deposition has probably declined since the loading facility parking lot was paved in 2011 and as drainage patterns within the bed have stabilized. Eelgrass depth limits in the developed Bay Creek area are now comparable to those at the largely undeveloped Bridget Cove bed, suggesting that Bay Creek eelgrass has recovered from any reduction of seaward extent that might have been caused by past development. The increasing trend in the production of reproductive shoots at Auke Nu Cove favors the likelihood of seedling recruitment.

Eelgrass characteristics differed between baseline and post-baseline years among developed and undeveloped beds. Beds associated with development (Auke Nu Cove and Bay Creek) showed long-term (2004-2010) patterns of significant decline in percent cover and shoot density that were twice as much as declines at the undeveloped Bridget Cove bed. In addition, biomass significantly declined in developed beds, but increased in the undeveloped bed. Shared declines in percent cover, shoot density, and biomass at both Auke Nu Cove and Bay Creek, despite different development timelines, suggest that coastal development can affect the overall health of a bed well past the active construction period.

Fauna

A diverse number of fish species utilize eelgrass beds in the CBJ. Of the 38 species that we identified, 11 are included in a fishery management plan for the Gulf of Alaska (NPFMC 2012). Another five species (i.e., Pacific herring; capelin; surf smelt, *Hypomesus pretiosus*; Pacific sand lance, *Ammodytes hexapterus*; and Pacific sandfish, *Trichodon trichodon*) are considered ecologically important forage fish (Mundy and Hollowed 2005). Forage fishes are important in the diet of other fishes, seabirds, and marine mammals (Springer and Speckman 1997). The Lynn Canal (Fig. 1) stock of Pacific herring is considered depressed in southeastern Alaska (Carls et al. 2008), and eelgrass appears to be an important habitat for that stock. In addition to capturing juvenile Pacific herring at some of our sites, we observed Pacific herring eggs on eelgrass at Bay Creek and Bridget Cove during our study. The eelgrass bed at Auke Nu Cove was once a critical spawning area for Pacific herring (USCOE 1984), but herring have not spawned in the cove since the 1980s (Carls et al. 2008).

Three of the captured fish species -- crescent gunnel, threespine stickleback, and tubesnout -- are commonly associated with eelgrass beds in northern southeastern Alaska (Harris et al. 2008, Johnson et al. 2012). Thus, declines in these three species at Auke Nu Cove south, coincident with the loss of eelgrass, are not surprising. Tubesnout was the most sensitive species to eelgrass loss. In contrast, Pacific staghorn sculpin numbers increased with declining eelgrass cover at Auke Nu north and south; reduced cover would likely have increased predation opportunities for this species. Although the above species are not commercially important, they are ecologically important. For example, crescent gunnel is prey for river otter (*Lutra canadensis*), pigeon guillemot (*Cepphus columba*), and other fishes (Golet et al. 2000, Jewett et al. 2002).

Grazing by green sea urchins may be another contributing factor to loss of eelgrass. At Auke Nu Cove south, seine catch of green sea urchins increased greatly from baseline to post-baseline years, and we observed grazing damage at the southern seaward edge of the bed in 2011. At nearby Funter Bay, high densities of green sea urchins (up to 160/m^2) effectively denuded approximately 550 m^2 of eelgrass between 2008 and 2010 (Harris unpublished data). Other cases of sea urchin overgrazing have been reported (Eklöf et al. 2008), but none involving the green sea urchin. Effects of green sea urchin grazing at Auke Nu Cove appeared to be restricted to the southern side of the bed during the study, and urchins were not caught in great numbers at Auke Nu Cove north. In May 2012, however, isolated patches of green sea urchins at densities estimated as high as 720/m^2 were observed at the north end of the cove at about − 1.2 m MLLW. Effects of overgrazing by green sea urchins could lead to increased erosion, resuspension of sediments, increased turbidity, and reduction of eelgrass productivity throughout the bed.

Temperature and Cloud Cover

High correlations of percent cover, shoot density, and biomass of eelgrass with July surface seawater temperatures at Auke Nu Cove and Bay Creek suggest a strong influence of temperature. For example, seawater temperatures in 2008 were $\geq 10^{\circ}$ C during the optimum eelgrass growing period only 55% of the time, and the mean July 2008 temperature (10.5° C) was significantly colder than July temperatures in all other years. During this coldest year, the lowest absolute and mean shoot densities and biomass weights measured from 2004 to 2011 were observed in Auke Nu Cove and Bay Creek. Positive relationships between seawater temperature and relative productivity in eelgrass have been reported (Short 1975). Cloud cover appeared to be an inadequate indicator of ambient light in relation to changes in eelgrass characteristics; accurate measurements can be obtained with in-situ photosynthetically active radiation (PAR) devices.

Monitoring

The consistent decline in eelgrass across all three beds in the CBJ reinforces the need for monitoring, especially given the limited eelgrass distribution and continued developmental pressure in the CBJ (Harris et al. 2008). The most immediate coastal development in the CBJ is an expansion of Statter Harbor in the Bay Creek estuary. The proposed project, now in the permitting stage, will fill 1.6 ha of fish habitat including 0.04 ha of the Bay Creek eelgrass bed (HDR 2010). Project-related changes in drainage patterns, and increased boat traffic could result in increased erosion, sedimentation, and turbidity. These changes can negatively affect eelgrass, and their effects should be monitored on regional and site-specific levels (Long and Thom 2001, Neckles et al. 2012). Therefore, all three CBJ beds in our study should be monitored for eelgrass health, with Bridget Cove as the regional, undeveloped reference bed

Based on our analyses of monitoring scenarios, we recommend biennial (every other year) monitoring of area and eelgrass characteristics at the three eelgrass beds. At a minimum, monitoring should include mapping the seaward eelgrass boundary and sampling percent cover at each bed. Mapping changes in the seaward extent of eelgrass can indicate changes in water quality (Duarte et al. 2006). Percent eelgrass cover is a sensitive indicator of eelgrass health and is the most economical characteristic to measure in terms of time and labor. Percent cover should be sampled with respect to tidal elevation because tidal block was a significant factor affecting cover. Coincident with eelgrass mapping and sampling, fauna should be sampled with a beach seine to monitor abundance of indicator fish (e.g., tubesnout) and invertebrate (e.g., green sea urchin) species. Thermographs and PARs should also be placed in monitored areas to continually track seawater temperatures and amount of ambient light.

CONCLUSIONS

1. Greatest declines in eelgrass percent cover and shoot density occurred at eelgrass beds with coastal development.
2. Greatest areal declines occurred at the eelgrass bed with the most recent coastal development.

3. Faunal assemblages changed and fish catch-per-unit-effort decreased at the bed with the most recent coastal development.
4. We recommend biennial monitoring of Auke Nu Cove, Bay Creek, and Bridget Cove eelgrass beds that includes, at a minimum, mapping the seaward extent of eelgrass and sampling percent eelgrass cover by tidal elevation; fauna should also be sampled with a beach seine on the same schedule.

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Table 1. -- Geographic locations of permanent transects, seine sites, and thermographs at eelgrass beds (*Zostera marina*) surveyed in the City and Borough of Juneau, Alaska, from 2004 to 2011. Baseline years are 2004-2007, and post-baseline years are 2008-2011. Shown are dates that eelgrass beds were mapped with global positioning system technology, locations of transects and dates of sampling for eelgrass characteristics (e.g., percent cover, shoot density), and locations and dates where fish and invertebrates were captured by beach seine. Latitude and longitude are in decimal degrees. A blank indicates no sampling occurred, and a dotted line indicates continuous sampling. Eelgrass locations and detailed maps of individual sites are shown in Figures 1-4.

Location			Baseline				Post-baseline			
description	Lat. (N)	Long. (W)	2004	2005	2006	2007	2008	2009	2010	2011
Auke Nu Cove										
map			8/1	6/22		8/14		8/21		7/1
transect	58.3811	134.6924	8/1	6/22	7/25	7/31	7/3	7/21	7/13	
seine (north)	58.3808	134.6917		6/24	7/25	7/31		7/21		6/19
seine (south)	58.3780	134.6919			7/25	7/31		7/21		6/19
thermograph	58.3800	134.6911	6/29	......	......	......	......	......	3/14	
Bay Creek										
map			6/17	6/21						7/4
transect	58.3857	134.6490	8/2	7/24	7/24		7/4	7/22	7/15	
seine	58.3853	134.6517		6/27	7/24	8/2		7/22		
Bridget Cove										
map			7/3	7/22		8/29		7/24		8/1
transect	58.6300	134.9480	7/5	7/22	8/10	7/30	7/2	7/24	7/14	
seine	58.6300	134.9480	6/4	7/7	8/10			7/24		
thermograph	58.6405	134.9552	6/1	......	5/30			6/26	4/30	

Table 2. -- Fish taxa caught by beach seine at four sites in eelgrass (*Zostera marina*) in the City and Borough of Juneau, Alaska, from 2004 to 2011. Total = total catch of a species in the period indicated; CPUE = catch-per-unit-effort (i.e., mean number of fish caught per seine haul). Percent frequency of occurrence (FO) = number of seine hauls in which a species was captured divided by the total number of seine hauls and multiplied by 100. Overall total catch, CPUE, and FO include all sites and seine hauls (n = 17). Taxa are listed in decreasing order of abundance based on total overall catch. *Myoxocephalus* species include frog sculpin, *M. stelleri*; great sculpin, *M. polyacanthocephalus*; and shorthorn sculpin, *M. scorpius*. Baseline years are 2004-2007, and post-baseline years are 2008-2011. An asterisk denotes species is included in a fishery management plan for Alaska. A blank indicates that no fish of that taxon was caught. Scientific names are shown in Appendix 5.

	Auke Nu Cove north				Auke Nu Cove south				Bay Creek			Bridget Cove			Overall		
	2005-2007		2009&2011		2005-2007		2009&2011		2005-2007		2009	2004-2006		2009	2004-2011		
Taxa	Total	CPUE	Total	CPUE	Total	CPUE	Total	CPUE	Total	CPUE	Total	Total	CPUE	Total	Total	CPUE	FO
Pacific herring	3	1	80	40	248	124	21	11			14	438	146	3,655	4,219	262	53
Tubesnout	625	208	195	98	506	253			99	33	19	468	156	3	1,914	96	71
Threespine stickleback	130	43	113	57	183	92	2	1	529	176	258	18	6	1	1,234	73	88
Crescent gunnel	164	55	87	44	47	24	19	10	302	101	16	258	86	20	913	54	100
Walleye pollock*					1	1						475	158	16	492	29	24
Chum salmon*			1	1			6	3				474	158	1	482	28	29
Pacific staghorn sculpin	53	18	78	39	11	6	76	38	37	12	7	22	7	2	286	17	94
Tubenose poacher	21	7	128	64	7	4	1	1			12	69	23	9	247	15	65
Myoxocephalus spp.	18	6	5	2	8	4	9	5	3	1	2	19	6	75	139	8	88
Capelin*							116	58							116	7	6
Pacific cod*					1	1						53	18	62	116	7	18
Coho salmon*	4	1			1	1	1	1			5	49	16	2	62	4	41
Pink salmon*							7	4				42	14		49	3	18
Silverspotted sculpin	22	7	5	3	2	1			1	<1		2	<1	6	38	2	47
Buffalo sculpin	2	1	3	2	4	2	17	9			1	9	3		36	2	41
Starry flounder	16	5			1	1	5	3	5	2		6	2		33	2	59
Padded sculpin	2	1	6	3	14	13								1	23	1	24
Surf smelt*												23	8		23	1	6
Bay pipefish	2	1										16	5		18	1	24

Table 2. -- (Cont.).

	Auke Nu Cove north				Auke Nu Cove south				Bay Creek			Bridget Cove			Overall		
	2005-2007		2009&2011		2005-2007		2009&2011		2005-2007		2009	2004-2006		2009	2004-2011		
Taxa	Total	CPUE	Total	CPUE	Total	CPUE	Total	CPUE	Total	CPUE	Total	Total	CPUE	Total	Total	CPUE	FO
Juvenile greenling	1	<1										15	5		16	1	18
Rock sole*	1	<1			1	1	1	1				13	4		16	1	29
Snake prickleback	5	2			1	1	1	1	3	1		3	1		13	1	29
Juvenile sculpin												3	1		3	<1	12
Whitespotted greenling			1	1			3	2				1	<1	3	8	1	24
Dolly Varden							1	1				4	1		5	<1	12
Pacific sand lance*	1	<1										3	1		4	<1	12
Northern sculpin	1	<1										2	1		3	<1	12
Juvenile flatfish					1	1						1	<1	1	3	<1	18
English sole												2	1		2	<1	6
Pacific sandfish*												2	1		2	<1	6
Tidepool sculpin									1	<1		1	<1		2	<1	12
Juvenile gunnel	1	<1							1	<1					2	<1	12
Manacled sculpin					1	1								1	2	<1	12
Pacific spiny lumpsucker					1	1						1	<1		2	<1	12
Crested sculpin														1	1	<1	6
Cutthroat trout												1	<1		1	<1	6
Juvenile snailfish									1	<1					1	<1	6
Masked greenling			1	1											1	<1	6
Penpoint gunnel												1	<1		1	<1	6
Red Irish lord												1	<1		1	<1	6
Yellowfin sole*									1	<1					1	<1	6
Total catch	1,068		703		801		280		983		334	2,495		3,859	10,523		
Number of hauls	3		2		2		2		3		1	3		1	17		
Species richness	18		13		19		16		11		9	30		17	38		
Mean catch per haul	356		352		401		140		328		334	832		3,859	619		

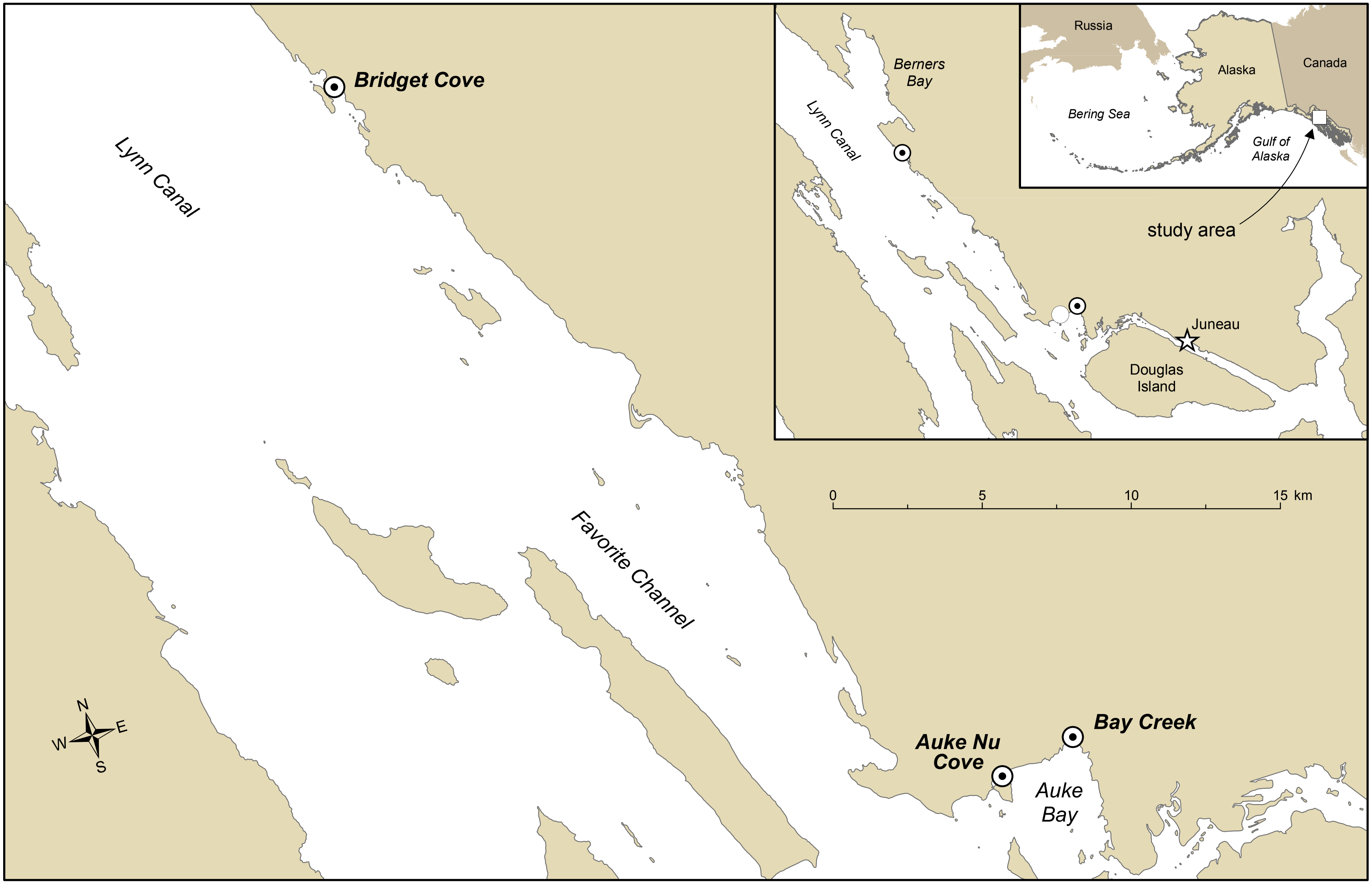

Figure 1. -- Eelgrass (*Zostera marina*) beds surveyed in the City and Borough of Juneau, Alaska, from 2004 to 2011. Each eelgrass bed was mapped and sampled for eelgrass characteristics (e.g., percent cover) and faunal assemblages. Individual beds are shown in Figures 2-4.

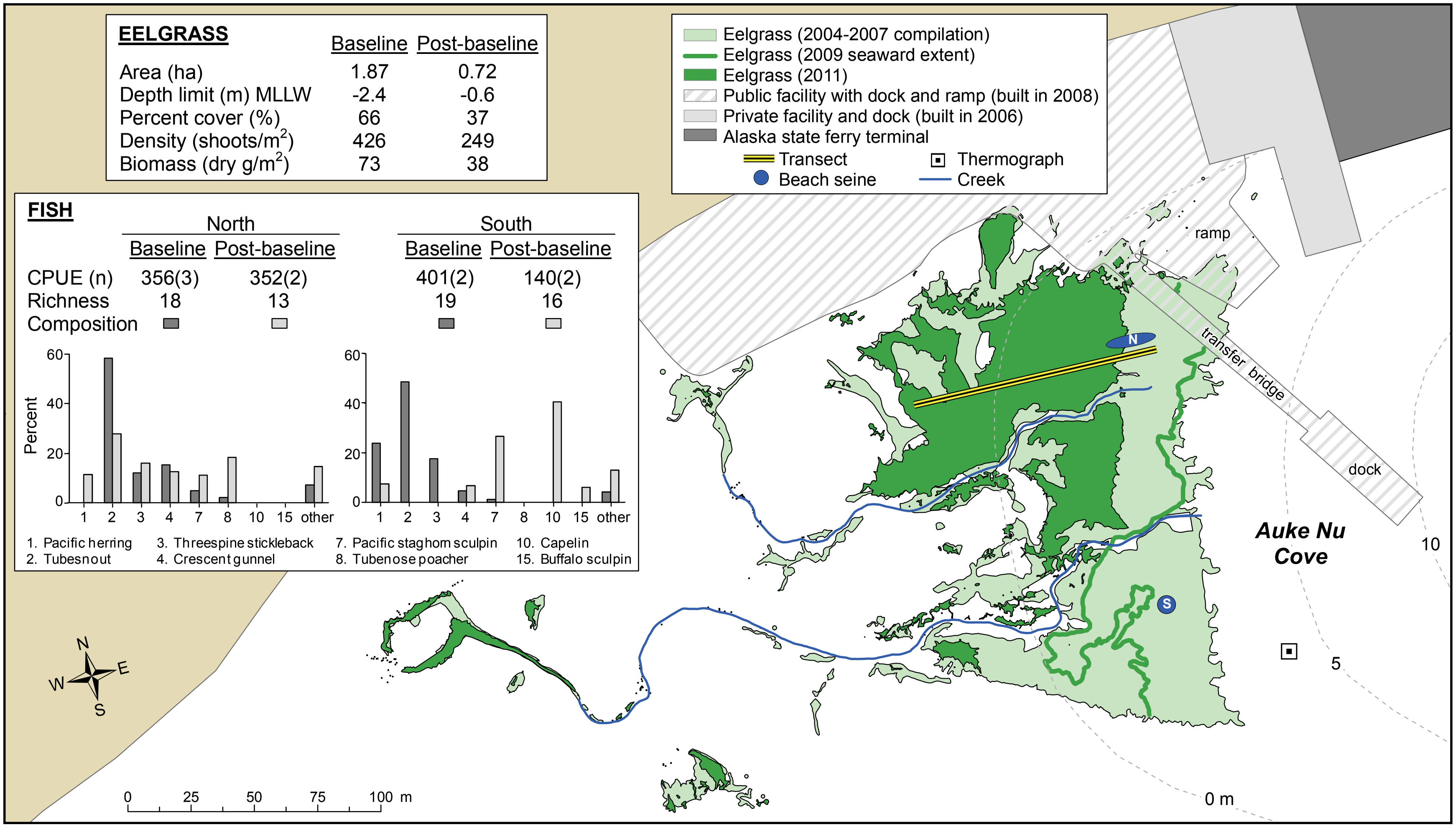

Figure 2. -- Eelgrass (*Zostera marina*) bed mapped and sampled at Auke Nu Cove in the City and Borough of Juneau, Alaska, from 2004 to 2011. Map shows compilation of baseline bed area (2004-2007), seaward boundary in 2009, and bed area in 2011. Also shown are developments and a thermograph site for measuring water temperature. Data panels show sampling for baseline (2004-2007) and post-baseline (2008-2011) years. Eelgrass characteristics (e.g., percent cover) were sampled along a permanent transect. Fish were sampled with a beach seine at two sites (north - N and south - S). For fish data, CPUE (n) = catch-per-unit-effort (number of seine hauls), richness = total number of species, and composition is shown as percent of total catch.

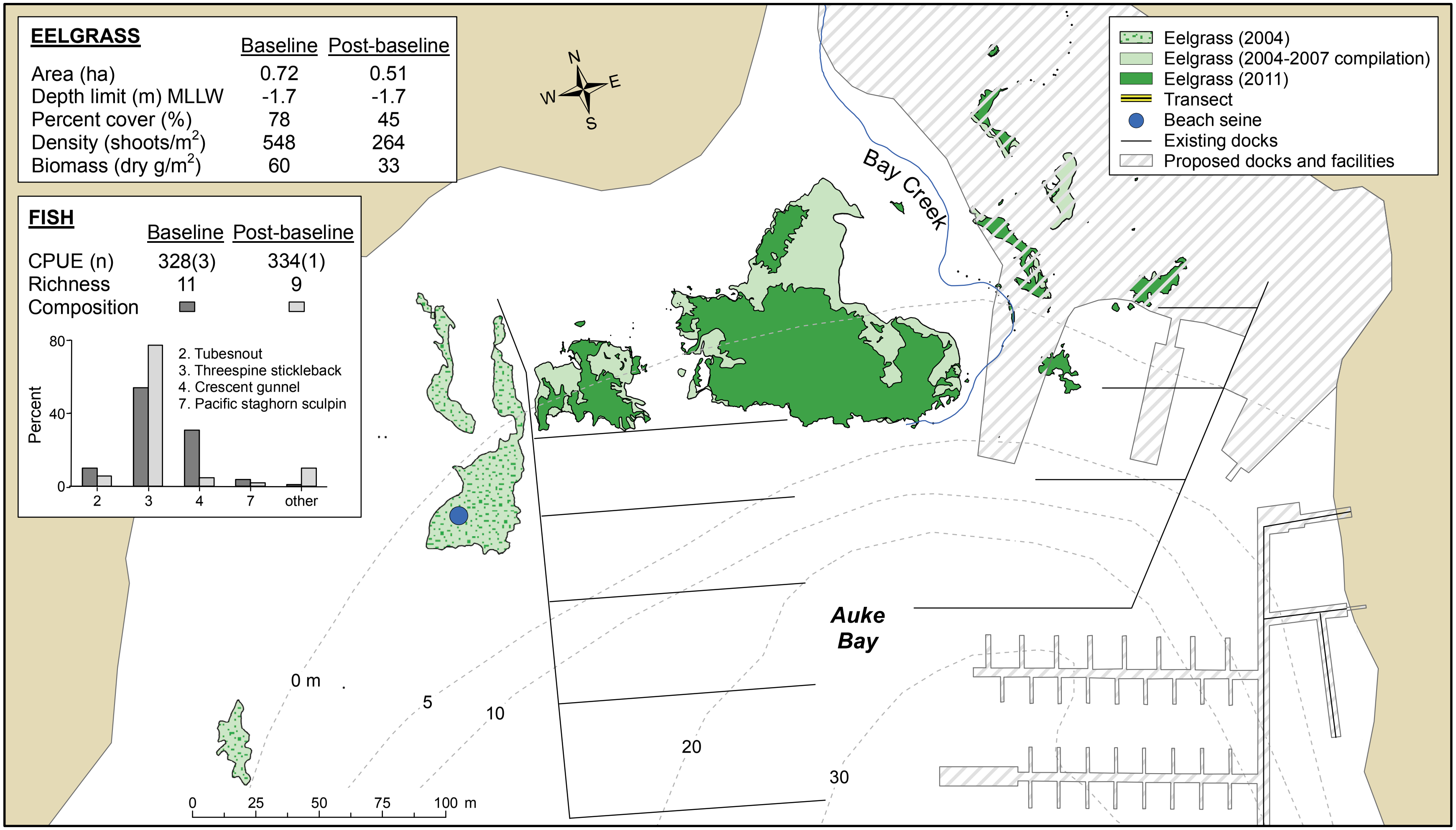

Figure 3. -- Eelgrass (*Zostera marina*) bed mapped and sampled at Bay Creek in the City and Borough of Juneau, Alaska, from 2004 to 2011. Map shows portions mapped in 2004 only, a compilation of baseline bed area mapped during 2004-2007, and bed area mapped in 2011. Also shown are current and proposed development. Data panels show sampling for baseline (2005-2007) and post-baseline (2008-2011) years. Eelgrass characteristics (e.g., percent cover) were sampled along a permanent transect. Fish were sampled with a beach seine at one site. For fish data, CPUE (n) = catch-per-unit-effort (number of seine hauls), richness = total number of species, and composition is shown as percent of total catch.

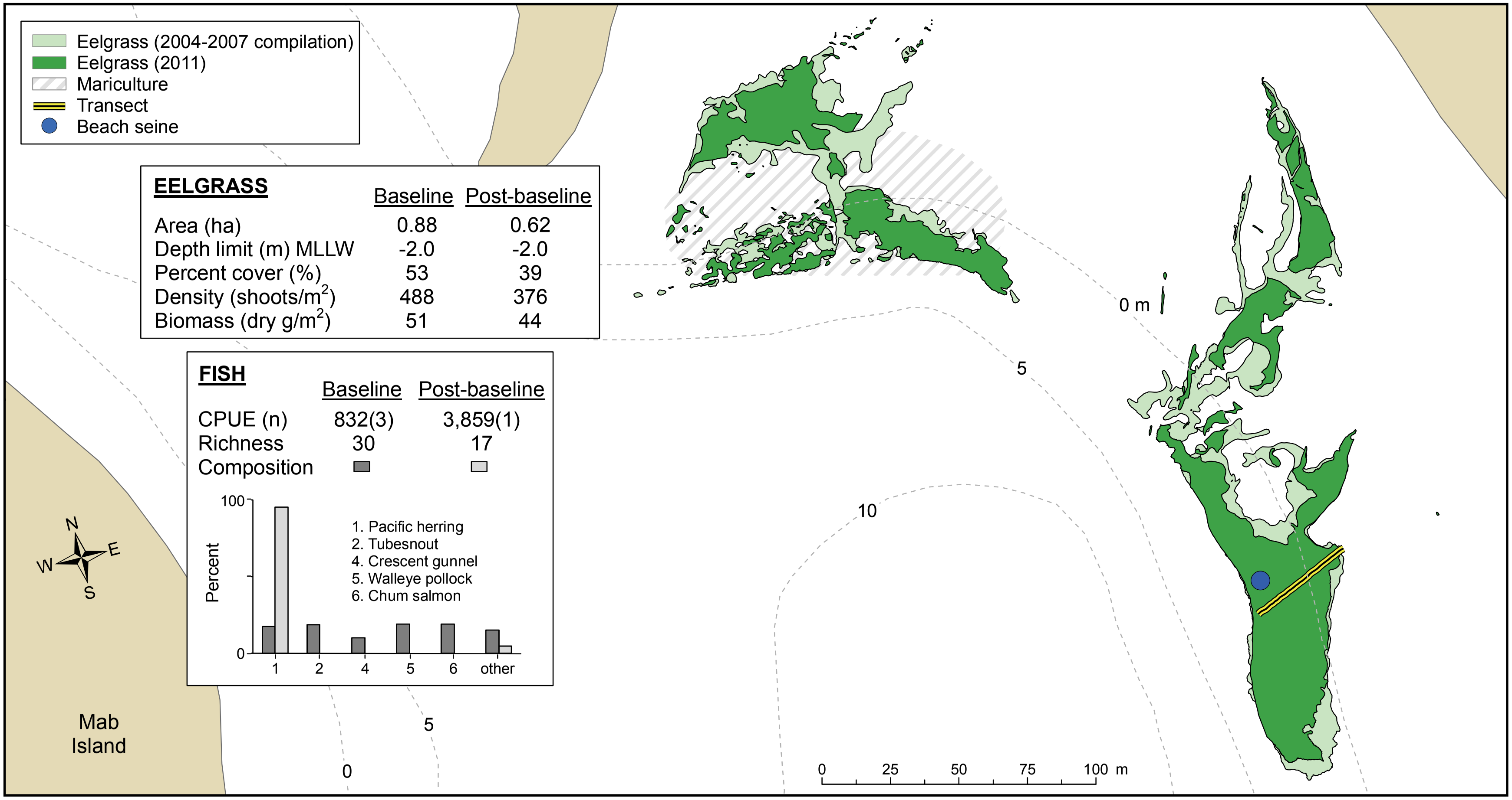

Figure 4. -- Eelgrass (*Zostera marina*) bed mapped and sampled at Bridget Cove in the City and Borough of Juneau, Alaska, from 2004 to 2011. Map shows compilation of baseline bed area (2004-2007) and bed area in 2011. Also shown is the location of a mariculture operation. Data panels show sampling for baseline (2004-2007) and post-baseline (2008-2011) years. Eelgrass characteristics (e.g., percent cover) were sampled along a permanent transect. Fish were sampled with a beach seine at one site. For fish data, CPUE (n) = catch-per-unit-effort (number of seine hauls), richness = total number of species, and composition is shown as percent of total catch. A thermograph for measuring water temperature was placed within Bridget Cove about 0.5 km northwest of the bed; thermograph coordinates are listed in Table 1.

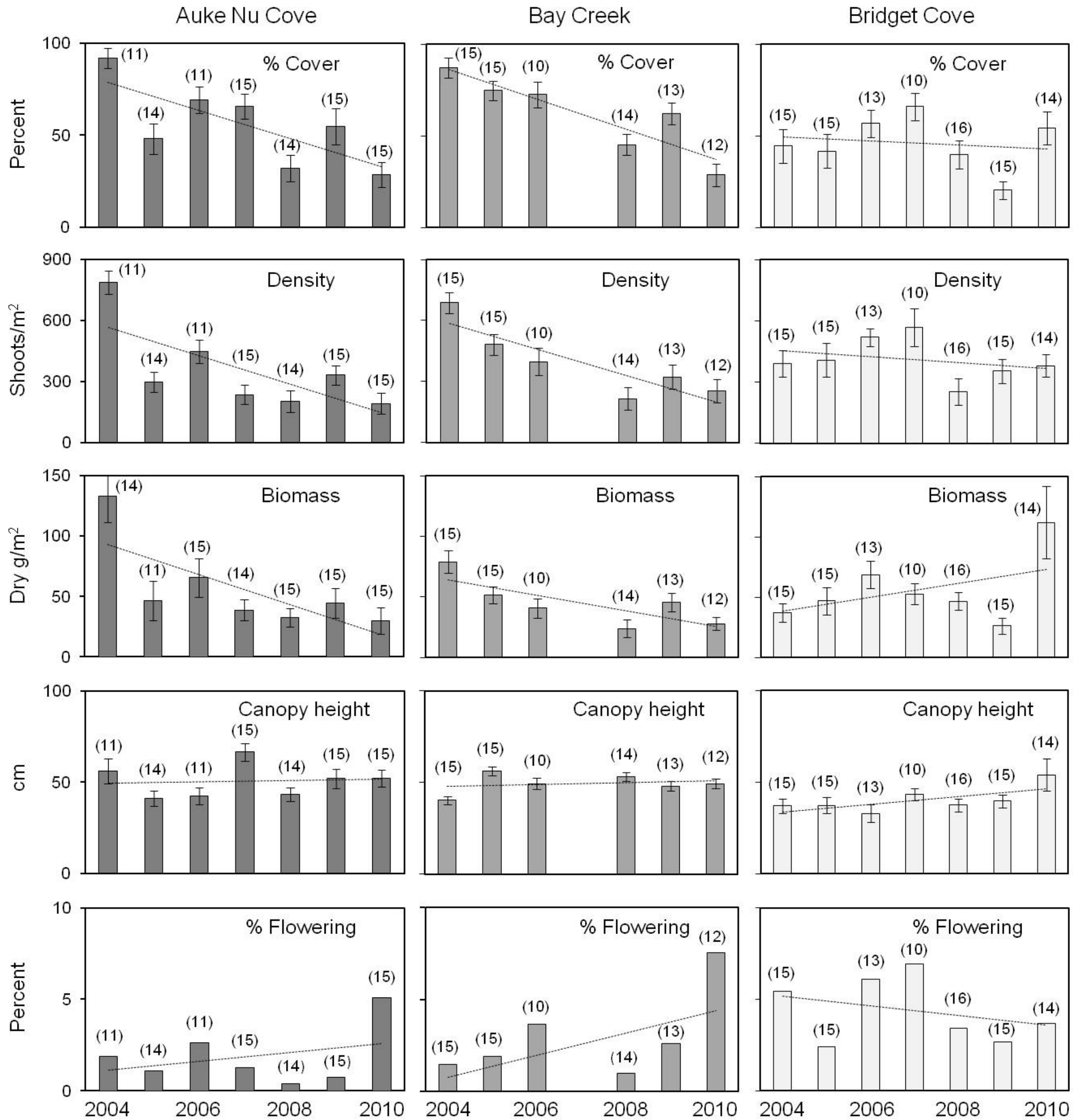

Figure 5. -- Interannual differences in eelgrass (*Zostera marina*) characteristics (percent cover, shoot density, biomass, canopy height, and percent flowering shoots) measured at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, in baseline (2004-2007) and post-baseline (2008-2010) years. Data are annual means (± SE) of samples collected at tidal elevations between −1.0 m and + 0.5 m relative to MLLW. Sample sizes are in parentheses, and dotted lines indicate overall trend. See Appendix 1 for significant differences.

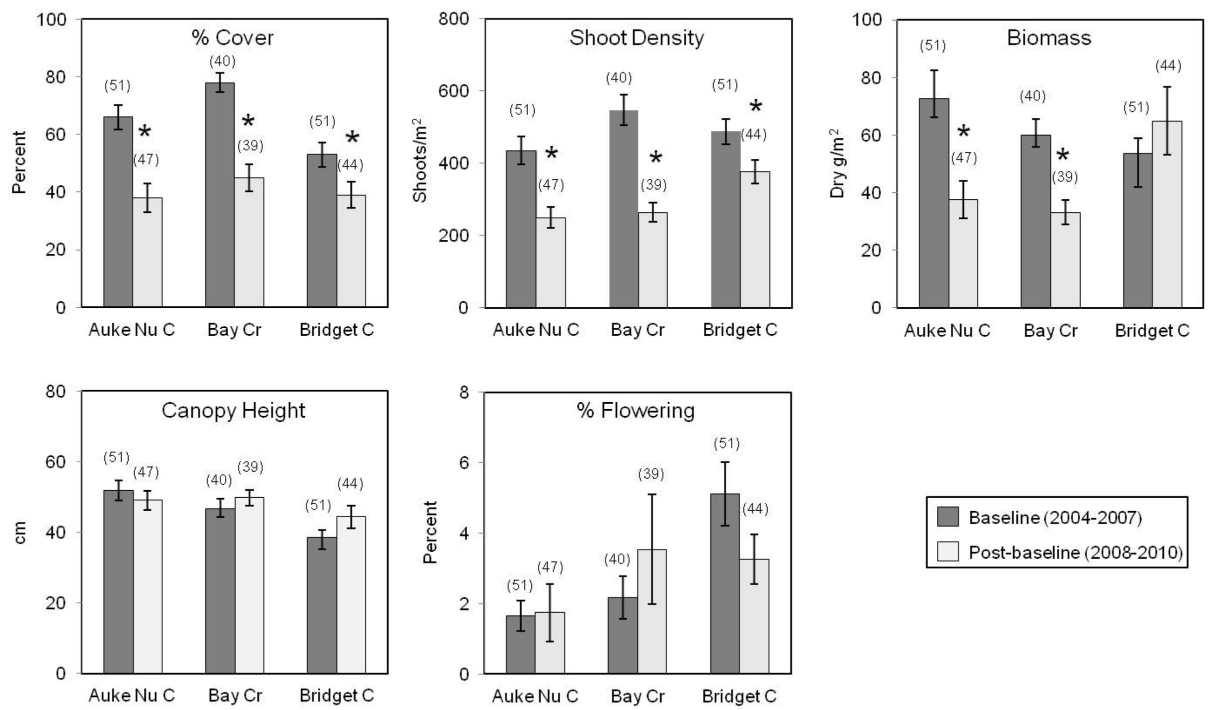

Figure 6. -- Eelgrass (*Zostera marina*) characteristics (percent cover, shoot density, biomass, canopy height, and percent flowering shoots) measured annually in summer at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, in baseline (2004-2007) and post-baseline (2008-2010) years. Data are means (± SE), sample sizes are in parentheses, and an asterisk denotes significant differences between baseline and post-baseline years within a bed. See Appendix 2 for significant differences.

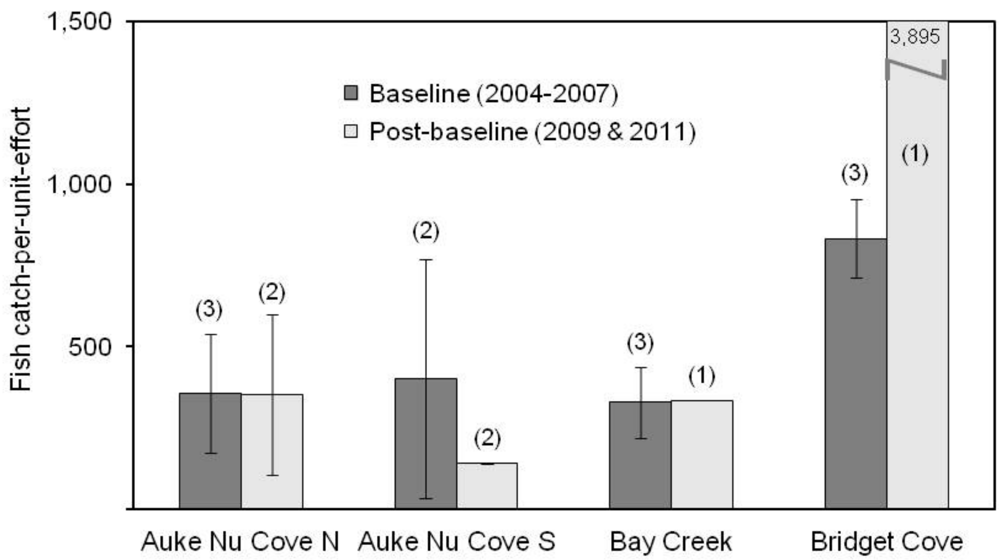

Figure 7. -- Fish catch-per-unit-effort (effort = beach seine haul) from four seine sites at three eelgrass (*Zostera marina*) beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, in baseline (2004-2007) and post-baseline (2009 and 2011) years. Vertical bars are (± SE), and number of seine hauls are in parentheses.

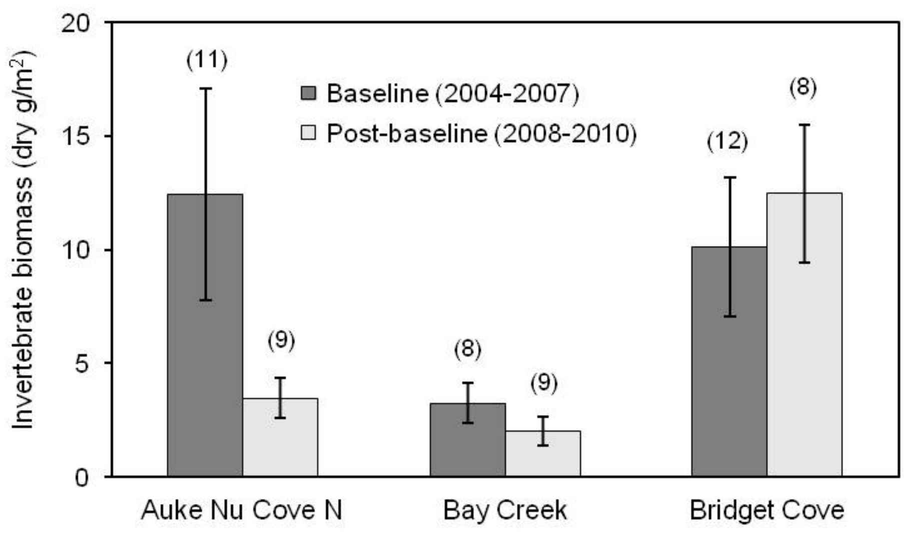

Figure 8. -- Mean dry biomass of invertebrate species epiphytic on eelgrass (*Zostera marina*) sampled in quadrats at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, in baseline (2004-2007) and post-baseline (2008-2010) years. Vertical bars are (± SE), and sample sizes are in parentheses.

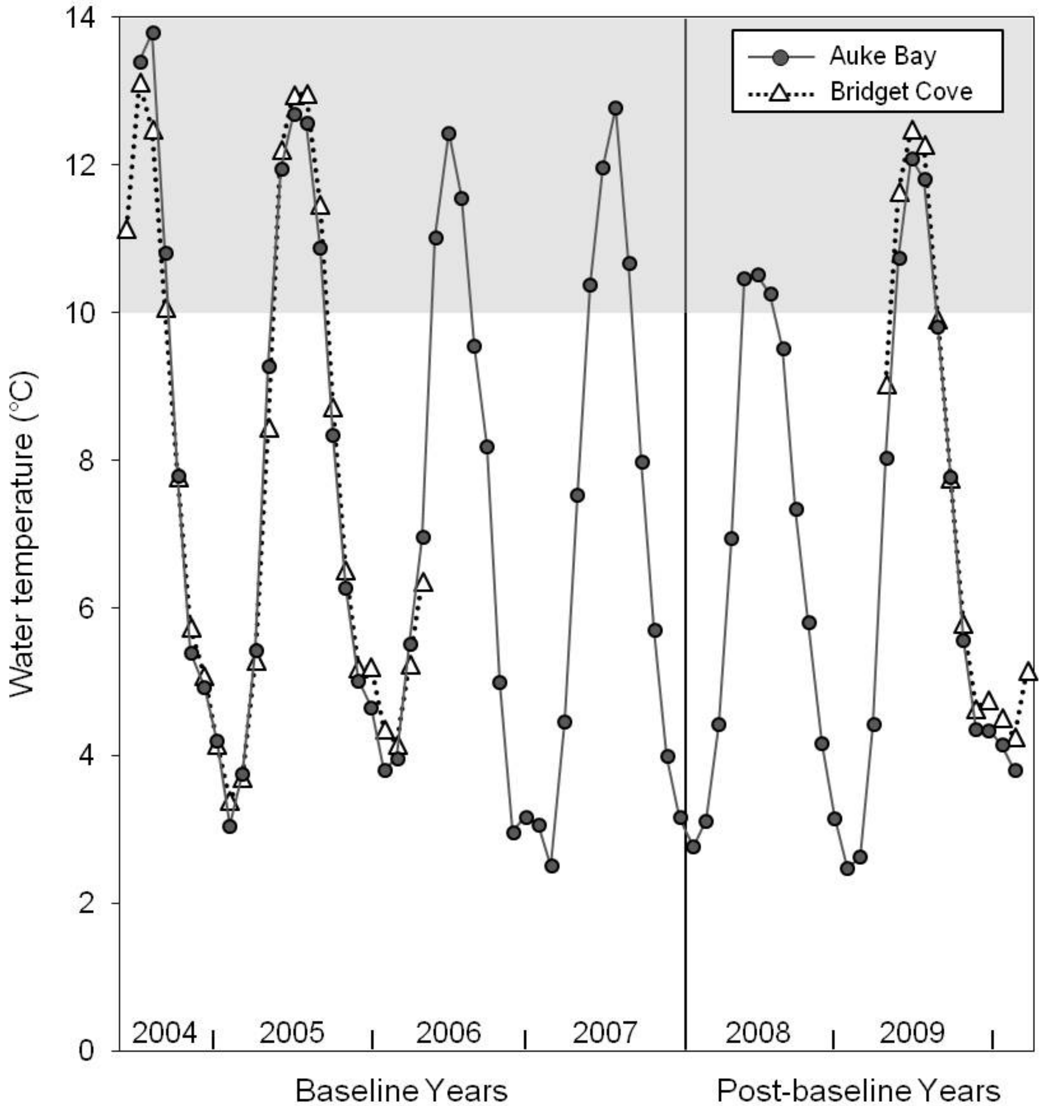

Figure 9. -- Surface seawater temperatures recorded by thermograph in Auke Bay and Bridget Cove in the City and Borough of Juneau, Alaska, in baseline (2004-2007) and post-baseline (2008-2010) years. The shaded area indicates optimum growing temperatures for eelgrass (*Zostera marina*).

Appendix 1. -- Analyses of interannual differences in eelgrass *(Zostera marina)* characteristics measured at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, from 2004 to 2010. Mean data values are presented in Figure 5. The first factor in each analysis was year, irrespective of categorization as a baseline (2004-2007) or post-baseline (2008-2010) year. The second factor was tidal block relative to MLLW; block 1 = − 1.0 m to − 0.5 m, 2 = − 0.5 m to 0.0 m, and 3 = 0.0 m to + 0.5 m. Analyses of interaction between year and tidal block were not possible due to empty cells. Significant *P*-values are bold, and significant differences between means are indicated with ">". Data transformations were arcsin sqrt for % cover and % flowering shoots, and sqrt for shoot density, biomass, and canopy height. ANOVA-1 and ANOVA-2 = 1- and 2-way ANOVA. Pair-wise multiple comparison tests used following ANOVA analysis are in parentheses.

Site	Year		Tidal block	
Characteristic	Significance	Analysis (Test)	Significance	Analysis (Test)
Auke Nu Cove				
% Cover	***P* < 0.001**	ANOVA-2	***P* = 0.011**	ANOVA-2
	2004 > 2008	(Holm-Sidak)	2 > 3	(Holm-Sidak)
	2004 > 2005			
	2004 > 2009			
	2004 > 2007			
	2004 > 2010			
	2006 > 2010			
	2006 > 2008			
	2007 > 2010			
Shoot density	***P* < 0.001**	ANOVA-2	*P* = 0.405	ANOVA-2
	2004 > 2010	(Holm-Sidak)		
	2004 > 2008			
	2004 > 2007			
	2004 > 2005			
	2004 > 2009			
	2006 > 2010			
Biomass	***P* < 0.001**	ANOVA-2	***P* = 0.006**	ANOVA-2
	2004 > 2008	(Holm-Sidak)	2 > 3	(Holm-Sidak)
	2004 > 2005			
	2004 > 2009			
	2004 > 2010			

Appendix 1. -- (Cont.).

Site Characteristic	Year Significance	Year Analysis (Test)	Tidal block Significance	Tidal block Analysis (Test)
Canopy height	***P* = 0.001** 2007 > 2005 2007 > 2008	ANOVA-2 (Holm-Sidak)	***P* < 0.001** 1 > 3 2 > 3	ANOVA-2 (Holm-Sidak)
% Flowering	*P* = 0.115	Kruskal-Wallis	*P* = 0.639	Kruskal-Wallis
Bay Creek				
% Cover	***P* < 0.001** 2004 > 2010	Kruskal-Wallis (Dunn's)	***P* = 0.043**	Kruskal-Wallis (Dunn's)
Shoot density	***P* < 0.001** 2004 > 2010 2004 > 2009 2005 > 2008 2004 > 2006 2005 > 2010	ANOVA-2 (Holm-Sidak)	*P* = 0.079	ANOVA-2
Biomass	***P* < 0.001** 2004 > 2008 2004 > 2010 2004 > 2009	ANOVA-2 (Holm-Sidak)	***P* = 0.006** 1 > 3 2 > 3	ANOVA-2 (Holm-Sidak)
Canopy height	*P* = 0.094	Kruskal-Wallis (Dunn's)	***P* < 0.001** 1 > 3 1 > 2 2 > 3	Kruskal-Wallis (Dunn's)
% Flowering	*P* = 0.463	Kruskal-Wallis	*P* = 0.749	Kruskal-Wallis
Bridget Cove				
% Cover	***P* = 0.003** 2007 > 2009 2010 > 2009 2006 > 2009	ANOVA-1 (Tukey)	*P* = 0.319	Kruskal-Wallis

Appendix 1. -- (Cont.).

Site Characteristic	Year		Tidal block	
	Significance	Analysis (Test)	Significance	Analysis (Test)
Shoot density	$P = 0.176$	ANOVA-2	$P = 0.790$	ANOVA-2
Biomass	$\boldsymbol{P = 0.006}$ 2010 > 2009 2010 > 2004	ANOVA-2 (Holm-Sidak)	$\boldsymbol{P = 0.002}$ 2 > 3 1 > 3	ANOVA-2 (Holm-Sidak)
Canopy height	$P = 0.214$	Kruskal-Wallis	$\boldsymbol{P < 0.001}$ 1 > 3 1 > 2 2 > 3	Kruskal-Wallis (Dunn's)
% Flowering	$P = 0.446$	Kruskal-Wallis	$P = 0.617$	Kruskal-Wallis

Appendix 2. -- Analyses of differences between eelgrass (*Zostera marina*) characteristics measured during summer in baseline (2004-2007) and post-baseline (2008-2010) years at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska. Mean data values are presented in Figure 6. The first factor in each analysis was time period: baseline or post-baseline. The second factor in each analysis was tidal block relative to MLLW; block 1 = − 1.0 m to − 0.5 m, 2 = − 0.5 m to 0.0 m, and 3 = 0.0 m to + 0.5 m. Analyses of interaction between time period and tidal block were performed. Significant *P*-values are bold, and significant differences between means are indicated with ">". Data transformations were arcsin sqrt for % cover and % flowering shoots, and sqrt for shoot density, biomass, and canopy height; density at Bridget Cove was not transformed. ANOVA-1 and ANOVA-2 = 1- and 2-way ANOVA. Pair-wise multiple comparison tests used following ANOVA analysis are in parentheses.

Bed	Time period		Tidal block		Period x Block	
Characteristic	Significance	Analysis (Test)	Significance	Analysis (Test)	Significance	Analysis (Test)
Auke Nu Cove						
% Cover	$\boldsymbol{P \leq 0.001}$ Baseline > Post-baseline	ANOVA-2 (Holm-Sidak)	$\boldsymbol{P = 0.044}$ 2 > 3	ANOVA-2 (Holm-Sidak)	$P = 0.341$	ANOVA-2
Shoot density	$\boldsymbol{P \leq 0.001}$ Baseline > Post-baseline	ANOVA-2 (Holm-Sidak)	$P = 0.241$	ANOVA-2	$P = 0.164$	ANOVA-2
Biomass	$\boldsymbol{P \leq 0.001}$ Baseline > Post-baseline	ANOVA-2 (Holm-Sidak)	$\boldsymbol{P = 0.013}$ 1 > 3 2 > 3	ANOVA-2 (Holm-Sidak)	$\boldsymbol{P = 0.005}$	ANOVA-2 (Holm-Sidak)
Canopy height	$P = 0.312$	ANOVA-2	$\boldsymbol{P \leq 0.001}$ 1 > 3 2 > 3	ANOVA-2 (Holm-Sidak)	$P = 0.179$	ANOVA-2
% Flowering	$P = 0.212$	Kruskal-Wallis	$P = 0.639$	Kruskal-Wallis	na	

Appendix 2. -- (Cont.).

Bed	Time period		Tidal block		Period x Block	
Characteristic	Significance	Analysis (Test)	Significance	Analysis (Test)	Significance	Analysis (Test)
Bay Creek						
% Cover	**$P \leq 0.001$**	ANOVA-2	**$P = 0.002$**	ANOVA-2	$P = 0.307$	ANOVA-2
	Baseline > Post-baseline	(Holm-Sidak)	1 > 3	(Holm-Sidak)		
			2 > 3			
Shoot density	**$P \leq 0.001$**	ANOVA-1	$P = 0.422$	ANOVA-1	na	
	Baseline > Post-baseline	(Tukey)				
Biomass	**$P \leq 0.001$**	ANOVA-2	**$P = 0.006$**	Kruskal-Wallis	$P = 0.644$	Kruskal-Wallis
	Baseline > Post-baseline	(Holm-Sidak)	1 > 3	(Dunn's)		
Canopy height	$P = 0.292$	ANOVA-1	**$P \leq 0.001$**	Kruskal-Wallis	na	
			1 > 3	(Dunn's)		
			1 > 2			
			2 > 3			
% Flowering	$P = 0.393$	Kruskal-Wallis	$P = 0.749$	Kruskal-Wallis	na	

Appendix 2. -- (Cont.).

Bed	Time period		Tidal block		Period x Block	
Characteristic	Significance	Analysis (Test)	Significance	Analysis (Test)	Significance	Analysis (Test)
Bridget Cove						
% Cover	***P* = 0.033** Baseline > Post-baseline	ANOVA-1 (Tukey)	*P* = 0.319	Kruskal-Wallis	na	
Shoot density	***P* = 0.045** Baseline > Post-baseline	ANOVA-2 (Holm-Sidak)	*P* = 0.639	ANOVA-2	*P* = 0.492	ANOVA-2
Biomass	*P* = 0.512	ANOVA-2	***P* = 0.003** 2 > 3 1 > 3	ANOVA-2 (Holm-Sidak)	*P* = 0.508	ANOVA-2
Canopy height	*P* = 0.195	ANOVA-2	***P* ≤ 0.001** 1 > 3 1 > 2 2 > 3	ANOVA-2 (Holm-Sidak)	*P* = 0.156	ANOVA-2
% Flowering	*P* = 0.298	Kruskal-Wallis	*P* = 0.617	Kruskal-Wallis	na	

Appendix 3. -- Pearson product moment correlations (r) between eelgrass (*Zostera marina*) characteristics sampled at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska, from 2004 to 2010. The number of data points in each correlation is n. Significant ($P \leq 0.05$) moderate to strong ($0.4 \leq r \leq 1.0$) correlations are bold, and significant weak to moderate ($0.2 \leq r < 0.4$) correlations are underlined.

Bed	Characteristic		Shoot density	Biomass	Canopy height	% Flowering
Auke Nu Cove						
	% Cover	n	92	82	92	88
		r	**0.733**	**0.790**	**0.491**	0.177
		P	< 0.001	< 0.001	< 0.001	0.098
	Shoot density	n		79		87
		r		**0.791**		0.223
		P		< 0.001		0.038
	Biomass	n				76
		r				0.256
		P				0.025
	Canopy height	n	89	79		87
		r	0.125	**0.465**		− 0.268
		P	0.242	< 0.001		0.805
Bay Creek						
	% Cover	n	78	74	77	74
		r	**0.579**	**0.627**	0.221	0.108
		P	< 0.001	< 0.001	0.054	0.358
	Shoot density	n		73		74
		r		**0.575**		− 0.048
		P		< 0.001		0.684
	Biomass	n				69
		r				0.022
		P				0.855
	Canopy height	n	76	72		74
		r	− 0.324	0.231		− 0.033
		P	0.004	0.051		0.783

Appendix 3. -- (Cont.).

Site	Characteristic		Shoot density	Biomass	Canopy height	% Flowering
Bridget Cove						
	% Cover	n	91	82	95	82
		r	**0.728**	**0.760**	**0.544**	0.337
		P	< 0.001	< 0.001	< 0.001	0.002
	Shoot density	n		76		82
		r		**0.670**		0.336
		P		< 0.001		0.002
	Biomass	n				69
		r				0.437
		P				< 0.001
	Canopy height	n	88	79		82
		r	0.260	**0.777**		0.199
		P	0.014	< 0.001		0.073

Appendix 4. -- Pearson product moment correlations (r) between eelgrass characteristics (July means), mean July surface seawater temperatures, and mean July cloud cover (percent clear days and percent cloudy days) at three eelgrass beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska. The number of data points in each correlation is n, and significant ($P \leq 0.05$) correlations are bold. A clear day is defined as 0% to 30% cloud cover; a cloudy day is defined as 80% to 100% cloud cover (NOAA National Weather Service 2012).

Bed	Characteristic		°C	% clear days	% cloudy days
Auke Nu Cove		n	6	4	4
	% Cover	r	**0.856**	0.623	− 0.013
		P	0.029	0.377	0.987
	Shoot density	r	**0.830**	0.939	− 0.762
		P	0.041	0.061	0.238
	Biomass	r	**0.822**	**0.951**	− 0.543
		P	0.045	0.049	0.457
	Canopy height	r	0.314	0.108	0.207
		P	0.542	0.892	0.793
	% Flowering	r	0.709	− 0.066	− 0.709
		P	0.115	0.934	0.291
Bay Creek		n	5	3	3
	% Cover	r	**0.988**	0.995	− 0.611
		P	0.002	0.066	0.582
	Shoot density	r	**0.950**	0.732	**− 0.998**
		P	0.013	0.477	0.038
	Biomass	r	**0.966**	0.864	− 0.961
		P	0.008	0.336	0.179
	Canopy height	r	− 0.604	0.159	0.605
		P	0.281	0.898	0.586
	% Flowering	r	0.290	− 0.237	− 0.540
		P	0.636	0.848	0.637

Appendix 4. -- (Cont.).

Bed	Characteristic		°C	% clear days	% cloudy days
Bridget Cove		n	4	4	4
	% Cover	*r*	0.354	− 0.062	0.288
		P	0.646	0.938	0.712
	Shoot density	*r*	0.870	− 0.022	0.274
		P	0.130	0.978	0.726
	Biomass	*r*	0.861	− 0.920	0.287
		P	0.139	0.080	0.713
	Canopy height	*r*	− 0.889	− 0.674	0.149
		P	0.111	0.326	0.851
	% Flowering	*r*	0.848	0.733	− 0.265
		P	0.152	0.267	0.735

Appendix 5. -- Fish species captured with a beach seine at three eelgrass (*Zostera marina*) beds (Auke Nu Cove, Bay Creek, and Bridget Cove) in the City and Borough of Juneau, Alaska. Seining occurred in summers in 2004-2011. Species are listed in decreasing order of abundance based on total catch. Misidentification problems with *Myoxocephalus* species (i.e., frog sculpin, *M. stelleri*; great sculpin, *M. polyacanthocephalus*; shorthorn sculpin, *M. scorpius*) prompted us to combine these three species. An * indicates species is included in a fishery management plan in Alaska. For details of catches at each site see Table 2.

Common name	Scientific name
Pacific herring	*Clupea pallasii*
Tubesnout	*Aulorhynchus flavidus*
Threespine stickleback	*Gasterosteus aculeatus*
Crescent gunnel	*Pholis laeta*
Walleye pollock*	*Theragra chalcogramma*
Chum salmon*	*Oncorhynchus keta*
Pacific staghorn sculpin	*Leptocottus armatus*
Tubenose poacher	*Pallasina barbata*
Frog, great, and shorthorn sculpins	*Myoxocephalus* spp.
Capelin*	*Mallotus villosus*
Pacific cod*	*Gadus macrocephalus*
Coho salmon*	*O. kisutch*
Pink salmon*	*O. nerka*
Silverspotted sculpin	*Blepsias cirrhosus*
Starry flounder	*Platichthys stellatus*
Padded sculpin	*Artedius fenestralis*
Buffalo sculpin	*Enophrys bison*
Surf smelt*	*Hypomesus pretiosus*
Bay pipefish	*Syngnathus leptorhynchus*
Rock sole*	*Lepidopsetta* spp.
Snake prickleback	*Lumpenus sagitta*
Whitespotted greenling	*Hexagrammos stelleri*
Dolly Varden	*Salvelinus malma*
Pacific sand lance*	*Ammodytes hexapterus*
Northern sculpin	*Icelinus borealis*
English sole	*Parophrys vetulus*
Pacific sandfish*	*Trichodon trichodon*
Tidepool sculpin	*Oligocottus maculosus*
Crested sculpin	*Blepsias bilobus*
Cutthroat trout	*O. clarkii*

Appendix 5. -- (Cont.).

Common name	Scientific name
Manacled sculpin	*Synchirus gilli*
Masked greenling	*Hexagrammos octogrammus*
Pacific spiny lumpsucker	*Eumicrotremus orbis*
Penpoint gunnel	*Apodichthys flavidus*
Red Irish lord	*Hemilepidotus hemilepidotus*
Yellowfin sole*	*Limanda aspera*

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