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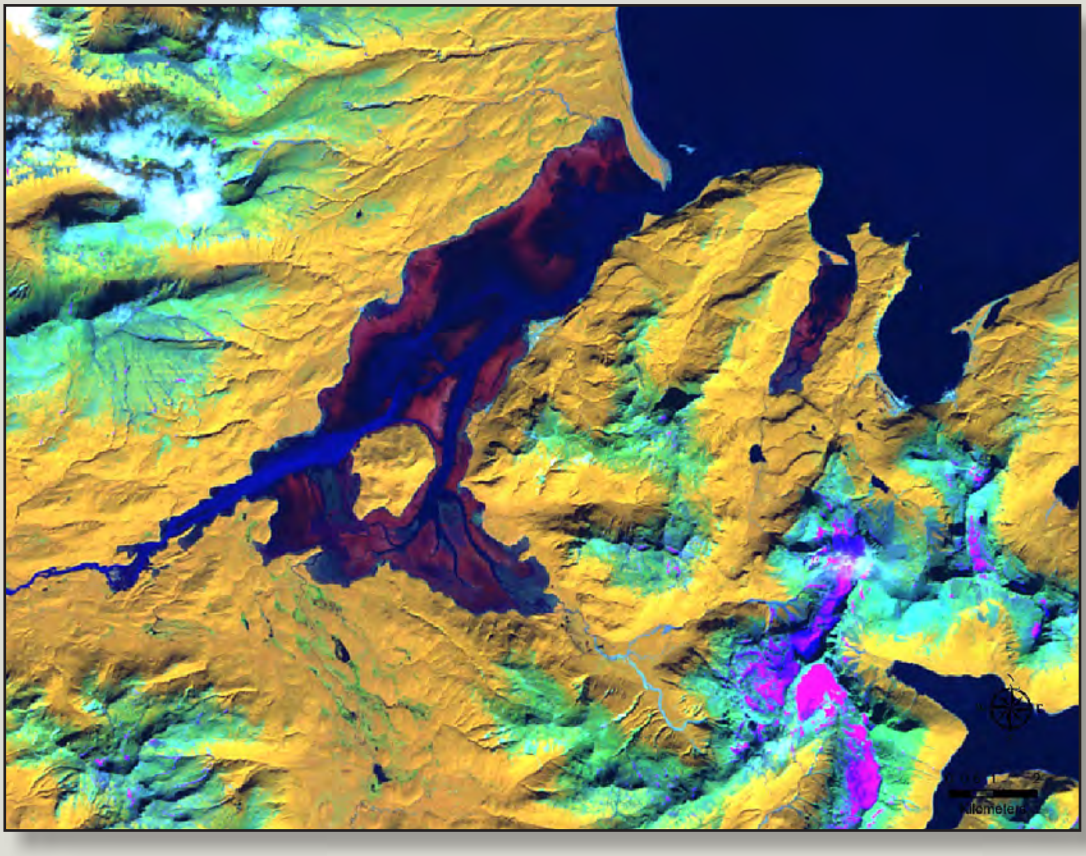
Eelgrass (*Zostera marina*) and Seaweed Assessments at Alaska Peninsula-Becharof National Wildlife Refuges, 2010



Open-File Report 2020–1144

U.S. Department of the Interior
U.S. Geological Survey

Cover. An August 2009 Landsat Enhanced Thematic Mapper Plus satellite image augmented to detect submerged aquatic vegetation in Chignik Lagoon and Mud Bay, Alaska. Landsat satellite imagery was downloaded from the USGS-Earth Resource and Observation Science Center web page, https://www.usgs.gov/centers/eros/data-tools.

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Contents

Abstract 1
Introduction 1
Methods 2
Eelgrass Mapping 2
Field Surveys 4
Results and Discussion 5
Chignik Lagoon 6
Mapping 6
Eelgrass and Seaweed Abundance 8
Mud Bay 11
Mapping 11
Eelgrass and Seaweed Abundance 11
Future Monitoring Needs 12
Eelgrass Mapping 12
Field Surveys 12
Acknowledgments iii
References Cited 13

Figures

Figure 1. Images showing a 1999 Landsat Enhanced Thematic Mapper Plus image and classification of eelgrass, unvegetated, and deep water in Chignik Lagoon and Mud Bay, Alaska 3
Figure 2. Maps showing inverse distance weighted interpolations of eelgrass standing crop and percentage cover based on June 2010 field survey data 7
Figure 3. Map showing inverse distance weighted interpolation of salinity measurements in Chignik Lagoon and Mud Bay, Alaska 8

Tables

Table 1. Spatial extent and percentage total cover of eelgrass and other cover types in Chignik Lagoon and Mud Bay, Alaska 6
Table 2. Diagonal matrices comparing field survey reference data from 2010 to the classified 1999 Enhanced Thematic Mapper Plus Landsat imagery for classification error of Chignik Lagoon, Alaska 6
Table 3. Mean estimates and standard error of abiotic properties and of seagrass and seaweed based on a sample of survey points across Chignik Lagoon and Mud Bay, Alaska, June 2010 9
Table 4. Seaweed genera and species identified on sample points in Chignik Lagoon and Mud Bay, Alaska, June 2010 10
Table 5. Diagonal matrices comparing field survey reference data from 2010 to 1999 Enhanced Thematic Mapper Plus Landsat imagery for classification error of Mud Bay, Alaska 11

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
grams per meter squared (g/m^2)	0.0209	pounds per square foot (lbs/ft^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Datum

Vertical coordinate information is referenced to the 1984 World Geodetic System (WGS 84).

Supplemental Information

Salinity is given in parts per thousand (ppt).

Abbreviations

APBNWR	Alaska Peninsula-Becharof National Wildlife Refuges
BB	Braun-Blanquet
EROS	Earth Resource and Observation Science
ETM+	Enhanced Thematic Mapper Plus
GCP	ground control point
GPS	global positioning system
IDW	inverse distance-weighted
INWR	Izembek National Wildlife Refuge
MLLW	mean lower low water
USGS	U.S. Geological Survey

Eelgrass (*Zostera marina*) and Seaweed Assessments at Alaska Peninsula-Becharof National Wildlife Refuges, 2010

By David H. Ward[1], Kyle R. Hogrefe[1], Tyronne F. Donnelly[1], Lucretia L. Fairchild[2], and Ron Britton[3]

Abstract

We conducted the first assessment of eelgrass (*Zostera marina*) and seaweed distribution and abundance along the coast of the Alaska Peninsula-Becharof National Wildlife Refuges in Chignik Lagoon and Mud Bay. Areal extent of eelgrass, as determined from remote-sensing techniques, was estimated to be 2,414 hectares in Chignik Lagoon and 188 hectares in Mud Bay, and eelgrass was the dominant marine macrophyte in each of the embayments. During an embayment-wide point survey of Chignik Lagoon, eelgrass and seaweeds were observed on 76 and 62 percent of survey points, respectively. Average percent cover was greater for eelgrass (82 percent) than for seaweeds (37 percent) when each was present at a survey point. In contrast, eelgrass and seaweeds were distributed nearly equally in Mud Bay, occurring on 64 and 70 percent of the points, respectively, and when present, cover of eelgrass and seaweeds were 70 and 60 percent, respectively. Brown and red seaweeds, such as *Polysiphonia pacifica*, *Saccharina latissima*, *Neorhodomela oregona*, and *Eudesme borealis*, were the most common seaweeds in Chignik Lagoon, while green seaweeds, particularly *Kornmannia leptoderma* and *Cladophora sericea*, were dominant in Mud Bay. Standing crop of eelgrass was 44 percent greater in Chignik Lagoon (98.0±6.4 grams dry weight per square meter) than in Mud Bay (68.3 ±6.7 grams dry weight per square meter) in 2010. Five types of macro-invertebrates were assessed during the point survey. At least one of these macro-invertebrates was observed on 45 percent of points in Chignik Lagoon and 64 percent of points in Mud Bay. Gastropods were the most common of the macro-invertebrates, occurring on 40–57 percent of points in each of the embayments. This assessment of eelgrass and seaweeds can serve as a baseline for determining future changes in the distribution and abundance of these marine macrophytes in Chignik Lagoon and Mud Bay.

Introduction

Seagrasses play an essential role in the health of estuarine and coastal ecosystems through their high productivity, stabilization and enrichment of sediments, and support of a complex trophic web (Hemminga and Duarte, 2000). They are often the dominant primary producers of estuaries, and any change to their distribution may have implications for ecosystem

[1]U.S. Geological Survey, Alaska Science Center
[2]U.S. Fish and Wildlife Service, Izembek National Wildlife Refuge
[3]U.S. Fish and Wildlife Service, Alaska Peninsula-Becharof National Wildlife Refuges

functions (for example, biochemical fluxes, trophic transfers, nutrient cycling) and diversity of species (Duffy, 2006). Seagrasses are among the most threatened marine habitats (Short and Wyllie-Echevarria, 1996; Orth and others, 2006) because of their sensitivity to shifts in water clarity, temperature, depth, hydrology, and wave action (Short and Neckles, 1999). Therefore, it is important to monitor the health of these critically important habitats.

In Alaska, eelgrass (*Zostera marina*) is the dominant seagrass and likely the predominant marine macrophyte of coastal areas bordering the Alaska Peninsula-Becharof National Wildlife Refuges (APBNWR) on the southern side of the Alaska Peninsula. Anecdotal observations, over more than 600 kilometers of coastline, suggest that eelgrass is abundant in protected shallow water embayments and inlets and is likely an important reason for the rich diversity of plant and animal species that characterizes the region. Nevertheless, estimates of annual and seasonal variation in the abundance and distribution of eelgrass are lacking.

As part of a broad scale program to inventory eelgrass and test methodology for monitoring long-term trends in the health of this seagrass along the coast of the APBNWR, we assessed the distribution and abundance of eelgrass at Chignik Lagoon, a key stopover site for migratory birds and an important commercial salmon fishery. In this report, we discuss progress in mapping spatial extent of eelgrass and assessing its abundance relative to the presence of associated seaweeds and macro-invertebrates in June 2010.

Methods

Eelgrass Mapping

Landsat satellite imagery was downloaded from the USGS-Earth Resource and Observation Science Center (EROS) website (U.S. Geological Survey, 2020) to develop baseline maps for assessment of areal extent of eelgrass in coastal waters adjacent to APBNWR. We searched the EROS Landsat archive for contemporary (1990–2010) imagery that had little cloud cover and that was taken at a low tide during summer (June–August) when eelgrass is most visible. A Landsat Enhanced Thematic Mapper Plus (ETM+; Ward and Hogrefe, 2022) image from August 28, 1999, met our criteria for assessing eelgrass in Chignik Lagoon and Mud Bay, Alaska (fig. 1). The image was acquired at a relatively low tide of +0.15 meters (m) mean lower low water (MLLW, the average height of the lowest daily tide during a 19-year recording period) as determined from tidal predictions at Anchorage Bay, 8 kilometers to the west of Chignik Bay (fig. 1). The image was projected in Universal Transverse Mercator (UTM) Zone 4 North using the 1984 World Geodetic Datum System (WGS 84) and had a spatial resolution of 30 meters (m). After reprocessing, we classified the embayment into three major land cover types: eelgrass, sand/mud (unvegetated), and deep water (fig. 1).

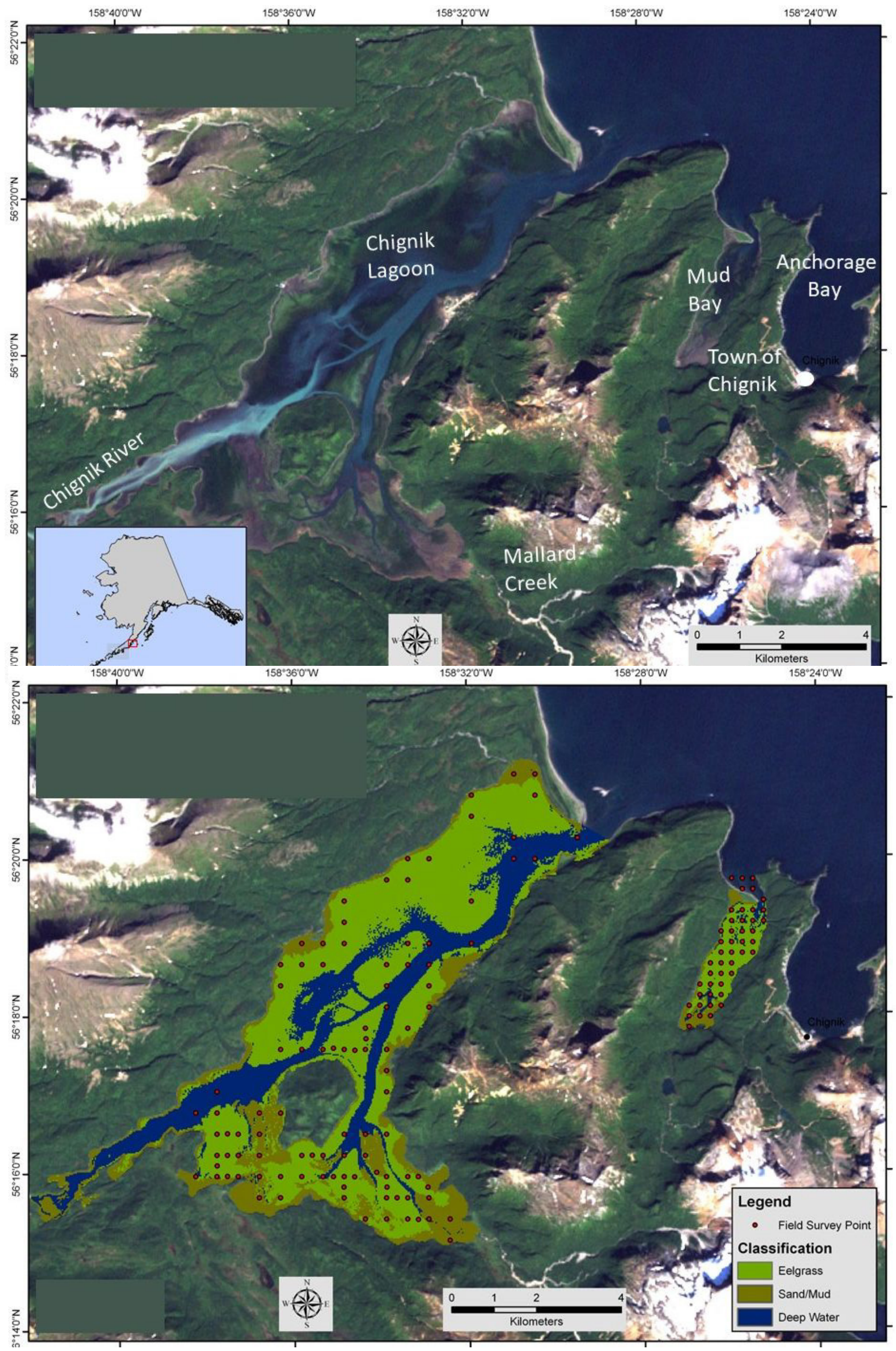

Figure 1. A 1999 Landsat Enhanced Thematic Mapper Plus image (top) and classification of eelgrass (*Zostera marina*), unvegetated (sand/mud), and deep water (bottom) in Chignik Lagoon and Mud Bay, Alaska. Landsat image retrieved at U.S. Geological Survey (2020).

The image was preprocessed to calibrate for at-sensor radiance, correct for atmospheric path interference, and check for georeferencing accuracy. Radiance calibration was performed using the ENVI 4.7 Landsat calibration tool following calibration factors and formulas established in Chander and others (2009). The images were corrected for atmospheric interference using the “dark pixel subtraction” method (Chavez, 1988). We verified the EROS georeferencing by comparing the position of prominent landmark features in the image with the position of those same features found on a NOAA nautical chart. We detected only a small (<1 pixel) offset between the image and the chart, and no additional georectification was made. However, careful field collection of ground control points using global positioning system (GPS) units may improve the spatial accuracy of the imagery and any products.

Classification of the imagery was conducted using an unsupervised isodata clustering algorithm to identify statistically separable spectral classes that were then used in a supervised maximum likelihood analysis (Ward and others, 1997; Ozesmi and Bauer, 2002). Visual interpretation of the imagery and field data collected during a boat survey of the embayments in June 2010 (Ward, 2021) were used to choose isodata clusters covering regions that provided the cleanest examples of the three major land cover types. These clusters were then used to extract training data for a maximum likelihood classification that assigned every pixel within the embayments to one of the three cover types. When considering the full spectral range of the image, we found that eelgrass covered by optically deep water (>1 m of depth) was misidentified as deep water over unvegetated substrate because of similarity in spectral signals. Therefore, we repeated the classification process, focusing on just the region classified as deep water, to narrow the spectral range being analyzed and enhance differentiation between submerged eelgrass and submerged unvegetated. This technique increased the eelgrass coverage estimates by 409 hectares (ha) in Chignik Lagoon and 44 ha in Mud Bay and increased the accuracy of these estimates by 2 and 10 percent, respectively.

Mapping accuracy of eelgrass extent was evaluated from a subset of percent cover determinations made during the June boat survey that were not used in the classification process. For this exercise, we simplified estimates of eelgrass percent cover to presence (≥5 percent eelgrass cover) or absence (<5 percent eelgrass cover) categories to approximate the cover needed to produce a spectral signal for eelgrass (Valta-Hulkkonen and others, 2003). Finally, we created maps of eelgrass density (percent cover) and abundance (standing crop) from the field survey data using the inverse distance weighted (IDW) interpolation method. The IDW interpolation method applies the assumption that locations in close proximity are more likely to be similar than those farther apart to create a raster surface for an entire area from localized point data (Valley and others, 2005).

Field Surveys

Abundance of eelgrass and macro-seaweeds and the presence of selected macro-invertebrate species were assessed to a depth of about -2.0 m MLLW in Chignik Lagoon from June 15 to 23 and in Mud Bay from June 24 to 27 in 2010. Although eelgrass may grow at deeper water depths, this restricted sampling area likely encompassed 90 percent or more of the distribution of eelgrass in these embayments. We used a point sampling approach with a systematic random design, where points were distributed across subtidal and intertidal areas (fig. 1). This design allowed for a proportional assessment of cover types and related physical attributes within each of the embayments. Points were located in the field by boat using a GPS unit and sampled by snorkeling in dry suits during high tide. At each point, we estimated water (surface) temperature and depth, salinity (surface), substrate type and depth, and water clarity as determined with a 20 cm-diameter Secchi disk. We assessed percent cover of eelgrass and seaweeds in four 0.25/m^2 quadrats that were spaced approximately 5 m apart in cardinal directions around the point. We also determined the presence or absence of five selected macro-invertebrate species: mussels (*Mytilus* spp.), sponges, sea stars (*Pisaster* and *Evasterias* spp.), gastropods, and *Telmessus* sp. crabs in these quadrats. Cover was defined as the part of the quadrat area obscured by a particular macrophyte while viewed in water from above. If eelgrass was present, three representative shoots were collected from each of the quadrats and measured for total (meristem to tip of longest leaf) and sheath (meristem to start of leaf growth) length. If seaweeds were present, we estimated cover for all species combined and for the dominant seaweed species in each of the four quadrats. If seaweeds were unidentifiable in the field, specimens were collected and later identified by Dr. Sandra Lindstrom of the University of British Columbia (see Ward, 2021).

To minimize among-observer differences in estimates of eelgrass and seaweed cover we assigned a cover score between 0 and 5 based on the Braun-Blanquet (BB) visual estimation technique (Braun-Blanquet, 1972: BB score of 0 percent =0; 1–5 percent =1; 6–25 percent =2; 26–50 percent =3; 51–75 percent =4; 76–100 percent =5). From these cover estimates we computed density, abundance, and frequency of occurrence of eelgrass and total seaweeds within each quadrat according to Fourqurean and others (2001). We also estimated percent cover (BB score) and harvested all shoots from 15 to 30 calibration quadrats placed at different intertidal depths of the eelgrass beds. We removed dead leaves and belowground parts of the plant and selected 10 representative shoots that were later measured for shoot and sheath length. We then dried samples to constant mass and weighed them to determine standing crop (aboveground biomass) per quadrat and scaled estimates to grams per square meter. Finally, we used linear regression to evaluate the relation between the abundance index (BB score multiplied by average shoot length) and aboveground biomass for each of the calibration quadrats. We then applied this relation to abundance index scores at surveyed points and determined the mean annual standing crop of eelgrass in Izembek Lagoon. We report means and standard errors. All data supporting this report are available in Ward (2021) and Ward and Hogrefe (2022).

Results and Discussion

The Landsat imagery (U.S. Geological Survey, 2020) was a good data source (30 m pixel size) for the assessment of eelgrass spatial extent in coastal waters adjacent to APBNWR. The 1999 imagery permitted an initial estimate of eelgrass spatial extent in Chignik Lagoon and Mud Bay (table 1). We were able to differentiate eelgrass from other cover types (that is water and unvegetated tidal flats) with a high degree of accuracy based on field survey point data (table 2).

Table 1. Spatial extent and percentage total cover of eelgrass (*Zostera marina*) and other cover types in Chignik Lagoon and Mud Bay, Alaska.

[Data taken from 1999 Landsat Enhanced Thematic Mapper Plus imagery (U.S. Geological Survey, 2020]

Cover type	Spatial extent, in hectares (and percentage of total cover)	
	Chignik Lagoon	Mud Bay
Eelgrass	2,414 (54)	188 (68)
Sand/mud	905 (20)	55 (21)
Deep water[1]	1,150 (26)	39 (11)
Total	4,469	276

[1]Water depths below -2 meters mean lower low water.

Table 2. Diagonal matrices comparing field survey reference data from 2010 to the classified 1999 Enhanced Thematic Mapper Plus Landsat imagery for classification error of Chignik Lagoon, Alaska.

[Total correct: Number of field survey points that were correctly classified with or without eelgrass (*Zostera marina*) in the 1999 Enhanced Thematic Mapper Plus Landsat imagery. Landsat imagery taken from U.S. Geological Survey (2020). —, not applicable]

1999 Enhanced Thematic Mapper Plus Landsat imagery	Field survey reference data				
	Eelgrass	No eelgrass	Total correct	Total survey points	Commission accuracy (percent)
Eelgrass	66	2	—	68	97.1
No eelgrass	6	30	—	36	83.3
Total correct	—	—	96	—	—
Total survey points	72	32	—	104	—
Omission accuracy (percent)	91.7	93.8	—	—	92.3

Chignik Lagoon

Mapping

Eelgrass represented the largest land cover type in Chignik Lagoon, comprising 54 percent of its spatial extent (fig. 1; table 1). Although the distribution of eelgrass was fairly consistent across most of the lagoon, eelgrass was absent near the mouth, in deeper (>3 m water depth) channels, and close to the inlet of the Chignik River and Mallard Creek (fig. 1). Eelgrass distribution was irregular in shallow areas near the head of the lagoon where mud flats became more predominant. We found only a small degree of error in the classification of the satellite imagery for determining eelgrass extent based on an accuracy assessment of 104 field survey points (table 2). Of these, 66 of the 72 “Eelgrass” points (91.7 percent producer’s accuracy) and 30 of the 32 “No Eelgrass” (93.8 percent producer’s accuracy) were classified correctly for an overall accuracy of 92.3 percent. Of the six misidentified “Eelgrass” points, one was classified as sand/mud while the other five were classified as deep water. All of the eight misidentified points were located in transition zones between cover types where differing resolution between the field data (1 m) and the satellite image (30 m) was the likely source of error.

Variation in density (percent cover) and abundance (standing crop, defined as grams dry weight per meter squared) of eelgrass across the lagoon is shown in figure 2. The main area of high eelgrass density (75–100 percent cover) was spread across the northwest two-thirds of the lagoon, though eelgrass was notably absent in the deeper channels and close to the lagoon mouth, with secondary concentrations to the southeast and southwest of Chignik Island. Eelgrass abundance followed the same general pattern except that areas of greatest abundance (137–229 g/m^2) were more concentrated. Eelgrass became increasingly sparse and less abundant while mudflats became more persistent in the shallow southwest third of the lagoon.

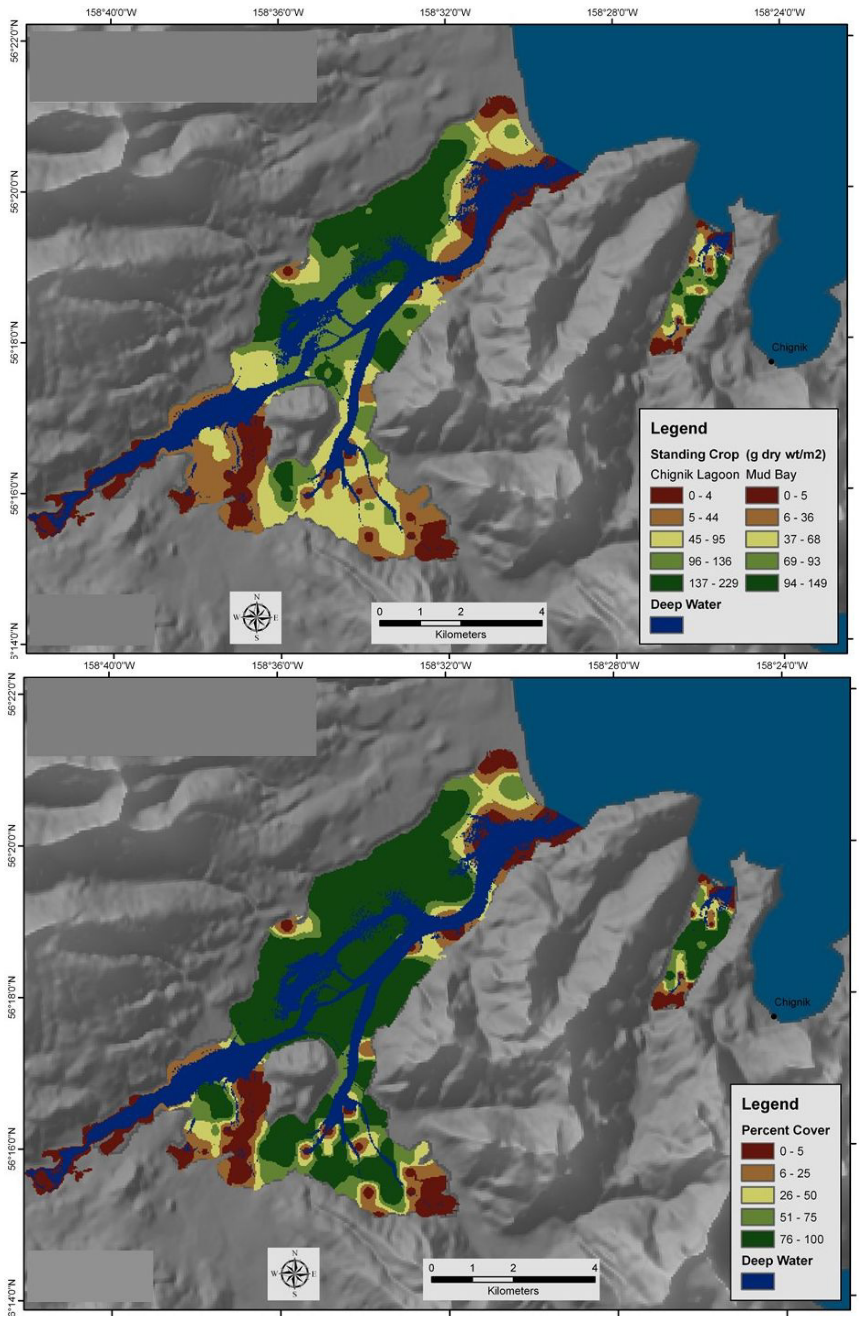

Figure 2. Inverse distance weighted interpolations of eelgrass (*Zostera marina*) standing crop (top) and percentage cover (bottom) based on June 2010 field survey data. G dry wt/m^2, grams dry weight per square meter.

Eelgrass and Seaweed Abundance

Chignik Lagoon was characterized by cold water temperature, very low salinity, shallow substrate depths, and deep-water depths. Average surface water temperature was 9.9±0.2 °C (range =8–14 °C) in June with colder temperatures near river outflows and warmer temperatures in the center of the lagoon. Outflow from the Chignik River and Mallard Creek was strong in June and caused relatively low average surface salinity of 11.6±0.8 ppt (range =1–25 ppt.; table 3) in the lagoon. Salinity was lowest near the river outlets and highest at the lagoon entrance (fig. 3). Although not reflected in the average water depths (table 3), Chignik Lagoon contained relatively deep-water channels averaging around -2 m MLLW in the central part and -5 m MLLW near the mouth of the lagoon. The lagoon substrate was composed primarily of fine sediments (86 percent: 53 percent mud and 33 percent sand) with the remaining composed of cobble rock (14 percent).

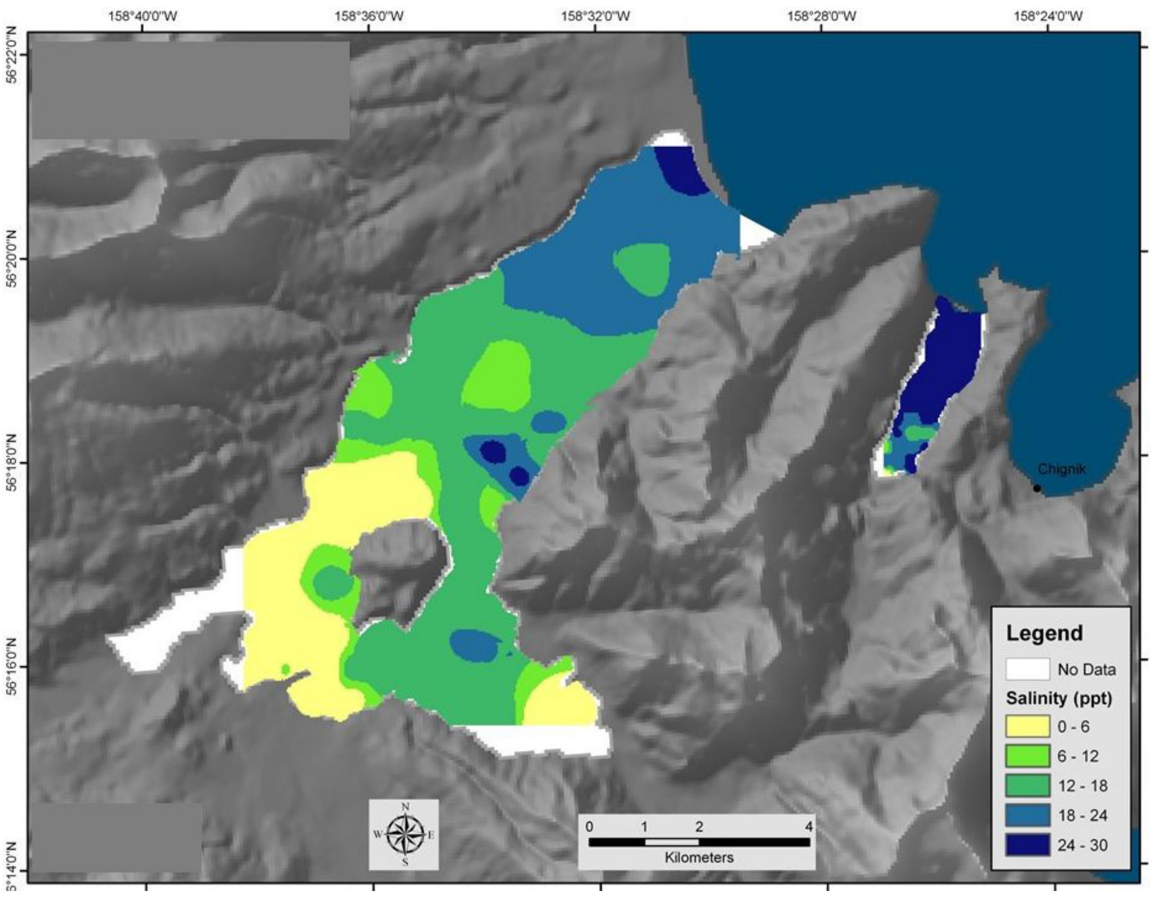

Figure 3. Inverse distance weighted interpolation of salinity measurements in Chignik Lagoon and Mud Bay, Alaska. See location of sampling points in figure 1.

Table 3. Mean estimates and standard error of abiotic properties and of seagrass and seaweed based on a sample of survey points across Chignik Lagoon and Mud Bay, Alaska, June 2010.

[*n*, number of survey points; SE, standard error; °C, degree Celsius; ppt, part per thousand; cm, centimeter; m, meters; MLLW, mean lower low water; g/m^2, gram dry mass per square meter].

Property	Chignik Lagoon			Mud Bay		
	n	Mean	SE	n	Mean	SE
Abiotic properties						
Water temperature (°C)	73	9.87	0.18	34	10.01	0.12
Salinity (ppt)	70	11.64	0.83	34	24.28	1.05
Water depth (cm)	72	81.03	4.18	36	93.47	6.95
Tidal depth (m, MLLW)	79	0.06	0.04	36	0.02	0.07
Substrate depth (cm)	97	3.71	0.30	43	7.27	0.98
Seagrass (*Zostera marina*) vegetable shoots						
Aboveground biomass (g/m^2) when eelgrass was present	79	97.95	6.41	30	68.29	6.72
Density[1] (0–5)	104	3.22	0.21	44	2.33	0.32
Abundance[1] (1–5)	79	4.30	0.12	30	3.62	0.25
Frequency (0–1)	104	0.74	0.04	44	0.61	0.07
Shoot length (cm)	79	61.18	3.47	30	58.71	3.33
Sheath length (cm)	79	15.42	1.00	30	15.47	1.02
Seaweed (all species) vegetable shoots						
Density[1] (0–5)	104	1.53	0.15	44	2.36	0.29
Abundance[1] (0–5)	79	2.54	0.15	36	3.24	0.24
Frequency (0–1)	104	0.56	0.04	44	0.68	0.06

[1]Braun-Blanquet visual estimation technique (Braun-Blanquet, 1972): 0 percent =0; 1–5 percent =1; 6–25 percent =2; 26–50 percent =3; 51–75 percent =4; 76–100 percent =5.

Eelgrass was present on 76 percent of points (*n*=104) scattered across the entire lagoon, and when present, eelgrass was abundant (BB score =4.3, approximately 82 percent cover) (table 3; fig. 2). Average tide height of points containing eelgrass was 0.06±0.04 m MLLW with points spread across intertidal flats from +1.0 to -1.4 m MLLW. Standing crop of eelgrass averaged 98.0±6.4 g/m^2 (range =6–228 g/m^2), an average value that was 44 percent greater in Chignik Lagoon than in Mud Bay (table 3). This difference in standing crop was likely due to the greater tidal depth and density and abundance of eelgrass that grew in Chignik Lagoon than Mud Bay (table 3).

Variation in standing crop was positively correlated with shoot lengths (R^2=0.48; P<0.001) and salinity (R^2=0.87; P<0.001) and negatively correlated with intertidal depth (R^2=0.24; P<0.001). Eelgrass standing crop increased intertidally to a depth of about -1.0 m MLLW and then declined. Average length of eelgrass shoots was 61.2±3.5 cm (range =15.3–143.2 cm) in early summer. On average, shoots were longer in this lagoon than in all other embayments surveyed to date in southwest Alaska (Ward and Amundson 2019; Ward and others 2022a, 2022b). The longest shoots, averaging >1 m in length, were found in the first third of the lagoon.

Table 4. Seaweed genera and species identified on sample points in Chignik Lagoon and Mud Bay, Alaska, June 2010.

[Seaweed taxonomy is based on Guiry and Guiry (2020). X, present; —, not present]

Number	Genus	Species	Location	
			Chignik Lagoon	Mud Bay
1	*Ahnfeltia*	*borealis*	X	—
2	*Alaria*	*marginata*	X	X
3	*Acrosiphonia*	*duriuscula*	—	X
4	*Blidingia*	*minima*	—	X
5	*Chorda*	*borealis*	X	—
6	*Chordaria*	*flagelliformis*	X	X
7	*Chordaria*	*gracilis*	X	X
8	*Cladophora*	*sericea*	X	X
9	*Coilodesme*	*cystoseirae*	—	X
10	*Coralline*	spp.	X	X
11	*Cystoseira*	*geminata*	—	X
12	*Desmarestia*	*viridis*	X	X
13	*Devaleraea*	*callophylloides*	—	X
14	*Dictyosiphon*	*tenuis*	X	X
15	*Dilsea*	*socialis*	—	X
16	*Ecotocarpus*	sp.	—	X
17	*Eudesme*	*borealis*	X	X
18	*Fucus*	*distichus*	X	X
19	*Halosaccion*	*firmum*	—	X
20	*Kornmannia*	*leptoderma*	X	X
21	*Leathesia*	sp.	X	X
22	*Melanosiphon*	*intestinalis*	X	—
23	*Monostroma*	*grevillei*	—	X
24	*Neorhodomela*	*aculeata*	—	X
25	*Neorhodomela*	*oregona*	X	X
26	*Nerocystsis*	*luetkeana*	X	X
27	*Petalonia*	*fascia*	X	X
28	*Polysiphonia*	*pacifica*	X	X
29	*Ptilota*	*asplendioides*	X	—
30	*Pylaiella*	sp.	X	X
31	*Rhodomela*	*tenuissima*	X	X
32	*Saccharina*	*latissima*	X	X
33	*Savoiea*	*bipinnata*	X	—
34	*Scagelia*	*occidentale*	—	X
35	*Scytosiphon*	*lomentaria*	X	X
36	*Scytosiphon*	sp.	X	—
37	*Soranthera*	*ulvoidea*	—	X
38	*Ulva*	*prolifera*	X	X
39	*Ulvaria*	*obscura, var blyttii*	X	X
40	*Wildemania*	*cuneiformis*	X	X
Total			28	34

Seaweeds, representing 28 different genera and species (table 4), were sparsely distributed in Chignik Lagoon, occurring on 62 percent of points (n=95) and nearly always in association with eelgrass (99 percent of occurrences). When present, seaweed abundance was also relatively low (BB score =2.5±0.15, approximately 37 percent cover) compared to eelgrass abundance (table 3). The most common seaweeds found in the lagoon were brown/red seaweeds, such as *P. pacifica*, *S. latissima*, *N. oregona*, and *E. borealis*. *P. pacifica* was most abundant in the low intertidal beds of eelgrass near the island and in parts of the bay. The next most common seaweeds were fine filamentous green blades, comprised mostly of *K. leptoderma* and to a lesser extent *Ulvaria obscura var. blyttii, and Monostroma grevillei. K. leptoderma* was found unattached in clumps at the base of eelgrass shoots or attached to eelgrass blades. Macro-invertebrates (presence of at least one of the five macro-invertebrates) were present on 45 percent of points (*n*=104) in Chignik Lagoon and always in association with eelgrass. The most common macro-invertebrates were gastropods (40 percent of points), *Caprillid* shrimp (13 percent of points), and mussels (12 percent of points). Sponges were present on 4 percent of points and no sea stars were observed on any of the points.

Mud Bay

Mapping

Classified Landsat imagery indicated that eelgrass meadows were the predominant cover type in Mud Bay, comprising 68 percent of its spatial extent with a fairly even distribution across the bay (fig. 1; table 1). As determined from the field survey data, our map was an accurate assessment of eelgrass distribution in this embayment (table 5). Of the 40 survey points, 27 of the 28 “Eelgrass” points (96.4 percent producer’s accuracy) and 9 of the 12 “No Eelgrass” points (75 percent producer’s accuracy) were classified correctly for an overall accuracy of 90.0 percent. Again, each of the four misidentified points were located in transition zones between cover types so that differing resolution between data sources was the likely cause of the error.

Table 5. Diagonal matrices comparing field survey reference data from 2010 to 1999 Enhanced Thematic Mapper Plus Landsat imagery for classification error of Mud Bay, Alaska.

[Landsat imagery retrieved from U.S. Geological Survey (2020). —, not applicable]

1999 Enhanced Thematic Mapper Plus Landsat imagery	Field survey reference data				
	Eelgrass	No eelgrass	Total correct	Total survey points	Commission accuracy (percent)
Eelgrass	27	3	—	30	90.0
No eelgrass	1	9	—	10	90.0
Total correct	—	—	36	—	—
Total survey points	28	12	—	40	—
Omission accuracy (percent)	96.4	75.0	—	—	90.0

The IDW interpolations of survey data indicated that the main area of high eelgrass density (75–100 percent cover) and abundance (94–149 g/m$^{2`}$) was in the central part of the bay (fig. 2). The general pattern of eelgrass distribution was similar to that of Chignik Lagoon, with the greatest abundance occurring in protected areas with moderate water depth and distant from freshwater inlets.

Eelgrass and Seaweed Abundance

In contrast to Chignik Lagoon, Mud Bay was characterized by higher salinity (2–30 ppt; fig. 3), deep substrate depths (1–20 cm), and shallow water depths (4–93 cm; table 3). Freshwater influx was minimal in June with inputs primarily confined to small streams at the head of the bay. Water temperature averaged 10.0±0.1 °C (range of 9–12 °C) and was similar to levels found in Chignik Lagoon. As the name implies, Mud Bay was comprised primarily of fine sediments (63 percent mud and 22 percent sand) with depths averaging twice those of Chignik Lagoon (table 3).

Unlike Chignik Lagoon, seaweeds were a dominant marine macrophyte in Mud Bay, comprising 82 percent of sample points (*n*=44). We detected 34 different genera and species of seaweeds with green seaweeds being the most dominant (71 percent of points) and abundant (table 4). Of these, *K. leptoderma*, *Cladophora sericea* and *Acrosiphonia duriuscula* were the most common. Other commonly observed seaweeds were *Alaria marginata*, *S. latissima*, and *Dictyosiphon tenuis*. *P. pacifica*, which was abundant in Chignik Lagoon, was rarely observed in Mud Bay. Seaweeds were frequently associated with eelgrass (81 percent of points), but it was not uncommon for them to occur in areas void of eelgrass and containing rockier substrates (19 percent of points).

Eelgrass occurred on slightly over 68 percent of points (*n*=44) in Mud Bay, and when present, eelgrass was abundant (mean abundance [BB] score= 3.2±0.24, approximately 55 percent cover). On average shoot lengths were shorter and standing crop of eelgrass was lower in Mud Bay than in Chignik Lagoon (table 3). Macro-invertebrates (presence of at least one of the five macro-invertebrates) were more common in Mud Bay than in Chignik Lagoon, occurring on 64 percent of points (*n*=44) and almost always (90 percent of points) in association with eelgrass. The most common macro-invertebrates in Mud Bay were gastropods (57 percent of points) and *Caprillid* shrimp (32 percent of points). Sea stars (9 percent of points), sponges (5 percent of points), and mussels (3 percent of points) were infrequently observed at a point.

Future Monitoring Needs

Based on findings in this report, we suggest the following monitoring activities for the Chignik Lagoon and Mud Bay areas.

Eelgrass Mapping

- Obtain higher-resolution satellite imagery to improve baseline maps of eelgrass spatial extent in Chignik Lagoon and Mud Bay.
- Acquire additional satellite imagery to map eelgrass extent in other biologically important embayments adjacent to APBNWR.

Field Surveys

- Establish stations to continuously monitor environmental factors such as water temperature, salinity, and water clarity that affect eelgrass abundance in Chignik Lagoon.
- Conduct other boat surveys to assess eelgrass and seaweed abundance and distribution in other embayments on the south side of the Alaska Peninsula.

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