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Eelgrass (*Zostera marina*) and Seaweed Abundance along the Coast of Nunivak Island, Yukon Delta National Wildlife Refuge, Alaska, 2010

Open-File Report 2020–1143

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

Cover. A sample quadrat containing eelgrass (*Zostera marina*) taken at a survey point within Duchikthluk Bay, Alaska, July 19–25, 2010. Photograph by Tyrone Donnelly, USGS-Alaska Science Center.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	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 kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
meter per year (m/yr)	3.281	foot per year (ft/yr)
	Mass	
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).

Abbreviations

BB	Braun-Blanquet
IDW	inverse distance weighted
NWR	National Wildlife Refuge

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Abstract

Eelgrass (*Zostera marina*) is a highly productive seagrass that plays an essential role in the health of the estuarine and coastal ecosystems; however, information about its abundance and distribution is insufficient in the Bering Sea along the Yukon Delta National Wildlife Refuge. We inventoried the spatial extent and abundance of eelgrass and seaweed in Duchikthluk and Shoal bays on Nunivak Island in July 2010. Using Landsat Thematic Mapper imagery, we estimated the spatial extent of eelgrass to be 1,232 hectares in Duchikthluk Bay and 40 hectares in Shoal Bay. The overall accuracy of the assessments was high (86–87 percent) based on ground truthing using field reference points. We used point-sampling methodology to assess eelgrass abundance relative to the presence of associated seaweeds and selected macro-invertebrates within each of bays. Eelgrass was found at water depths ranging from 0.1 to 2.9 meters across both bays, but the greatest density (>75 percent cover) occurred primarily in moderate to deep water (0.7–1.4 meters) in Duchikthluk Bay and deeper water (>2 meters) in Shoal Bay. The mean aboveground biomass was 39.4±4.0 grams per meter squared in Duchikthluk Bay. The eelgrass biomass was greater (67.6±11.0 grams per meter squared) in Shoal Bay, but this estimate was based on a small sample size (*n*=3). Seaweeds, representing six species, occurred in low abundance across both bays and were primarily associated with eelgrass. Gastropods were the most common macro-invertebrate, occurring at 45 percent of field points in Duchikthluk Bay.

Introduction

In the southeast Bering Sea, eelgrass (*Zostera marina*) is a dominant marine macrophyte, forming expansive meadows in protected shallow water embayments and coastal inlets (Ward and Amundson, 2019; Ward and others, 2022). Eelgrass is highly productive (McRoy, 1966), an important habitat for waterfowl (King and Dau, 1981; Wilson, 2019), and nursery for many species of fish, including key sport and commercial fisheries (for example, *Oncorhynchus* spp. and *Clupea pallasii*) in Alaska (Murphy and others, 1995; Weiland and others, 2003; Johnson and Thedinga 2005). Coastal ecosystems of the Bering Sea may be particularly vulnerable to the impacts of global climate change because they are affected by both: (1) land-based changes in precipitation and temperature (Chapin and others, 1997; Hinzman and others, 2005) and (2) sea-based increases in sea level and storm-driven tides (Douglas, 1995; Rahmstorf and others, 2007). Even subtle changes in topography and wetland extent may alter patterns of primary productivity and hence the abundance and distribution of primary consumers (Smith and others, 2005). Baseline data are urgently needed to understand and predict how losses or gains will affect habitats for marine species. Therefore, it is important to inventory and monitor the health of this critically important habitat.

Eelgrass is thought to be a dominant marine plant adjacent to the Yukon Delta National Wildlife Refuge (NWR). Anecdotal observations indicate eelgrass is abundant along much of the coast of Nunivak Island (Abe David, Mekoryuk resident, pers. commun., 2010), but to date, no coastal surveys of eelgrass have been made on this island. As part of a broad-scale program to inventory and monitor long-term trends in the health of eelgrass in western Alaska, we conducted the first inventory of eelgrass at two known eelgrass sites on Nunivak Island in Duchikthluk and Shoal bays (fig. 1). This report describes the results of surveys to estimate spatial extent of eelgrass and assess eelgrass abundance relative to the presence of associated seaweeds and selected macro-invertebrates in these two bays in July 2010.

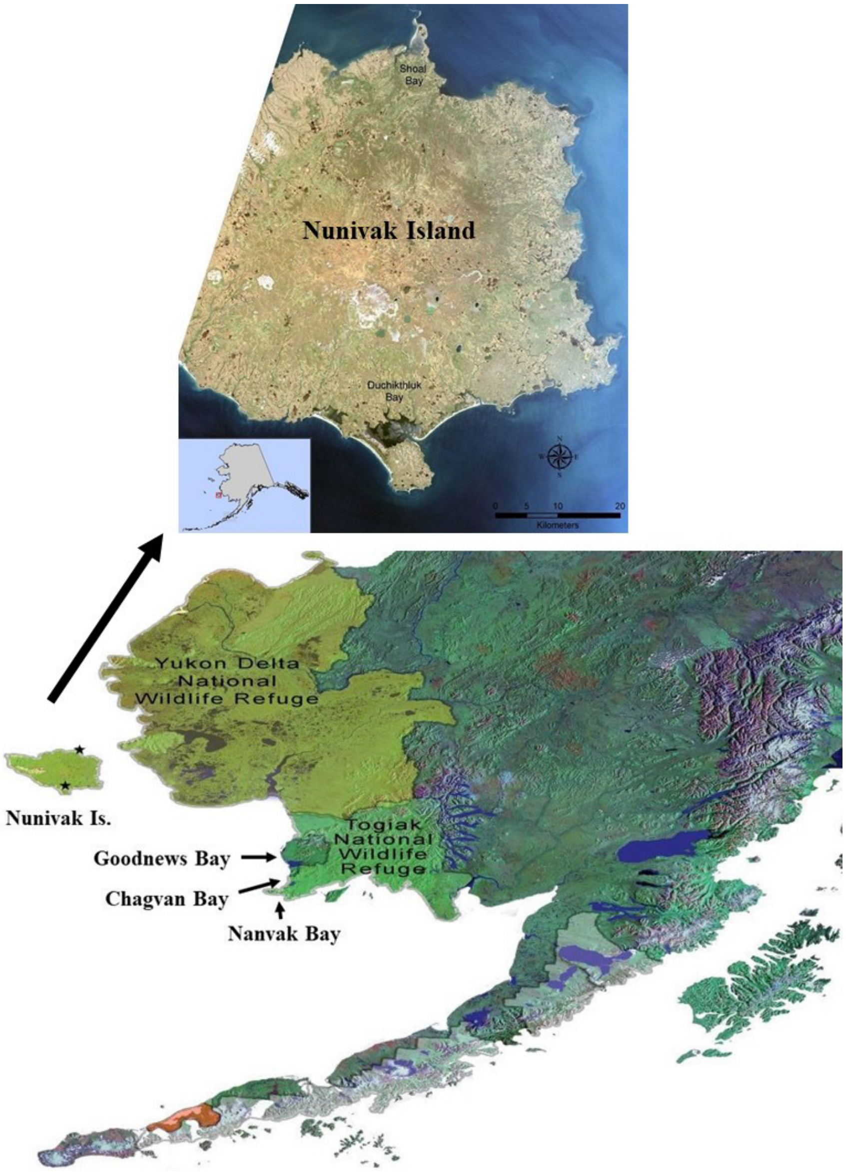

Figure 1. 2005 Landsat Thematic Mapper image of Duchikthluk and Shoal bays, Nunivak Island (top) relative to Yukon and Togiak National Wildlife refuges, Alaska (bottom).

Methods

Eelgrass Mapping

A Landsat TM (Thematic Mapper) image from June 27, 2005 was used to assess abundance and distribution of eelgrass on Nunivak Island in Duchikthluk and Shoal bays. The image was acquired at a tide height of about 0.3 meters (m) mean lower low water as determined by tidal predictions at Tachikuga Bay, the closest tidal gauge location to these sites on Nunivak Island. The image was projected in Universal Transverse Mercator Zone 4 North using the 1984 World Geodetic System datum and had a spatial resolution of 30 m. After preprocessing, we classified the embayment areas into three major land cover classes: eelgrass, sand/mud, and deep water.

The image was preprocessed to calibrate for at-sensor radiance, correct for atmospheric path interference, and checked for georeferencing accuracy. Radiance calibration was performed following calibration factors and formulas established in Chander and others (2009). The images were corrected for atmospheric interference using the “dark pixel subtraction” methodology (Chavez, 1988). We verified the spatial accuracy of the image at each of the targeted bays by comparing the position of prominent landmark features in the image with the position of those same features found on National Ocean and Atmospheric Administration nautical charts and found the image to be accurate within 1 pixel (30 m) offset.

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 information from the 2010 field survey points were used to choose isodata clusters that provided the best examples of the three cover classes. These clusters were then used to extract training data for a maximum likelihood classification of each pixel within the embayments to one of the three cover classes. In order to account for difficulty identifying submerged eelgrass in deep water (>1 m depth) using the full spectral range of the image, we narrowed the spectral range to enhance differentiation between submerged eelgrass and unvegetated areas. This more focused enhancement increased estimates of eelgrass coverage by 210 hectares (ha) in Duchikthluk Bay and 53 ha in Shoal Bay and accuracy of the estimates by 10 percent and 57 percent, respectively.

We evaluated mapping accuracy of eelgrass extent using the percent cover determinations made during the 2010 field survey. We classified 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). Accuracy was estimated using a confusion matrix comparing cover classifications to field survey data in order to estimate errors of omission and commission. For each cover type, omission accuracy assessed the percentage of the map data that agreed with the field survey data assuming that the survey data were correct, while commission accuracy evaluated the percentage of the field survey data that agreed with the map data making the assumption that the map was correct. We created maps of eelgrass density (percent cover) and abundance (aboveground biomass) from the field survey data using the inverse distance weighted (IDW) interpolation. The IDW interpolation method assumes that closer locations 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). The base map used to generate eelgrass spatial extent is in Ward (2022).

Bay-Wide Surveys

Abundance of eelgrass and seaweeds, and the presence of selected macro-invertebrate species, were assessed in Duchikthluk and Shoal bays from July 19 to 25, 2010. Although eelgrass may grow deeper in the subtidal, this restricted sampling area encompassed most 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 of each bay (for example, fig. 2). This design allowed for a proportional assessment of cover classes and related physical parameters within each of the embayments. Points were located by boat using a GPS unit and sampled by snorkeling in dry suits during high tide. At each point, we estimated (1) water temperature, depth, and salinity (at surface), (2) substrate type (sand, mud, cobble rock) and depth, and (3) percent cover of eelgrass and seaweeds. Estimates were done within four 0.25 m^2 quadrats that were spaced approximately 5 m apart in each cardinal direction around each point. We determined the presence/absence of sessile macro-invertebrates: mussels (*Mytilus* spp.), sponges, sea stars (*Pisaster*/*Evasterias* spp.), gastropods, and *Telmessus* sp. crabs within each quadrat. Cover was defined as the portion of the quadrat area obscured by each macrophyte while viewed in water from above. If eelgrass was present, three representative shoots were collected from each of the quadrats and measured for width and length. If seaweeds were present, we estimated cover for all genera and species combined within each of the four quadrats. Seaweeds were identified in the field, but when this was not possible; specimens were collected and later identified by Dr. Sandra Lindstrom of the University of British Columbia.

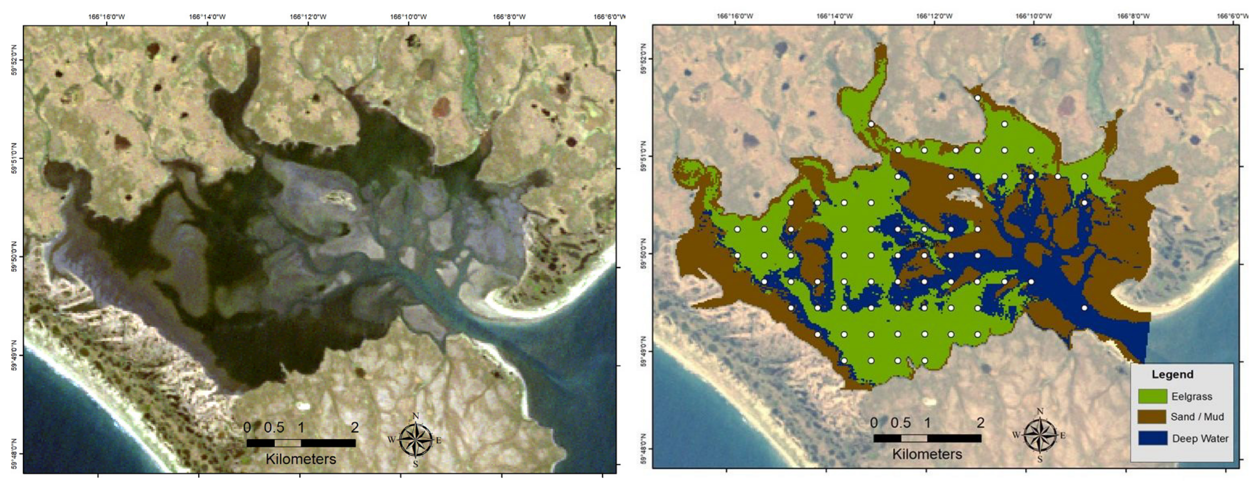

Figure 2. 2005 Landsat Thematic Mapper image (left) and habitat classification (right) of Duchikthluk Bay, Nunivak Island, Alaska. White dots represent eelgrass (*Zostera marina*) sampling locations.

To minimize among-observer differences in estimates of eelgrass or 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 three statistics for eelgrass and total seaweeds: density, abundance, and frequency of occurrence according to Fourqurean and others (2001). We also calculated an Abundance Index (BB score × mean shoot length) to estimate aboveground biomass for each quadrat at a point.

Estimates of aboveground biomass of eelgrass in each of the bays were based on collections of shoots from 25 calibration quadrats taken in Duchikthluk Bay. We estimated percent cover (BB score), collected all eelgrass shoots within each quadrat, removed dead leaves and belowground portions of the plant, and selected 10 representative shoots that were later measured for shoot length (meristem to tip of longest leaf) and shoot width. We dried the entire samples to constant mass and weighed them (in grams) to determine biomass per quadrat, which was scaled to grams dry weight per meter squared (g/m^2). Linear regression was used to evaluate the relationship between Abundance Index and aboveground biomass for the calibration quadrats and applied this relationship (biomass=0.5219 × Abundance Index, R^2=0.83) to determine aboveground biomass for each quadrat at a point. Means and standard errors are reported unless otherwise indicated. Field survey data summarized in this report is in Ward and Hogrefe (2022).

Results and Discussion

The 2005 Landsat imagery permitted an initial determination of eelgrass spatial extent in Duchikthluk (1,232 ha) and Shoal (40 ha) bays (table 1). We were able to differentiate eelgrass from other cover classes (that is, water and unvegetated tidal flats) in the two bays with a high degree of accuracy (>85 percent) using field survey point data that were not designed for ground truthing the imagery.

Table 1. Spatial extent in hectares (percentage cover) of eelgrass (*Zostera marina*) and other cover classes in Duchikthluk and Shoal bays, Nunivak Island, Alaska.

Cover class	Duchikthluk Bay	Shoal Bay
Eelgrass	1,232 (34)	40 (7)
Sand/mud	1,202 (33)	39 (53)
Deep water	668 (33)	21 (40)
Total	3,102	100

Duchikthluk Bay

Eelgrass Mapping

Eelgrass was the largest cover class in Duchikthluk Bay, comprising 34 percent of its spatial extent (fig. 2; table 1). Eelgrass distribution was concentrated primarily in moderately deep (0.7–1.4 m) pools of water in the western half and northern reaches of the bay but was absent in the deep channels (>3 m), especially near the mouth of the bay. Mud flats predominated across the bay where depths were shallowest (<0.65 m).

We detected a high degree of classification accuracy in the spatial assessment of eelgrass in Duchikthluk Bay based on 70 field reference points (table 2). Of these, 42 of the 48 “Eelgrass” points (88 percent omission accuracy) and 19 of the 22 “No Eelgrass” (86 percent omission accuracy) were classified correctly for an overall accuracy of 87 percent. Of the 6 misidentified “Eelgrass” points, one was classified as sand/mud while the other five were classified as deep water. Most (seven of nine) misidentified points were in transition zones between cover classes, where differing resolution between the reference data (1 m) and the satellite image (30 m) was the likely source of error. The two other misidentified eelgrass points occurred in relatively low-density habitats (<25 percent cover) more than 100 m from eelgrass meadows.

Table 2. Diagonal matrix of field survey reference data from 2010 showing eelgrass (*Zostera marina*) classification accuracy of a 2005 Landsat Thematic Mapper image of Duchikthluk Bay, Alaska.

[—, not present]

Thematic Mapper classification	Field survey reference data				
	Eelgrass	No eelgrass	Total correct	Total survey points	Commission accuracy (percent)
Eelgrass	145	3	—	45	93.3
No eelgrass	6	19	—	25	76.0
Total correct	—	—	61	—	—
Total survey points	48	22	—	70	—
Omission accuracy (percent)	87.5	86.4	—	—	87.1

Variability in density (percent cover) and abundance (biomass) of eelgrass across this bay are shown in figure 3. The main areas of greatest density of eelgrass (range =76–100 percent cover) were closely associated with the moderately deep pools of water while high biomass (range =51–124 g/m^2) followed roughly the same pattern but were more concentrated in deeper portions of the pools.

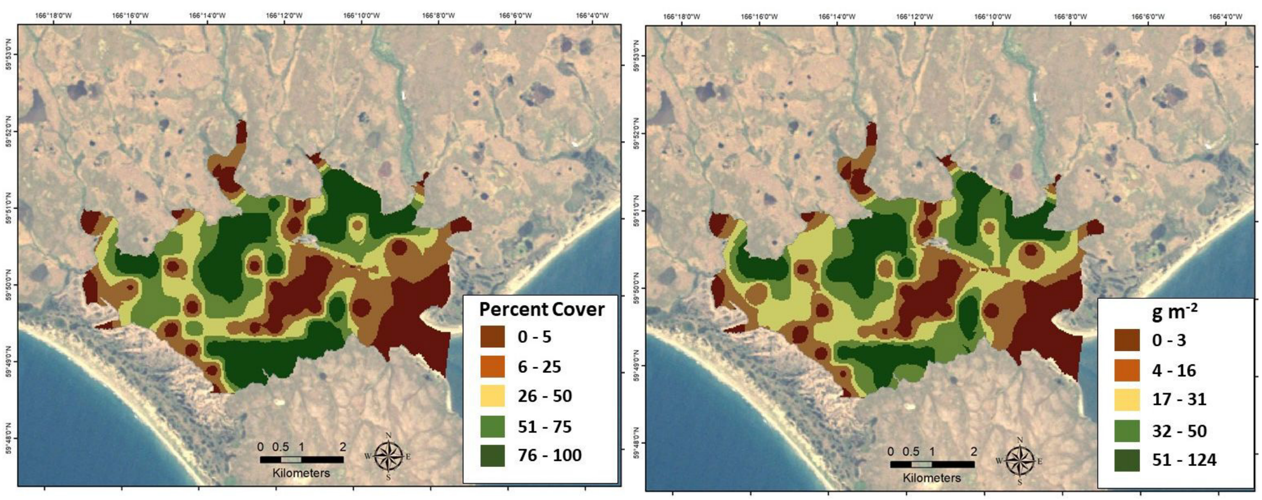

Figure 3. Landsat Thematic Mapper images of distribution of eelgrass (*Zostera marina*) percentage cover (left) and aboveground biomass (right) in Duchikthluk Bay, as determined from inverse distance weighted interpolations of field survey data, July 2010. g m^{-2} (g/m^2), grams per square meter.

Distribution of eelgrass is highly influenced by light availability (for example, water depth and clarity), wave and tidal action, sediment transport, and nutrient availability (Hemminga and Duarte, 2000). The absence of eelgrass near the bay entrance and in deep (>3 m depth) channels may be due to poor water clarity and depths too deep for light penetration for eelgrass to maintain energy levels through photosynthesis. Wave and tidal action are also likely strong at the entrance of the bay preventing shoots from taking root. Eelgrass survival in the shallow locations of the bay may be limited by exposure to winter freezing temperatures and ice scouring. Eelgrass was most abundant at moderate water depths in the pooled areas away from the mouth of the bay and wave action but near channels that deliver essential nutrients.

Eelgrass and Seaweed Abundance

Duchikthluk Bay was characterized by cold water temperature, high salinity, deep substrate depths, and shallow water depths (table 3). The average surface water temperature was 10±0.1 degrees Celsius (°C, range =9–12 °C) in July with colder temperatures near river outflows and warmer temperatures in the center of the bay. The average salinity was 30±0.3 parts per thousand (range =17–32 parts per thousand) with lower levels near stream and creek outflows and higher levels in channels close to the Bering Sea. The substrate was primarily composed of fine sediments (59 percent mud and 36 percent sand with a mean depth of 11±1.2 centimeters [cm]) and cobble rock (5 percent).

Table 3. Mean estimates (and standard error) of abiotic properties and seagrass and seaweed abundance based on a sample of survey points across in Duchikthluk (July 21–25) and Shoal (July 19 and 28) Bays, Alaska, in 2010.

[n, number of survey points; SE, standard error; °C, degree Celsius; ppt, part per thousand; cm, centimeter; g/m^2, gram dry mass per square meter; mm, millimeter]

Property	Duchikthluk Bay			Shoal Bay		
	n	Mean	SE	n	Mean	SE
Abiotic properties						
Water temperature (°C)	71	10.20	0.07	14	8.69	0.23
Salinity (ppt)	71	30.17	0.31	14	29.37	0.37
Water depth (cm)	71	94.70	4.49	14	199.79	18.63
Substrate depth (cm)	64	10.51	1.18	11	5.09	1.08
Seagrass (*Zostera marina*) vegetative shoots						
Aboveground biomass (g/m^2) when eelgrass was present	58	39.44	3.95	3	67.56	11.01
Density[1] (0–5)	67	3.06	0.25	3	3.92	0.44
Abundance[1] (1–5)	59	3.59	0.22	3	3.92	0.44
Frequency (0–1)	67	0.79	0.04	3	1.00	
Shoot length (cm)	59	18.24	1.19	9	38.58	3.00
Seaweed (all species combined) vegetative shoots						
Density[1] (0–5)	68	0.21	0.05	3	0.42	0.42
Abundance[1] (1–5)	22	1.35	0.12	1	1.25	
Frequency (0–1)	68	0.14	0.03	3	0.33	0.33

[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 at 80 percent of the points (n =70) across the entire bay, and when present, eelgrass was abundant (average BB abundance score=3.6±0.22, 65 percent cover; table 3; fig.3). This abundance score was comparable to or slightly lower than those recorded in nearby bays adjacent to Togiak NWR (Goodnews Bay: 3.3±0.23, 57 percent cover; Nanvak Bay: 4.2±0.16, 80 percent cover; Chagvan Bay 4.0±0.16, 75 percent cover; Ward and others, 2022) during the same time period (July 2010). Mean length of eelgrass shoots, however, was considerably shorter for eelgrass shoots in Duchikthluk Bay (18.2±1.2 cm; range =5.0–47.2 cm; table 3) than in the three bays of Togiak NWR (Nanvak Bay: 35±2.5 cm; Chagvan Bay: 45±2.4 cm); Goodnews Bay: 74±7.1 cm; Ward and others, 2022) during July 2010. Aboveground biomass is primarily driven by shoot length; accordingly, mean aboveground biomass was also low (39.7±3.7 g/m^2; range =1–124 g/m^2; table 3) in Duchikthluk Bay when compared to biomass estimates in the more southerly bays in Togiak NWR (Nanvak Bay: 47±4 g/m^2; Chagvan Bay: 69±7 g/m^2; Goodnews Bay: 74±15 g/m^2) during July 2010 (Ward and others, 2022).

Seaweeds, representing five different genera were sparsely distributed in Duchikthluk Bay (table 4), occurring on 33 percent of points (n =67) and mostly in association with eelgrass (86 percent of points). When present, seaweed abundance was low (mean BB abundance score =1.4±0.12, 15 percent cover; table 3) and lower than the seaweed abundance scores in the nearby bays of Togiak NWR (range of mean BB abundance scores =2.3–3.3, 32–57 percent cover) in July 2010 (Ward and others, 2022). The most common seaweeds found in the bay were *Ectocarpus siliculosus* and blue-green algae, possibly *Oscillatoria submembranacea*. Macro-invertebrates were found on an average of 57 percent of points (n =70) and always in association with eelgrass. The occurrence of macro- invertebrates in Duchikthluk Bay resembled their occurrence in the three bays of Togiak NWR (Nanvak Bay: 40 percent of points; Chagvan: 59 percent of points; Goodnews: 65 percent of points). The most common macro-invertebrate in Duchikthluk Bay was gastropods (45 percent of points). We did not detect any crabs, starfish, or sponges at the survey points.

Table 4. Seaweed genera and species identified in Duchikthluk and Shoal bays, Alaska. Seaweed taxonomy is based on Guiry and Guiry (2020).

[—, not present]

Number	Genus	Species	Location	
			Duchikthluk	Shoal
1	*Chorda*	*borealis*	X	—
2	*Dictyosiphon*	*foeniculaceus*	—	X
3	*Ectocarpus*	*siliculosus*	X	—
4	*Eudesme*	*borealis*	X	—
5	*Oscillatoria*	sp.	X	—
6	*Scagelia*	*occidentale*	X	—
Total			5	1

Shoal Bay

Mapping

Sandflats and deep channels comprised approximately 93 percent of Shoal Bay (table 1; fig. 4). We were not able to field survey the upper part of bay from the ground or boat, but we did observe extensive sandflats and no eelgrass from a plane flying at a low altitude during low. These observations were later confirmed that this part of the bay was sandy, very shallow and exposed to wind-driven waves, especially during storms and likely did not contain eelgrass (Abe David, Mekoryuk resident, pers. commun., 2010). Nevertheless, this part of the bay should be surveyed for eelgrass at depth in the upper reaches of the channels that may be more protected from waves and sedimentation.

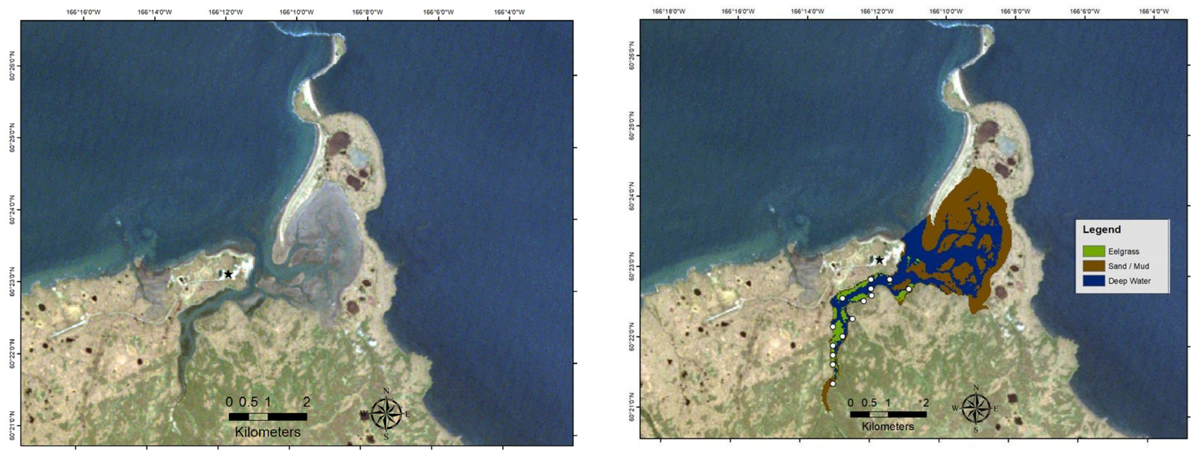

Figure 4. Landsat Thematic Mapper images (left) and habitat classification (right) of Shoal Bay, Nunivak Island, Alaska. White dots represent where eelgrass (*Zostera marina*) sampling occurred.

Eelgrass appeared to be sparse in Shoal Bay, comprising only seven percent of the spatial extent of the bay (fig. 4, table 1). Eelgrass was primarily concentrated at the mouth of the Mekoryuk River (fig. 4), though the sample size of field survey points was small (n =14).

Our spatial assessment of eelgrass in this bay was accurate (table 5). Of the 10 “Eelgrass” points, 8 were classified correctly (80 percent omission accuracy) while all 4 “No Eelgrass” were classified correctly (100 percent omission accuracy) for a total accuracy of 86 percent. Both misidentified points were in transition zones between cover classes where differing resolutions between the reference data (1 m) and Landsat TM image (30 m) was the likely source of error.

Table 5. Diagonal matrix of field survey reference data from 2010 showing eelgrass (*Zostera marina*) classification accuracy of a 2005 Landsat Thematic Mapper image Shoal Bay, Alaska.

[—, not present]

Thematic Mapper classification	Field survey reference data				
	Eelgrass	No eelgrass	Total correct	Total survey points	Commission accuracy (percent)
Eelgrass	8	0	—	8	100.0
No eelgrass	2	4	—	6	66.7
Total correct	—	—	12	—	—
Total survey points	10	4	—	14	—
Omission accuracy (percent)	80.0	100.0	—	—	85.7

Eelgrass density was greatest (75–100 percent cover) in and near the channel of the Mekoryuk River (fig. 5). This part of the river is sheltered from the wave action of the Bering Sea by a protective spit and is close to tide-driven nutrients. Eelgrass biomass was collected at only three survey points, so an abundance map was not created. Additional field data should be collected to assure an accurate characterization of eelgrass distribution in Shoal Bay.

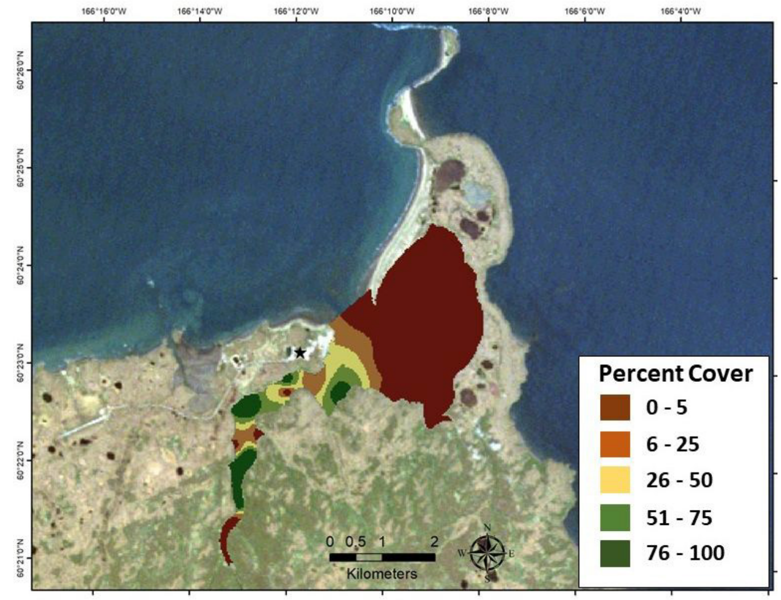

Figure 5. Landsat Thematic Mapper image of distribution of eelgrass (*Zostera marina*) percentage cover in Shoal Bay, as determined from inverse distance weighted interpolations of field survey data, July 2010.

Eelgrass and Seaweed Abundance

Mean water temperature at the mouth of the Mekoryuk River was 8±1.1 °C (table 3). Of the 14 points sampled in Shoal Bay, all but two contained eelgrass (86 percent of points). Eelgrass occurred mostly at deep water depths (average water depth =2.0 m) and mostly beyond the reach of the divers. We reported estimates of density and abundance for eelgrass and seaweeds (table 3), but these estimates should be considered cautionary because of the small number of measurements made at sample points in the bay (n=3). Mussels and gastropods were observed at one of the sampled points and one species of seaweed, *Dictyosiphon foeniculaceus*, was identified (table 4) in the bay that was not detected in Duchikthluk Bay.

Future Research Needs

Mapping

- Conduct additional surveys in Duchikthluk and Shoal bays to improve on initial estimates of the distribution and abundance of eelgrass in these bays.
- Incorporate the knowledge of residents to identify other locations on Nunivak Island for eelgrass mapping.
- Acquire satellite imagery to map eelgrass extent in other embayments along the coast of the Yukon Delta NWR, such as in the Kuskokwim Shoals.

Field Surveys

- Place sensors at key eelgrass locations within the refuge to monitor physical drivers of eelgrass change, such as water temperature, light levels, and salinity.

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