Prepared in cooperation with the U.S. Fish and Wildlife Service

Distribution of Eelgrass (*Zostera marina*) in Coastal Waters Adjacent to Togiak National Wildlife Refuge, Alaska

Open-File Report 2020–1080

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

Cover. Satellite image showing the eelgrass distribution (green) in the study area of coastal waters adjacent to Togiak National Wildlife Refuge, Alaska.

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Contents

Figures

Table

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	
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)

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 the1984 World Geodetic System (WGS84).

Horizontal coordinate information is referenced to the referenced to the 1927 North American Datum (NAD27).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

GPS	global positioning system
TM	Thematic Mapper
TNWR	Togiak National Wildlife Refuge
UTM	Universal Transverse Mercator

Distribution of Eelgrass (*Zostera marina*) in Coastal Waters Adjacent to Togiak National Wildlife Refuge, Alaska

By David H. Ward[1], Kyle R. Hogrefe[1], Tyronne F. Donnelly[1], and Michael A. Swaim[2]

Abstract

Declines in the distribution and abundance of seagrasses worldwide have prompted a need for baseline distribution maps of eelgrass (*Zostera marina*) in Alaska. We used high-resolution digital-color aerial photography and multi-spectral satellite imagery to map the distribution and spatial extent of eelgrass at 21 sites in coastal waters adjacent to Togiak National Wildlife Refuge (TNWR) in northwestern Bristol Bay and southern Kuskokwim Bay. The total spatial extent of eelgrass meadows was estimated to be 6,489 hectare (ha) almost equally divided between Bristol Bay (3,001 ha) and Kuskokwim Bay (3,488 ha). The four largest eelgrass beds occurred in Chagvan Bay (1,933 ha), the north side of Hagemeister Island (1,168 ha), Goodnews Bay (874 ha), and Nanvak Bay (599 ha). This report provides key baseline data useful for establishing a monitoring plan to assess trends in eelgrass along the coast of TNWR.

Introduction

Eelgrass (*Zostera marina*), like other seagrasses, plays an essential role in the health of estuarine and coastal ecosystems through its high productivity, stabilization and enrichment of sediments, and support of a complex trophic web (McRoy, 1966; Hemminga and Duarte, 2000; Orth and others, 2006). These tidally inundated meadows provide high-value ecosystem services compared to other marine and terrestrial ecosystems. For example, the global value of seagrasses/seaweeds is substantial with each hectare providing an estimated $19,000 worth of ecosystem services per year, which is only exceeded by estuaries ($23,000 hectares/year [ha/yr]) and swamp/flood plains ($20,000 ha/yr; Costanza and others, 1998, 2014). Changes in eelgrass distribution has potential implications for ecosystem functions such as biochemical fluxes, trophic transfers, nutrient cycling and associated species diversity (Duffy, 2006).

Seagrasses are sensitive to shifts in marine ecosystems (Short and Wyllie-Echeverria 1996; Orth and others, 2006; Waycott and others, 2009) because of their vulnerability to changes in hydrology, wave action, water clarity, temperature, and depth (Short and Neckles, 1999). Declines in seagrasses in North America have been attributed to a variety of human-induced effects (Short and Burdick, 1996; Hemminga and Duarte, 2000; Ward and others, 2003; Harris and others, 2012) as well as natural events (Eyerdam, 1971; Muehlstein, 1992; Short and others,

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1996; Plus and others, 2003). While eelgrass beds have remained relatively pristine in Alaska, there are concerns in some regions of the state (Argonne National Laboratory, 2007; Harris and others, 2012).

Eelgrass is the predominant seagrass in Alaska, and populations in the Bering Sea comprise some of the largest seagrass beds in the world (Ward and others, 1997; Green and Short, 2003). The eelgrass meadows of the Bering Sea are an important source of nutrients for the nearshore coastal food web which includes virtually the entire population of the Pacific black brant (*Branta bernicla nigricans*) and cackling goose (*Branta hutchinsii*; Ward and Stehn, 1989), Steller's eider (*Polysticta stelleri*; King and Dau, 1981), salmon (*Oncorhynchus* spp.), rockfish (*Sebastes* spp.), herring (*Clupea pallasi*; Murphy and others, 1995; Weiland and others, 2003), and harbor seal (*Phoca vitulina richardsi*; Johnson and others, 1989). Eelgrass and adjacent beds of seaweeds (kelp) also provide a key substrate for the spawn of Pacific herring (*Clupea pallasii*), an important fishery for the region. Between 1993 and 2002, the Togiak area herring sac roe fishery was valued at approximately $3.2 million making it the largest such fishery in Alaska (Weiland and others, 2003). The extensive eelgrass beds, associated fish, and wildlife resources found within the nearshore waters of southeastern Bering Sea were an important consideration in the designation of Togiak National Wildlife Refuge and Cape Newenham State Game Refuge.

Coastal waters adjacent to Togiak National Wildlife Refuge (TNWR) contain extensive beds of eelgrass, but the status and trends of this seagrass are unknown. Winfree (2005; 2008) conducted aerial surveys to identify the location and boundaries of eelgrass beds along the coast of the TNWR. Twenty-three sites were identified to contain significant beds of eelgrass (≥1 hectare [ha] of areal extent). Here, we summarize an effort to classify and map the spatial extent of eelgrass and other substrates at these 23 sites using higher resolution remote sensing techniques.

Study Area

The study area included nearshore waters adjacent to TNWR, extending from the east side of Togiak Bay to Goodnews Bay and encompassing approximately 600 kilometers of shoreline (fig. 1). Of the 23 sites that were previously identified as containing eelgrass, 18 were in northwest Bristol Bay and five in southern Kuskokwim Bay. The coastline of the study area was generally undeveloped and uninhabited except for the coastal villages of Goodnews Bay, Togiak, Twin Hills, and Platinum with human population sizes below 500 residents each. Northwestern Bristol Bay was characterized by rocky shorelines that were buffered from prevailing winds and resulting wave action by Hagemeister Island and several adjacent smaller islands. The coastline on the southern Kuskokwim Bay was unprotected except for a series of enclosed bays with soft bottom substrates. While the relatively narrow entrances to these protected bays minimize wave action and water turbidity in the front half of these bays, the water quality in the distal ends where rivers and streams discharge sediments, was quite turbid and lower in salinity (Ward and others, 2020). The variation in tidal height (low to high tide) is extreme, ranging up to 4 meters (m) in southern Kuskokwim Bay and up to 5 m in northwest Bristol Bay.

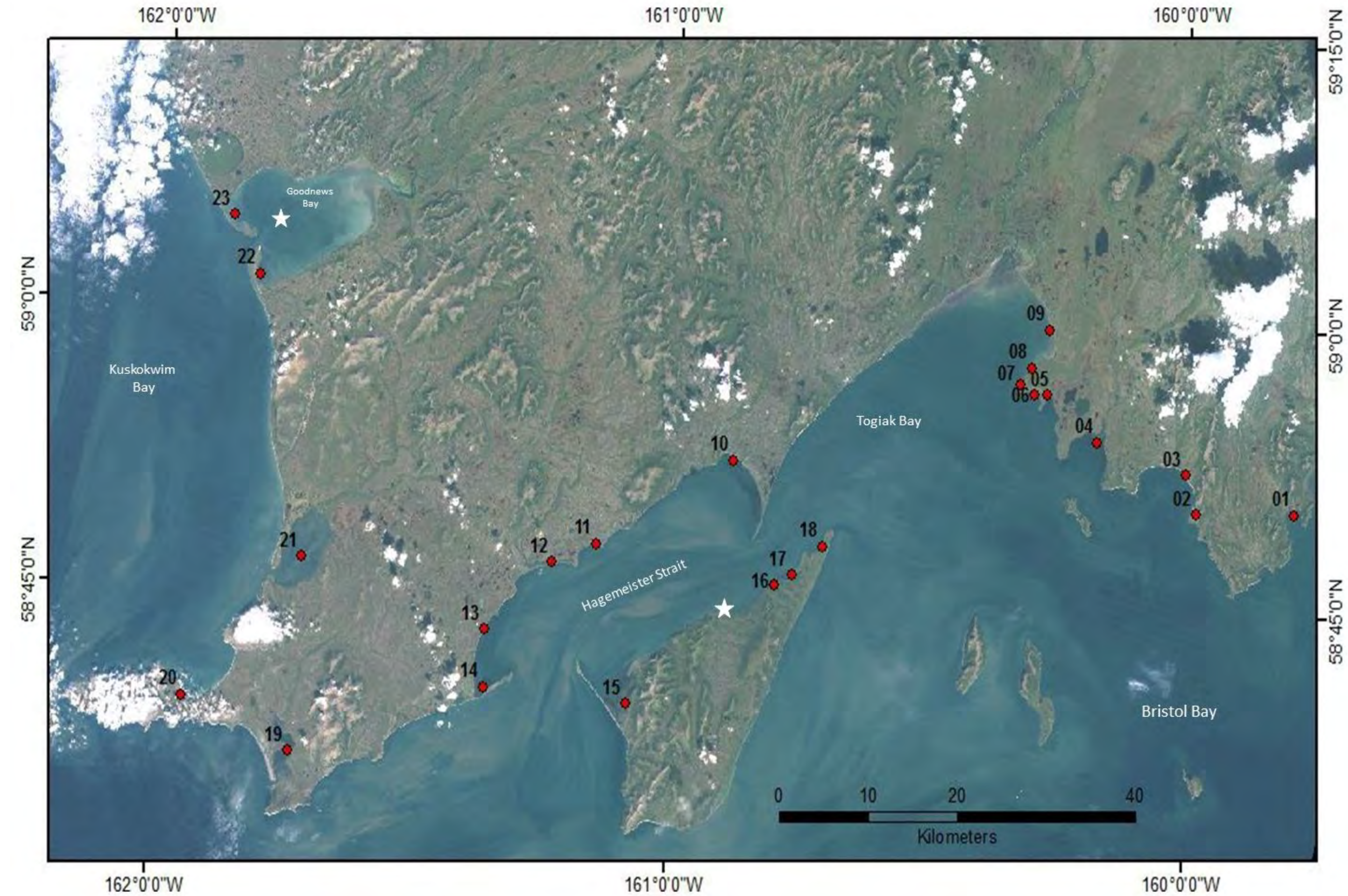

Figure 1. Locations of the 23 sites identified by Winfree (2005, 2008 [for site information see table 1]) and 2 new sites (stars) as containing significant (>1 hectare) spatial extent of eelgrass (*Zostera marina*) in coastal areas adjacent to Togiak National Wildlife Refuge, Alaska.

Methods

Image Acquisition and Preparation

We assessed the distribution and spatial extent of eelgrass beds along the coast of TNWR using aerial photography and satellite imagery. All imagery was obtained during low tides and peak seasonal abundance of eelgrass (June–September). Aerial photography was acquired by the U.S. Fish and Wildlife Service from 2005 to 2012 (table 1). The images were taken at an altitude of 2,500–7,000 feet (ft), depending on the size of the site, using a Nikon D200 color digital camera mounted to the belly port of a Cessna 206. Images in all years except 2007 were mosaicked at AeroMetric, Inc. (Anchorage, Alaska) and georeferenced to U.S. Geological Survey (USGS) topographic maps projected in NAD27 (1927 North American Datum) UTM (Universal Transverse Mercator) projection Zone 4 North using a program provided by PCI Geomatica, Inc. The resulting photomosaics were then georeferenced to a Landsat TM (Thematic Mapper) image from August 31, 2007 and projected in the WGS84 (1984 World Geodetic System) datum, UTM Zone 4 North that encompassed the entire study area and served as the base map. In 2007 aerial images of Nanvak Bay were mosaicked with a program provided by PCI Geomatica, Inc. and georeferenced to a Landsat 7 Enhanced Thematic Mapper Plus satellite image in the WGS84 datum, UTM projection Zone 4 North using ArcGIS. Most photomosaics had an initial resolution of less than 1 m and were standardized to 1 m resolution except the photomosaic of Hagemeister Spit, which had an initial resolution of greater than 1 m and was resampled to a 2 m resolution.

We acquired five satellite scenes, four from Ikonos2 and one from the Quickbird2 sensor series, to assess the eelgrass distribution in the study area (table 1). The five scenes spanned 3 years (2002–04) and included one to three sites per scene. The imagery was obtained through the USGS Earth Resource and Observation Science Center archives and projected in UTM Zone 4 using the WGS 84 (1984 World Geodetic System) datum. The spatial resolution of the multi-spectral data was 4 m for Ikonos-2 and 1.7 m for Quickbird-2 imagery. Satellite images were checked for georeferencing accuracy, calibrated for atmospheric radiance using formulas and guidance provided by GeoEye, Inc., and calibrated for atmospheric path interference using dark pixel subtraction (Chavez, 1988; Andrefouet and others, 2001). Information on imagery and associated data are in Ward (2021) and Ward and Hogrefe (2022).

Field Surveys

We performed boat-based sampling at Nanvak Bay in 2008–10, Chagvan Bay in 2010 and Goodnews Bay (Ward and others, 2022) during peak eelgrass biomass (July–August). Survey points were distributed across each of these embayments using a systematic random design and accessed by boat using a global positioning system (GPS) unit. We sampled points by snorkeling in dry suits during high tide. At each point, we estimated substrate type and depth and percent cover of eelgrass and seaweeds within four 0.25 m^2 quadrats. We used the survey points to guide selection of training polygons for each classification category (Ozesmi and Bauer, 2002). This approach enabled the selection of training data across thousands of pixels in each of the images, greatly improving the accuracy of the classifications (Ward and others, 2022).

Table 1. Site number, location name, and baseline estimates of spatial extent of eelgrass (*Zostera marina*) adjacent to Togiak National Wildlife Refuge, Alaska, based on aerial and remotely sensed techniques.

[Preliminary estimates of eelgrass spatial extent: determined from aerial photography in 2004 (Winfree, 2005). Remotely sensed estimates of eelgrass spatial extent: determined by remote sensing techniques. Verification year: based on point sampling by U.S. Geological Survey (Ward, 2022) or viewing from shore or airplane by U.S. Fish and Wildlife Service (Winfree 2008). USGS, U.S. Geological Survey; USFW, U.S. Fish and Wildlife Service; ND, no data.]

Site no.	Location	Preliminary estimate of eelgrass spatial extent (ha)	Remotely sensed estimates of eelgrass spatial extent (ha)	Remote sensing technique	Date of imagery acquisition	Verification year	
						USGS	USFWS
			Bristol Bay				
1	Metervik Bay	53	150	Aerial photography	August 5, 2013		2006
2	Nunavachak Bay	13	8	Aerial photography	August 5, 2013		2006
3	Nunavachak Bay	45	32	Aerial photography	August 9, 2012		2006
4	Ungalikthluk Bay	470	550	Ikonos2	August 7, 2002		2006
5	Togiak Bay (Rocky Point1)	70	61	Ikonos2	August 7, 2002		2006
6	Togiak Bay (Rocky Point2)	13	ND	ND	ND		2006
7	Togiak Bay (Rocky Point3)	5	ND	ND	ND		2006
8	Togiak Bay (Rocky Point4)	67	ND	ND	ND		2006
9	Togiak Bay	717	283	Aerial photography	July 29, 2008		2006
10	Matogak Point	1,416	372	Aerial photography	July 29, 2008		2006
11	Osviakestus Point	58	14	Ikonos2	September 20, 2002		2006
12	Osviakestus Lagoon	103	34	Ikonos2	September 20, 2002		2006
13	Hagemeister Strait	62	ND	ND	ND		2006
14	Asigyukpak Spit	257	228	Ikonos2	August 21, 2003		2006
15	Hagemeister Spit	1,269	1,168	Aerial photography	August 15, 2005		2006
New	Hagemeister Strait (Central)	ND	2	Ikonos2	June 30, 2002		2006
16	Hagemeister Strait (North End)	36	7	Ikonos2	June 30, 2002		2006
17	Hagemeister Strait (North End)	37	31	Ikonos2	June 30, 2002		2006
18	Hagemeister Strait (North End)	71	61	Ikonos2	June 30, 2002		2006
	Subtotal	4,761	3,001				
			Kuskokwim Bay				
19	Nanvak Bay	791	599	Aerial photography	August 7, 2007	2008–10	2006
20	Security Cove	92	82	Aerial photography	August 15, 2005		2006
21	Chagvan Bay	2,552	1,933	Aerial photography	July 29, 2008	2010	2006
22	Goodnews Bay (South Spit)	43	501	Quickbird2	June 29, 2004	2010	2006
23	Goodnews Bay (North Spit)	363	191	Quickbird2	June 29, 2004		2006
New	Goodnews Bay (Central)	ND	182	Quickbird2	June 29, 2004		
	Subtotal	3,840	3,488				

Classification

We classified the satellite imagery and aerial photomosaics into three substrate classes (eelgrass, bare ground, water) using an unsupervised isodata algorithm to identify statistically separable spectral clusters for determining training classes in subsequent supervised maximum likelihood analyses (Ward and others, 1997; Ozesmi and Bauer 2002; Hogrefe and others, 2014). This approach minimized classification errors resulting from variable light conditions and increasing water depths within substrate types in the photomosaics and in both the photomosaics and satellite imagery, respectively.

Maximum water depth of eelgrass in the study area was about -1 to -2 m mean lower low water, which is the average height of the lowest daily tide during a 19-year recording period. During the processing of the photomosaics, we derived 15–20 isodata clusters and assigned them to training classes that were defined by the substrate type, light conditions (as effected by the flight line direction or glare) and relative water depth (no, shallow, or deep water). Depending on photomosaic quality, this resulted in 4–10 training classes used in the subsequent maximum likelihood classification. Indistinct isodata clusters were left unassigned during training class creation; however, during the application of the maximum likelihood algorithm, we assigned each pixel within the area of interest to the class to which it was most statistically similar. For the satellite imagery, we derived 30–35 isodata clusters and assigned them to training classes based only on substrate type and relative water depth as light conditions were consistent across each image. With this consistent spectral quality, we were able to create seven standardized training classes.

To improve eelgrass detection where deep water obscured its presence, a second iteration of the isodata/maximum likelihood classification process was conducted focusing on areas previously classified as water. For the final step in creating maps of eelgrass distribution, we combined the multiple classes from the photomosaics and satellite imagery into the three substrate categories of eelgrass, bare substrate, and water.

Results

We determined the spatial extent of eelgrass at 19 (83 percent) of the 23 sites that were originally identified by Winfree (2005, 2008) as containing eelgrass beds at least 1 ha in size (figs. 1–11). Distribution of eelgrass at four sites, three along the west side of Togiak Bay (site nos. 6–8) and one in Hagemeister Strait (site no. 13), were not mapped because of the lack of suitable imagery (table 1). These sites likely contained smaller sized eelgrass beds (<70 ha each or <150 ha total; Winfree, 2005, 2008); therefore, nearly all (~98 percent) of the known spatial extent of eelgrass was mapped in this study area.

We applied a second iteration of the classification process to the imagery at 10 of the 19 sites where deep water obscured the presence of eelgrass at the time of image acquisition, such as in Ungalikthluk Bay, Togiak Bay, Estus Point, and Hagemeister Strait. This extra processing step increased the spatial extent of eelgrass in the study area by 15 percent or 1,003 ha eelgrass.

Our assessment expanded the previous estimate of areal extent of eelgrass in south Goodnews Bay from 43 to 501 ha. This new estimate is likely higher than what we report because a portion of the satellite image was obscured by clouds (fig. 11). We identified two new eelgrass sites during review of imagery of Hagemeister Island and central Goodnews Bay that were not identified by Winfree (2005), increasing the areal extent of eelgrass 2 and 182 ha, respectively. These new sites are included in the overall estimate of eelgrass in the study area (table 1). The assessment also identified significant (>100 ha) reductions in areal extent of eelgrass from previous estimates made at Matogak Point, and Togiak, Nanvak, Chagvan, and Goodnews (North Spit) bays (table 1). Differences between our estimates and those of Winfree (2005, 2008) are likely the result of methodological differences in how the area was mapped (that is, pixel-based classifications of high-resolution multi-spectral imagery vs. coarse-scale aerial mapping by GPS) and not actual changes in the areal extent of eelgrass in the study area.

The total estimated areal extent of all 21 eelgrass beds was 6,489 ha with 54 percent found in Kuskokwim Bay (3,488 ha) and 46 percent in Bristol Bay (3,001 ha; table 1). We determined the four largest eelgrass meadows (Chagvan, Goodnews and Nanvak bays in Kuskakwim Bay and Hagemeister Spit in Bristol Bay) to be in well-protected embayments and accounted for 70 percent (4,574 ha) of the total eelgrass cover. Habitat maps for each of the 21 sites, showing the distribution of eelgrass, unvegetated substrates (mud, sand, or rock), and water (greater than approximately -0.5 m at mean lower low water), are shown in figures 2–11, which can be found at the end of this report.

Discussion

The northern Bering Sea and southern Chukchi Sea represent the northern limit for eelgrass in western North America (McRoy, 1968; Wyllie-Echeverria and Ackerman, 2003). The estimated 6,489 ha of eelgrass cover adjacent to TNWR is one of the largest known eelgrass meadow complexes in the Bering Sea, third only to the eelgrass meadows of Izembek Lagoon (16,816 ha) and the Port Moller complex (7,816 ha; Port Moller, Herendeen Bay and Nelson Lagoon combined; Hogrefe and others, 2014).

This study improves upon the estimates of eelgrass spatial extent by Winfree (2005, 2008) because the spatial extent of eelgrass meadows was mapped using higher resolution (≤4 m) multi-spectral imagery. Maps of eelgrass distribution were produced for 19 of the 23 previously identified sites and new eelgrass beds were detected at two sites (Goodnews Bay and Hagemeister Island). This mapping effort, in conjunction with the work previously completed by Winfree (2005, 2008), represents the first comprehensive assessment of eelgrass in the Bristol Bay and southern Kuskokwim Bay regions.

We found it difficult to collect aerial photography to map eelgrass because of the difficulty in obtaining favorable weather (light winds on a clear day) during periods with low tides and sufficient light (high sun angle). The high resolution (≤4 m) Ikonos and Quickbird satellite imagery provided a higher quality data source for mapping eelgrass across the study area than the digital color aerial photography.

Accuracy assessments of the mapped cover types were conducted at Nanvak and Chagvan bays in 2010. These evaluations indicated a classification accuracy of greater than or equal to 78 percent for eelgrass and unvegetated (water and bare ground combined) substrates, a level that exceeds accepted standards within the remote sensing field used to monitor trends in eelgrass spatial distribution (Foody, 2002). Errors in detection of eelgrass were generally associated with misidentification of this seagrass as green seaweeds, a common issue in remotely sensed data of submerged aquatic vegetation because of their similarity in spectral signature. Nanvak and Chagvan bays are dominated by soft (mud/sand) substrates which favor the rooted and rhizomal growth of eelgrass. In contrast, seaweeds lack roots and rhizomes (for attachment in soft substrates) and are more commonly found in hard (rocks and shells) substrates.

In embayments with soft substrates, seaweeds drift with the tides and winds, but if winds and tides are mild, they can settle at the base of the eelgrass shoots, where they often become stationary. Seaweeds at Nanvak and Chagvan bays, like other embayments with soft substrate in the Bering Sea, occur in low densities and generally in eelgrass meadows (Hogrefe and others, 2014; Ward and others, 2022). Soft bottom substrates dominate embayments in most of the study area, and at these sites, we believe the mapping accuracy to be high, accuracy levels comparable to those sites with ground-truthing data (that is, ≥78 percent accuracy). We are less certain of the classification accuracy at sites where hard (rocky) bottom substrates with seaweeds likely dominate, such as along the eastern shoreline of Togiak Bay in Nunavachak and Metervik bays and the northeast end of Hagemeister Island (Winfree, 2008) because of the lack of ground-truthing data. At these sites, the areal extent of eelgrass may be overestimated.

This study establishes a baseline of eelgrass distribution that can be used in future monitoring plans to assess trends and health of eelgrass adjacent to TNWR. Our distribution maps provide an accurate assessment of the presence (≥5 percent cover) and absence (<5 percent cover) of eelgrass across most study sites. The eelgrass distribution maps, however, offer little information about the abundance (for example, above- and below-ground biomass, shoot length and width) and (or) health (for example, shoot density, productivity) of the eelgrass meadows at a site. This is because the percent cover of eelgrass meadows identified in the distribution maps may range anywhere from 5 to 100 percent (that is, low to high cover). Future assessments may indicate little or no change in the areal extent of eelgrass at a site, yet eelgrass (shoot) density and canopy height may be increasing or decreasing dramatically. Currently, the best method for embayment-wide assessments of abundance (biomass) and health (structure and productivity) of eelgrass meadows is through boat surveys. Such surveys were conducted at three of the study sites (Nanvak, Chagvan, and Goodnews bays; Ward and others, 2022) and provide the best data for change detection of eelgrass in the study area. Boat surveys of eelgrass and seaweeds were also conducted over multiple years (2008–10) at Nanvak Bay, providing a good baseline for assessing long term trends of eelgrass abundance (for example, Ward and Amundson, 2019).

We encourage use of a hierarchical approach to eelgrass monitoring that incorporates assessments integrated across different spatial scales to maximize efficiency and effectiveness (Neckles and others, 2012; Hogrefe and others, 2014). Such an approach relies on a 3-tier framework of

1. Coarse scale, remotely sensed data to monitor location and extent of eelgrass over broad areas (for example, mapping with satellite imagery);
2. Moderate resolution field survey data to describe the physical and biological characteristics of a sample of seagrass meadows within the study area (for example, boat-based surveys to estimate percent cover and biomass); and, if necessary,
3. Fine-scale field survey data at a subset of sites to more intensively assess the drivers of ecological change and systemic response (for example, monitoring production and abundance relative to simultaneous measurements of light, salinity and temperature).

References Cited

Andrefouet, S., Muller-Karger, F.E., Hochberg, E.J., Hu, C., and Carder, K.L., 2001, Change detection in shallow coral reef environments using Landsat 7 ETM+ data: Remote Sensing of Environment, v. 78, no. 1–2, p. 150–162.

Argonne National Laboratory, Environmental Science Division, 2007, Proceedings of the North Aleutian Basin information status and research planning meeting, November 28–December 1, 2006: U.S. Minerals Management Service, Alaska Continental Shelf Region, OCS Study MMS 2007–031, 133 p.

Chavez, P.S., Jr., 1988, An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data: Remote Sensing of Environment, v. 24, no. 3, p. 459–479.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and van den Belt, M., 1998, The value of the world's ecosystem services and natural capital: Nature, v. 387, no. 6630, p. 253–260.

Costanza, R., de Groot, R., Sutton, P., van der Plogeg, S., Anderson, S., Kubiszewski, I., Farber, S., and Turner, R.K., 2014, Changes in the global value of ecosystem services: Global Environmental Change, v. 26, p. 152–158.

Dale, V.H., and Beyeler, S.C., 2001, Challenges in the development and use of ecological indicators: Ecological Indicators, v. 1, no. 1, p. 3–10.

Duffy, J.E., 2006, Biodiversity and the functioning of seagrass ecosystems: Marine Ecology Progress Series, v. 311, p. 233–250.

Eyerdam, W.J., 1971, Flowering plants found growing between pre- and post-earthquake high-tide lines during the summer of 1965 in Prince William Sound, *in* Committee of Alaska Earthquake of the Division of Earth Sciences, National Research Council, eds., The Great Alaska Earthquake of 1964: Washington, D.C., National Academy of Science, p. 69–81.

Foody, G.M., 2002, Status of land cover classification accuracy and assessment: Remote Sensing of Environment, v. 80, no. 1, p. 185–201.

Fourqurean, J.W., Willsie, A., Rose, C.D., and Rutten, L.M., 2001, Spatial and temporal pattern in seagrass community composition and productivity in south Florida: Marine Biology, v. 138, no. 2, p. 341–354.

Green, E.P., and Short, F.T., 2003, World atlas of seagrasses: Berkley, University of California Press.

Harris, P.M., Neff, A.D., and Johnson, S.W., 2012, Monitoring habitat and faunal assemblages at three eelgrass beds in the City and Borough of Juneau, Alaska: Seattle, National Marine Fisheries Service, Alaska Fisheries Science Center.

Hemminga, M.A., and Duarte, C.M., 2000, Seagrass ecology: Cambridge, United Kingdom, Cambridge University Press, p. 298.

Hogrefe, K.R., Ward, D.H., Donnelly, T.F., and Dau, N., 2014, Establishing a baseline for regional scale mapping of eelgrass (*Zostera marina*) habitat on the lower Alaska Peninsula: Remote Sensing, v. 6, no. 12, p. 12447–12477.

Johnson, S.R., Burns, J.J., Malme, C.I., and Davis, R.A., 1989, Synthesis of information on the effects of noise and disturbance on major haulout concentrations of Bering Sea pinnipeds: Anchorage, Alaska, U.S. Minerals Management Service, Final Report, No. 14-12-0001-30361, 267 p.

King, J.G., and Dau, C.P., 1981, Waterfowl and their habitats in the eastern Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The eastern Bering Sea shelf: Seattle, University Washington Press, Office of Marine Pollution Assessment, National Oceanic and Atmospheric Administration, Oceanography and Resources, v. 2, p. 739–754.

McRoy, C.P., 1966, Standing stocks and ecology of eelgrass (*Zostera marina*) at Izembek Lagoon, Alaska: Master of Science thesis, Seattle, Washington, University of Washington, 138 p.

McRoy, C.P., 1968, The distribution and biogeography of *Zostera marina* (eelgrass) in Alaska: Pacific Science, v. 22, p. 507–513.

Muehlstein, L.K., 1992, The host-pathogen interaction in the wasting disease of eelgrass, *Zostera marina*: Canadian Journal of Botany, v. 70, no. 10, p. 2081–2088.

Murphy, R.L., Shaul, A.R., and Berceli, R.S., 1995, North Alaska Peninsula commercial salmon annual management report, 1994: Kodiak, Alaska, Alaska Department of Fish and Game, 121 p.

Neckles, H.A., Kopp, B.S., Peterson, B.J., and Pooler, P.S., 2012, Integrating scales of seagrass monitoring to meet conservation needs: Estuaries and Coasts, v. 35, no. 1, p. 23–46.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Forqurean, J.W., Heck, K.L., Jr., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., and Williams, S.L., 2006, A global crisis for seagrass ecosystems: Bioscience, v. 56, no. 12, p. 987–996.

Ozesmi, S.L., and Bauer, M.E., 2002, Satellite remote sensing of wetlands: Wetlands Ecology and Management, v. 10, no. 5, p. 381–402.

Plus, M., Deslous-Paoli, J.-M., and Dagault, F., 2003, Seagrass (*Zostera marina* L.) bed recolonization after anoxia-induced full mortality: Aquatic Botany, v. 77, no. 2, p. 121–134.

Shaughnessy, F.J., Gilkerson, W., Black, J.M., Ward, D.H., and Petrie, M., 2012, Predicted eelgrass response to sea level rise and its availability to foraging black brant in Pacific coast estuaries: Ecological Applications, v. 22, no. 6, p. 1743–1761.

Short, F.T., and Burdick, D.M., 1996, Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquiot Bay, Massachusetts: Estuaries, v. 19, no. 3, p. 730–739.

Short, F.T., and Neckles, H.A., 1999, The effects of global climate change on seagrasses: Aquatic Botany, v. 63, no. 3–4, p. 169–196.

Short, F.T., and Wyllie-Echeverria, S., 1996, Natural and human-induced disturbance of seagrasses: Environmental Conservation, v. 23, no. 1, p. 17–27.

Ward, D.H., 2021, Point sampling data for eelgrass (*Zostera marina*) and seaweed distribution and abundance in bays adjacent to the Togiak National Wildlife Refuge, Alaska: U.S. Geological Survey data release, https://doi.org/10.5066/P92BMFTH.

Ward, D.H., and Amundson, C.L., 2019, Monitoring annual trends in abundance of eelgrass (*Zostera marina*) at Izembek National Wildlife Refuge, Alaska, 2018: U.S. Geological Survey Open-File Report 2019–1042, 8 p., https://doi.org/10.3133/ofr20191042.

Ward, D.H., and Hogrefe, K.R., 2022, Mapping data of eelgrass (*Zostera marina*) distribution, Alaska and Baja California, Mexico: U.S. Geological Survey data release, https://doi.org/10.5066/P9WEK4JI.

Ward, D.H., Hogrefe, K.R., Donnelly, T.F., Fairchild, L.L., and Britton, R., 2022, Eelgrass (*Zostera marina*) and Seaweed Assessments at Alaska Peninsula-Becharof National Wildlife Refuge, 2010: U.S. Geological Survey Open-File Report 2020–1144, 14 p., https://doi.org/10.3133/ofr20201144.

Ward, D.H., Markon, C.J., and Douglas, D.C., 1997, Distribution and stability of eelgrass beds at Izembek Lagoon, Alaska: Aquatic Botany, v. 58, no. 3-4, p. 229–240.
Ward, D.H., Morton, A., Tibbitts, T.L., Douglas, D.C., and Carrera-Gonzalez, E., 2003, Long-term change in eelgrass distribution at Bahia San Quintin, Baja California, Mexico, using satellite imagery: Estuaries, v. 26, no. 6, p. 1529–1539.
Ward, D.H., and Stehn, R.A., 1989, Response of brant and other geese to aircraft disturbances at Izembek Lagoon, Alaska: U.S. Fish Wildlife Service Final Report No. 14-12-0001-30332.
Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Jr., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., and Williams, S.L., 2009, Accelerating loss of seagrasses across the globe threatens coastal ecosystems: Proceedings of the National Academy of Sciences of the United States of America, v. 106, no. 30, p. 12377–12381.
Weiland, K.A., Morstad, S., Sands, T., Higgins, C., Fair, L., Crawford, D., West, F., and McKinley, L., 2003, Alaska Department of Fish and Game Annual Management Report for Bristol Bay Area.
Winfree, M., 2005, Preliminary aerial reconnaissance surveys of eelgrass beds on Togiak National Wildlife Refuge, Alaska: Togiak, Alaska, U.S. Fish Wildlife Service.
Winfree, M., 2008, Verification of eelgrass presence on previously identified beds on Togiak National Wildlife Refuge, Alaska: Togiak, Alaska, U.S. Fish Wildlife Service.
Wyllie-Echeverria, S., and Ackerman, J.D., 2003, Seagrasses of the Pacific coast of North America, *in* Green, E.P., and Short, F.T., eds., World atlas of seagrasses: Berkeley, University of California Press, UNEP World Conservation Monitoring Centre, p. 199–206.

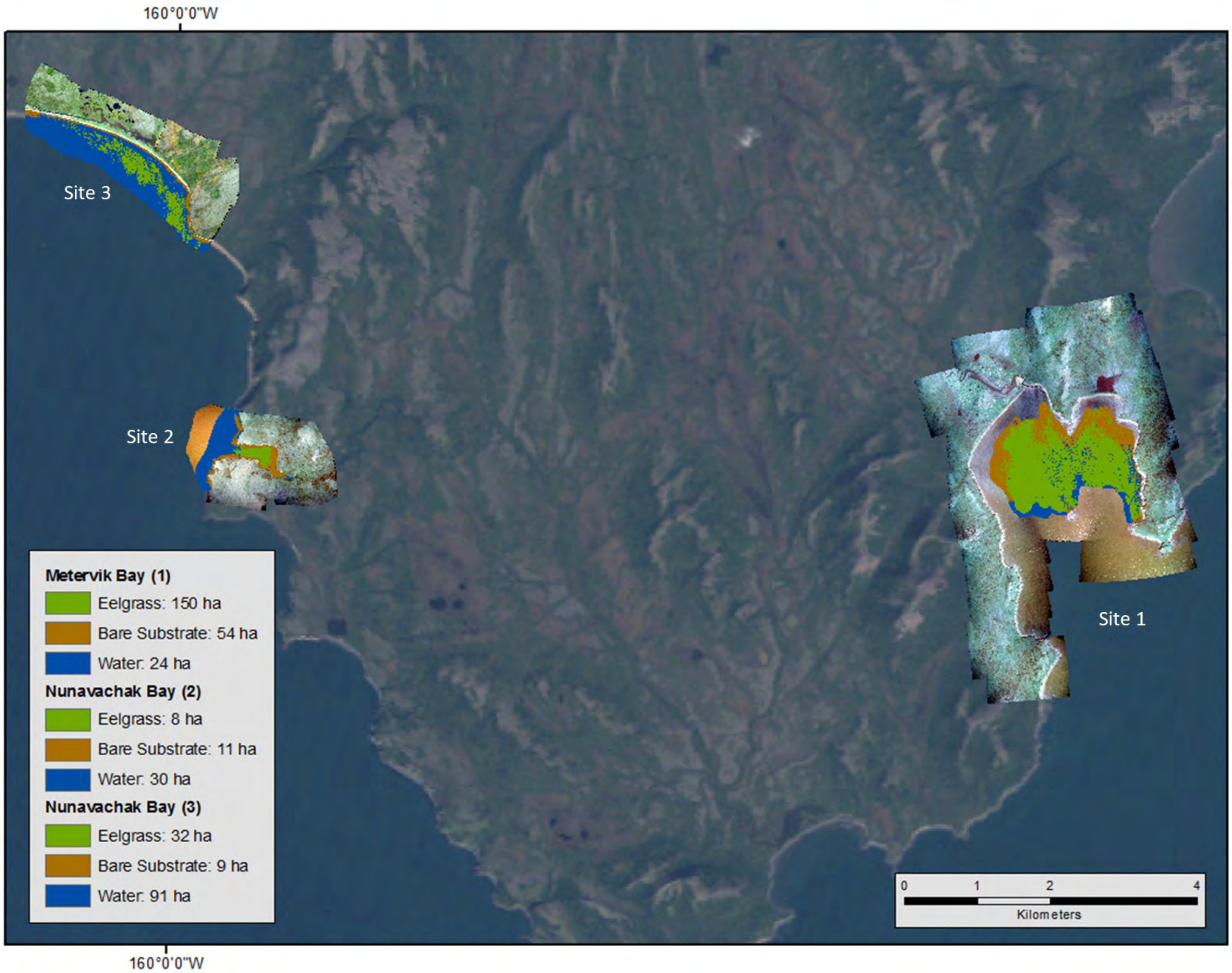

Figure 2. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Metervik Bay (site 1 [for site information see table 1 and fig. 1]) and Nunavachak Bay (sites 2 and 3), Alaska.

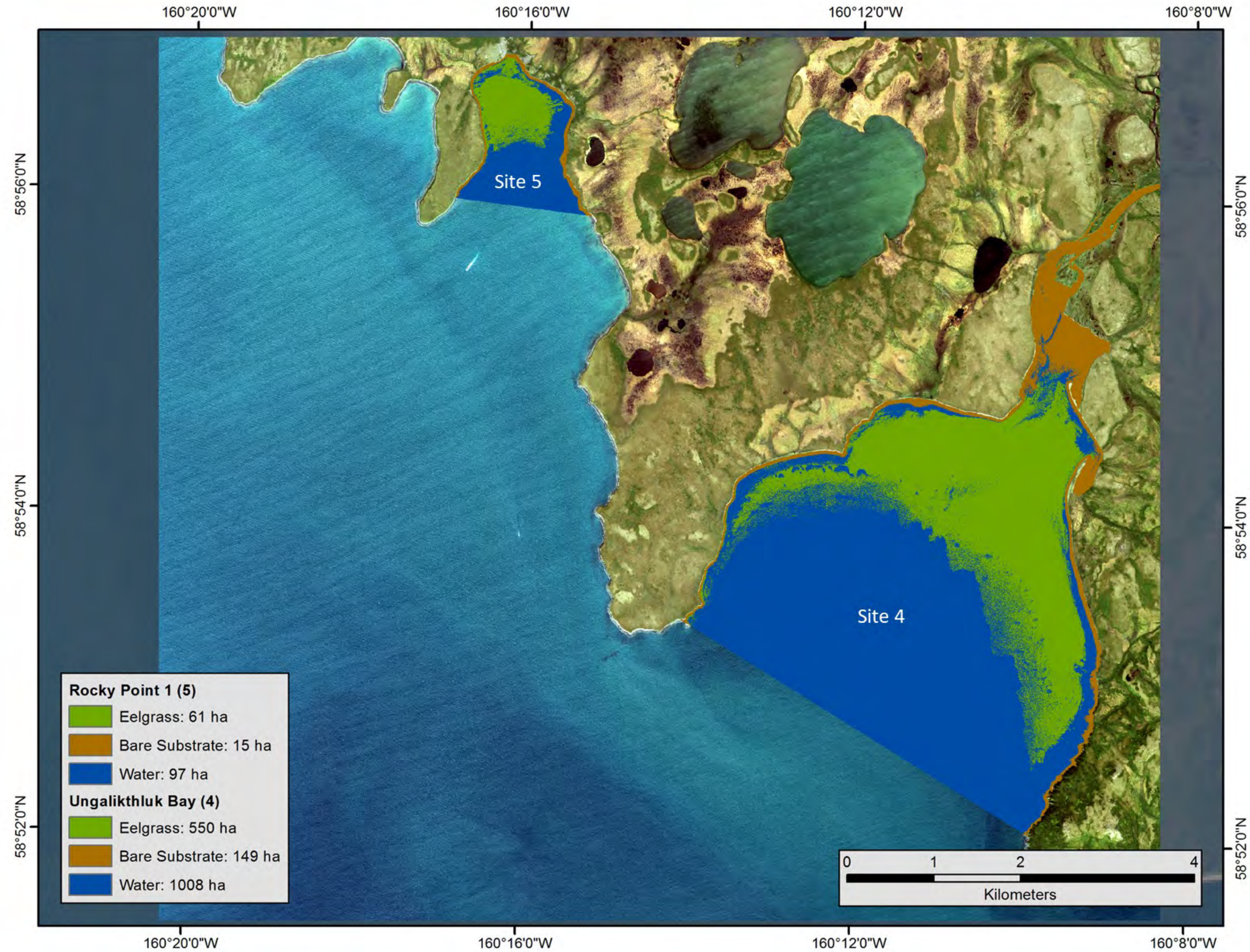

Figure 3. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Ungalikthluk Bay (site 4 [for site information see table 1 and fig. 1]) and Rocky Point 1 (site 5), Alaska.

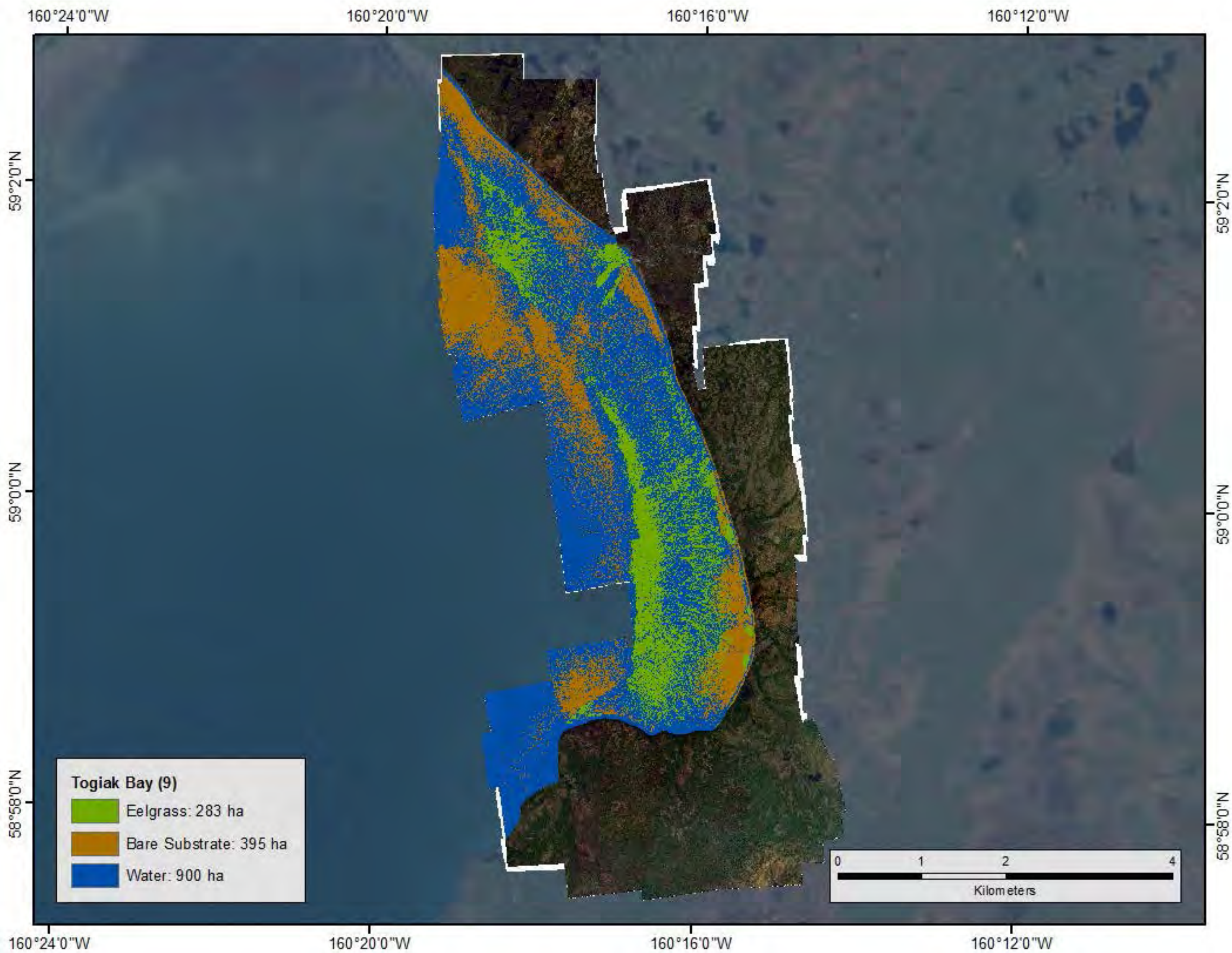

Figure 4. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Togiak Bay (site 9 [for site information see table 1 and fig. 1]), Alaska.

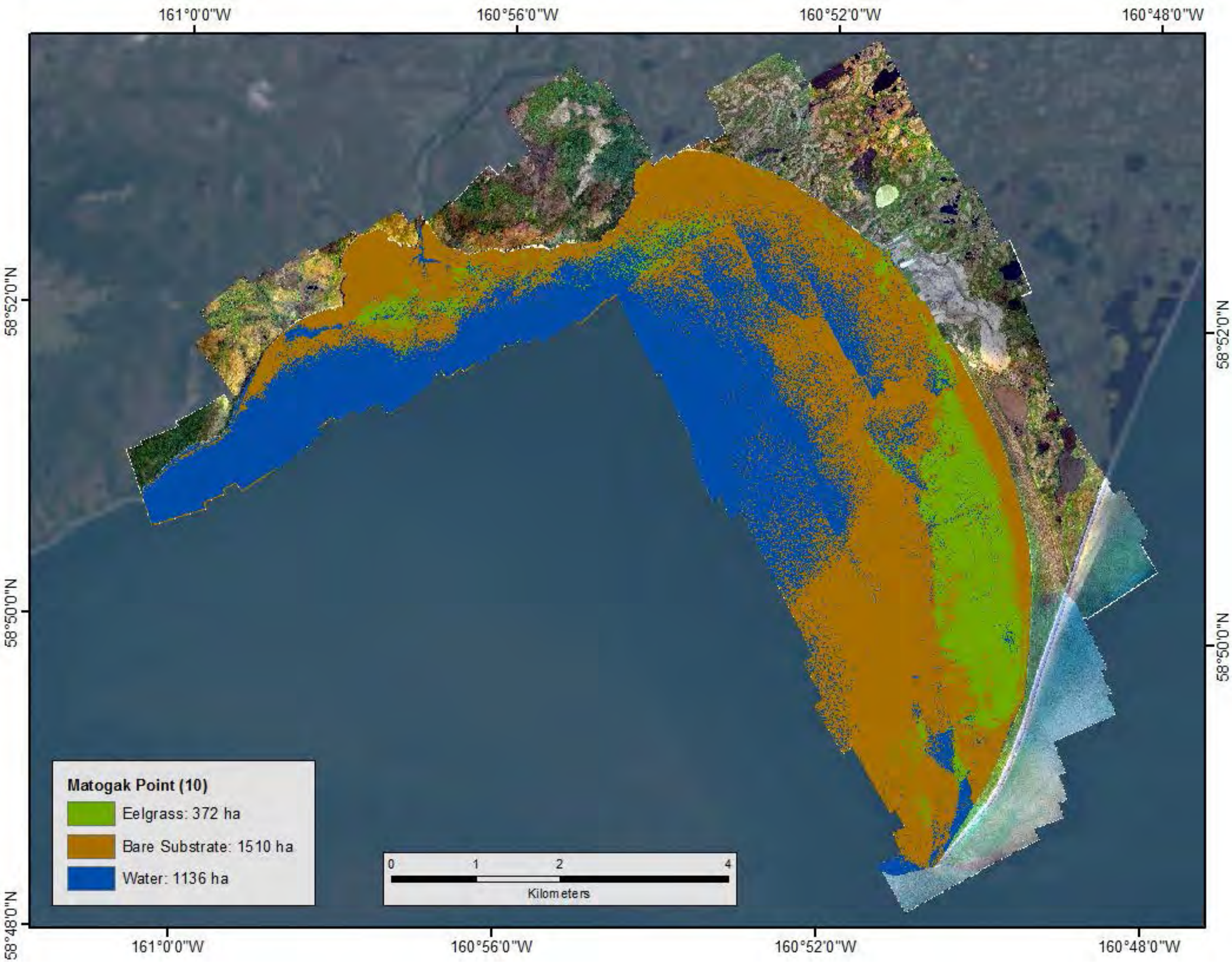

Figure 5. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water at Matogak Point (site 10 [for site information see table 1 and fig. 1]), Alaska.

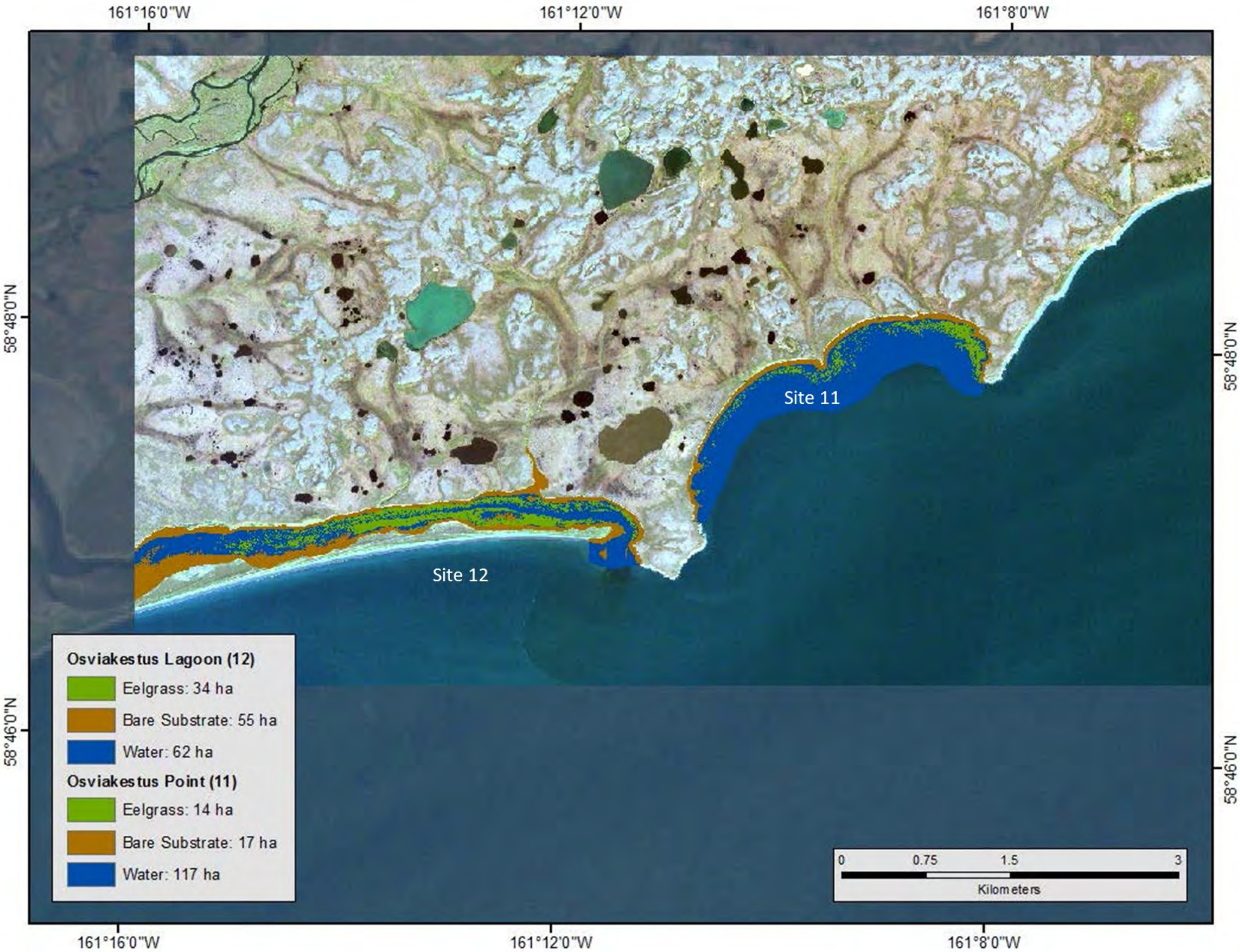

Figure 6. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water at Estus Point (Osviakestus Lagoon, site 11 [for site information see table 1 and fig. 1]) and Osviakestus Point (site 12), Alaska.

Figure 7. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water at Asigyukpak Spit (site 14 [for site information see table 1 and fig. 1]) and Hagemiester Spit (site 15), Alaska.

Figure 8. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water along the west end of Hagemiester Island (sites 16–18 [for site information see table 1 and figure 1]) and Hagemeister Straight, Alaksa.

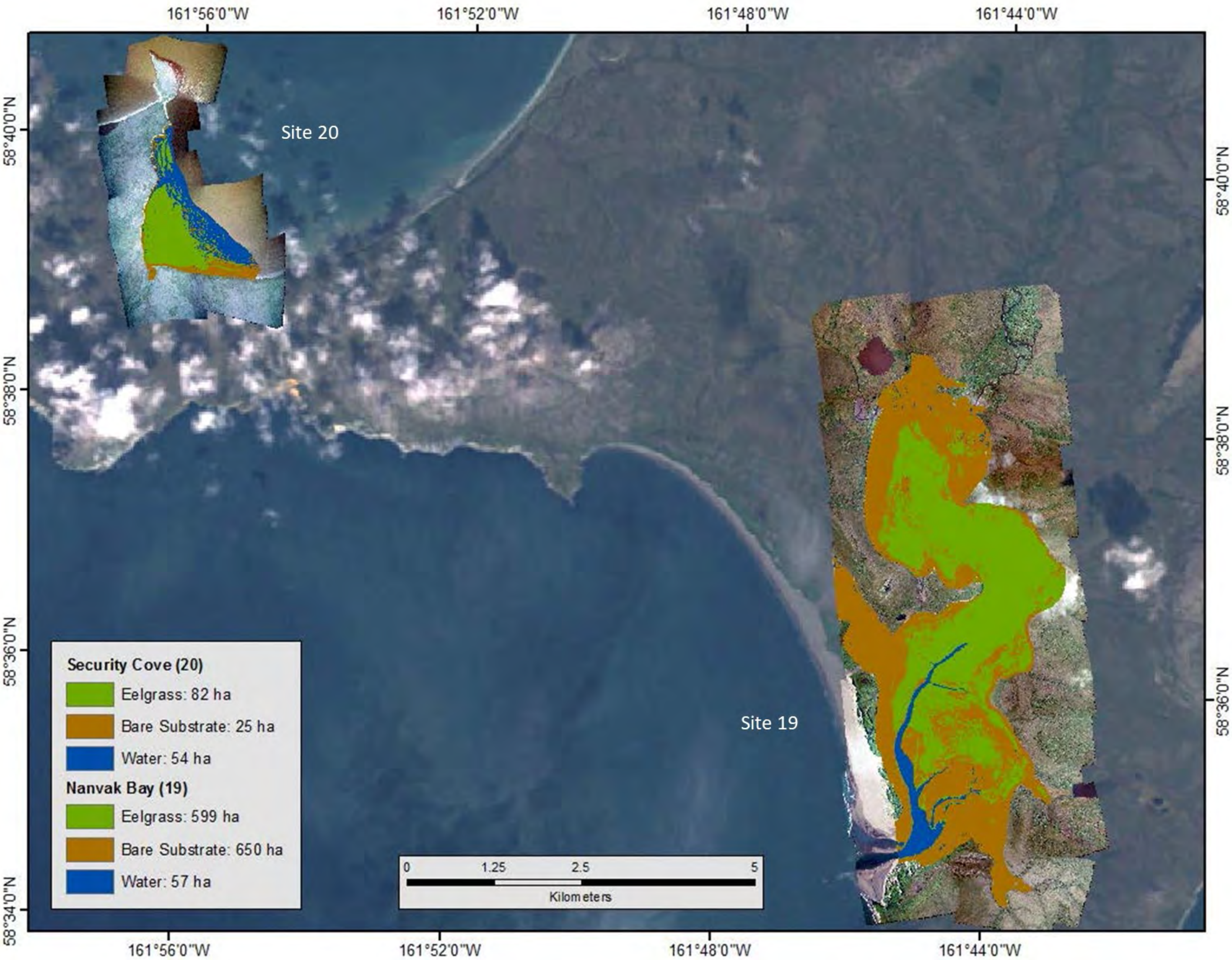

Figure 9. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Nanvak Bay (site 19 [for all site information see table 1 and fig. 1]) and Security Cove (site 20), Alaska.

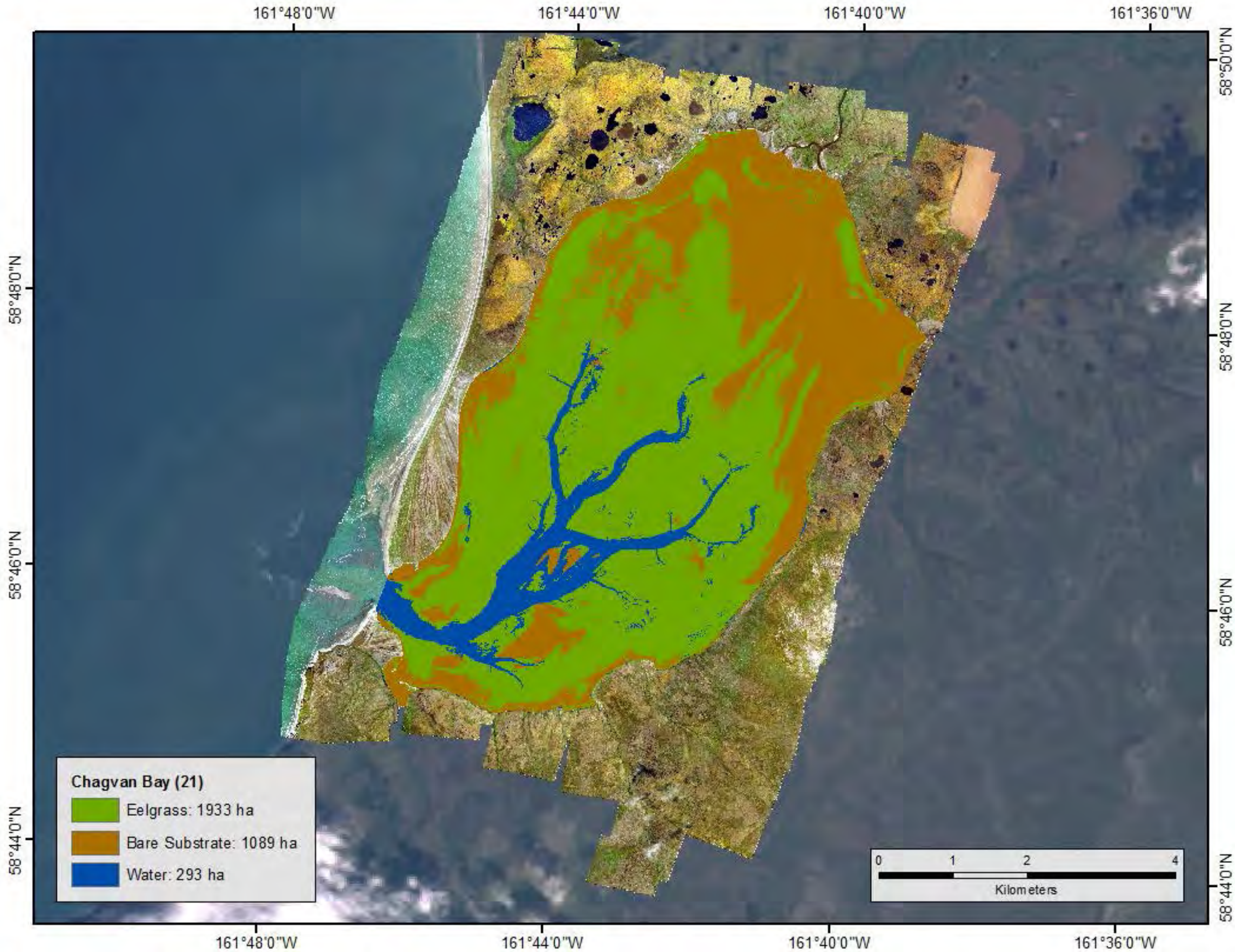

Figure 10. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Chagvan Bay (site 21 [for site information see table 1 and fig. 1]), Alaska.

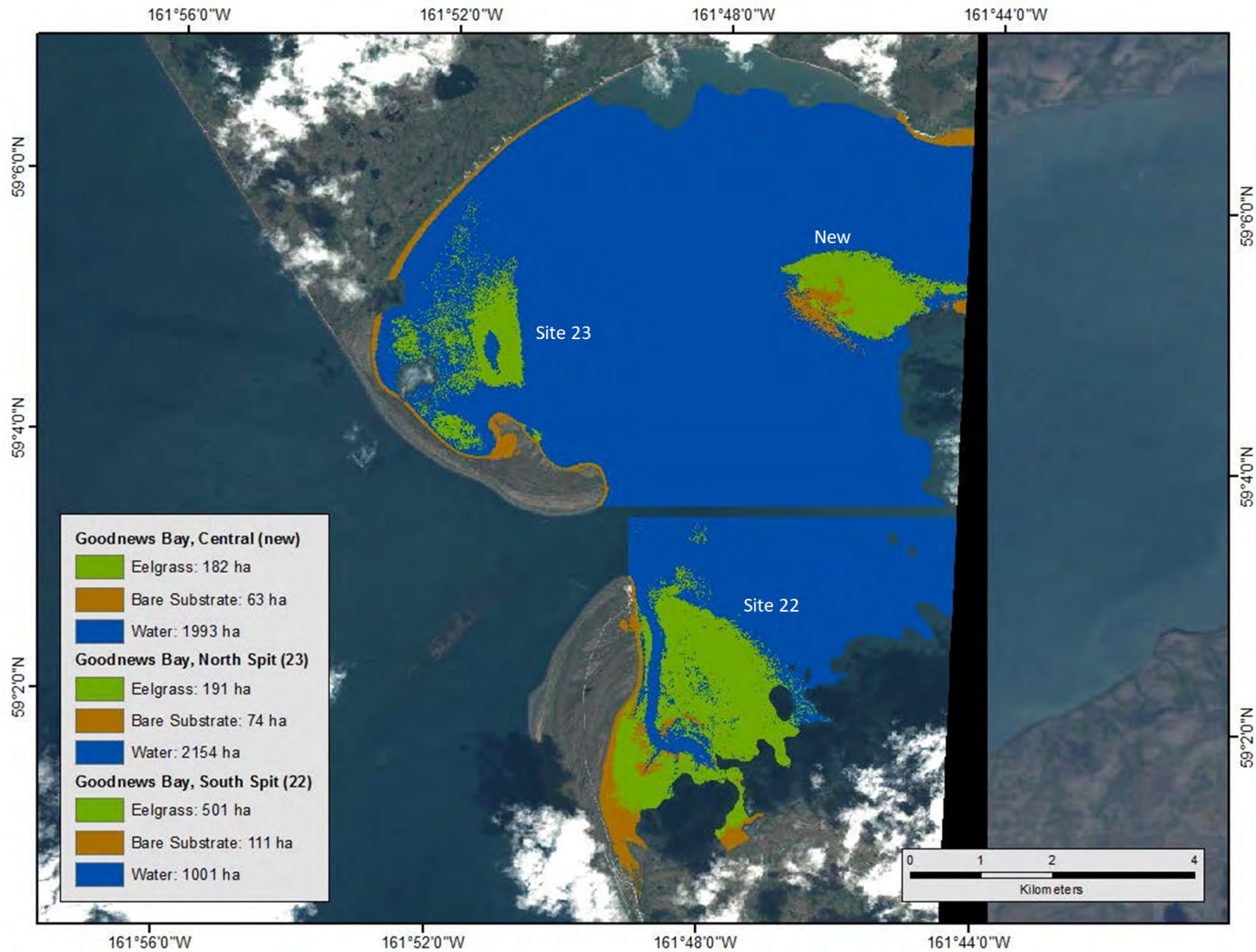

Figure 11. Distribution and spatial extent of eelgrass (*Zostera marina*), bare substrate, and deep water in Goodnews Bay (sites 22–23 [for site information see table 1 and fig. 1]) and at Goodnews Bay Central (a new site), Alaska.

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