OCS Study
BOEM 2019-075

Assessment of nearshore communities and habitats: Lower Cook Inlet Nearshore Ecosystem 2015-2018

US Department of the Interior
Bureau of Ocean Energy Management
Alaska Region

BOEM
Bureau of Ocean Energy Management

OCS Study
BOEM 2019-075

Assessment of nearshore communities and habitats: Lower Cook Inlet Nearshore Ecosystem 2015-2018

[December / 2019]

Authors:
Tahzay Jones, Susan Saupe, Katrin Iken, Brenda Konar, Sarah Venator, Mandy Lindeberg, Heather Coletti, Benjamin Pister, Joel Reynolds, and Katlyn Haven

Prepared under M15PG00037
By
National Park Service – Alaska Region
240 W. 5th Ave.
Anchorage, Alaska
99501

US Department of the Interior
Bureau of Ocean Energy Management
Alaska Region

DISCLAIMER

This study was funded, in part, by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, through Intra-Agency Agreement Number M15PG00037 with the National Park Service. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2019-075. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

Jones, T., S. Saupe, K. Iken, B. Konar, S. Venator, M. Lindeberg, H. Coletti, B. Pister, J. Reynolds, and K. Haven. 2019. Assessment of nearshore communities and habitats: Lower Cook Inlet Nearshore Ecosystem 2015-2018. Anchorage (AK): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2019-075. 221 p.

ABOUT THE COVER

Intertidal zonation shown by the color bands that reflect seaweeds that flourish at different tidal heights. Scott Island, Iniskin Bay. Photograph by M. Lindeberg.

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AGL	Above Ground Level
AMBON	Arctic Marine Biodiversity Observing Network
ANOVA	Analysis of Variance
AOOS	Alaska Ocean Observing System
BOEM	Bureau of Ocean Energy Management
CIRCAC	Cook Inlet Regional Citizens Advisory Council
CORS	Continuously Operating Reference System
CSE	Council of Science Editors
DEM	Digital Elevation Model
DOI	US Department of the Interior
DPP	Development and Production Plan
EIS	Environmental Impact Statement
ENVI	Environment for Visualizing Images
EP	Exploration Plan
ESP	Environmental Studies Program
ESPIS	Environmental Studies Program Information System
EVOS	Exxon Valdez Oil Spill
GEM	Gulf Ecosystem Monitoring
GPS	Global Positioning System
GWA	Gulf Watch Alaska
IA	Interagency Agreement
IfSAR	Interferometric Synthetic Aperture Radar
KBRR	Kachemak Bay Research Reserve
LTM	Long-term Monitoring
MARINe	Multi-Agency Rocky Intertidal Network
MHHW	Mean Higher-High Water
MLLW	Mean Lower-Low Water
MSL	Mean Sea Level
NAD	North American Datum
NEPA	National Environmental Policy Act
NIR	Near-Infrared Radiation
nMDS	Non-metric Multidimensional Scaling
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NWLON	National Water Level Observation Network
OCS	Outer Continental Shelf
OCSEAP	Outer Continental Shelf Environmental Assessment Program
OPUS	NOAA’s Online Positioning User Service
PERMANOVA	Permutational multivariate analysis of variance
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
PPK	Post-Processed Kinematic (GPS surveying)
RGB	Red-Green-Blue

RPC	Random Point Contact
RTK	Real-time Kinematic (GPS surveying)
SfM	Structure-from-Motion
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle

1 Introduction

1.1 Bureau of Ocean Energy Management (BOEM) Needs

This project was undertaken to provide information on nearshore habitats in areas adjacent to the Outer Continental Shelf (OCS) Cook Inlet Planning Area. BOEM's OCS Oil & Gas Leasing Program 2012-2017 included Lease Sale 244 in the Cook Inlet Planning Area in June 2017, during which several leases were purchased that may lead to oil and gas development and production. Subsequently, the current National OCS Program that took effect in July 2017 includes one sale in the Cook Inlet Program Area, and the potential exists for additional areas or lease sales in the 2019-2024 National OCS Oil and Gas Leasing Proposed Program.

Prior to the preparation of an Environmental Impact Statement (EIS) for Lease Sale 244, an OCS Cook Inlet Lease Sale National Environmental Policy Act (NEPA) analysis has not been undertaken since 2003. Updated information regarding the physical and biological environment, including variability in oceanographic conditions, nearshore benthic communities, and data related to sensitive species, was needed to support NEPA analyses for that and future lease sales. This project will also provide information crucial for the accurate review of potential future Exploration Plans (EPs), and Development and Production Plans (DPPs).

The overall objective of this project was to acquire meaningful data in a usable form and timely manner so that required environmental analysis can occur. Specific information needs included (1) collate existing baseline information, (2) identify habitats with little historical information, and (3) characterize biological populations and ecological systems that are potentially most subject to impact from petroleum exploration and development. Given that nearshore habitats are often most at risk, the focus of this work was in the nearshore area, specifically the intertidal and shallow subtidal zones adjacent to the northern portion of the Cook Inlet Planning Area, where Lease Sale 244 was focused.

The nearshore is considered an important component of the Gulf of Alaska ecosystem because it provides: a variety of unique habitats for resident organisms (e.g., sea otters, harbor seals, shorebirds, seabirds, nearshore fishes, kelps, seagrasses, clams, mussels, and sea stars); nursery grounds for marine animals from other habitats (e.g., crabs, salmon, herring, and seabirds); feeding grounds for important consumers, including killer whales, harbor seals, sea otters, sea lions, sea ducks, shorebirds and many fish and shellfish; a source of animals important to commercial and subsistence harvests (e.g., marine mammals, fishes, crabs, mussels, clams, chitons, octopus, and kelp); an important site of recreational activities including fishing, boating, camping, and nature viewing; and a source of primary production for export to adjacent habitats (primarily by kelps, other seaweeds, and eelgrass) (Dean and Bodkin 2006, Dean et al. 2014).

1.2 Historical Nearshore Assessments in Southcentral Alaska and Cook Inlet

Previous work has occurred or been proposed in the littoral zone of lower Cook Inlet in two major phases. The first phase was in the 1970's with the creation of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which was to ensure that proposed OCS development and production activities would not irreparably damage the marine environment and its resources. The second phase was triggered by the *Exxon Valdez* Oil Spill (EVOS) in 1989. Programs that followed included the Gulf Ecosystem Monitoring (GEM) Program, with a primary objective to "sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities." CIRCAC (Cook Inlet Regional Citizens Advisory Council) was formed by the Oil Pollution Act of 1990, and one of its tasks is to develop a monitoring program to evaluate potential environmental impacts of oil industry operations in Cook Inlet. To meet this mandate, they conduct habitat assessments and contaminants monitoring programs in Cook Inlet. Additional existing federal programs include the National Park Service Inventory and Monitoring Program and most recently (2012) the Gulf Watch Alaska program, partially funded by the *Exxon Valdez* Oil Spill Trustee Council with multi-agency support. Although each program was developed to meet a variety of objectives, all have a common goal to provide information to the public, resource managers, industry, policy-makers, and consumers.

A summary of previous intertidal research in the affected area was conducted in advance of the 2015 field season. This information was used to help identify geographic gaps where research had not occurred in western lower Cook Inlet. Results of the study were compiled into a relational geodatabase suitable for mapping locations of research sites and species occurrences from each study at the site level.

The compiled information indicated that relatively few previous intertidal studies had occurred in the project's study area. Of the publications, reports, and journal articles identified, only sixteen were in the study area, provided specific study site locations, and documented intertidal or shallow subtidal algal and invertebrate species occurrences. These were primarily authored by one of six different affiliations: the OCSEAP, CIRCAC, the National Park Service (NPS), Pebble Partnership, and companies Dames & Moore and Pentec Environmental. Limited beach surveys related to the EVOS were also conducted in the southernmost part of the study area.

Despite previous assessment and monitoring efforts in Cook Inlet, very limited data have been collected on one of the habitats that is relatively unique to Kamishak Bay and represents a large portion of the shorelines in the study area – extremely wide and low-angle rock ramps. Of the 114 unique sites visited in the historical studies, 69% were on soft sediment, while only 16% were on rocky or mostly rocky sites. Of the numerous intertidal sampling methods that have been applied to various monitoring programs throughout Alaska (e.g., NPS Southwest Alaska Network nearshore program, Gulf Watch Alaska nearshore program, Coastal Habitat Injury Assessment Studies after the *Exxon Valdez* oil spill, etc.), none are appropriate for this habitat, as they use fixed tidal heights, typically in areas of higher angle, narrower beaches, where zonation occurs typically parallel to the shoreline.

1.3 Project Overview

A major challenge for this project was to develop and apply methods that would sufficiently characterize the algal and invertebrate community assemblages existing on the small-scale topographical changes that occur across the rock platform and reef habitats common to the study area. Aerial imagery and limited prior on-the-beach surveys showed that the biological habitat mirrors the geology and geomorphology of the rock platforms, with repeating patterns that can be at considerable angles to the shoreline.

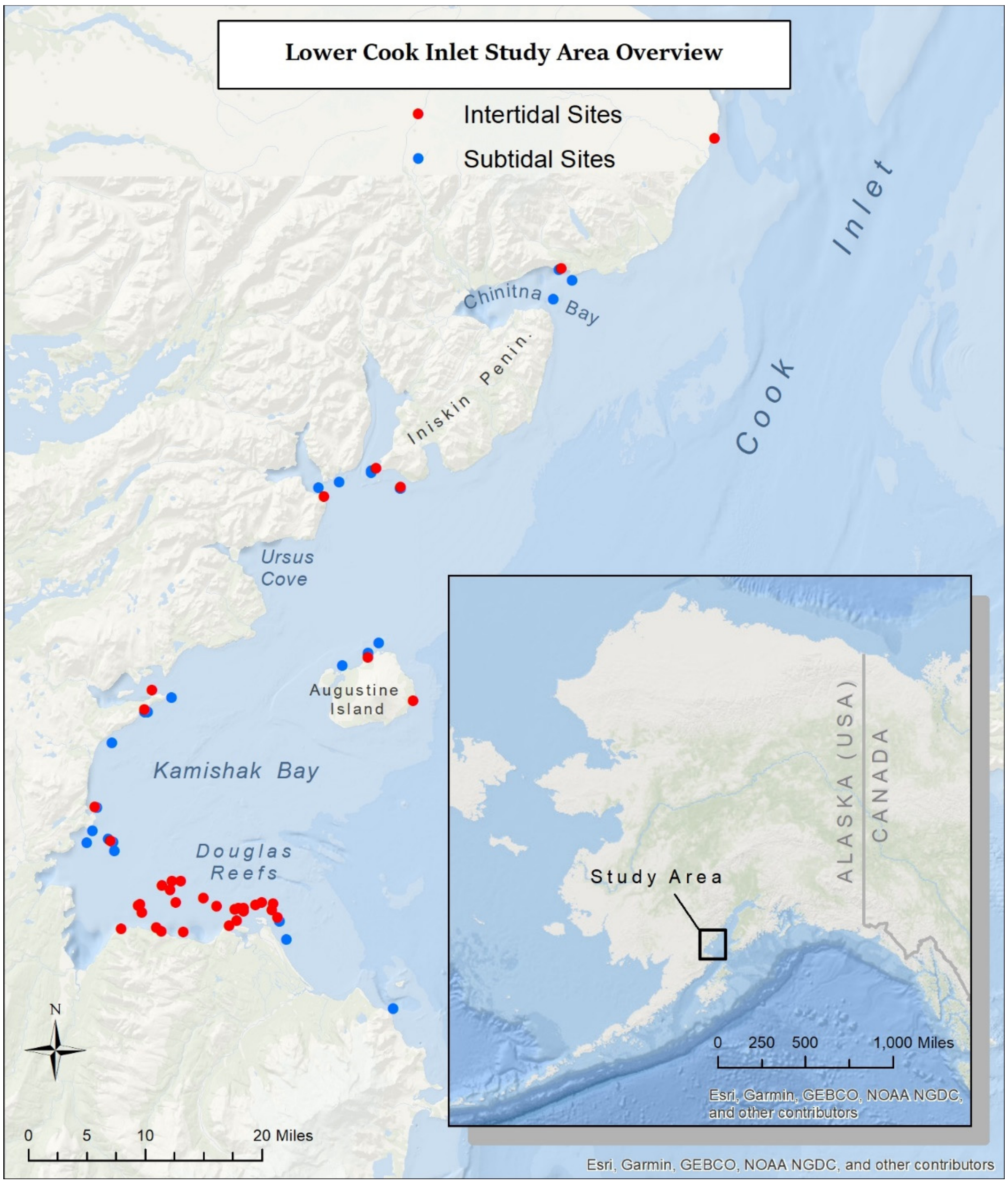


Figure 1.3.1. Map showing State of Alaska with project area.

An underlying premise was that assessment methods will provide information about the nearshore rocky habitats while simultaneously conducting comparisons of sampling methods that will guide future decisions on how best to sample western lower Cook Inlet's relatively unique rocky habitats – namely the wide, low-angle rocky ramps and platforms that dominate rocky habitat in the area. The knowledge gained through the testing of sampling methods and the data collected about the distribution of habitats and community assemblages in the study area will guide recommendations for potential future longer-term monitoring programs. Forcing a geographic spread of sampling sites within the overall study area can also provide information about potential latitudinal gradients along the axis of Cook Inlet in species diversity and assemblages.

An initial pilot project included field work in June 2015 (Coletti et al. 2017), which led to a four-year Interagency Agreement (IA) between BOEM and the National Park Service (NPS) to conduct an additional three years of sampling (2016-2018). The combined 2015-2018 data are reported here and include assessments of rocky shorelines between the mouth of the Douglas River in the south and Tuxedni Bay in the north, and includes several islands and bays (Figure 1.3.1). In 2014, potential sampling sites were randomly selected from within a population of rocky sites based on *ShoreZone* coastal habitat classifications (BC Class 1-10). The focus for sampling was on collecting detailed site characterizations of tidal heights and topography with survey-grade Real-Time Kinematic (RTK) GPS system, documenting intertidal and shallow subtidal invertebrate and algal species distributions through various methods, and collecting algal voucher collections. Later in the project, opportunities to collect even higher resolution spatial data and digital elevation data were provided through Structure from Motion (SfM) image surveys using manned and unmanned aircraft.

1.3.1 **Study Approach**

The goal of the agreement between NPS and BOEM was to support the collation of existing information and conduct assessments on intertidal and shallow subtidal benthic species across multiple habitat types that are found in proximity of the BOEM Cook Inlet Planning Area proposed in the Final OCS Oil & Gas Leasing Program 2012-2017 and 2017-2022. The approach of this work was multi-phased. The first phase was to collate historical information and data for the study area and provide it in an online geospatial data portal. The second phase was to utilize the existing historical datasets to guide site selection for assessments in habitats with little historical data. The third phase was to develop methods and conduct field assessments to collect new information in those nearshore habitats in areas that may be susceptible to oil spills due to their proximity to potential lease sale activities.

1.3.2 **Objectives**

Specific objectives of the pilot project were (Coletti et al. 2017):

- Compile existing historical intertidal and shallow subtidal data and literature from Cook Inlet. This information was used in planning the overall study design and selecting study sites for the 2015 pilot study and the longer-term (2016-2018) sampling.

- Conduct rocky intertidal and shallow subtidal (< 15 m water depth) field reconnaissance of important habitats at sites selected either due to their historical relevance, or through a habitat modeling based approach that uses existing data. Metrics used in site selection and assessments included: accessibility, susceptibility to oiling, biological relevance (either represents a large portion of the OCS area or is biologically unique), cost effective to study, and appropriate for long-term monitoring.

- Create sampling plans and recommendations for more extensive evaluations based on the historical analysis and field assessments of the intertidal and subtidal kelp habitats biota in lower Cook Inlet. Recommendations will utilize existing sampling protocols when possible to ensure comparability of results across a broad range of areas.

Specific objectives for the continued assessment project (2016-2019):

- Describe lower Cook Inlet nearshore habitats, including invertebrate and algal communities, using existing *ShoreZone* data and imagery and the results of prior intertidal and shallow subtidal sampling programs including recent sampling in Kamishak Bay in 2015. Information will be used to describe, assess, monitor, and/or quantify various habitat strata in lower Cook Inlet.

- Develop a sampling plan to obtain information across different habitat strata in lower Cook Inlet with a focus on previously unsampled habitat types and areas. Provide suggestions for areas and habitats that should be included in a long-term monitoring program to provide baseline conditions.

- Conduct intertidal and shallow subtidal sampling based on recommendations from the sampling plan developed. The sampling area should target appropriate habitats within Kamishak Bay and north to Tuxedni Bay.

- Evaluate the sampling methods and results in order to make recommendations for potential future sampling plans for evaluating habitats and, where possible, build on existing sampling protocols (such as Gulf Watch Alaska) to aid comparability of results across a broader area.

1.3.3 **Study Area Description**

Cook Inlet is in the northwestern Gulf of Alaska and extends in a SW to NE direction from its mouth north of Kodiak Island. The upper Inlet is north of a pinch point between the east and west Forelands north of the middle Inlet and the lower Inlet further south. There are several other distinct bodies of water associated with Cook Inlet including Knik and Turnagain arms in the upper Inlet and Kachemak and Kamishak bays on the east and west sides of the lower Inlet, respectively. Numerous other bays occur around the perimeter of the Inlet, especially along the west side and the lower Inlet in and near Kachemak Bay (Figure 1.3.3.1). The northern OCS Cook Inlet Planning Area includes portions of the lower Inlet. BOEM Lease Sale 244 was wholly contained in the lower Inlet and was adjacent to Kamishak Bay and west of Kachemak Bay (Figure 1.3.3.2).

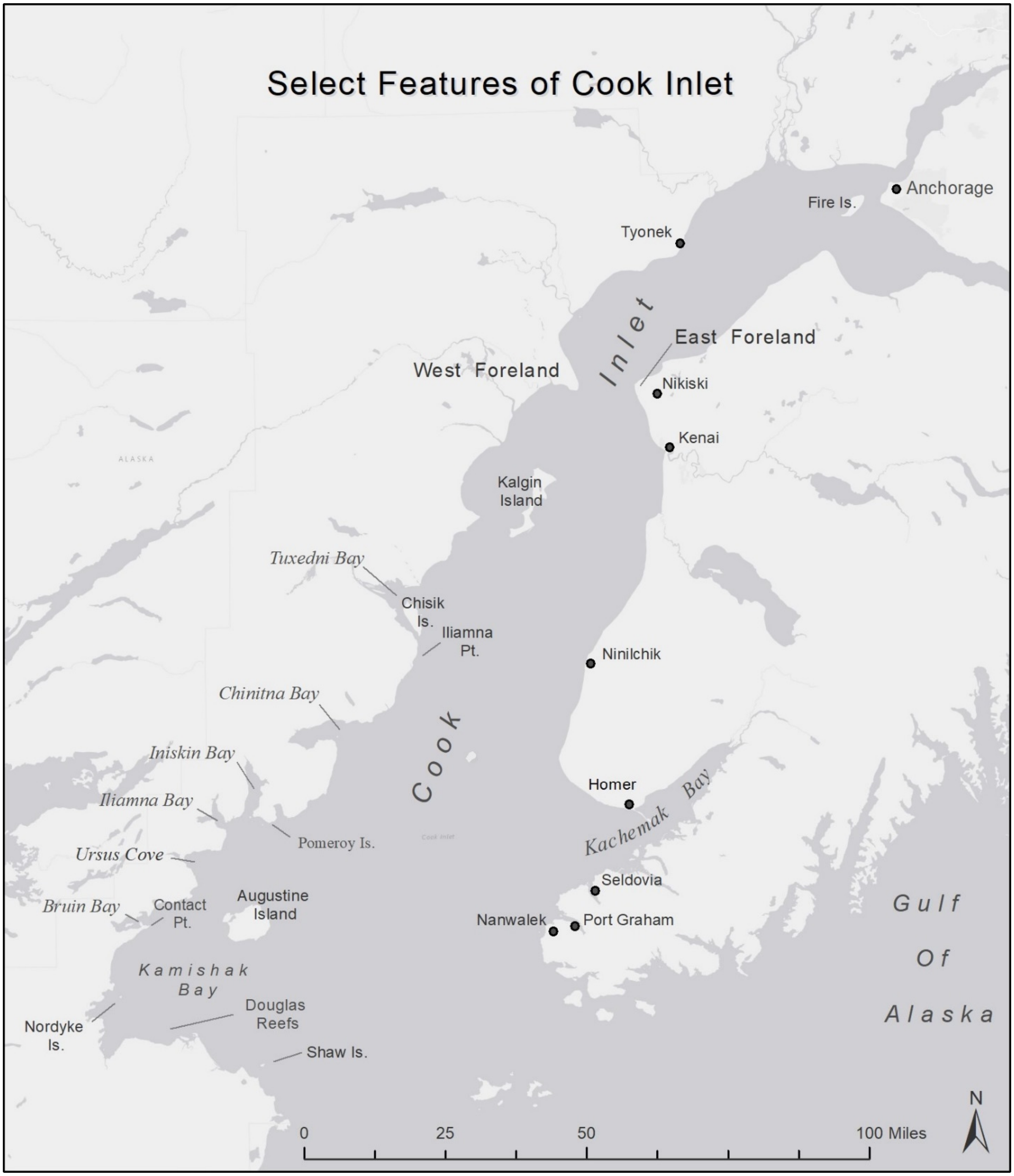


Figure 1.3.3.1. Features of Cook Inlet.
Map showing the general area and place names for reference.

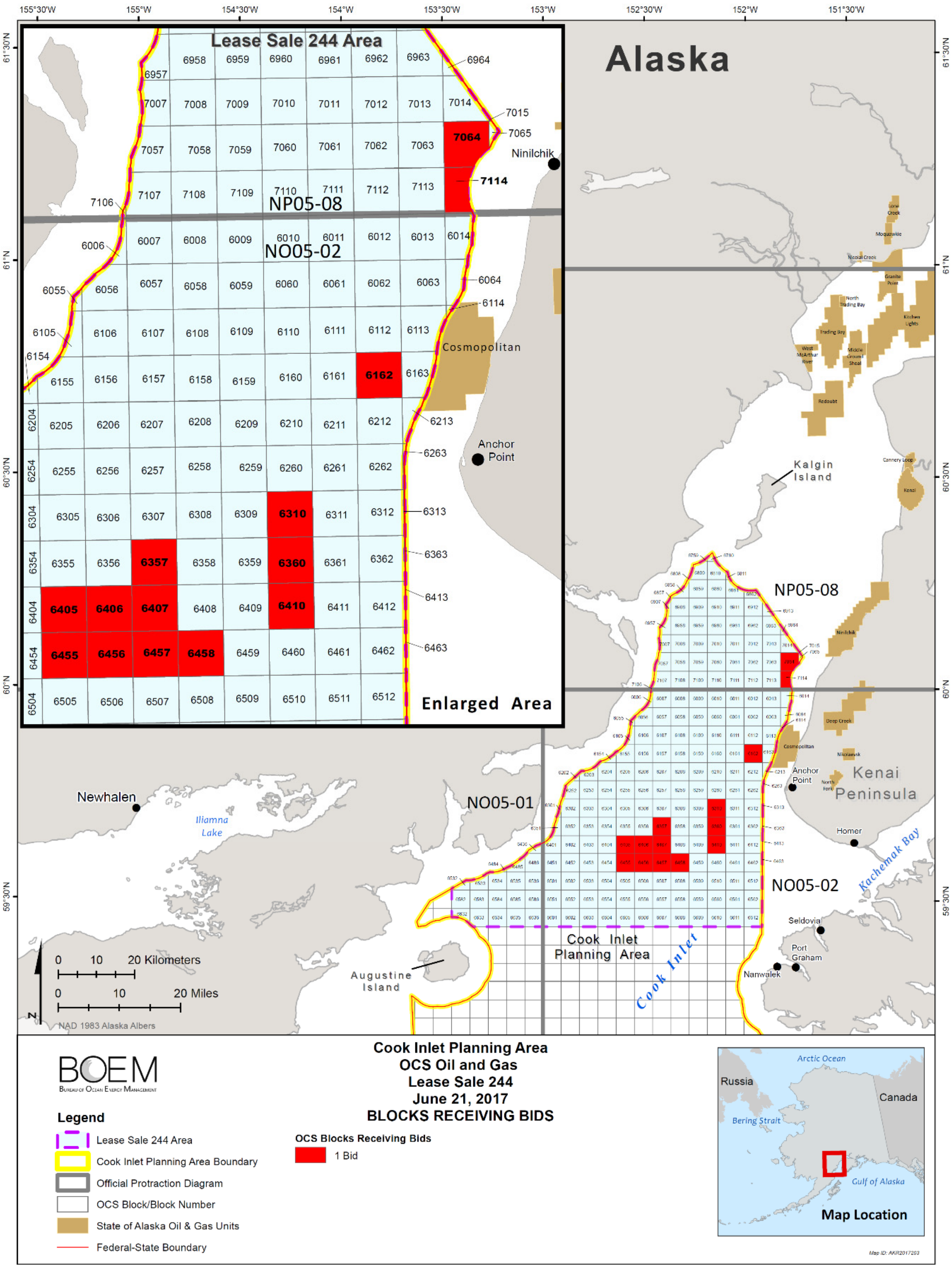


Figure 1.3.3.2. Map of northern portion of the Outer Continental Shelf (OCS) Cook Inlet Planning Area that includes Least Sale 244 Area and blocks, including leased blocks (red).
Map from https://www.boem.gov/Map-of-Blocks-Receiving-Bids/.

The Inlet averages 60 m in depth, with several deeper channels oriented along the axis of the main Inlet (Figure 1.3.3.3). Much of the upper Inlet is shallower than 60 m and the lower Inlet near the mouth is roughly 100 m depth. Kamishak Bay and Kachemak bays are adjacent to the OCS Cook Inlet Planning Area, to the west and east, respectively, and many smaller bays are located around the perimeter of Cook Inlet.

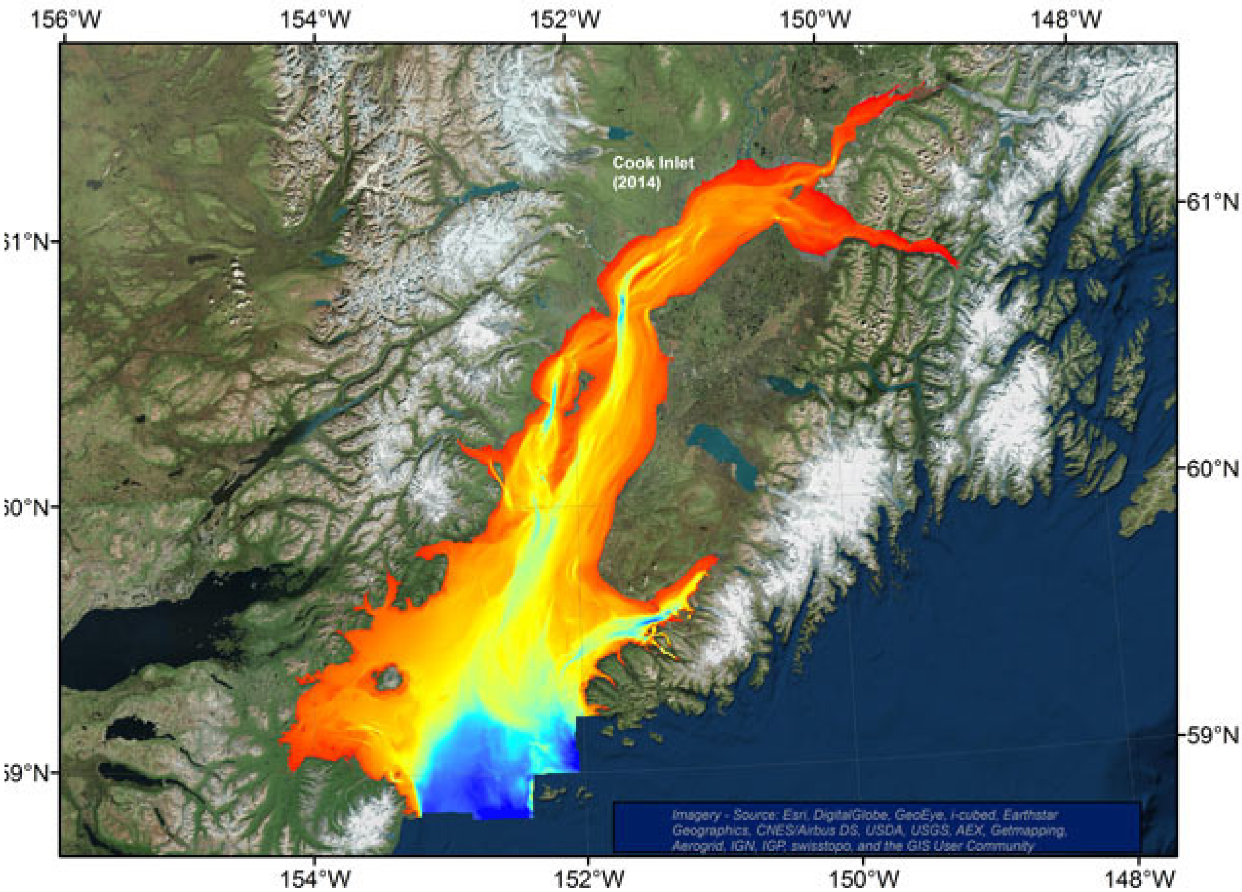


Figure 1.3.3.3. Cook Inlet bathymetry from https://www.afsc.noaa.gov/RACE/groundfish/Bathymetry/images/Bathy_road_map_web_CI.jpg.

Cook Inlet circulation is influenced by tides, wind, upwelling of cold and saline water near the eastern entrance, the seasonal influx of the surface freshwater-driven Alaska Coastal Current, and riverine sources of freshwater. Three major rivers, the Knik, Matanuska, and Susitna rivers, discharge large volumes of freshwater into upper Cook Inlet and, along with numerous other freshwater systems draining into the upper and middle Inlet (e.g. Beluga, Kenai, Kasilof, Big, Drift, and Tyonek rivers), influence surface circulation in Cook Inlet, with a net north to south flow along western Cook Inlet (Figure 1.3.3.4).

Figure 1.3.3.4. CIRCAC model of the net surface circulation in lower Cook Inlet. Adapted from the circulation schematic in Burbank (1977).

Many of the rivers introduce fine glacial sediments to Cook Inlet, with seasonally variable freshwater volumes and sediment concentrations. Suspended sediments introduced by the rivers are transported downstream of Cook Inlet's currents, some of which are deposited in low flow or low turbulence shallow areas around the edges of Cook Inlet. A large portion is also transported to the lower Inlet and Shelikof Strait, as shown by chemical fingerprinting of benthic sediments (Boehm 2001). Sediment plumes from the upper Inlet carried along the western side of Cook Inlet from the upper Inlet can be observed in many satellite images collected and archived by SeaWiFS satellite and satellites housing MODIS instruments (Figure 1.3.3.5).

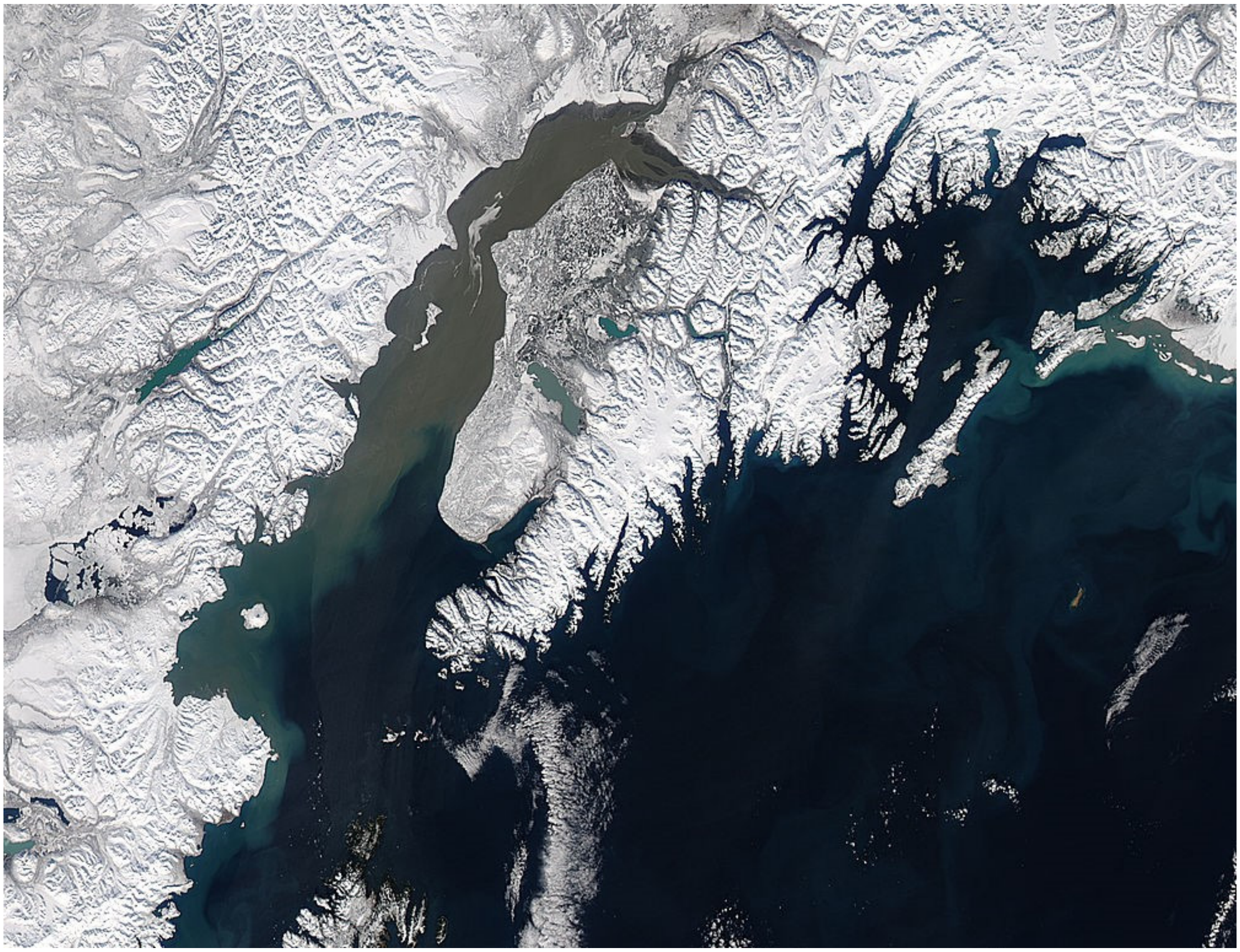


Figure 1.3.3.5. True-color image of Cook Inlet surface sediment plumes captured by Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Aqua satellite 12 March 2013.

Cook Inlet surface freshwater also influences the formation and accumulation of sea ice, mainly as mobile broken ice north of the Forelands, though it can be carried to the lower Inlet. Considerable landfast can also form in shallow Kamishak Bay, as well as at the heads of smaller bays (Danielson et. al. 2016). When ice moves against or into the shoreline, ice can scour intertidal and subtidal substrates, impacting epifaunal, and even infaunal, organisms.

Though freshwater influences the net movement of water in Cook Inlet, tidal currents dominate local currents, the instantaneous sea surface height, and turbulent mixing. Cook Inlet has semidiurnal tides with the natural resonance of the inlet being nearly equal to the daily tidal interval. This creates extreme tidal ranges, especially in the upper Inlet, and tides at the mouth are almost exactly out-of-phase with tides in the extreme upper Inlet. So, for example, when it is low tide at Seldovia it is close to high tide near Anchorage, and *vice versa.* The vertical tidal range varies in the Inlet, with the largest range in the far upper Inlet (where the mean tidal range is 9 m with extreme tidal ranges up to 11 m during the largest spring tides). The mean range tidal range is about 5 m in much of the lower Inlet. The massive volumes of water that move in and out of the Inlet with each tide cause tidal currents that vary with the Inlet's morphology, depth, and tidal range. The interaction of tidal currents with Cook Inlet's bathymetry, create tidal "rips," also known as shear zones, where waters converge or diverge.

Circulation in Cook Inlet strongly influences nearshore substrates by influencing coastal erosion and sediment deposition. Shoreline habitats in the OCS Cook Inlet Planning Area were reported in BOEM's shoreline risk analysis as being roughly 49% exposed rocky shore. Although exposed rocky habitats are considered to have short-term impacts from spilled oil, rugose substrate with complex fractures, indentations, and gravel can create pockets that can retain oil. In western lower Cook Inlet, rocky habitat includes relatively smooth silt and sandstone, highly rugose conglomerate, boulders and cobble on and within bedrock outcrops, boulder and cobble beaches, representing a wide range of oil retention potential. The wide rock platforms and reefs can also experience a range of wave exposures, where wave energy can dissipate over seaward shallow substrate on the seaward, reducing the effective wave energy reaching a more shoreward portion of the intertidal or shallow subtidal zones.

2 Methods

2.1 Defining the Sampling Area and Sites

This study area focused on the western portions of Cook Inlet. While there are some areas of eastern Cook Inlet that require additional study, those areas were not included in this program's field operations for two specific reasons: relative size and proximity to other studies. Lower Cook Inlet is approximately 100 miles long with the majority of that area on the western side of the inlet lacking in depth intertidal surveys, while the majority of the eastern side has had various surveys completed, leaving only a small portion of the western lower Kenai Peninsula without recent in-depth intertidal studies. A part of the reason for this is the proximity to population centers, ease of access, and the Kachemak Bay Research Reserve (KBRR). The KBRR has conducted studies along a major portion of the reserve, while the State of Alaska has conducted numerous studies in the soft sediments of the coastal intertidal region to the north of Kachemak Bay; thus, the majority of eastern lower Cook Inlet has already had intertidal surveys conducted. Therefore, a decision was made to focus on the relatively understudied western Cook Inlet.

Since the entire Cook Inlet shoreline was surveyed and mapped to Alaska *ShoreZone* protocols (Harper and Morris 2004) in 2001-2004 and reimaged in 2009, that habitat dataset (www.*ShoreZone*.org and https://alaskafisheries.noaa.gov/mapping/szflex/) was used to select specific habitat types for the study. *ShoreZone* classifications were used in ArcGIS to identify rocky or mixed rock and gravel shorelines (BC Class of 1-10). Spatially balanced random points were generated within the shoreline segments. The sites were numbered from 1-100 in order of random generation, then selected using the lowest numbers in order until all sites were chosen. The first ten random sites were examined using ArcGIS, *ShoreZone* imagery and aerial photographs and narrowed to six sites using the following criteria:

1. Where a site was within 5 miles of another site, only one site was selected by random draw and the other discarded. In one instance, three sites of the same habitat, exposure and aspect fell within a total of a ten-mile distance (e.g., the middle site was within 5 miles of the two outer sites). Thus, of these three, one was randomly selected.

2. No random sites in the top 10 fell into the southern region of the study area. The lowest numbered site in that region, Site 19, was selected to ensure a site fell in the southernmost region and thereby filled an approximately 10-mile gap in coverage. This site was selected as the sixth site to provide greater geographic coverage.

3. A contingency field protocol was developed. If a site could not be surveyed in the field, the nearest sampleable location would be surveyed instead. This contingency was applied only once, when onshore swells precluded landing the boats onshore at the random site (or anywhere within walking distance for that tide) on Augustine Island. The site was moved to the nearest sampleable rocky habitat.

Due to weather-related difficulties accessing some of our sites in 2017 and 2018, we added nearest sampleable sites with rocky or mixed rock and sediment *ShoreZone* shoreline categories that were more protected (Sites BB1, SI1, and TR1; Figure 2.1.1; Table 2.1.1). This effort also expanded the physical wave exposure range of the study area.

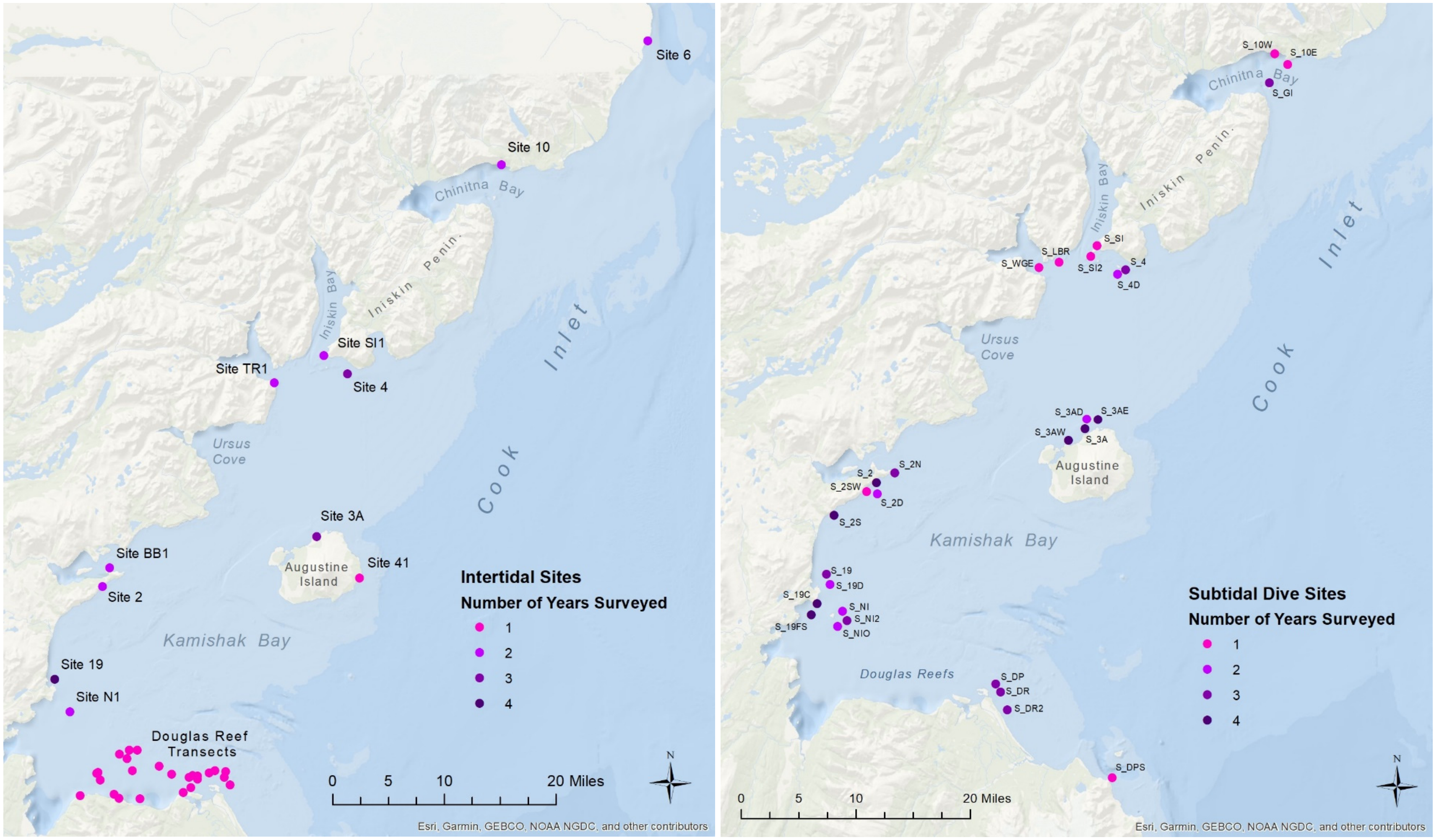


Figure 2.1.1. Maps of the study area indicating the location of the sample sites and the number of years surveyed. Intertidal sampling sites are found on the left side image and subtidal sampling sites are on the right side image.

Table 2.1.1. Table of intertidal sites with the years sampled.

Site Code	Site Name	Survey 2015	Survey 2016	Survey 2017	Survey 2018
2	Contact Point	Yes	Yes	No	No
4	Pomeroy Island	Yes	Yes	No	Yes
6	Iliamna Point	Yes	No	Yes	No
10	Chinitna Bay	Yes	No	No	Yes
19	Chenik Head	Yes	Yes	Yes	Yes
41	Augustine East	No	No	No	Yes
3A	Augustine Island	Yes	Yes	Yes	No
BB1	Bruin Bay	No	No	Yes	Yes
N1	Nordyke Island	No	Yes	Yes	No
SI1	Scott Island	No	No	Yes	Yes
TR1	Turtle Reef	No	No	Yes	Yes
DR_84	Douglas Reef Site 84	No	Yes	No	No
DR_East	Douglas Reef East	No	Yes	No	No
DR_T01	Douglas Reef Transect 1	No	No	Yes	No
DR_T02	Douglas Reef Transect 2	No	No	Yes	No
DR_T03	Douglas Reef Transect 3	No	No	Yes	No
DR_T04	Douglas Reef Transect 4	No	No	Yes	No
DR_T05	Douglas Reef Transect 5	No	No	Yes	No
DR_T06	Douglas Reef Transect 6	No	No	Yes	No
DR_T07	Douglas Reef Transect 7	No	No	Yes	No
DR_T08	Douglas Reef Transect 8	No	No	Yes	No
DR_T09	Douglas Reef Transect 9	No	No	Yes	No
DR_TR10	Douglas Reef Transect 10	No	No	No	Yes
DR_TR11	Douglas Reef Transect 11	No	No	No	Yes
DR_TR12	Douglas Reef Transect 12	No	No	No	Yes
DR_TR13	Douglas Reef Transect 13	No	No	No	Yes
DR_TR14	Douglas Reef Transect 14	No	No	No	Yes
DR_TR15	Douglas Reef Transect 15	No	No	No	Yes
DR_TR16	Douglas Reef Transect 16	No	No	No	Yes
DR_TR17	Douglas Reef Transect 17	No	No	No	Yes
DR_TR18	Douglas Reef Transect 18	No	No	No	Yes
DR_TR19	Douglas Reef Transect 19	No	No	No	Yes
DR_West	Douglas Reef West	No	Yes	No	No
DR13	Douglas Reef East Site 13	No	Yes	No	No
DR18	Douglas Reef East Site 18	No	Yes	No	No
DR20	Douglas Reef Site 20	No	Yes	No	No

Table 2.1.2. Table of subtidal sites with the years sampled.

Site Code	Site Name	Survey 2015	Survey 2016	Survey 2017	Survey 2018
S_10W	Site 10 West	Yes	No	No	No
S_10E	Site 10 East	Yes	No	No	No
S_GI	Gull Island	Yes	Yes	No	Yes
S_SI	Scott Island (new)	No	Yes	No	No
S_SI2	Scott Island	Yes	No	No	No
S_LBR	Lees Black Reef	Yes	No	No	No
S_WGE	White Gull Eat	Yes	No	No	No
S_4	BOEM 4	Yes	Yes	No	Yes
S_4D	BOEM 4 deep	Yes	Yes	No	No
S_3AE	BOEM 3A east	Yes	Yes	Yes	Yes
S_3AD	BOEM 3A deep	Yes	Yes	No	No
S_3A	BOEM 3A	Yes	Yes	Yes	Yes
S_3AW	BOEM 3A west	Yes	Yes	Yes	Yes
S_2N	BOEM 2 north	No	Yes	Yes	Yes
S_2	BOEM 2 shallow	Yes	Yes	Yes	Yes
S_2SW	North of BOEM 2	Yes	No	No	No
S_2D	BOEM 2 deep	Yes	Yes	No	No
S_2S	BOEM 2 south	Yes	Yes	Yes	Yes
S_19S	BOEM 19 shallow	Yes	No	No	No
S_19D	BOEM 19 deep	Yes	No	No	No
S_19C	BOEM 19 close south	Yes	No	Yes	Yes
S_NI	Nordyke Island	Yes	Yes	No	No
S_NI2	Nordyke new	No	Yes	Yes	Yes
S_19FS	BOEM 19 far south	Yes	No	Yes	Yes
S_NIO	Nordyke outer	No	Yes	Yes	No
S_DP	Douglas Point	No	Yes	Yes	Yes
S_DPS	Douglas Point South	No	No	No	Yes
S_DR	Douglas Reef	No	Yes	Yes	Yes
S_DR2	Douglas Reef 2	No	Yes	Yes	Yes

2.2 Subtidal and Intertidal Transect and Quadrat Sampling

2.2.1 Study Design Factors

Intertidal sampling methods were designed to address several challenges to sampling the unique, but ubiquitous rocky habitat in the lower Cook Inlet study area. These challenges included the following: (1) the habitat to be sampled typically extends hundreds of meters between high and low tides; (2) most of the biota is restricted to mid and low tidal elevations; and (3) the majority of available habitat occurs within wide, very low-angle rock platforms, ramps, and reefs with very little change in vertical elevation over tens to hundreds of meters of horizontal distance. This type of rocky habitat dominates much of the study area in western lower Cook Inlet.

Sampling methods that have typically been applied in other Gulf of Alaska intertidal rocky habitat studies focus on several specific tidal heights (typically three: high, mid, and low), along transects running parallel to shore. On the wide rock platforms, ramps, and reefs that dominate the study area, this sampling approach could put hundreds of meters between the horizontal transects, which would preclude sampling a site in a single low tide. Horizontal transects also sample only at specific tidal elevations, therefore only allowing for estimation of trends at a specific elevation. Transects that run perpendicular to the shoreline, as in this study, sample across all elevational zones (Irvine 2001).

To ensure our sampling represented the entire intertidal habitat, there were several factors considered:

1. The sampling area needed to represent the entire tidal range exposed on the day of sampling. This was accomplished by haphazardly sampling along a shoreline-perpendicular transect that ran from Mean Higher High Water (MHHW) to the lowest water on the day of sampling. This ensured that sampling crossed the entire habitat – including any foreshore beach faces, the entire rock platform, ramp, or reef, and any habitat exposed below the Mean Lower Low Water (MLLW), *i.e.* below "zero tide". When laying out each transect, MHHW was estimated based on geomorphological and biological indicators. Subsequent measurements of tidal height using survey-grade GPS as described later allowed for corrections to all tidal heights estimated in the field.

2. Sampling needed to be accomplished in no more than one tide per site, limiting the total number of quadrats that could be sampled while intertidal habitat was exposed. Often, the largest vertical gradients occurred in relatively short horizontal distances at the top of transects and below MLLW, with little elevational changes along the longest sections of the transects at mid-elevations (Figure 2.2.2.1). Long distances between quadrats along a transect could miss those shorter areas where much of the elevational changes occurs. Thus, as described below, quadrat sampling was forced into all tidal elevations and the number of quadrats sampled within a section was scaled to its length.

3. The long transect lengths stretching from MHHW to MLLW required considerable time to collect quadrats along its entire length, minimizing the amount of time that could be spent on any individual quadrat. Thus, two common rocky-intertidal quadrat sampling methods were incorporated in the study design: (1) a point-contact method that collects species data through all epibenthic layers but takes substantial time on site and requires a certain level of taxonomic expertise for identifying invertebrates and algae, and (2) a photo-quadrat method that takes little time on-site but only shows the top layers of algae and invertebrates when interpreted after leaving the field.

2.2.2 **Intertidal Transect and Quadrat Placement**

At each sampling location, a transect tape was stretched from field-estimated MHHW to the water line at low tide, as perpendicular to the low water line as possible. Major physical breaks were defined (e.g., major change in slope or substrate), and zero tide was estimated with a handheld surveyor level and noted on the transect tape. The total tape distances between these breaks were used to determine how many random quadrats would be sampled within each of the sections along each transect. The following was done to ensure that quadrats were sampled throughout the entire vertical tidal range because several sites are dominated by a mid-intertidal low-angle platform, which might preclude quadrats landing in some of the other tidal range habitats (e.g., a short, steep beach face or shorter and steeper subtidal bench):

- For sections with tape distances < 10 m, 6 quadrats were placed within the section.
- For sections with tape distances ≥ 10 m and < 30 m, 10 quadrats were sampled within the section.
- For sections with tape distances ≥ 30 m and < 100 m, 20 quadrats were sampled within the section.
- Finally, for sections with tape distances ≥ 100 m, 30 quadrats were sampled within the section.

The tape distance for each section was divided by the appropriate number of quadrats for the section length and then divided by two (to account for teams sampling on both sides of the transect) to determine the distance between quadrats (Distance X). Then, a random start was established along the transect tape within each section by multiplying the inter-quadrat distance by a random number between 10 and 1 (Distance Y). Distance Y was the tape distance at which each team member stood and haphazardly tossed a quadrat marker within 5 m half-circle to the left or right of the transect tape (making the possible sampling area a 10 m swath centered on the transect tape). Where the marker landed became the upper left corner of the sampling quadrat (with the upper edge of the quadrat placed parallel to the shoreline). Subsequent quadrats within a section were then placed by haphazardly throwing the quadrats within the 5 meter swath to the left and right of the transect tape, standing "Distance X" from the previous tape distance within that section. Photo quadrats (described below) were collected at every sampling quadrat. At every 4^{th} quadrat (from a randomly selected initial quadrat within a section), a point-count quadrat was sampled (described below).

Each beach transect and quadrat lay-out was divided into four sections based on morphology (Figure 2.2.2.2). Using one site as an example, the section closest to MHHW was > 10 m but < 30 m, so 10 quadrats were sampled within that section. On that particular site, the first section included a large portion of the vertical change along the transect (Figure 2.2.2.1). The second and third sections were both on a long flat platform. One section was > 100 m long and 30 quadrats were sampled within that section. The third section was > 30 m but < 100 m so 20 quadrats were sampled. Finally, the lower end of the transect closest to the waterline encompassed a relatively short horizontal distance but included all of the tidal zonation between MLLW and the waterline during a minus low tide. The tape distance was > 10 m but < 30 m, so 10 quadrats were sampled in the lowest section to the waterline. Red circles show the location of each 0.5 m x 0.5 m quadrat along the transect (symbols are much larger than the quadrat itself) where data for both point-count quadrats and photo quadrats were collected. The orange circles are photo quadrats only.

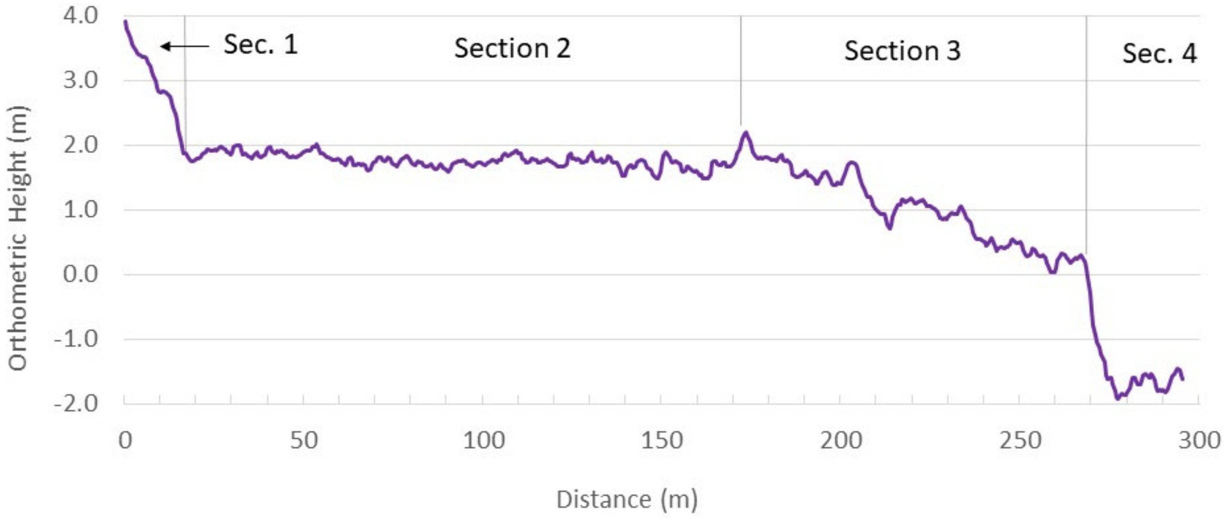


Figure 2.2.2.1. Profile of representative intertidal site transect showing section breaks.

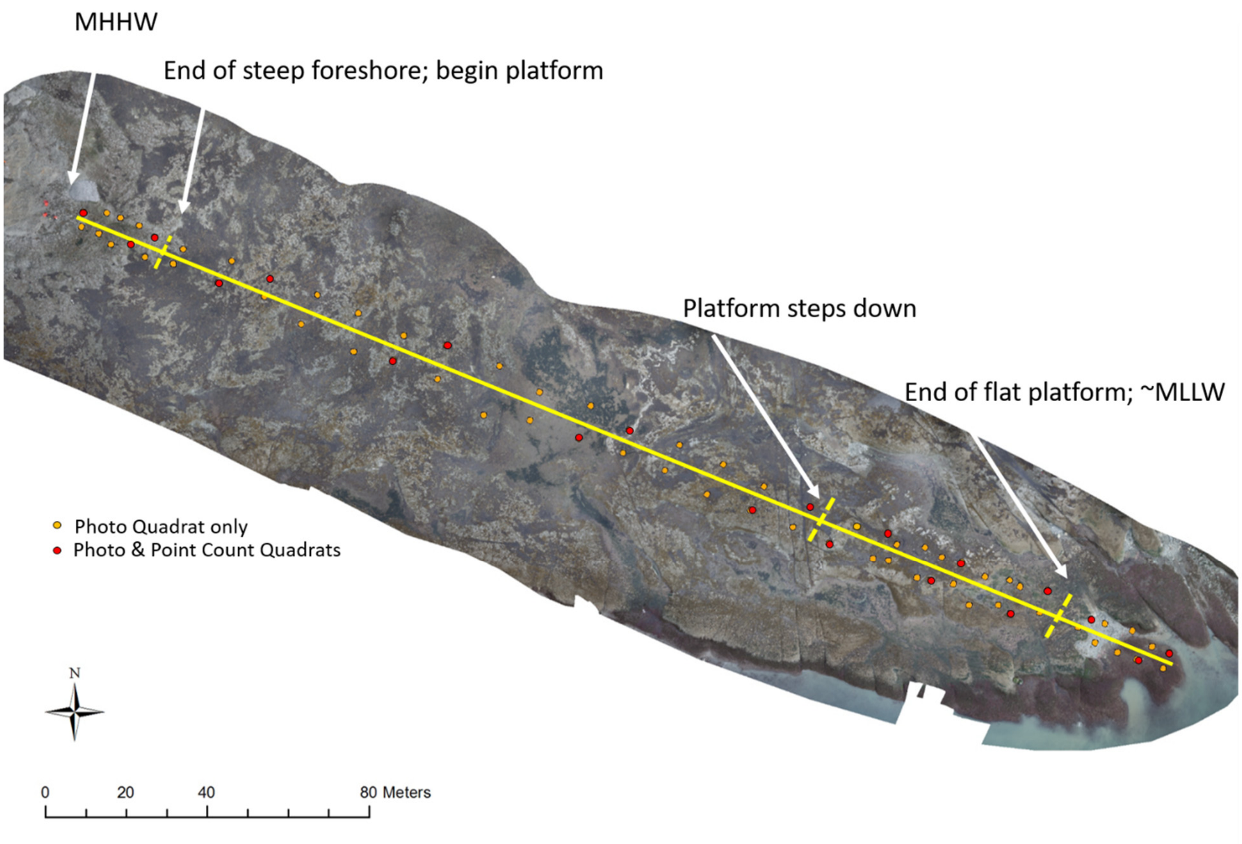


Figure 2.2.2.2. Example transect and quadrat layout on a representative intertidal site. The aerial imagery was collected in 2018 by Unmanned Autonomous System (UAS) with RGB sensor camera. The transect stretches from MHHW to the waterline and is separated into 4 sections based on site morphology. Quadrats were placed according to section distance rules where a photo quadrat was collected at each quadrats location. Point-count data (through the layers of epiflora) was collected at every fourth quadrat within a section (from a randomized quadrat start).

2.2.3 **Subtidal Sampling**

The subtidal sampling protocols followed a modified version of the standardized sampling procedure developed for hard bottom macroalgal-dominated communities within Census of Marine Life (Rigby et al. 2007). The target subtidal sites sampled were directly offshore from the randomly chosen intertidal sites. Our target depth was 5 m; however, because of tides and available appropriate habitat, there was some variability in depth and location. In addition to our offshore site, we also sampled satellite sites on either side of the intertidal site at the most appropriate depth/habitat (i.e., rocky points where hard substrate could be found). Where possible, we targeted historical subtidal sites for these satellite sites. In 2015, all sites were collected for biomass and for percent cover (see below for details). In subsequent years (2016-2018), only the main site (those aligned with the intertidal sites) were sampled for biomass and all sites were sampled for percent cover.

At each site, one 30 m transect was laid along the approximately 5 m depth contour. All sea stars and large anemones were identified and counted within 1 m of both sides of the transect. Along the transect, ten haphazardly placed 1 x 1 m replicate quadrats were quantified for all macrophytes and conspicuous macrofauna (>2 cm length). For this, large solitary macroalgae (i.e., kelp stipes) and conspicuous fauna such as crabs, seastars, sea cucumbers, etc., were counted and an estimate of percent cover was made for all macroalgae, other colonial or encrusting organisms, and bare rock. In the percent-cover data, we estimated overstory percent cover (kelps) separate from the rest of the community. In addition to the 1 x 1 m quadrats, we destructively sampled ten 50 x 50 cm quadrats to determine macroalgal and invertebrate biomass. For this, all macrophytes and fauna within each quadrat were carefully and completely removed and placed into separate fine mesh bags. Macroalgae were only collected if the holdfast fell within the quadrat. The quantitative samples were brought back to the vessel and sorted to the lowest possible taxa, wet weight was determined, and a herbarium/invertebrate voucher was prepared if the specimen was unknown.

2.2.4 **Intertidal Sampling**

To effectively sample the full intertidal habitat in the study area, field sampling was scheduled during one spring tidal series each year. Efforts were made to sample during a late May or early June tide series each year, though the low-tide series did not occur during the same time of month each year. Additionally, the sea-level height of low tide differs each day and in a roughly 7-day window where the lowest tide of each day is below MLLW, there can be over a 1.5 m difference in vertical range exposed during that low-tide series.

Instead of normalizing all sampling to a common tidal range, which would preclude sampling the lowest intertidal habitats exposed during the lowest tides of the series, sampleable habitat was considered to be the lowest tidal height for that day on that beach. Thus, the tidal range sampled varied spatially during any one sampling period and when comparing an individual site over multiple years. Although MLLW (a tidal datum) is referenced in this report, a lack of tide gauges in the project area has resulted in a lack of official tidal heights. Thus, elevations for each quadrat were collected in orthometric heights, where 0 is equivalent to modeled mean sea level

(MSL). Orthometric heights were adjusted to an unofficial MLLW tidal datum that was made available during revisions to this report. Refer to Section 2.3 for additional information.

Photos were taken at all of the quadrat locations. This was done by placing a placard with the quadrat name (reflecting site, team, and quadrat number) within the photo frame. At least two photographs were taken that included the 0.5 m x 0.5 m quadrat frame, taking care to minimize shadowing and reflections and zooming in so the quadrat filled the frame. Additional photographs were often taken that zoomed into specific areas of a quadrat to provide the photo-interpreter with additional higher resolution imagery of species assemblages, as needed. For every fourth quadrat within each section (from a randomly chosen starting quadrat), point-count quadrat data were collected by each team (left and right side of tape). Point-count quadrat data (also called random point contact) included recording identification of contacted species to the lowest taxonomic level, invertebrate count, and identification of presence of non-contacted species.

2.2.4.1 **Point-Count Quadrats at Intertidal Sites**

For point-count data collection, a 0.5 m x 0.5 m quadrat was strung to create a 25-point grid. Beneath each intersecting point of the grid, all species were recorded that occurred through the layers of attached epifaunal invertebrates and seaweeds. Substrate under each point was also recorded. Point-count quadrat data were converted to percent cover by summing the number of points under which a taxa occurred and dividing by the total number of possible points in the quadrat. Mobile invertebrates were counted within the quadrats and species within the quadrat that did not land under a point were also recorded and their percent cover estimated. Species observed on the beach that did not land in quadrats were also recorded to provide comprehensive taxa lists for each site. Note that point-count percent cover summed for all species can be > 100% because all taxa are recorded through the layers (i.e., taxa were identified beneath overlain taxa).

2.2.4.2 **Photo Quadrats at Intertidal Sites**

The photographs from the photo quadrats were interpreted by an intertidal ecologist with ample experience identifying Alaskan seaweeds and invertebrates but who had not participated in collecting data during the lower Cook Inlet field study. This decision was made to aid future decisions on field efforts in regards to the trade-offs in cost and the quality of data collected in the field by trained taxonomists versus sending non-taxonomist field technicians out to collect photographs.

Interpretation of quadrat photographs was done on a desktop computer following the field collections. Photographs with the entire quadrat frame in the image were scaled to a known size on the monitor. Taxa observed were identified to the lowest possible taxonomic level. Alternatively, if a species could not be identified, a morphological or descriptive term was assigned (e.g. green blade, unknown hermit crab). For photo quadrats, taxa and bare substrate were recorded for only one layer. That is, no overlapping cover for understory was recorded (since underlying taxa or substrate are not visible in a photograph).

Percent cover of each observed taxa or substrate was recorded to the nearest whole number percent observed. To aid cover estimates, templates of known size relative to the scaled photograph were overlaid on the photo. If additional zoomed-in photographs were available, those were reviewed to allow identification of species to the highest taxa possible. Taxon that were present at less than 1% cover were recorded as 0.1% to represent those rare species. Estimated percent covers for all taxon plus bare space summed to 100% cover for each quadrat. Rare species (those that occurred at less than ~0.5% and thus not rounded up to 1%) were reported as 0.1% due to the inability to estimate accurately to the tenth decimal place. This ensured that rare species were captured in species richness analyses but did not contribute significantly to overall quadrat percent cover. The addition of 0.1% for rare species allowed quadrats with one or more rare species to total slightly more than 100% cover. All observed mobile invertebrates were also counted and recorded.

2.2.4.3 **Intertidal Site Species and Voucher Collections**

A representation of algal species and their various morphologies were collected, pressed and vouchered for taxonomic identification during the 2015-2018 field efforts. Weatherproof digital cameras were used on the beaches to capture benthic marine algae in their natural habitat and for species that cannot be easily removed or preserved (e.g., coralline and crustose algae). Collected specimens were preserved using a wet-mount technique to display their morphology on herbarium paper and then dried in a plant press (Figure 2.2.4.3.1). Pressings were digitally scanned and select specimens archived at the University of British Columbia Herbarium. A listing of the collection will be shared with the Smithsonian and specimens donated upon request. A complete taxonomic listing of benthic marine algae, seagrasses and a digital catalog for the region are provided in a separate NOAA Technical Memorandum publication (Lindeberg and Lindstrom, in progress).

Figure 2.2.4.3.1. Preserving voucher specimens using a wet mount technique to display benthic marine algae morphology and drying in a plant press.

2.2.4.4 **Douglas Reef Transect and Quadrat Sampling**

Special considerations needed to be taken for the Douglas Reef area in southern Kamishak Bay on the northern edge of the Alaska Peninsula that is offshore of the northern reaches of Katmai National Park and Preserve. Douglas Reef is a 4-mile-wide x 24-mile-long reef with three distinct subunits separated by two large channels. The size and length of the reef precluded the use of identical sampling operations. To conduct sampling in this area, it was necessary to modify the approach taken throughout the rest of the study area to address these complicating factors.

Many methods used in the intertidal sampling scheme were not applicable to the offshore reefs. *ShoreZone* classification was not conducted on those reefs, so using *ShoreZone* coastline with certain substrate classes was not an option. Additionally, creating a transect line from beach to low tide was not possible on the reefs, since they are offshore and partially submerged, lack a beach, and possess variable but unknown tidal depths.

An estimated MLLW line was drawn around the reefs using NOAA nautical charts and 2012 low-tide color infrared aerial imagery acquired by Katmai National Park and Preserve. In mapping software, random points were generated inside of the reefs, and also within a 100 m buffer of the MLLW mark. The points were assigned random numbers.

The reef was divided into west, central, and east sections. During sampling, the lowest random numbered points in each section were visited during one field day. The following day, the lowest random numbered points in the next section were visited. This reduced time lost traveling between random transects. Because unknown portions of the reefs would be exposed or submerged at different times in the tide cycle, a rule was implemented that the helicopter would land near the water line closest to the random point, which might be submerged. One-hundred-meter transects were run perpendicular to the water line. If the tide was falling, a transect line would be started near where the team was dropped off, and work down with the falling tide. If the tide was rising, the transect would work its way up to the interior of the reef. This allowed for sites with a range of tidal heights to be surveyed.

As in the intertidal methods, quadrats were sampled by a haphazard toss at set intervals along the transect. In 2017, due to limited aircraft capacity, only one team sampled each reef transect, rather than the two-team model used in the intertidal surveys. A 10 m distance between quadrats was used for the reefs, yielding 10 quadrats per transect. In 2018, the aircraft had capacity to carry two teams of two. One team (“Fixed transect team”) surveyed 10 quadrats along the transect line, while the other team (“Random team”) threw quadrats haphazardly, and examined the areas for additional species as time allowed.

2.2.5 **Data Entry and QA/QC**

Point-count quadrat data and site species data were entered in excel files in the field. The separate field data excel worksheets for point counts, mobile invertebrate counts, and additional site species occurrences for each year were subsequently integrated into a relational database that linked to additional quadrat and site information (e.g., digital elevation data from RTK). Species data were entered using data entry codes that represented the identified taxonomic level. During the course of the four-year study, there were numerous name changes or corrections to field identifications based on an expert taxonomist’s evaluation of voucher specimens. All data entry codes were corrected to the most recent recognized name change and linked in the database to a table of taxonomic classifications for each reported taxon. All original data entry files were retained and corrections were made by building queries with “code-correction” tables.

In the database, each algal taxon was assigned a morphological classification based on classifications by Lindeberg and Lindstrom (2015) or recommendations by the authors.

Invertebrates were assigned a classification that combined their mobility (sessile or mobile) and feeding strategy. This allows future analyses of organisms to be lumped to ecosystem function instead of just through taxonomic level. A cross-reference table was also made for the algae that were lumped and described by form and color for those instances where photo interpretation was not possible taxonomically to allow direct comparisons of point-count data and photo-quadrat data.

2.2.6 Subtidal Data Analysis

Biomass of macroalgae and invertebrates was treated separately for data analysis because macroalgae always occurred in much higher biomass than invertebrates. In addition, it was of interest to analyze whether algal and invertebrate assemblages showed similar patterns in space and time. The taxa making up the two assemblages were assessed to see if taxon composition was distinct for sites and stable over time. All data were transformed to address non-normal distributions. Assemblage composition was evaluated with non-metric Multidimensional Scaling (nMDS) on transformed data in a Bray Curtis resemblance matrix. To account for highly unevenly distributed weights (e.g., kelps), macroalgal data were first dispersion weighted and then square-root transformed, while invertebrate data were fourth-root transformed. A negligible dummy variable of 0.001 was used in the Bray Curtis resemblance matrix to deal with the high number of zero values and to preclude undefined resemblance values. The effects of sampling site and year for both the macroalgal and invertebrate assemblages were also assessed with PERMANOVA, with site as fixed factor and year as random factor. To assess if high interannual variability in community composition could be alleviated by sampling a site several years, community variability was assessed by averaging community data in an iterative process over two, three or four years, depending on how many times a sites was sampled. For example, if a sites was sampled for three years, community data were averaged over years 1 and 2, 1 and 3, 2 and 3, and lastly over all 3 years. Similarities among these averaged site compositions were assessed in a Bray Curtis resemblance matrix and visualized in a non-metric multidimensional scaling plot. All statistics were conducted using the software package Primer v7.

For the percent-cover data, macroalgae and invertebrates were treated together. The overstory cover of large kelps was combined with the understory percent-cover data, meaning that total percent cover could exceed 100%. Data were dispersion weighted and then square-root transformed before analysis. In addition, similarity of satellite sites was compared to community composition of the nearby main sites. For this, main and associated satellite sites were grouped by major “region” to assess if satellite coverage assisted in describing various regions of the overall study area. Sites within regions were: S_GI, S_10W, S_10E in Chinitna region; S_4, S_4D, S_SI, S_SI2, S_LBR, S_WGE in Ilimana region; S_3A, S_3AD, S_3AE, S_3AW in Augustine region; S_2, S_2D, S_2S, S_2N, S_4D, S_4, S_SI, S_I2 in Contact region, S-NI, S-NI2, S_NIO in Nordyke region, S_19S, S_19D, S_19C, S_19FS in Chenik region, and S_DP, S_DR, S_DR2, S_DPP in Douglas region.

2.2.7 Intertidal Data Analysis

Detailed data analyses for the intertidal sites are described below. In summary, species richness was estimated for all quadrats to facilitate comparisons of field methods. Systematic differences in total site richness among methods were quantitatively assessed using a generalized linear mixed model using a Poisson distribution. Observed elevational ranges of intertidal species were initially determined based on modeled MSL (0 height in the orthometric datum) because an offset to a tidal datum (MLLW) was not available at time of data analysis. An unofficial conversion to MLLW datum has subsequently been made available and data has been converted (see section 2.3). To examine the variation in community assemblage (percent cover) across sites (spatial variation) and across years at specific sites (temporal variation), nMDS plots were created as visualizations. Overall site descriptions are also provided in section 3 and include summaries of physical attributes such as slope, substrate type and aspect.

2.2.7.1 **Quantitative Assessment of Field Sampling Methods: Site Richness**

To determine how the use of photo-quadrat versus point-count methods impacted species richness, a rigorous comparison of the two methods was made, first by comparing richness values for only attached epiflora and epifauna recorded for the two methods. Additional comparisons were made for more time-intensive data collections, including counts of mobile invertebrates and the species observed by experts on site that may not have been recorded within quadrats. The data that were used for each of the seven different data sampling and measurement comparisons are:

(i) Photo-quadrat identification of attached epiflora and epifauna for only those quadrats where point-count quadrat data were also collected,

(ii) Point-count identification of attached epiflora and epifauna for only the “top layer,”

(iii) Point-count identification of attached epiflora and epifauna through all layers,

(iv) Photo-quadrat identification of attached epiflora and epifauna for all photo quadrats (a sample size 4 times that of the point-count quadrats),

(v) Photo-quadrat identification of attached epiflora and epifauna and mobile invertebrates (includes all photo-quadrats),

(vi) Point-count identification of attached epiflora and epifauna and mobile invertebrates through all layers,

(vii) Point-count identification of attached epiflora and epifauna through all layers, mobile invertebrates, and species observed by unconstrained expert search within each site that included taxa that may not have landed within any quadrats.

As described above, photo-quadrat interpretation was conducted by a coastal ecologist with experience identifying Alaska seaweeds, but who had not participated in the field study or observed species lists for any site. This was to provide an “extreme” example of one method for field sampling; sending opportunistic samplers (who may have no taxonomic experience) into the field to collect photo-quadrats for later interpretation by experienced Alaskan ecologists. Point-count quadrat and species lists were collected on-site by coastal ecologists with ample experience identifying Cook Inlet algae and invertebrates.

Comparison of (i), (ii), and (iii): By including only those photo quadrats where point-count quadrat data were collected, the comparison between **(i)** and **(ii)** removes differences in sample size, since more photo quadrats were collected at each site. **Method ii** only includes the top layer data from point count quadrats; thus, it removes the differences due to the inability to see “understory” species in the photographs and focuses the comparison on the ability to identify taxa from photographs when the observer has no on-site data collected by experts on which to rely. Photo interpretation can be limited by photo quality (e.g., resolution, glare, shadows, dirty lens, etc.) and the inability to examine the species on-site. **Method iii** adds data for organisms beneath the top layer in point-quadrats; layers that cannot be observed in the photographs (i.e. understory species that are covered by another species).

Comparison between (ii) and (iii) identifies the number of taxon missed if only surface point-count quadrat data are collected on-site. This is a relatively rapid method of collecting on-site data compared to collecting data through all layers, but emphasizes “overstory” organisms.

Comparisons between (iii) and (iv) represent the differences in attached epiflora and epifauna richness with greater sample coverage and reduced “information resolution” ((iv), photo interpretations at 4x the number of quadrats as point-count quadrats) versus fewer samples that are more intensively measured (iii).

Comparisons between (v) and (vi) represent a similar tradeoff as between (iii) and (iv), but additionally includes mobile invertebrates. Counting mobile invertebrates within quadrats takes considerable time on-site or during photo interpretations, especially when there are high numbers of grazing littorine snails or juvenile limpets.

Comparisons between (vi) and (vii) show the gain in species richness of having an ‘expert search’ to include species that may not have been observed in the haphazard quadrats but that occur on-site.

For all data in the above comparisons, the taxonomic data included all taxonomic levels. For example, if in the photo-quadrat interpretations, *Neorhodomela aculeata* was identified on that site, and filamentous red algae was also identified, they were both included in the analyses even though the species called filamentous red algae might have been *N. aculeata* but not identifiable due to the photo quality. The same rule was applied for the point-count quadrat data. Thus, the data represent an “inclusive” interpretation of taxonomic richness. Later, we provide examples where the comparisons were more conservative and the assumption was made that if a taxon was also recorded at a lower taxonomic level, the higher taxon was removed. In the *N. aculeata* example, “filamentous red algae” would be removed from the taxon list if *N. aculeata* was identified.

2.2.7.2 **Multivariate Analyses of Intertidal Data**

The variation in intertidal community assemblages were explored at various levels of taxonomy (e.g. “lumping’) using nMDS analyses. NMDS seeks to find an adequate low-dimensional representation of the ‘distances’ among collections. A good two-dimensional nMDS is a 2-d mapping that retains the relative ordering (rankings) of Bray-Curtis distances among all pairs of collections. Adequacy was judged with respect to its ‘stress’ value. While there are no objective thresholds for judging adequacy (such a threshold depends on both the number of collections and the number dimensions or taxon) (Krzanowski 1993), Clarke et al. (2014) summarize simulation studies and practical applications with the following rule-of-thumb regarding stress: < 0.05 = excellent representation; < 0.1 = good ordination with little chance of misleading interpretations that would be clarified looking at higher dimensions; < 0.2 = potentially useful 2-d picture, though examine higher dimensions to avoid misinterpretations; > 0.3 = useless, effectively a random mapping.

The nMDS projections were based on the Bray-Curtis distances for various year, site, site-year, and tidal height combinations. First, all years of observations from the 10 "core" (non-reef sites, 24 total collections) looking at site-level and year-specific mean percent-cover data for each of the lumped taxon (Chlorophyta (all), Rhodophyta-not Corallines, Rhodophyta-Corallines, Ochrophyta-not kelps, Ochrophyta-kelps, sessile invertebrates, and bare substrate). The mean percent cover was calculated to account for the stratified data collection design.

Further nMDS analyses included the full species assemblages at each site (over all tidal heights), estimated using the lowest taxonomic level data from point-count quadrat data. The estimation followed the stratified design of the data collection process at each site & year: for each 'taxon' of interest, the mean percent cover was estimated for each strata; the weighted average of the strata mean estimates was calculated using the relative length of each transect segment as the 'strata weights' (Cochran 1977). A similar approach allowed estimation of the standard errors for each taxon's site-level mean percent cover (for that year of observation). NMDS were also calculated distinguishing binned tidal heights for site and year combinations.

Projections for the 10 core sites were also fit using binned tidal height data for percent cover by site and year. Douglas Reef sites (only one time sampling at each site location) were based on the Bray-Curtis distance between binned tidal height (relative to MLLW) mean percent-cover data.

A variety of transformations of the site-level mean percent-cover estimates were considered (these were applied prior to the calculation of the similarity matrices and calculations of the nMDS): arcsin, square root, 4th root (square root of the square root), and base-10 logarithm of "% Cover + 1" (Clark et al. 2014). An nMDS was fit for each transformed data set for each of the 5, 4, 3, and 2 dimensional mappings and the resulting stresses compared to identify an acceptable transformation, if any, and dimensionality of the nMDS. The transformations 'down-weight the importance of the highly abundant species' (ibid), effectively increasing the importance of less common species. The more nonlinear the transformation, the greater the down-weighting (e.g., more down-weighting under 4th root than under square root). Note that the percent-cover estimates were already constrained to the same range of possible values, [0,1]; subsequently, common standardization methods such as rescaling each taxon to its maximum value, etc., were not found to be useful and thus not employed.

Based on a scree plot of stress values from nMDS under a variety of data transformations and desired number of mapping dimensions, the 4th root transformation was applied (Appendix D). Given that the 2-d and 3-d nMDS solutions still generated stresses in the 0.10 < stress < 0.20, attention focused on the 2-d nMDS and using other assessments of consistency to check for higher-dimensional structure obscured in the 2-d maps. The assessments of the performance of the final nMDS are provided in Appendix D.

2.3 Survey-Grade GPS

This section describes the methods used to collect GPS data (e.g., Real-Time Kinematic (RTK), Post-Processed Kinematic (PPK), or handheld recreational grade). It will also clarify where we have digital elevation models (DEM) and how GIS data are used to provide high-resolution elevation and position data to place each quadrat within the RTK grid or the need to acknowledge that not all sites have an RTK grid.

In order to evaluate intertidal communities on the wide, low-angle habitat of this study, it is important that high-resolution tidal-elevation data can be linked to the sampling locations (data transects and quadrats). A survey-grade RTK GPS system (Trimble® R8-3 base station with Trimble® R8-3 or R10 Rovers) was used to collect GPS data during the intertidal surveys. The RTK system is capable of collecting data to an accuracy and precision of approximately 2-3 cm horizontally and vertically, following post processing. The resolution depends on the distance from control stations and other survey or geodetic monuments, and on whether or not the location data can be corrected using NOAA's Online Positioning User Service (OPUS). PPK is similar to RTK, was used in situations where radio contact with the base station was interrupted due to distance or obstructions, and requires an additional post-processing step to achieve high accuracy and precision.

Vertical positional information was collected in the vertical datum of ellipsoidal height. The vertical datum was transformed to orthometric height (NAVD88) with the Geoid12B model. Orthometric height was used because 0 elevation represents modeled mean sea level (MSL) based on a gravity model.

It is important to recognize that while all of these elevations are accurately measured relative to the earth and each other, even with these corrections, the orthometric heights are not tied to a tidal datum such as MLLW. The sea surface is variable and is assessed through the use of tidal stations to create tidal datums. Official tidal datums for the western Cook Inlet have not been established due to a lack of official or public tide stations in the lower portion of western Cook Inlet. After data analysis was done for this report, an unofficial table providing the offset from orthometric heights to MLLW heights at each site was provided to us by a private company, JOA Surveys, LLC. All elevations in the tidal datum (MLLW) presented in this report or derived from the conversion table are approximations based on estimates from private or unpublished temporary tide gauges at Gull Island in Chinitna Bay and near Amakdedori Beach (Figure 2.3.1), and should not be considered official elevations or used in an official capacity.

Figure 2.3.1. Location of unofficial or private tide gauges used to create MLLW datum conversion. Amakdedori Tide Gauge location is approximate.

Table 2.3.1. Unofficial Conversion from Orthometric MSL to MLLW for Intertidal Sites
MLLW = H-N, where H is orthometric height, and N is the offset from Orthometric 0 to MLLW.

Site Name	Offset from Orthometric 0 to MLLW (m)
Site 2	0.992
Site 4	0.918
Site 6	1.413
Site 10	0.985
Site 19	1.018
Site 3A	0.96
Site BB1	0.971
Site N1	0.998
Site SI1	0.852
Site TR1	0.926

Table 2.3.2. Unofficial Conversion from Orthometric MSL to MLLW for Douglas Reef Transects
MLLW = H-N, where H is orthometric height, and N is the offset from Orthometric 0 to MLLW.

Transect Name	Offset from Orthometric 0 to MLLW (m)
DR 13	0.958
DR 18	0.964
DR 20	0.972
DR 84	0.982
DR East	0.961
DR T01	0.966
DR T02	0.966
DR T03	0.965
DR T04	0.964
DR T05	0.957
DR T06	0.962
DR T07	0.977
DR T08	0.979
DR T09	0.979
DR T10	0.959
DR T11	0.97
DR T12	0.966
DR TR13	0.974
DR TR14	0.977
DR TR15	0.981
DR TR16	0.981
DR TR17	0.978
DR TR18	0.978
DR TR19	0.983
DR West	0.982
41	0.969

2.3.1 Survey control

A base station consisting of a tripod and a Trimble® R8-3 base GPS receiver was set up above the high-tide line near the top of each transect (transect placement described below). When possible, the base station was set up on an existing survey monument or on bedrock in an area with a clear view of the planned sampling transect (transect layout described below). In the absence of exposed bedrock, the base station was set up on a large boulder. OPUS solutions necessary to post-process the data were achieved at all sites, which required a minimum 4-hour occupation of each base station site.

2.3.2 GPS Settings and File Management

At each site, a new job was created on the GPS controllers using the Trimble Access program. Each job used the NAD 1983 (2011) State Plane Alaska Zone 5 coordinate system, and vertical datum Geoid 12A (Alaska). Map units were meters. Two Trimble® GPS rover units (R8-3 and R-10) were used to collect point data. The intertidal survey group was divided into two teams, "A" and "B," and one rover was dedicated to each team. Each rover's job file was given a unique name identifying project, operator, site, and date. Naming conventions were also used at the individual point level for data management. Quadrat locations were collected in the "topo" method set to collect and average five seconds of GPS data for each point.

2.3.3 GPS Field Methodology

Each of the two rovers were mounted on a 2 m fixed-height pole with an attached bipod. Points were recorded at the start and end of each transect, at visually estimated tidal stages such as mean sea level, and at the upper left corner of each quadrat. In initial surveys within the first year of sampled sites, rovers were used on fixed height mobile rods and collected points every 10 cm in a grid pattern over the site. This method was not continued in following years because of safety and time concerns. In 2018, the lower-right corner of each quadrat was also collected for more accurate positioning of the data relative to additional high-precision aerial imagery.

2.3.4 Data Download

Data were downloaded from the data loggers and base station daily and backed up each night. Each rover's daily data were imported into Trimble Business Center® as a new job. Each new job was created in the same coordinate system that the data were collected: NAD 1983 (2011) State Plane Alaska Zone 5, vertical datum Geoid 12A (Alaska), meters. In subsequent years Geoid 12B was used, but there is no difference between Geoid12A and Geoid12B in Alaska so this did not affect comparison of data between years.

2.3.5 Data Processing

To achieve positional accuracy of 1-3 cm, all GPS data were post-processed against the OPUS-adjusted base station data.

2.4 Structure from Motion (SfM): Aerial imaging for high-resolution digital elevation data

This section describes methods for collecting high-resolution imagery for Structure from Motion (SfM) using both manned and unmanned aircraft. SfM is a modern photogrammetry method that utilizes computer algorithms to match points between images rendering a three-dimensional model of the site with detail based on the resolution of the images and precision based on ground control points or precisional accuracy of the GPS unit associated with the images.

2.4.1 Manned Aircraft

The collection of aerial imagery was conducted predominantly using manned aircraft with a camera and GPS system collecting images through a belly port of the aircraft (Figure 2.4.1.1). A manned aircraft was chosen to cover the large spatial area being surveyed in the limited time available in sampleable low-tide windows of the tidal cycle.

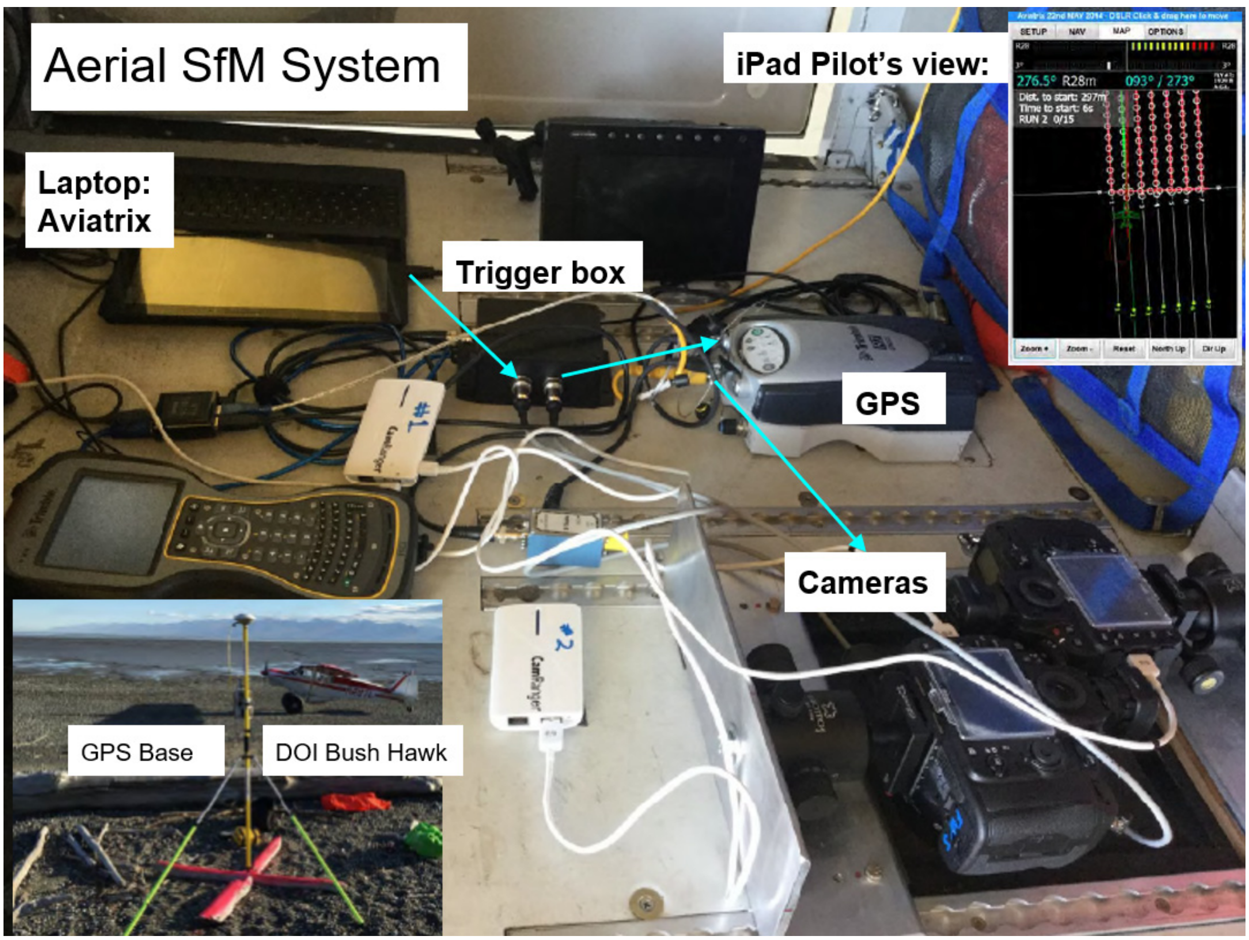


Figure 2.4.1.1 Aerial SfM system used to collect manned aerial imagery for subsequent photogrammetric processing.
The process is described in section 2.4.2.

2.4.2 **Survey Areas and Methods – Manned Aircraft**

The aircraft used for this operation was a Found® Bushhawk, being flown at either 1800 or 2400 ft above ground level (AGL) at approximately 80 kts. The Bushhawk was outfitted with two Sony® D810 (in 2018 D850) cameras fitted with Nikon® 24 mm lenses. One camera was collecting RGB imagery (Red, Green, Blue) while the other camera was modified to collect NIR, G, and B wavelengths (Near-infrared, green, and blue). The cameras were connected to a trigger box that sent a signal to the cameras to take pictures while simultaneously sending a signal to a Trimble® R7 GPS data logger to log the event. The signal was triggered by the aerial imagery flight planning software Aviatrix®. The flight planning software was used to plan the aerial transects and identify the specific x,y,z coordinates (set to an allowable 100 ft deviation) in the air for the aircraft to collect imagery (Figure 2.4.2.1). During flights the pilot was given transect and image collection locations via the flight planning software, and locations for the GPS and the software were provided via an aircraft mounted survey antenna. This combination of equipment and operation allowed the aircraft to collect images with a ground-sample pixel size of approximately 10 cm. This was equivalent to the RTK grid originally being collected.

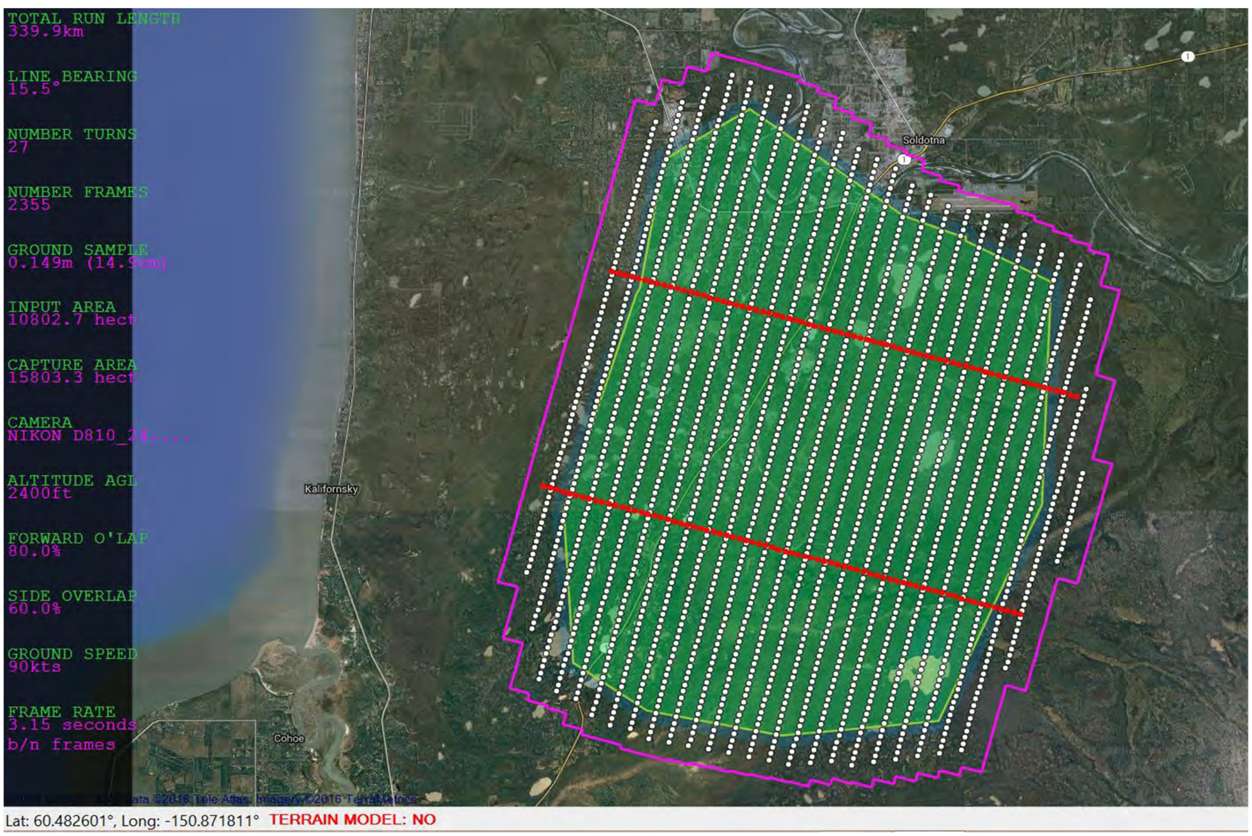


Figure 2.4.2.1. Aerial flight planning software indicating a planned grid pattern for flights. The green indicates the area of interest to be surveyed, the red and white dots indicate positional location of pictures to be collected, the purple line indicates the total area to be encompassed by pictures if all photos are taken.

Aerial imagery collection followed a defined process that established high-resolution positional information of the aircraft, cameras, and events (images collected) throughout the entire flight. All flights were planned to coincide within ±2 hours of the lowest lows of the low-tide cycles no earlier than mid-May and no later than mid-July. Later or earlier in the year would not affect the ability to get elevation information, provided there was no snow or ice on the ground, but it would affect the images when used for habitat assessment information as the macro-algae community changes as it grows and senesces throughout the year. Flights to collect aerial imagery, once timing was established, began with an initial landing to establish a nearby GPS base station within 50 miles of the survey location. A Trimble® R8-3 or R10 was used as the base collecting positional information at 10 Hz. Camera systems were tested to ensure proper functioning (triggering, recording, and focus), and the software with the survey location information was prepared for flight operations. The aircraft GPS system was then initialized on the ground with a sample rate of 10 Hz, and logging was started. Once the aircraft was airborne, it headed directly to the survey location. The software operator selected the appropriate survey elevation and entered trigger mode. The pilot then proceeded to fly the grid pattern for the survey site. Images were collected with an 80% forward overlap of images and a 60% side overlap to ensure optimal photogrammetry results. The equipment operator continuously monitored functioning of the system throughout the flight. Once the aircraft was finished with surveys for the day, the aircraft returned to the base station, shut down the aircraft GPS, and then ended the base station survey. Complete overlap between the collection of the base station's positional data and the aircraft's positional data is critical for post processing.

2.4.3 Unmanned Aircraft

Unmanned aircraft flights were flown at site-specific location in 2018. These flights were conducted using a 3DR® Solo UAV (unmanned aerial vehicle). UAV aircraft are able to collect high-resolution imagery over a much smaller area as compared to manned aerial imagery, with image resolution of approximately 1 cm per pixel. Limitations in battery life restrict flight time to 20 minutes maximum, yielding a relatively small area imaged.

2.4.3.1 Survey Areas (Sites), methods

The UAV was outfitted with a single RGB camera for the missions. The aircraft flight-planning software that came with the unit was used to plan the altitude and GPS location where aerial transects would be conducted. Locations for the GPS were provided via an aircraft mounted differential GPS antenna. Images were taken continuously throughout the flight. This combination of equipment and operation allowed the aircraft to collect images with a ground sample pixel size calculated to approximately 1 cm.

Aerial imagery collection followed a defined process that established high-resolution positional information of the final processed data. All flights were planned to coincide within ±30 minutes of the lowest lows of the low-tide cycles during a ground sampling event. A Trimble® R8-3 was used as the base station on site collecting positional information at 1 Hz. The flight plan established for the site was uploaded to the UAV. Camera systems were set to automatically collect every second, once initially triggered. The aircraft GPS system was then initialized on the ground. Following confirmation of GPS signal, the camera was triggered and the flight plan initiated. Once the aircraft was airborne, and tested for safe flight controls, the pilot turned over control to the autopilot and it headed directly to the survey location. The UAV then proceeded flying the grid pattern for the survey site. Images were collected with an 80% forward overlap of images and a 60% side overlap to ensure optimal photogrammetry results. The pilot continuously monitored functioning of the system throughout the flight. Because of the lack of high-precision

GPS on the UAV, ground-based targets were surveyed using the RTK equipment. Ten targets were randomly set out along the site transect for ground control point purposes and another 5 were set out randomly for model assessment purposes. Once the aircraft was finished with surveys, the pilot reestablished control of the aircraft and returned to the landing site.

2.4.3.2 **Image Processing**

Image processing for both the UAV and the manned aircraft was similar (Figure 2.4.3.2.1) with the exception that the manned aircraft required post processing of the GPS information to tie the data to the image locations. An OPUS solution for the base station was used to correct positional data for both SfM aerial imagery collection styles.

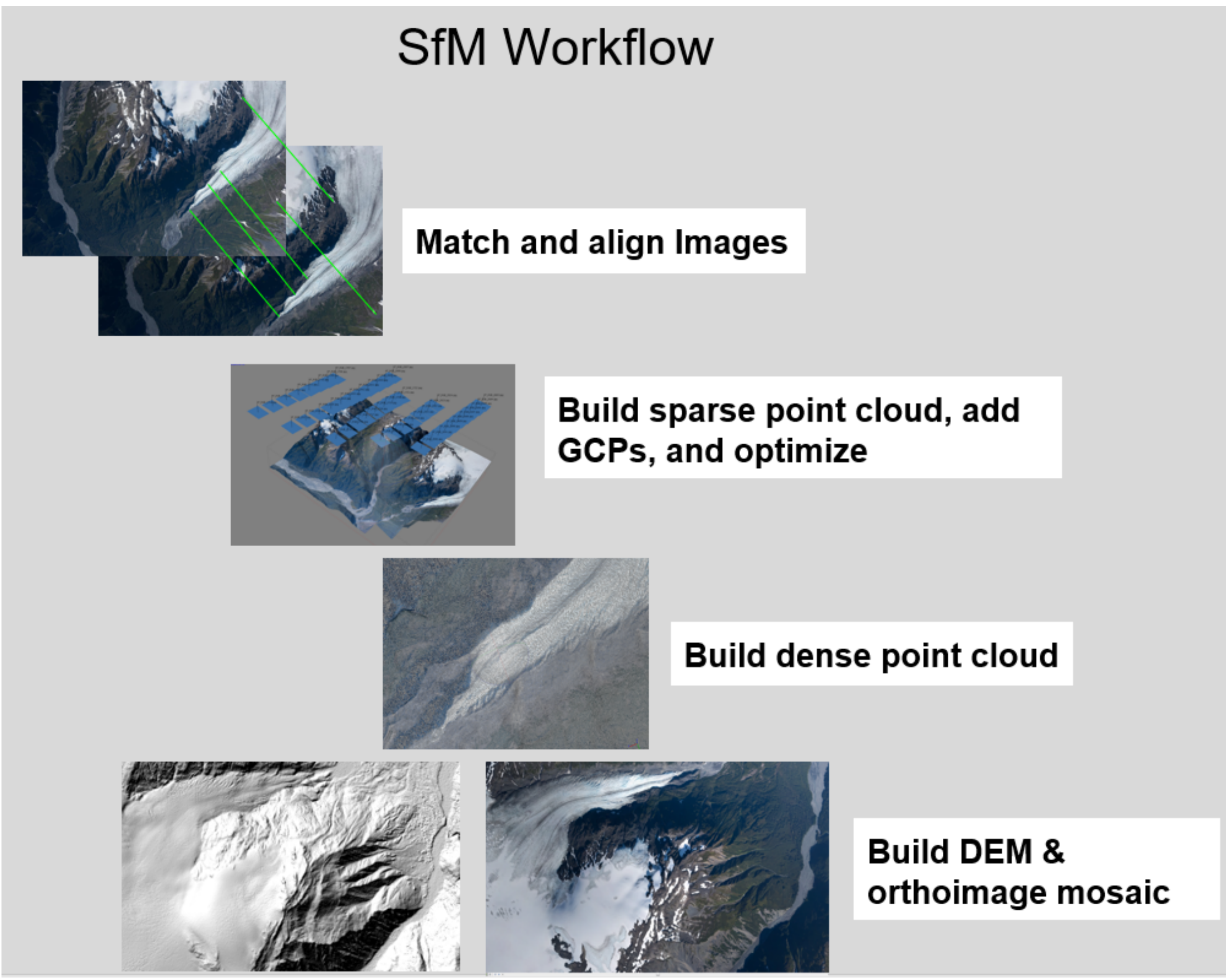


Figure 2.4.3.2.1. Workflow processing for imagery associated with Structure from Motion processing.
This process is specific to the software used, but follows a general photogrammetry practice.

Manned aircraft GPS data were entered into Trimble Business Center where the base station was tied to the flight lines and event data. This positional information was corrected using the OPUS solution, and the event data points (GPS positions of the images) were exported.

All of the images were imported into Agisoft® Photoscan. The locational information was added to the manned aerial imagery. The Photoscan process was subsequently used to develop the DEM from the image data. The process included aligning the images, then building a sparse point cloud from the image tie points. Ground control points were added to the model and the model was optimized. Following optimization, a dense point cloud was developed, from which the DEM was created. An orthomosaic was created to overlay on the DEM for visualization of the site and subsequent habitat assessments.

2.4.4 Scaling Quadrat Data to Habitat Maps

The program ENVI was used for habitat mapping. To conduct habitat mapping assessments, the RGB and IR blended orthomosaics were combined in ENVI to create a 4-band image consisting of the red, green, and blue bands from the RGB image and the IR band from the IR image. Subsequently added to the image was the modeled digital surface elevation from the SfM model, creating a 5-band image of red, green, blue, IR, and elevation (Figure 2.4.4.1).

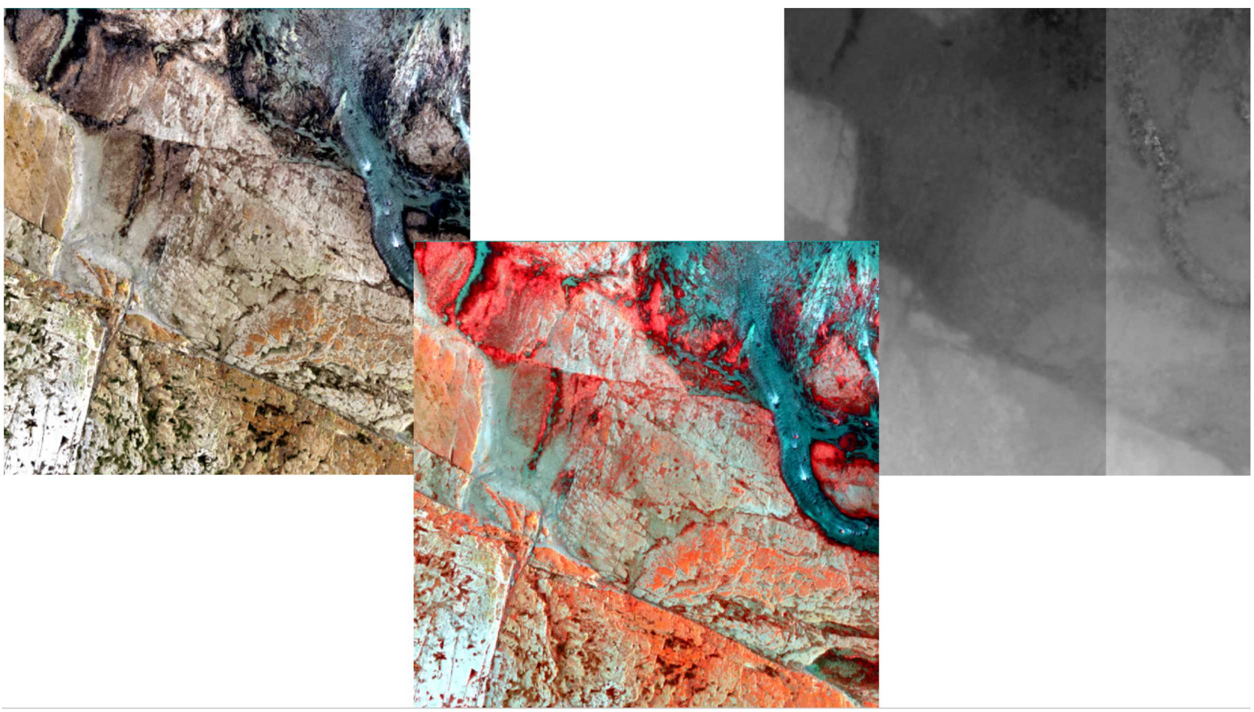


Figure 2.4.4.1. RGB, IR and DEM images combined to form a single "5-band" image. Graphical representation of the blended image can only occur on 3 bands at a single time; the computer algorithms examine all 5 simultaneously when conducting segmentation and feature extraction.

In a feature-based classification program such as ENVI, multiple layers of input data such as the image color bands and a digital surface model are segmented into objects with similar spectral or other properties in order to create a classification schema. Within ENVI, the first step in classification was to determine the optimal segmentation algorithms. This was ultimately determined to be a segmentation setting using an edge algorithm with a scale level 10 and a merge setting with a full lambda schedule algorithm with a merge level of 80. Using the determined merge settings, site 19 was chosen as the test site for habitat map testing. Site 19 was chosen because of the combination of aerial imagery from both UAV and manned aircraft, along with image derived surface elevation models using SfM photogrammetry. These factors allowed for future comparisons of techniques.

Following the determination of appropriate segmentation parameters, feature extraction was attempted using example-based extractions. Two methods were attempted – importing of ground-truth data from quadrats, and selectively training the algorithms. It was determined that the best method was selective training of the algorithm, which saved the ground-truth information from the quadrats to be used for accuracy assessments.

Habitat mapping was an iterative process working through priority efforts to determine the appropriate level of detail possible from the manned aerial imagery (Figure 2.4.4.2). Priorities were established through progressively segmenting major habitat differences within the intertidal zone.

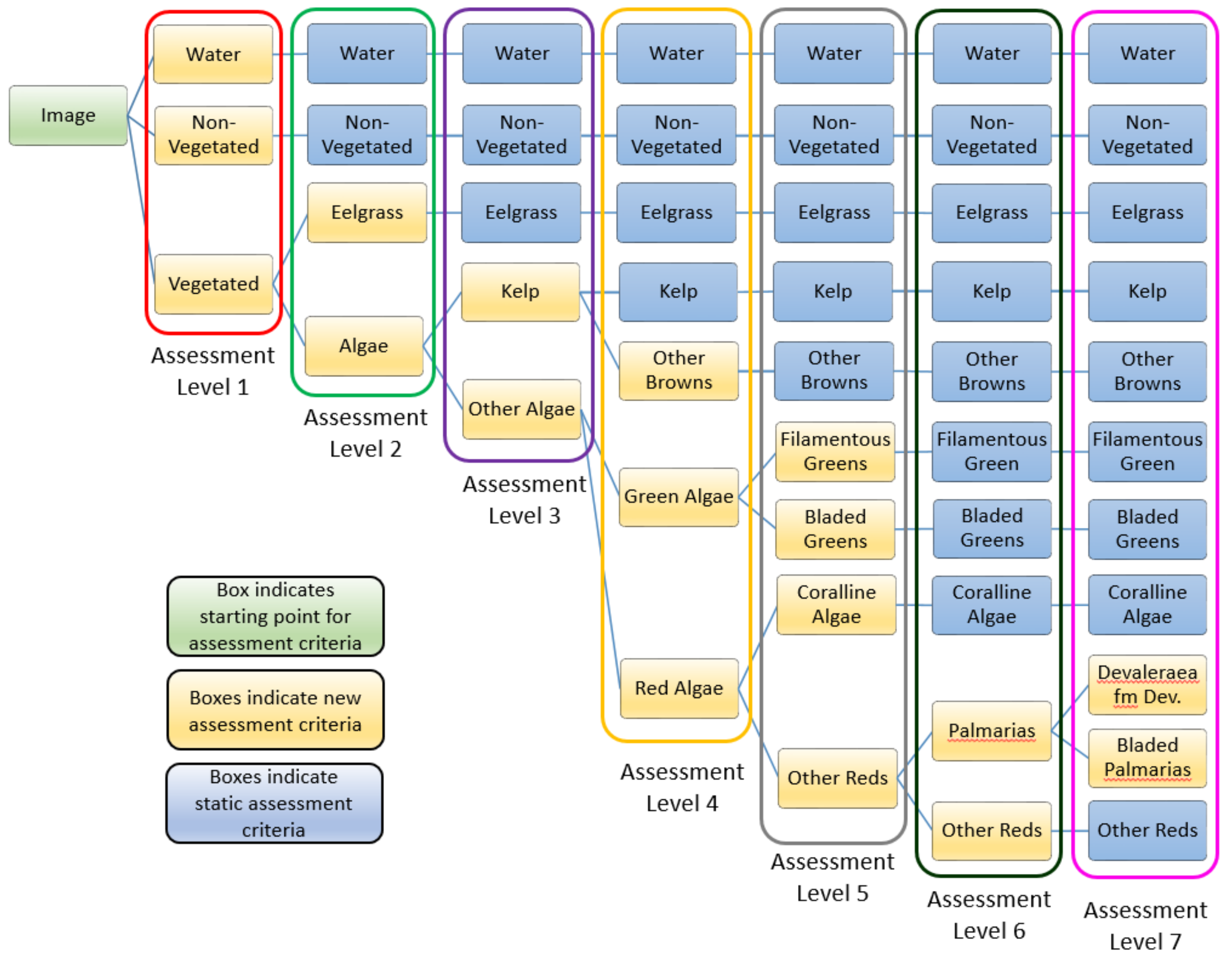


Figure 2.4.4.2 Assessment criteria for habitat mapping assessments using ENVI for lower Cook Inlet 4 band imagery (R, G, B, IR) plus digital surface model data.

3 Results

3.1 Databases

3.1.1 Historical Database

A summary of previous intertidal research in the affected area was conducted in advance of the 2015 project field season to identify geographic gaps in the study area where research had not occurred (Figure 3.1.1.1). This summary indicated that rocky habitat had been underrepresented in previous studies, with only 16% of historic study sites located at rocky or mostly rocky sites (see Figure 3.1.1.2; Coletti et al. 2017).

Tables holding data for references, study sites, algae occurrences, and bivalve occurrences were combined into a georeferenced relational database. The database recorded species presence at given sites, and included study metrics, such as whether biomass or percent cover was measured for a given species at a given site, and whether tissues were sampled for contaminants or other constituents. The database will be publicly available online through the Alaska Ocean Observing System portal (https://aoos.org/aoos-data-resources/). Links to PDFs of the source references will also be available. The compiled information will make historical data more readily available to researchers and the public, and may be used by BOEM and others in development of ecological studies as well as for use in permitting processes and environmental assessments.

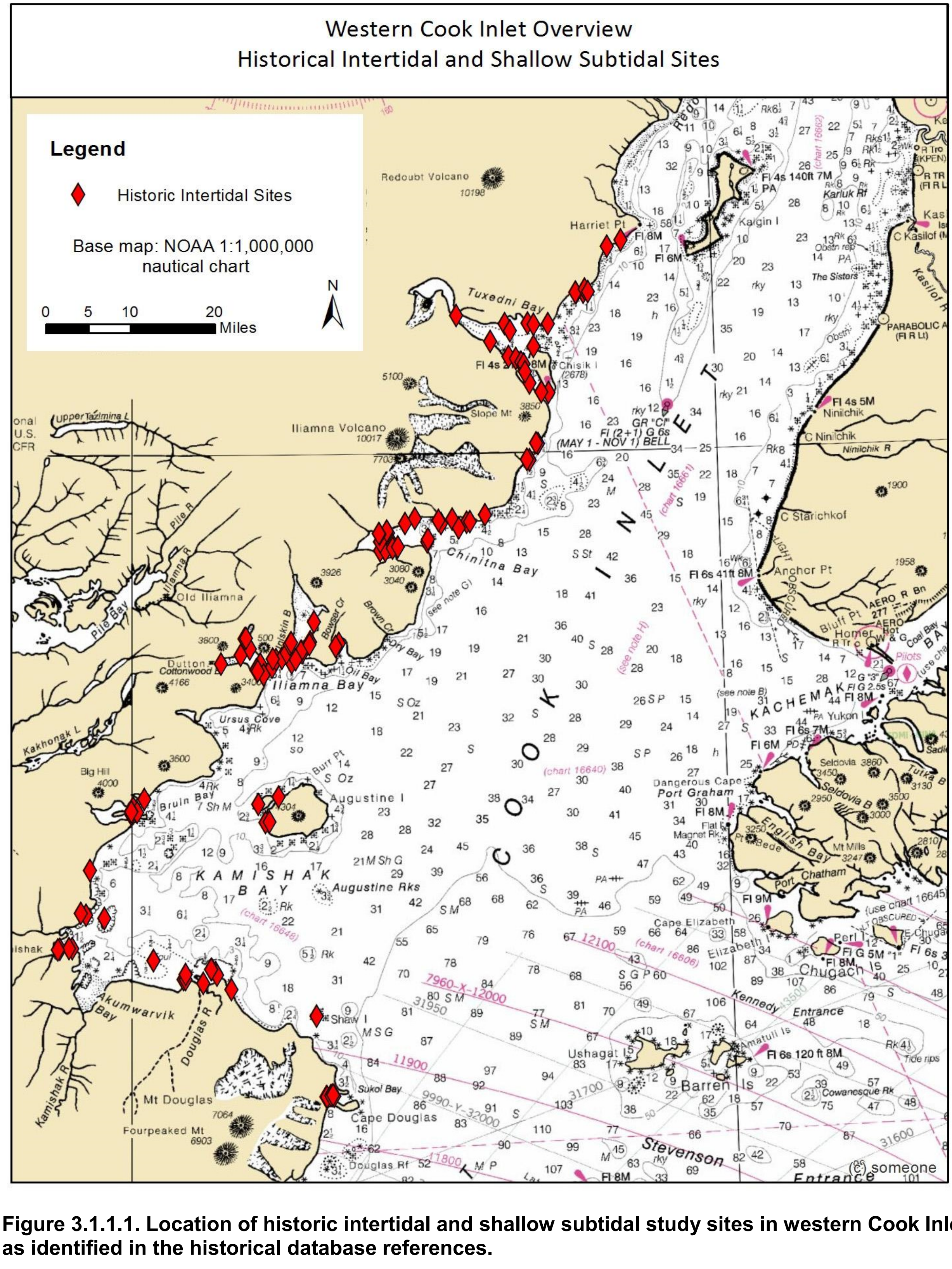


Figure 3.1.1.1. Location of historic intertidal and shallow subtidal study sites in western Cook Inlet as identified in the historical database references.

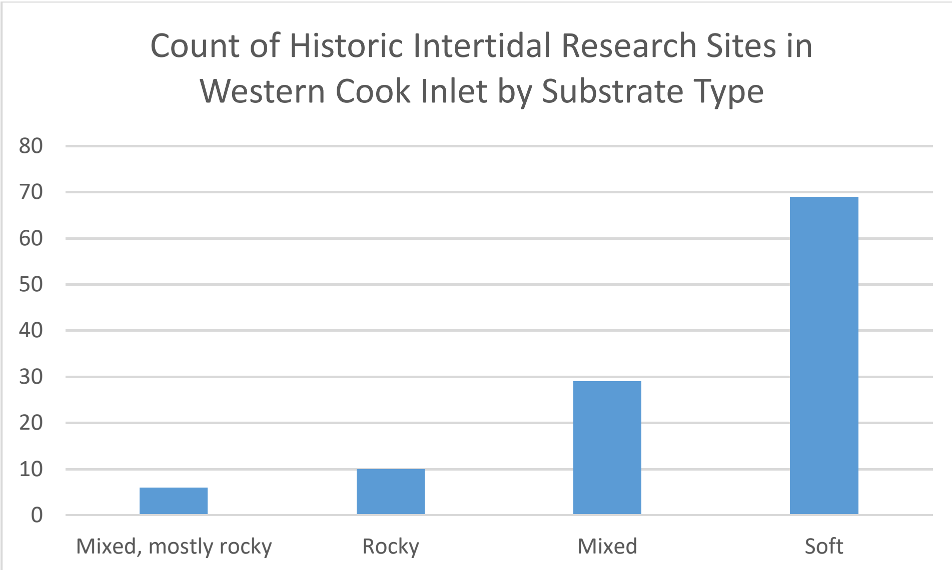


Figure 3.1.1.2. Results of an assessment of previously studied intertidal and shallow subtidal sites by substrate indicated that soft-sediment habitat had been studied more thoroughly than rocky habitat in the project area.

3.1.2 **Project Database**

A relational database was built in Microsoft Access for the results of the 2015-2018 field surveys (Figure 3.1.2.1). Biological survey data are stored in separate tables for point intercept data, mobile invertebrate counts, occurrences of taxa not contacted in point intercepts, and occurrences of taxa present on site but not in quadrats. Additional tables hold percent cover and mobile invertebrate counts from third-party photo interpretation. Tables with taxonomic information, morphological codes for algae, and invertebrate feeding strategy codes add context and the ability to query by taxonomic level and other biological information.

Site characteristics and descriptions, quadrat information, survey date and team information, and geospatial information are included. One-to-many relationships between tables with enforced referential integrity have been built to enable querying. Two sets of query results that were used in analysis for this report have been added to the final version as standalone tables.

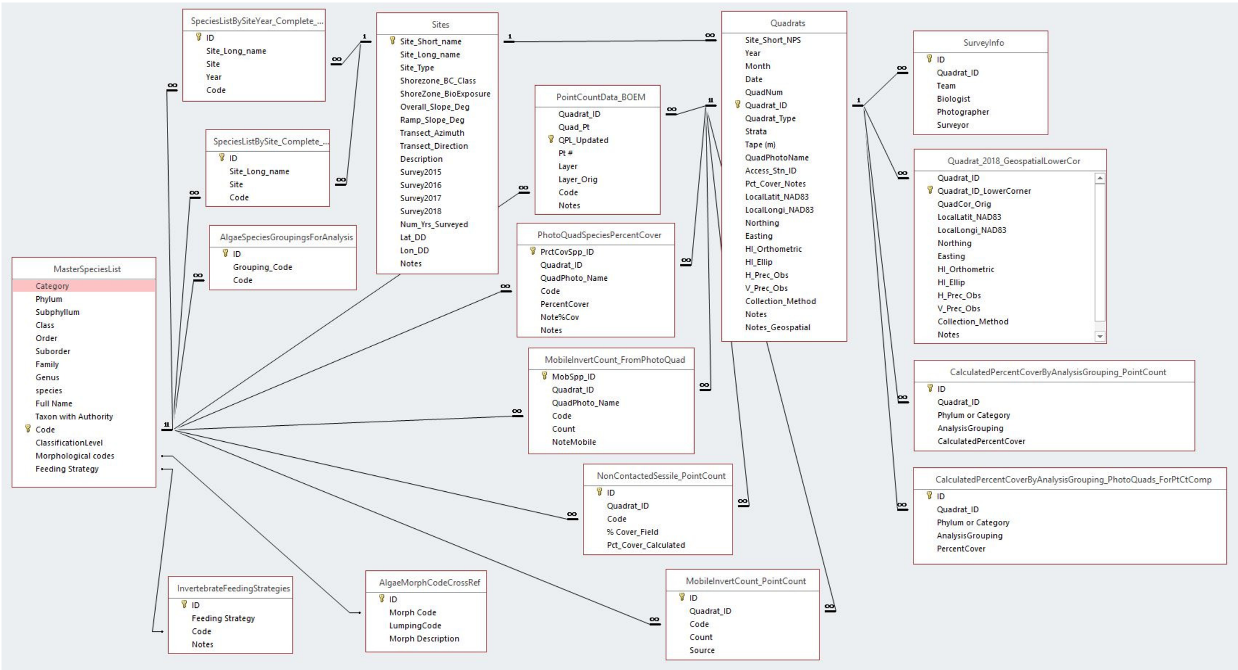


Figure 3.1.2.1. Diagram of relational database used in the current BOEM study.

3.2 Intertidal Site Summaries (Attributes)

3.2.1 Intertidal Site Descriptions:

3.2.1.1 Site 2: Contact Point

Contact Point is a headland at the south entrance of Bruin Bay. Site 2 is southwest of Contact Point at the base of the high steep and eroding cliffs. The cliff behind Site 2 is actually a hanging wall fused to the footwall by a felsic dike that intrudes along a fault plane. Erosion is active and landslides were observed to the southwest and northeast of the site. As well, continuous shedding created a dangerous work environment near the top of the transect. The top of the transect begins near the top of the sand and granular beach face and runs SSE towards the waterline, crossing a long (>200 m) low angle (~0.5º) bedrock platform. The upper end of the platform is smooth and bare but transitions to erosional patterns of parallel ridges and channels within the bedrock. These features are not shoreline parallel and create a series of higher elevation ridges and lower water-filled channels that angle from offshore to onshore. Tide pools and several deeper channels are interspersed across the bedrock ramp. The site is highly exposed to local storm waves and ocean swells arriving from the Gulf of Alaska.

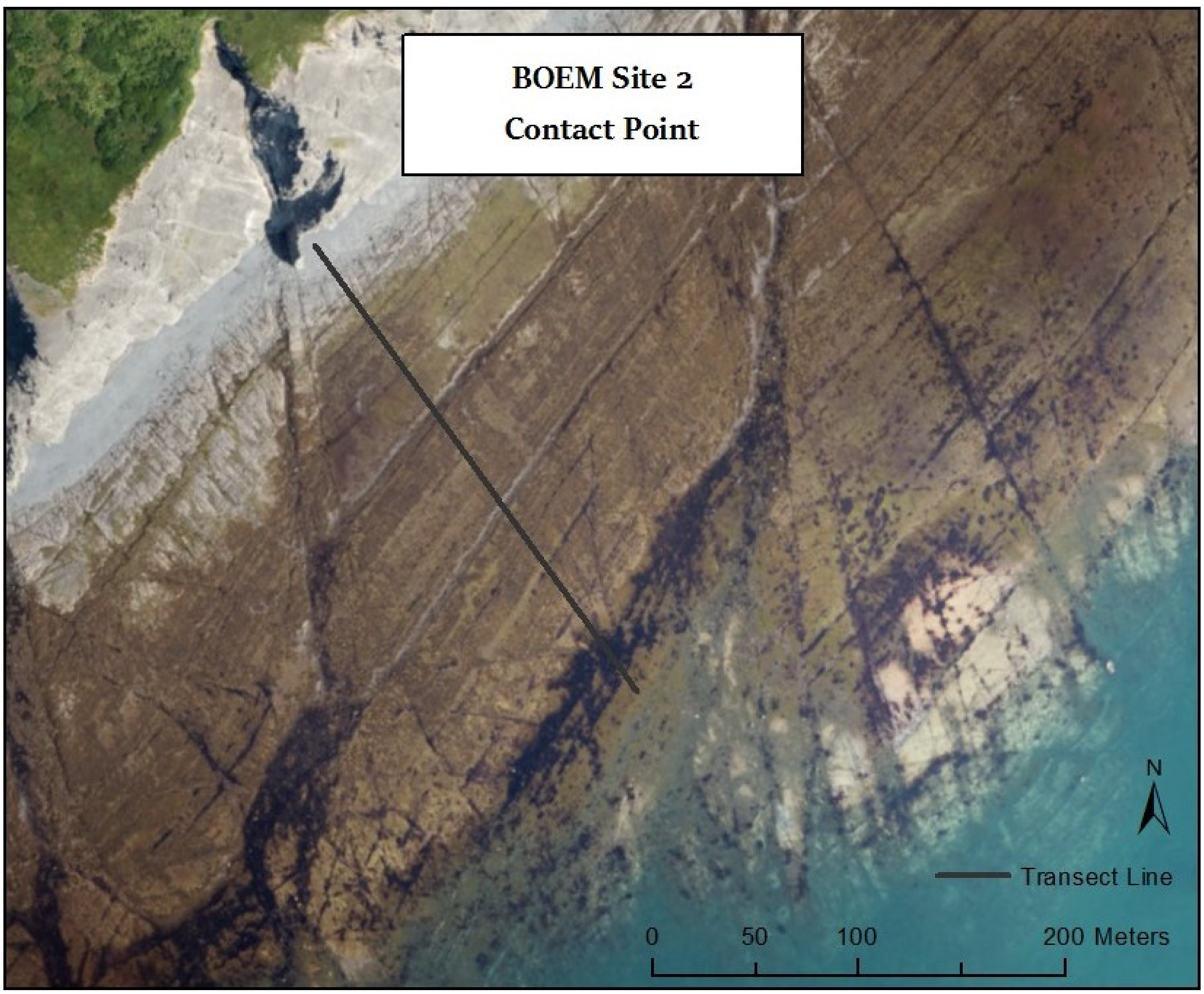


Figure 3.2.1.1.1. Aerial orthoimage of Site 2 near Contact Point west of Augustine Island.

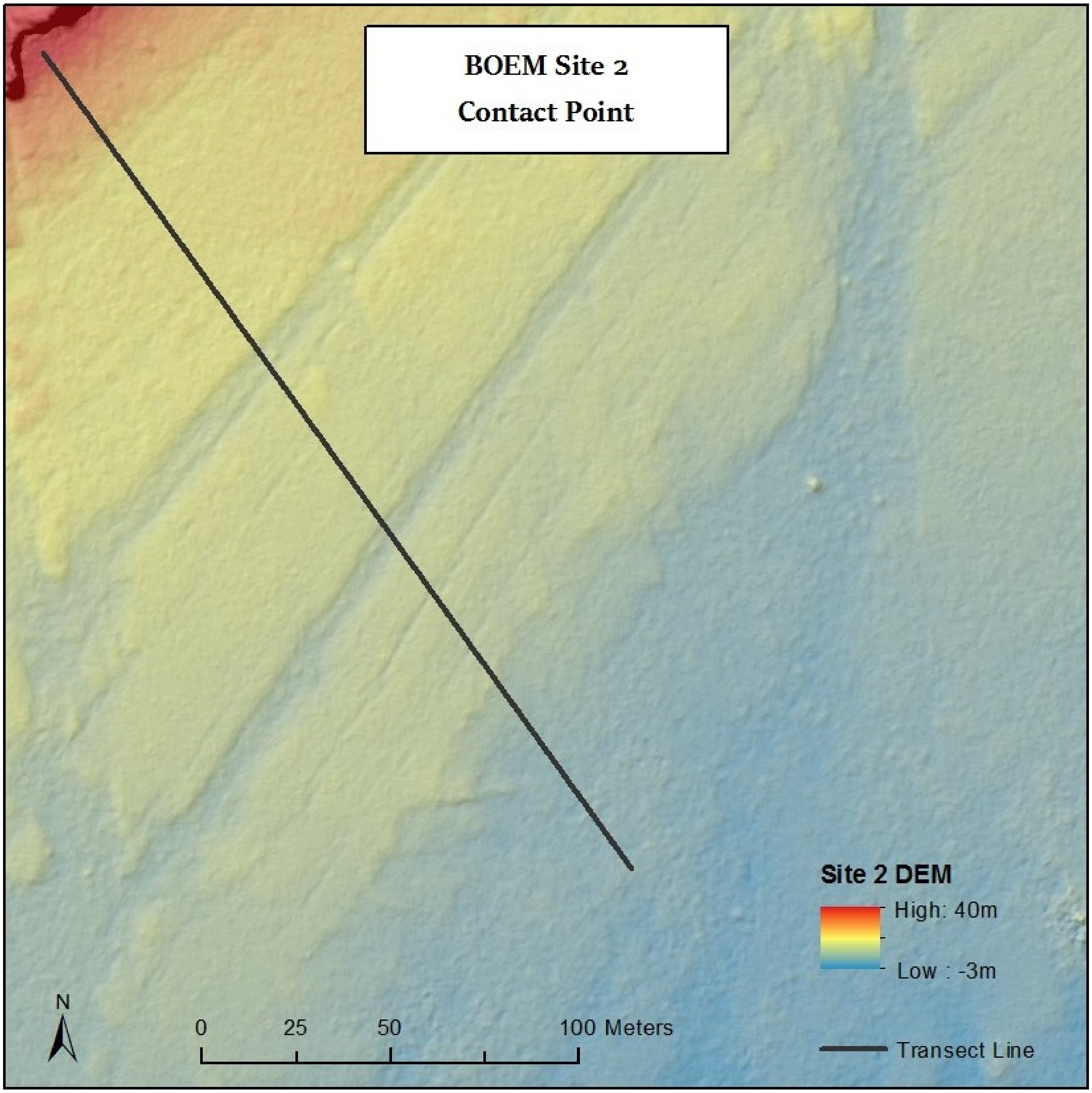


Figure 3.2.1.1.2. Digital surface model of Site 2.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.2 **Site 3A: Augustine Island**

The original Site 3 was unsampleable due to weather in 2015, and after relocating to the nearest sampleable rocky habitat, Site 3A was established on northern Augustine Island, west of Burr Point. The transect is oriented due north (2º Azimuth). The top of the transect is a sand and pebble beach in the foreshore with a moderately angled slope (~5º). At the base of the gravel beach are boulders (some several meters per side) embedded in sand grading to a long (>300 m) extremely low-sloped habitat of mixed gravel (mainly cobble and sand with pebbles and boulders). This habitat along the extremely low-angle transect is highly rugose compared to most other sites and provides protected habitat in the cracks between boulders and cobbles. There are also wide shallow tide pools overlying the sandy habitat at the shoreward end of the almost flat ramp. This site is protected by Burr Point to the east that protrudes out and provides a slight lee from northerly and easterly storm waves and ocean swells. However, the waves can wrap around Burr Point, making it difficult to reach the site at certain tides. A narrow sand channel provides access to the inner beach, if careful to avoid scattered subtidal boulders.

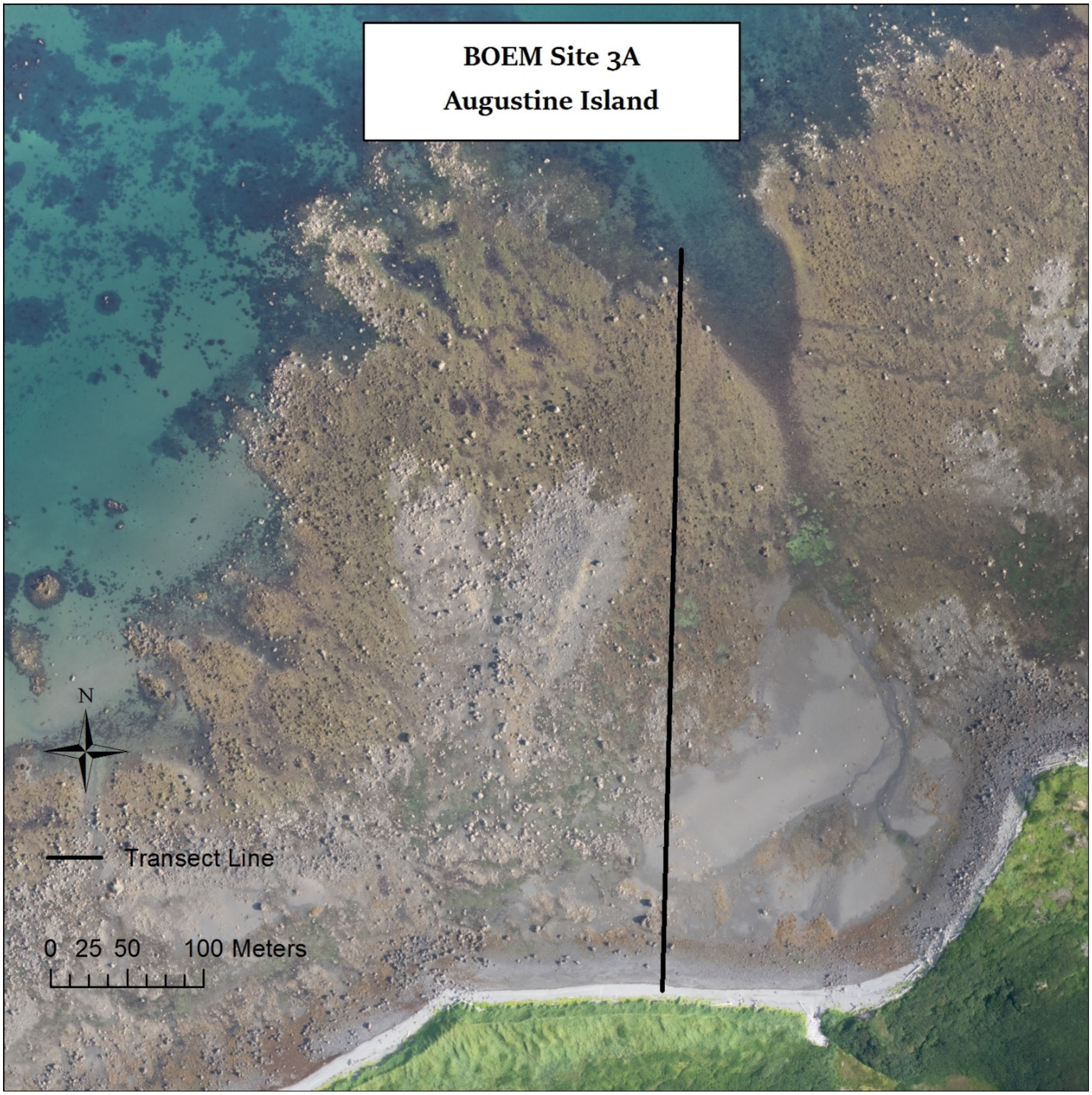


Figure 3.2.1.2.1. Aerial orthoimage of Site 3A, Augustine Island, showing location of survey transect line.

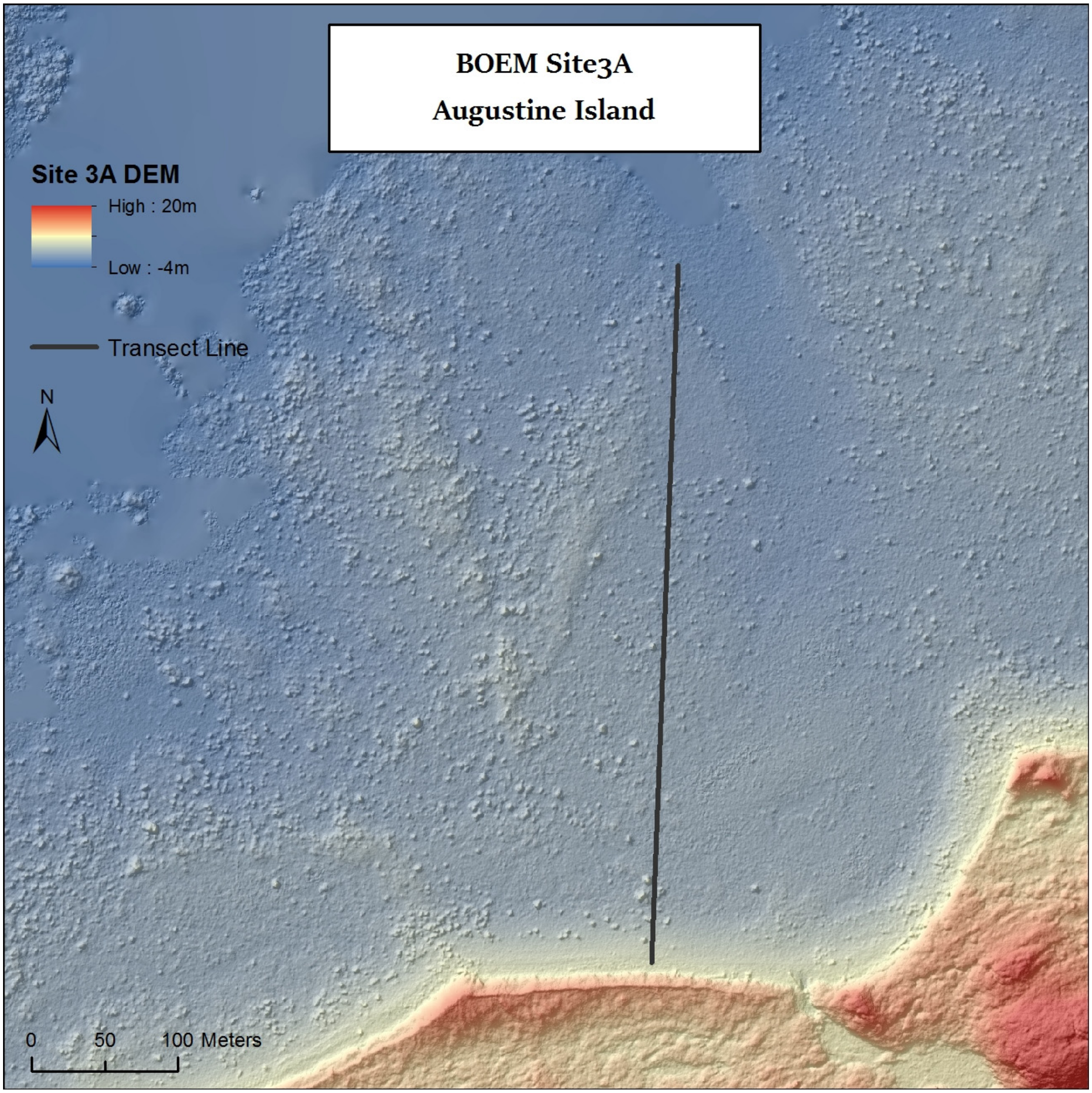


Figure 3.2.1.2.2. Digital surface model along transect of Site 3A.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.3 Site 4: Pomeroy Island

Site 4 is located on the eastern side of Pomeroy Island near the mouth of Iliamna Bay. Pomeroy Island is vegetated with grasses and with a grove of trees on its western side. The island is surrounded by steep cliffs and bedrock outcrops, with gravel beaches near the lower intertidal on portions of the island. The eastern side of the island where Site 4 is located is exposed to local storm waves and ocean swells, making it difficult to access in heavy seas. However, there is a gravel beach on the far western end of the island that can be approached in a lee. The transect is oriented SE from MHHW to the waterline. The top of the transect is at the base of a rocky bluff and on top of a smooth rock ramp. There are several very large (>3 m) angular blocks resting on bedrock at the top of the transect. Below MHHW, near the top of the transect there are scattered rounded boulders grading into a smooth bedrock ramp that extends to roughly MLLW. Below MLLW, the bedrock is broken by channels and deep tide pools and scattered with boulders.

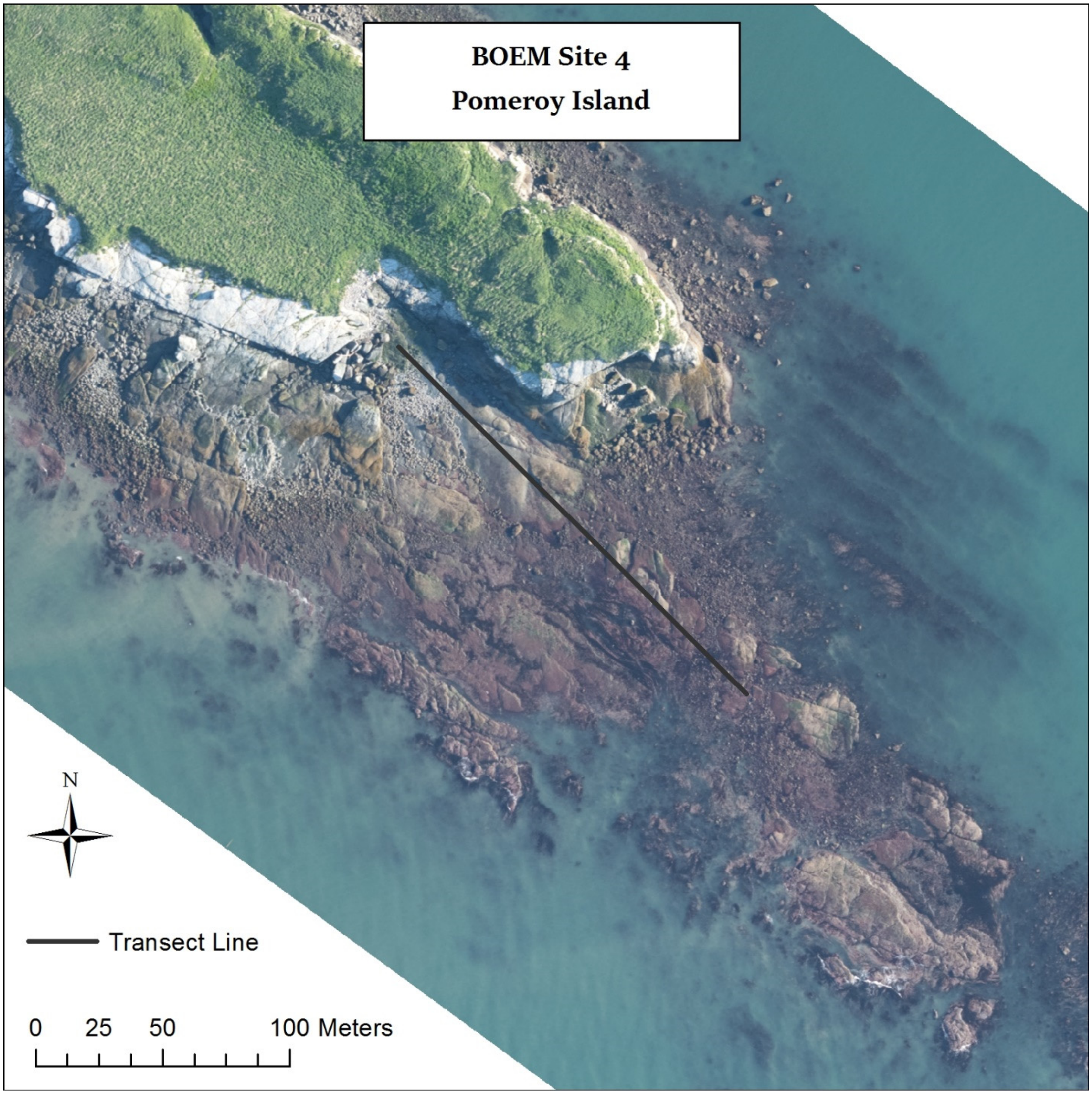


Figure 3.2.1.3.1. Aerial orthoimage of Site 4, Pomeroy Island, showing location of survey transect line.

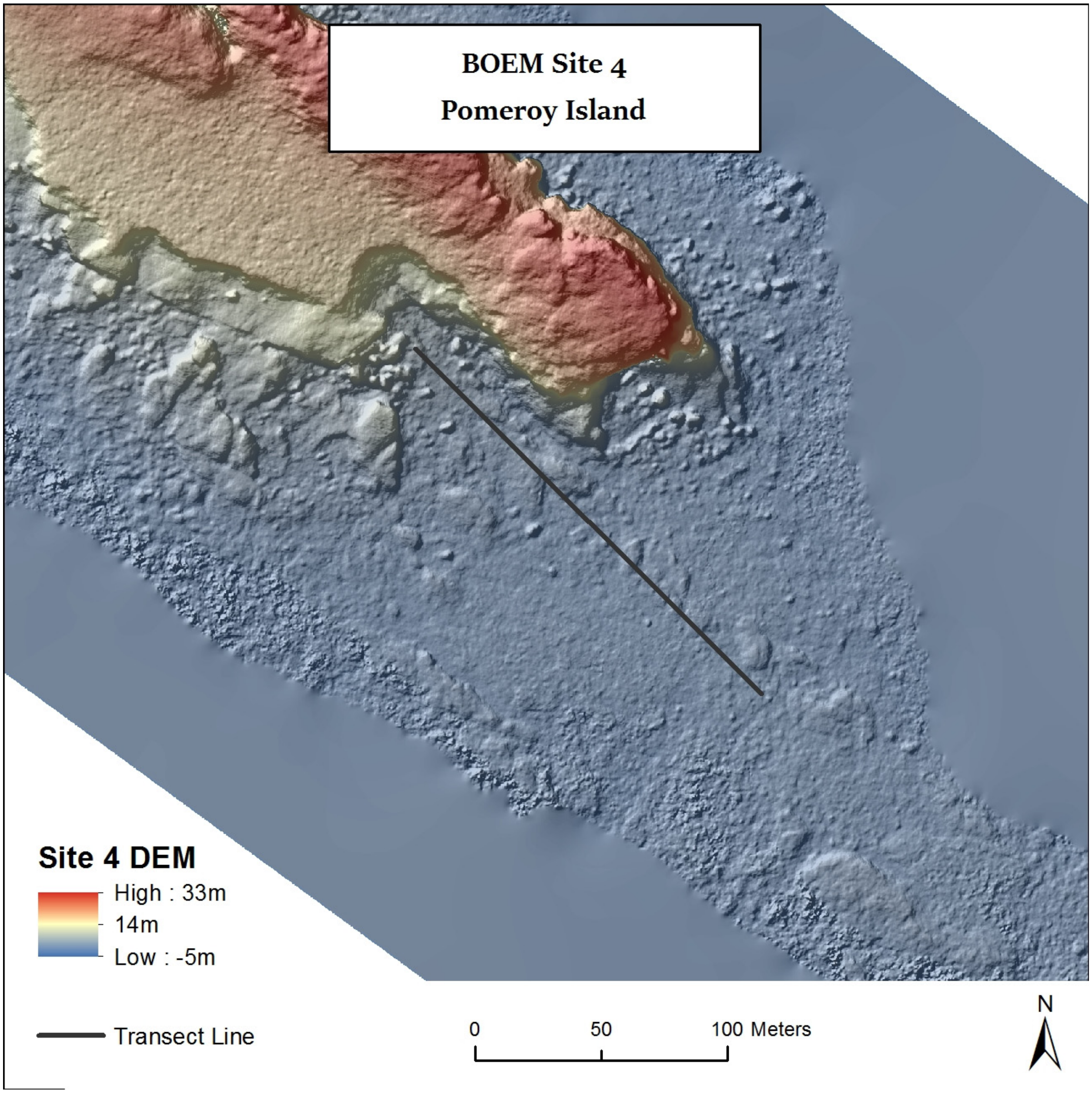


Figure 3.2.1.3.2. Digital surface model along transect of Site 4.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.4 **Site 6: Iliamna Point**

Site 6 is the northernmost site, and it is situated along the shoreline between Tuxedni and Chinitna Bays at Iliamna Point. Behind the transect is a steep rock cliff, which is backed by a heavily vegetated steep bank and hill. The transect starts at MHHW on steep smooth bedrock and extends ESE towards the waterline across a bedrock ramp that has an average 2º slope. Near the shoreward start of the ramp, large boulders overlay bedrock. Seaward, there is a series of "ridges" and "channels" in the bedrock due to variations in erosional rates of the matrix, generally oriented parallel to the shoreline. Near the seaward end of the transect, there is a taller outcrop ridge that rises and then drops steeply to the waterline and into the subtidal zone. The site is exposed to both local Cook Inlet storm waves and ocean swells arriving from lower Cook. The site is difficult to access in heavy weather.

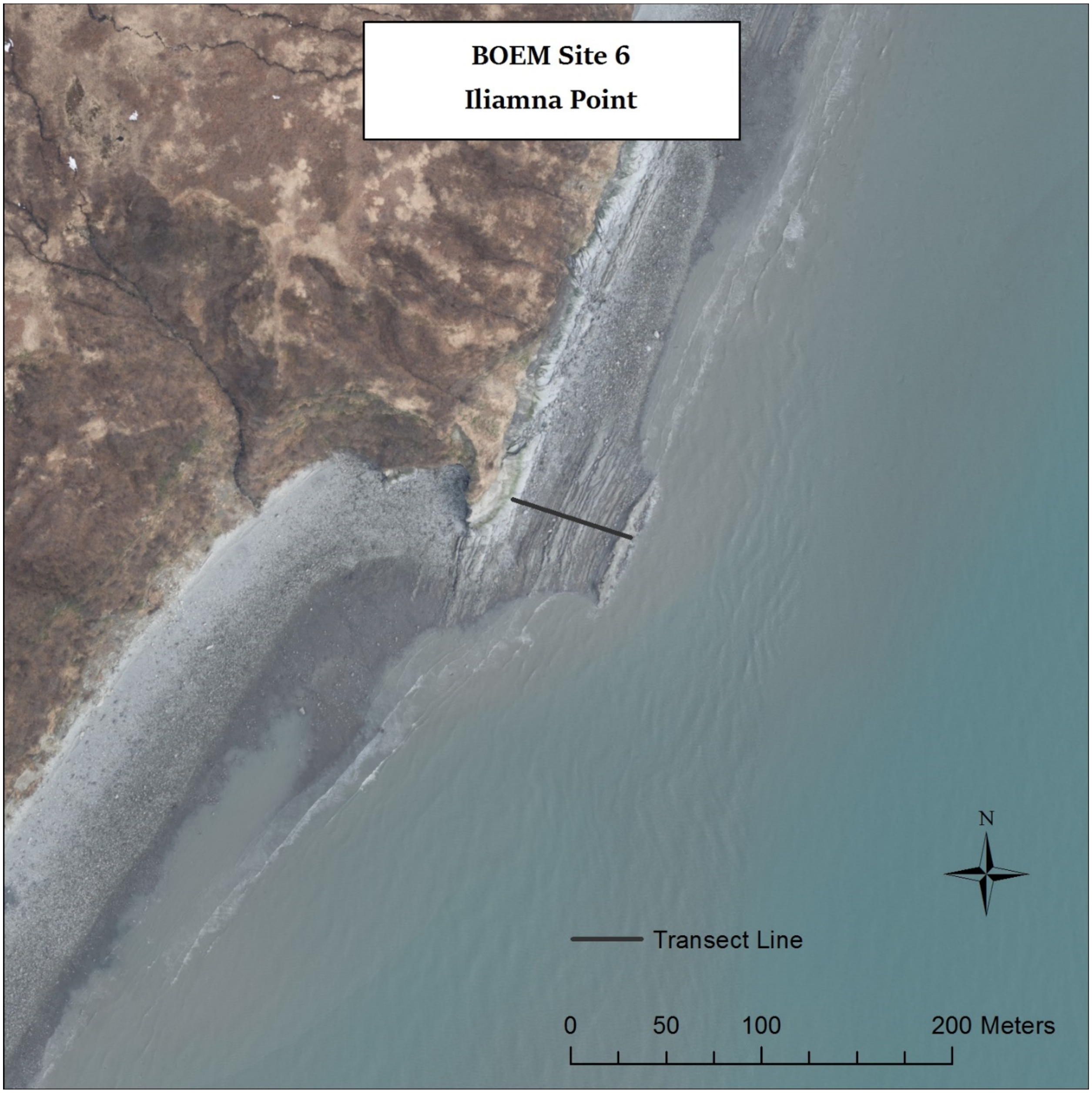


Figure 3.2.1.4.1. Aerial orthoimage of Site 6, Iliamna Point, showing location of survey transect line.
Location at Iliamna Point between Tuxedni and Chinitna Bay. Height is orthometric (0= modeled MSL).

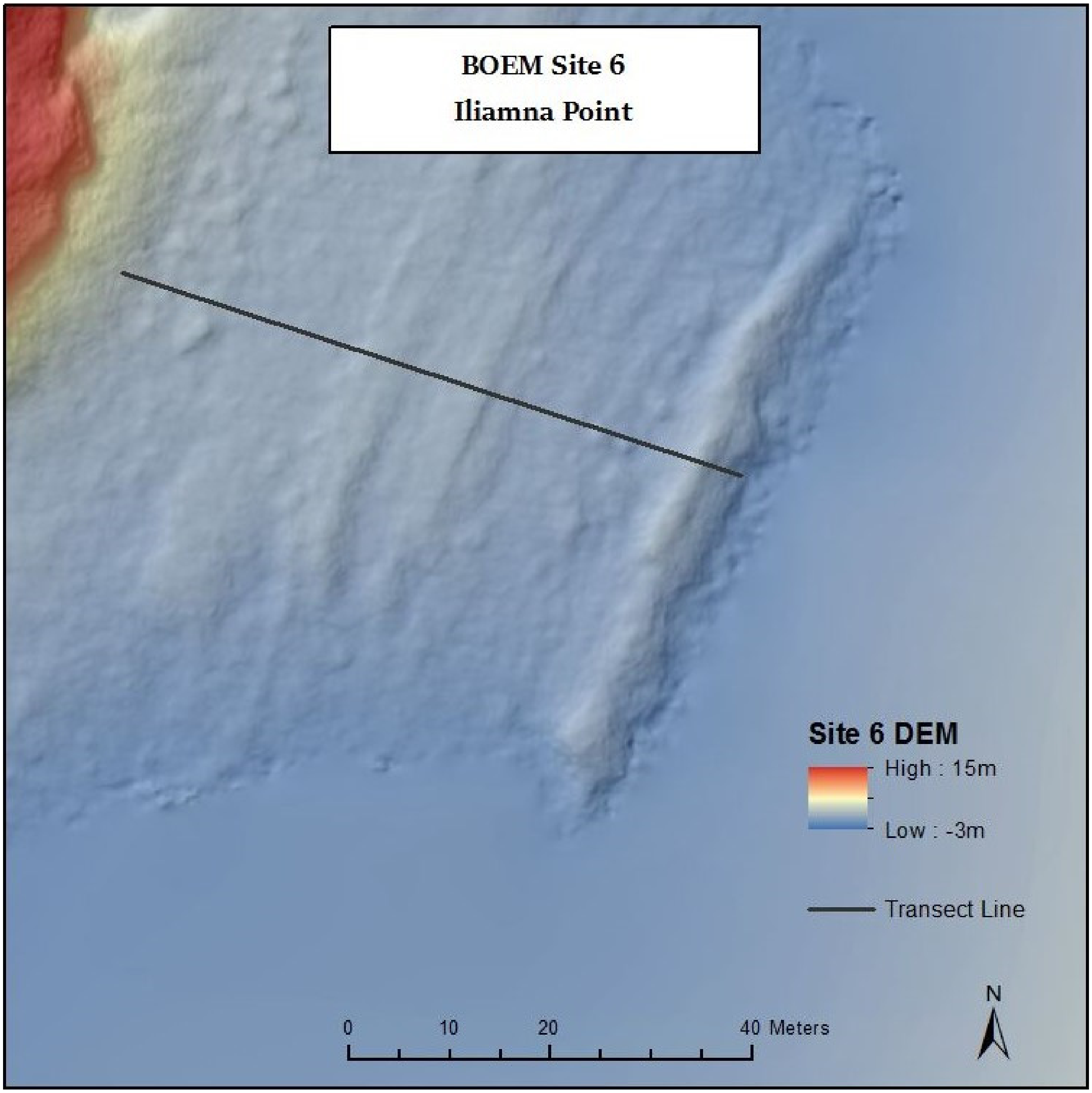


Figure 3.2.1.4.2. Digital surface model along transect of Site 6.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.5 Site 10 Chinitna Bay

Site 10, located on the north side of Chinitna Bay, is a large boulder beach bracketed along the shoreline by sand and granular beach faces and low-angle rock ramps. A small freshwater stream enters the top of the beach from the vegetated hill above. Near MHHW, the stream becomes subsurface. The transect runs from MHHW in a SSW direction to the waterline. The beach is semi-exposed; the entrance of Chinitna Bay provides some protection from ocean swells, but there is the potential for a long fetch for storm waves from the SE. The top of the beach face is mostly sand and pebble with scattered semi-rounded boulders transitioning down the transect to large semi-rounded boulders (some >3 m on a side) embedded in a sand and granular substrate. Near the base of the beach face and near MLLW, the slope lessens and the boulders are smaller and mixed with more cobble. Near the waterline at low tide, the substrate transitions abruptly to sand. The beach collects many large bleached shells, which are crammed into the crevices between boulders and stacked up against each other. These were mainly *Mya arenaria*, *Siliqua patula*, and *Clinocardium* sp., confirming that this beach is adjacent to or down current from large populations of these clams.

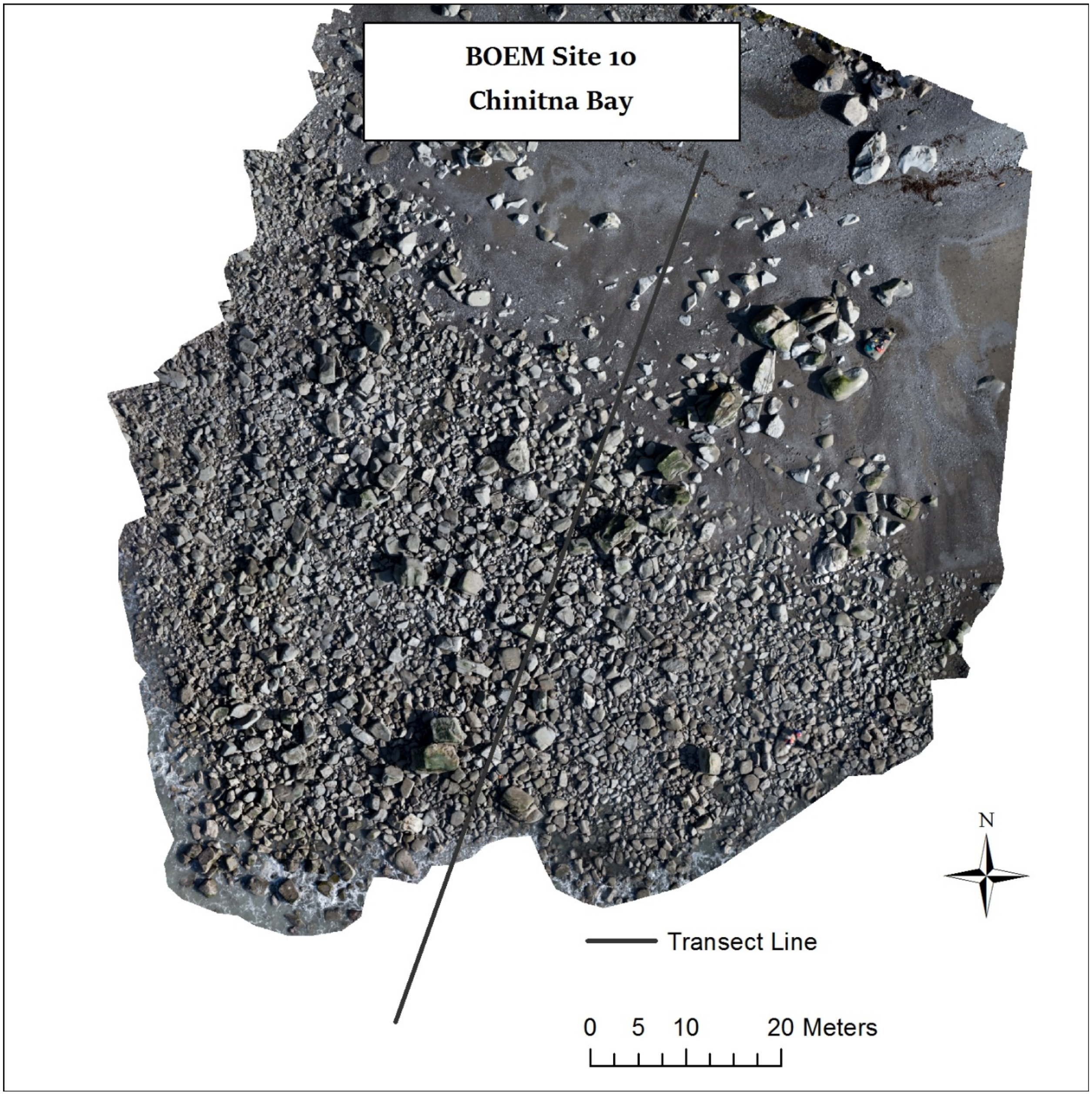


Figure 3.2.1.5.1. Aerial orthoimage of Site 10, Chinitna Bay, showing location of survey transect line.
This imagery was acquired using a drone (UAS), rather than from a fixed-wing aircraft.

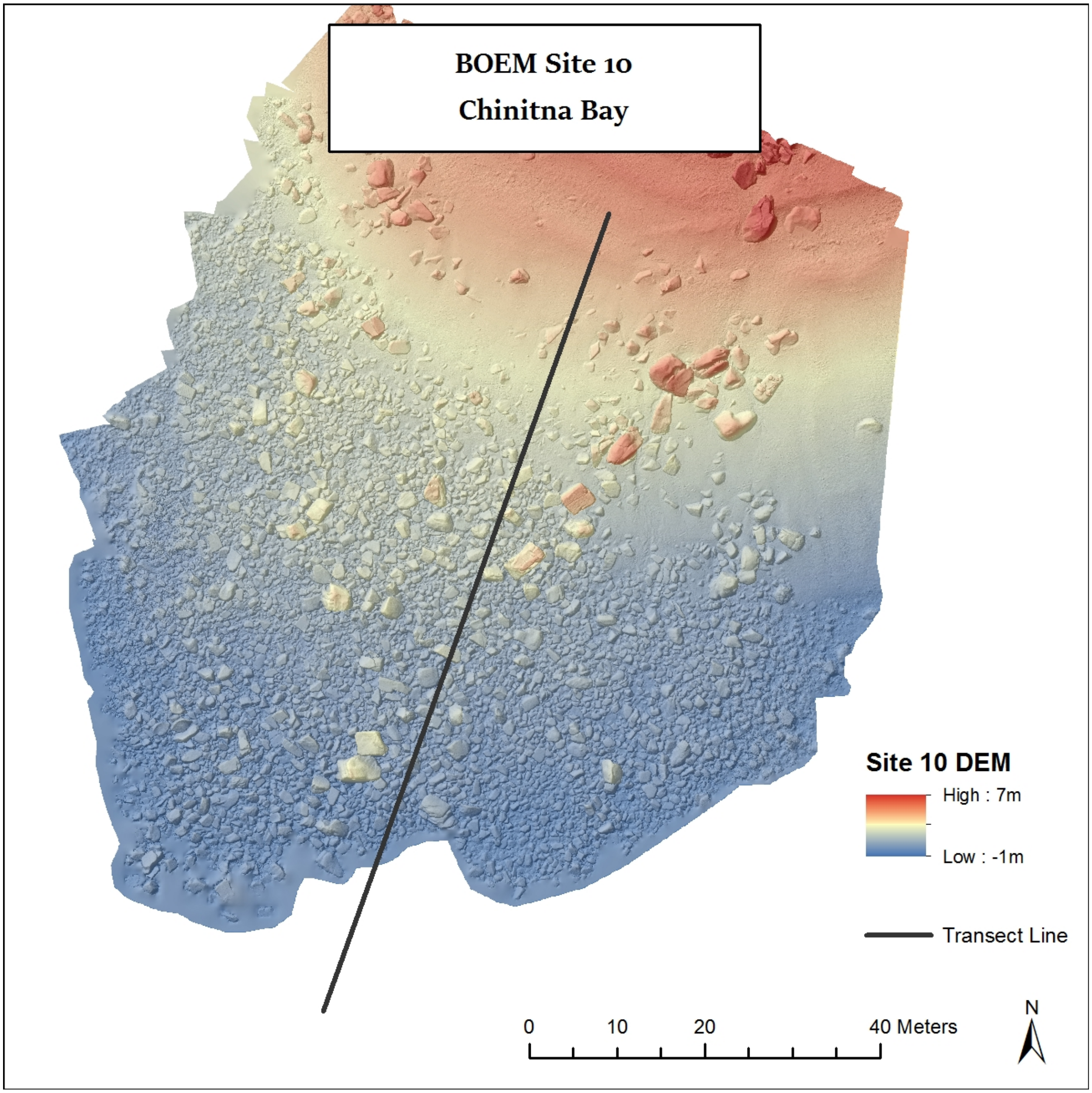


Figure 3.2.1.5.2. Digital surface model along transect of Site 10.
Digital surface model derived from UAS aerial imagery and survey-grade GPS. Height is orthometric (0= modeled MSL).

3.2.1.6 **Site 19: Chenik Head**

Chenik Head is on the mainland in western Kamishak Bay south of Amakdadori. Rocky platforms and ramps extend from shore and nearby small islands creating a network of flat intertidal habitat. Site 19 is on a small island just north of Chenik Head and runs ESE from MHHW to the waterline. The foreshore is a steep conglomerate bedrock outcrop located above a wide, flat conglomerate bedrock bench that extends ESE over 250 meters to MLLW. The site substrate is comprised mostly of pebbles, cobbles, and small boulders in the rock matrix. Near outer edges of the bench the bedrock is mostly just finer-grained sedimentary rock like what comprises the smooth conglomerate matrix. The bench is covered with shallow tide pools. Below MLLW the bedrock steps down to another small bench that is only exposed during minus tides. The shoreward end of this short bench is covered by rounded cobbles and small boulders, and near the waterline the bench is covered with vegetated flat bedrock. The site can be difficult to access in heavy weather, but there is a short channel that can provide some lee when approaching.

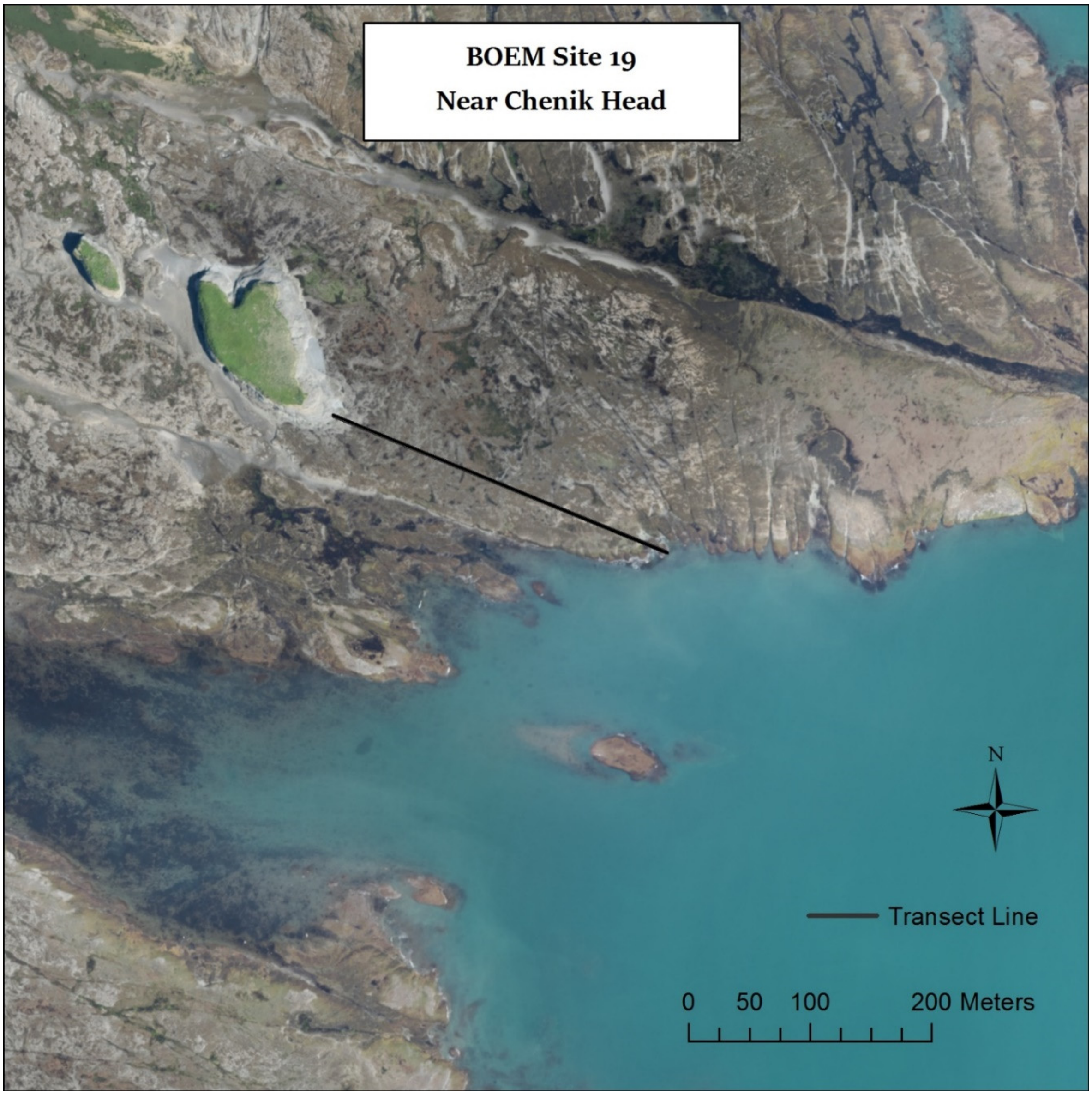


Figure 3.2.1.6.1. Aerial orthoimage of Site 19, Chenik Head, showing location of survey transect line.

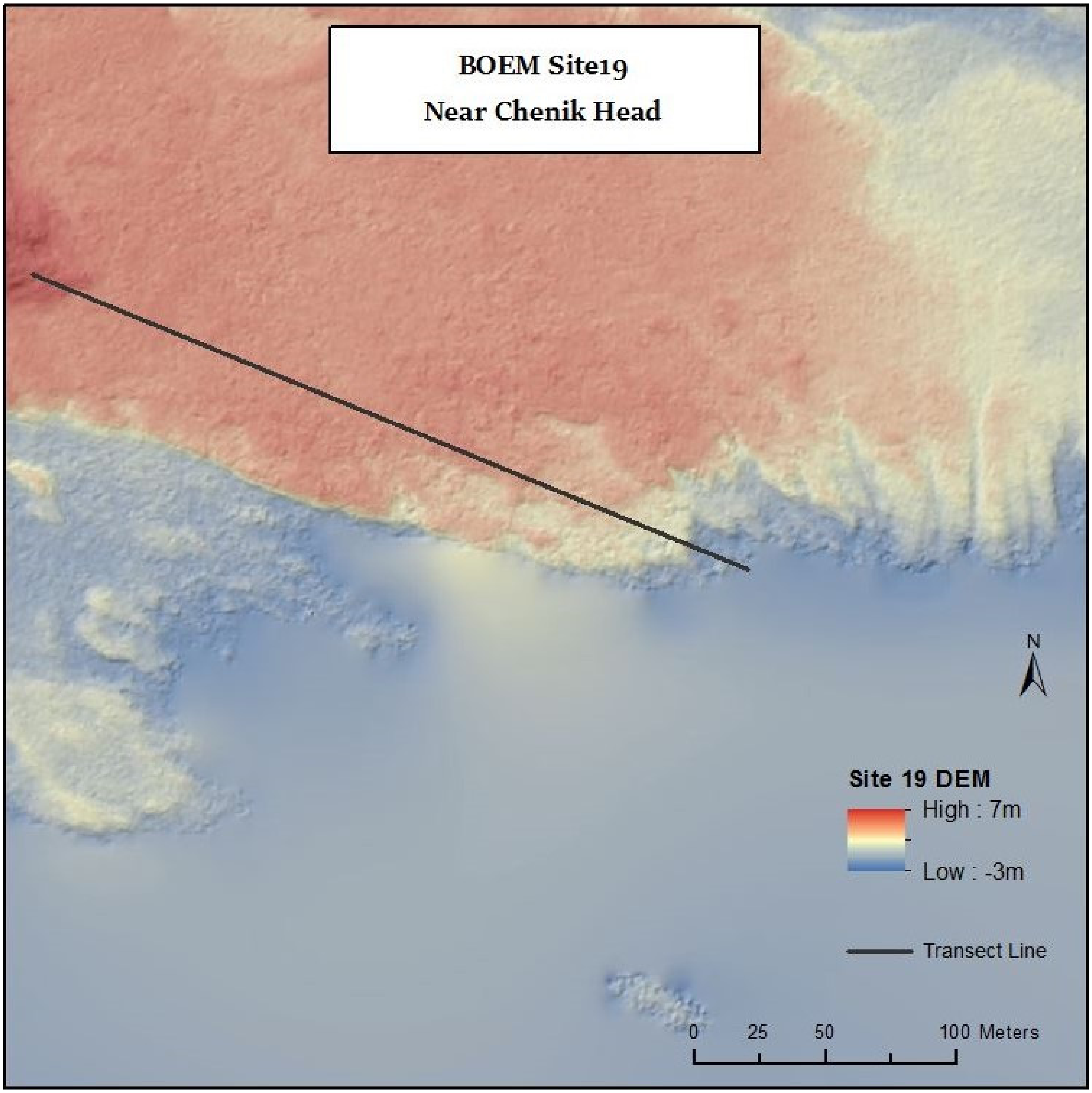


Figure 3.2.1.6.2. Digital surface model along transect of Site 19.
Surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.7 **Site SI1: Scott Island**

Scott Island is a heavily wooded island near the entrance to Iniskin Bay. On the north and northeast side is a series of small bedrock outcrop islands that are eroding at the base faster than at the top, creating the appearance of mushrooms, known as the Mushroom Islets. One of the larger of these islands, on the NE side of Scott Island, is attached to Scott Island during low tide. A bedrock reef extends seaward of the small island (Site is named SI1 for Scott Island, Site 1). The transect begins at MHHW on a steep conglomerate bedrock wall and runs ENE to the waterline. A short flat platform and a steep slope comprise the foreshore and a low-angle bedrock platform extends to MLLW and beyond. Scattered semi-angular boulders are scattered on top of the bedrock and piled along the edge of the rocky reef. The site is fairly rugose compared to many of the bedrock platforms in western Kamishak Bay, providing habitat for a wide range of invertebrates.

Note that the transect was originally laid out during a higher tide than what is shown in the *ShoreZone* aerial image in Figure 4. At different tide levels, the waterline can be oriented at very different angles to the MHHW line, making it tricky to determine the best way to cross the intertidal from MHHW to below MLLW. Thus, the orientation of the transect at this site does not cross the main section of the reef, but its species assemblages looked similar to the main section of reef and it shared habitat features with adjacent substrate.

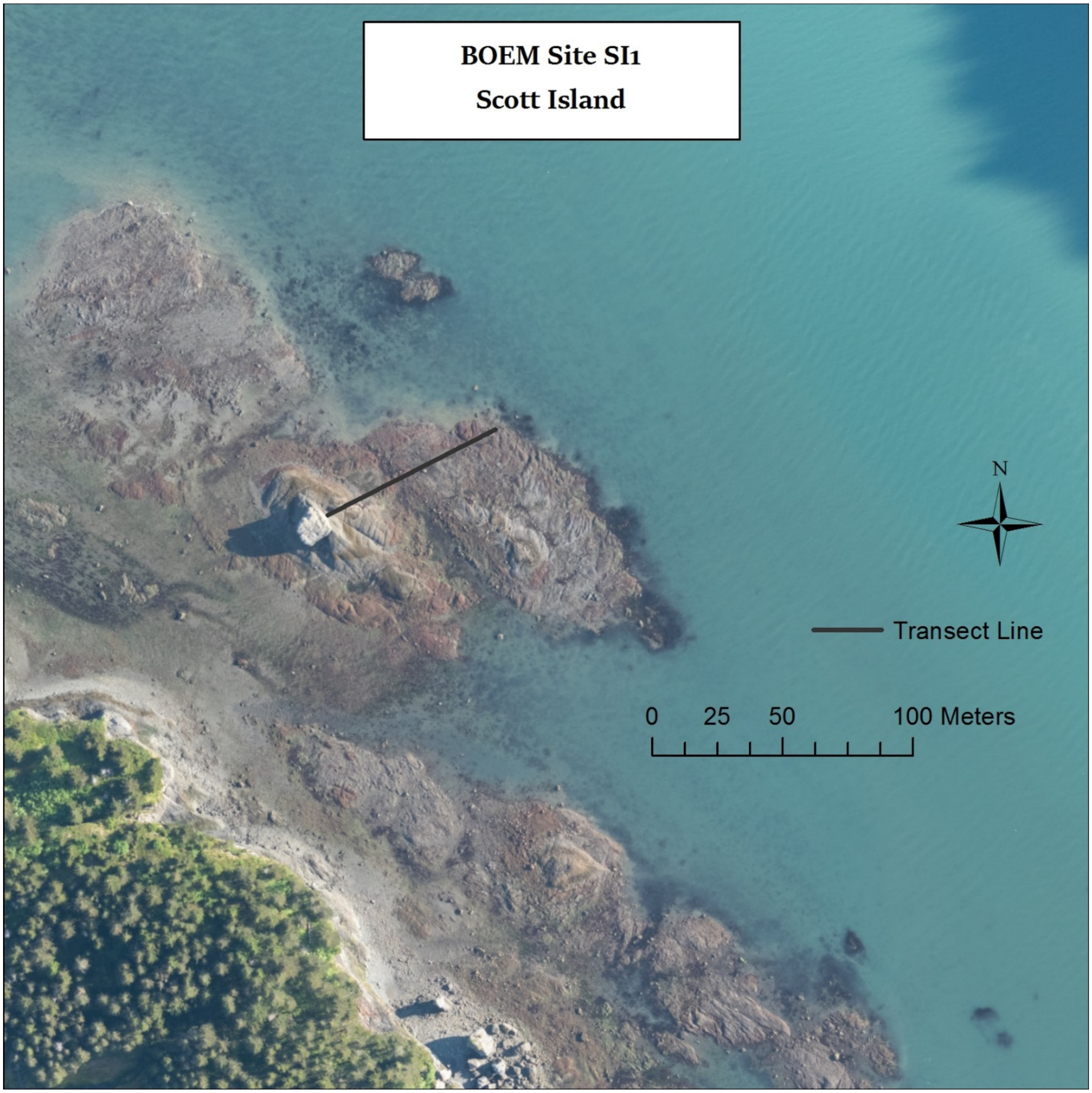


Figure 3.2.1.7.1. Aerial orthoimage of Site SI1, Scott Island, showing location of survey transect line.
Location near the mouth of Iniskin Bay.

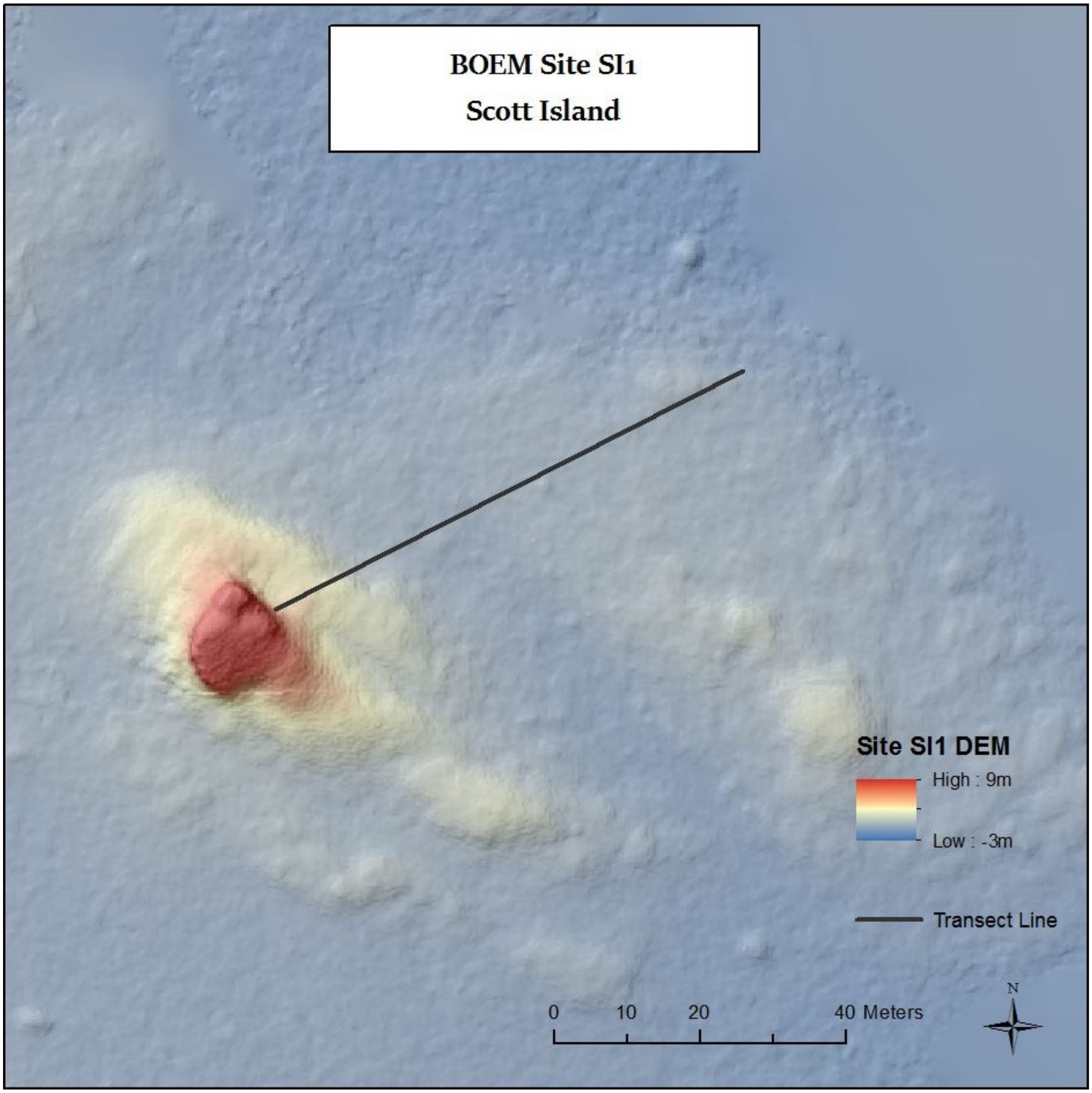


Figure 3.2.1.7.2. Digital surface model along transect of Site SI1.
Surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.8 **Site TR1: Turtle Reef**

Site TR1, Turtle Reef

This site is at the entrance of Iliamna Bay in the Turtle Reef area. The site is situated between a rocky reef/gravel beach complex and a gravel spit. The transect, which runs ENE, is exposed to local storm waves from the east, but it is protected from southerly or northerly storm waves and from ocean swells. The transect crosses a wide moderately sloped sand and gravel beach and extends roughly 200 m seaward across a low-angle ramp of mainly boulders and cobble overlying mixed sand and granular substrate.

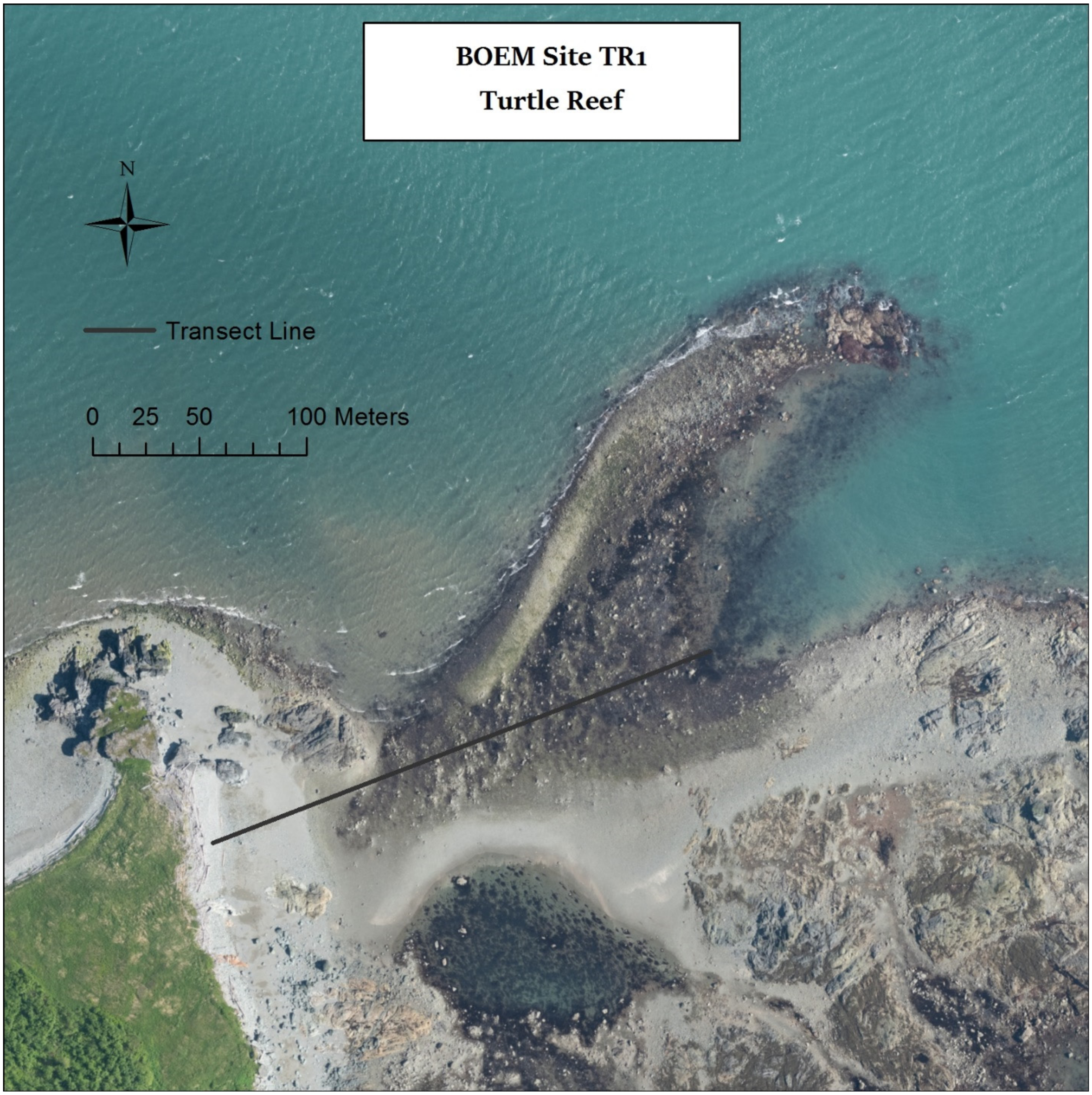


Figure 3.2.1.8.1. Aerial orthoimage of Site TR1, Turtle Reef, showing location of survey transect line.
Location at the mouth of Iliamna Bay.

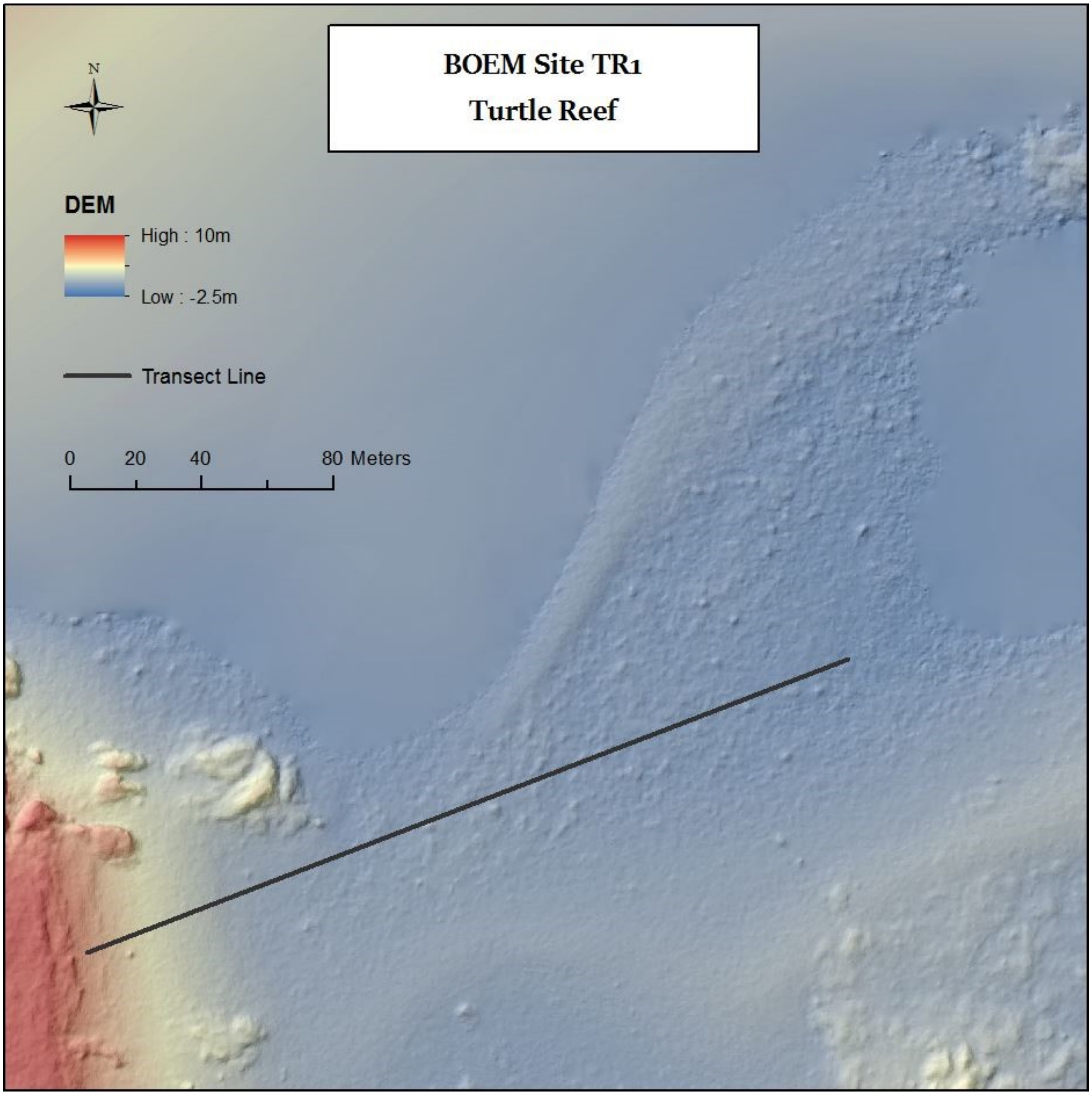


Figure 3.2.1.8.2. Digital surface model along transect of Site TR1.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.9 **Site BB1: Bruin Bay**

Site BB1 is in the outer portion of Bruin Bay, just west of the south entrance. The site is at the base of a steep cliff with a foreshore beach of bare sand and granular substrate. The transect runs ENE towards the waterline and crosses a bedrock ramp. The erosional patterns within the bedrock create closely spaced parallel ridges and shallow channels, and near the seaward end of the transect, a few larger channels provide lower tidal habitat. Due to a combination of weather and site access, no digital surface model was derived at this site.

Note that the photograph in Figure 3.2.1.9.1 was taken before the tide had fully retreated and additional habitat was exposed for sampling.

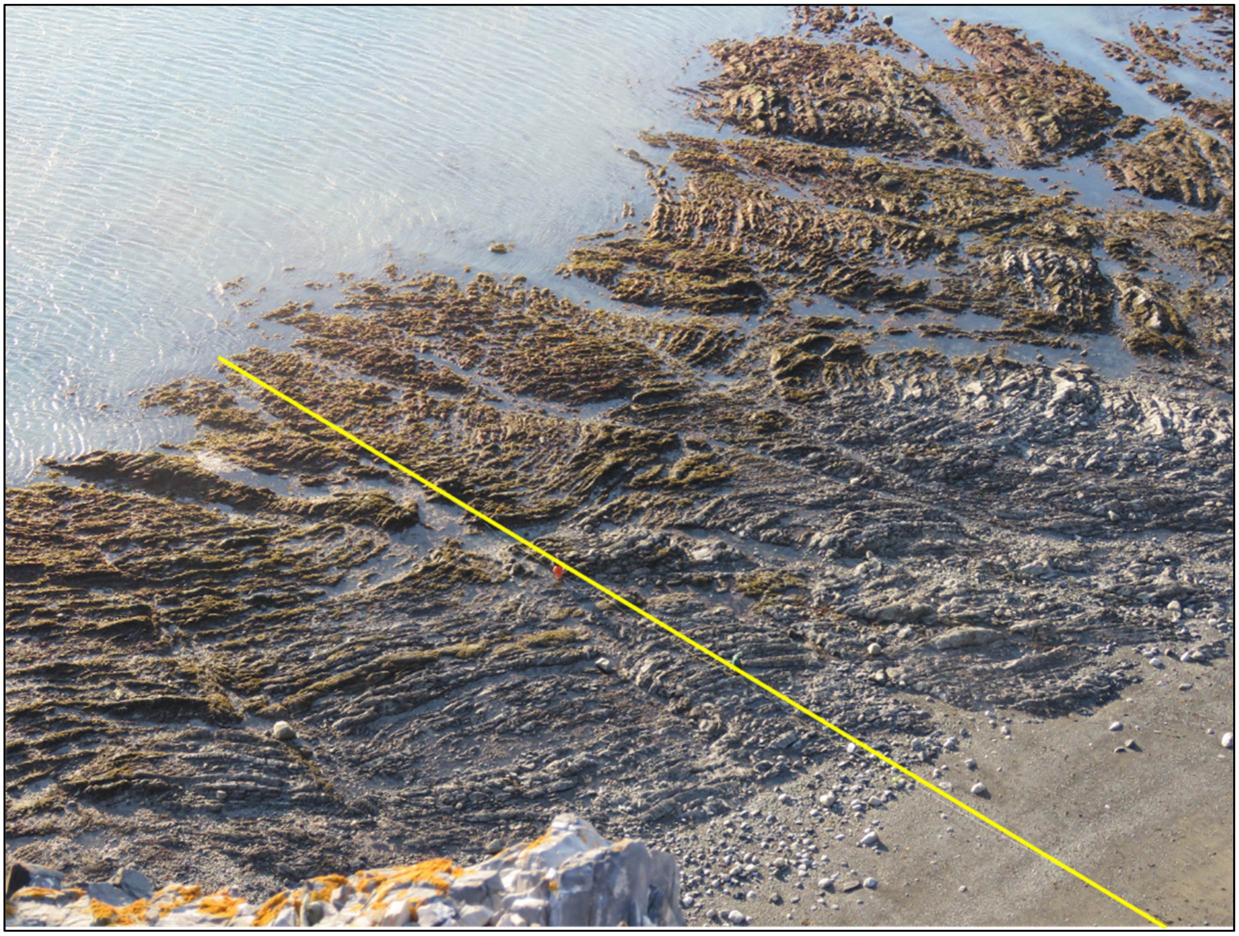


Figure 3.2.1.9.1. On-site photo taken during the 2018 survey at Site BB1 in Bruin Bay.
Yellow line shows transect placement.

3.2.1.10 **Site N1 Nordyke Island**

Nordyke Island is tucked into the southwest corner of Kamishak Bay, just east of Chenik Head on the mainland. The island is flat and vegetated mainly by grasses. It is surrounded by extensive intertidal reefs and bedrock platforms. Site N1 is on the NE corner of Nordyke Island where there is no gravel foreshore. The transect starts at estimated MHHW on a steep conglomerate bedrock outcrop. The conglomerate is mainly cobble and pebble embedded in the rock matrix. At the base of this foreshore, the slope changes to a very low angle (0.2º slope) platform overlain with extensive shallow tide pools. The transect runs ESE towards the waterline. The slope increases slightly near the lower end of the transect, where it is crossed by a few deeper channels, providing additional low intertidal habitat. The site is highly exposed to local storm waves and ocean swells from the Gulf of Alaska, although access can be made on the west side of the island in some storm conditions.

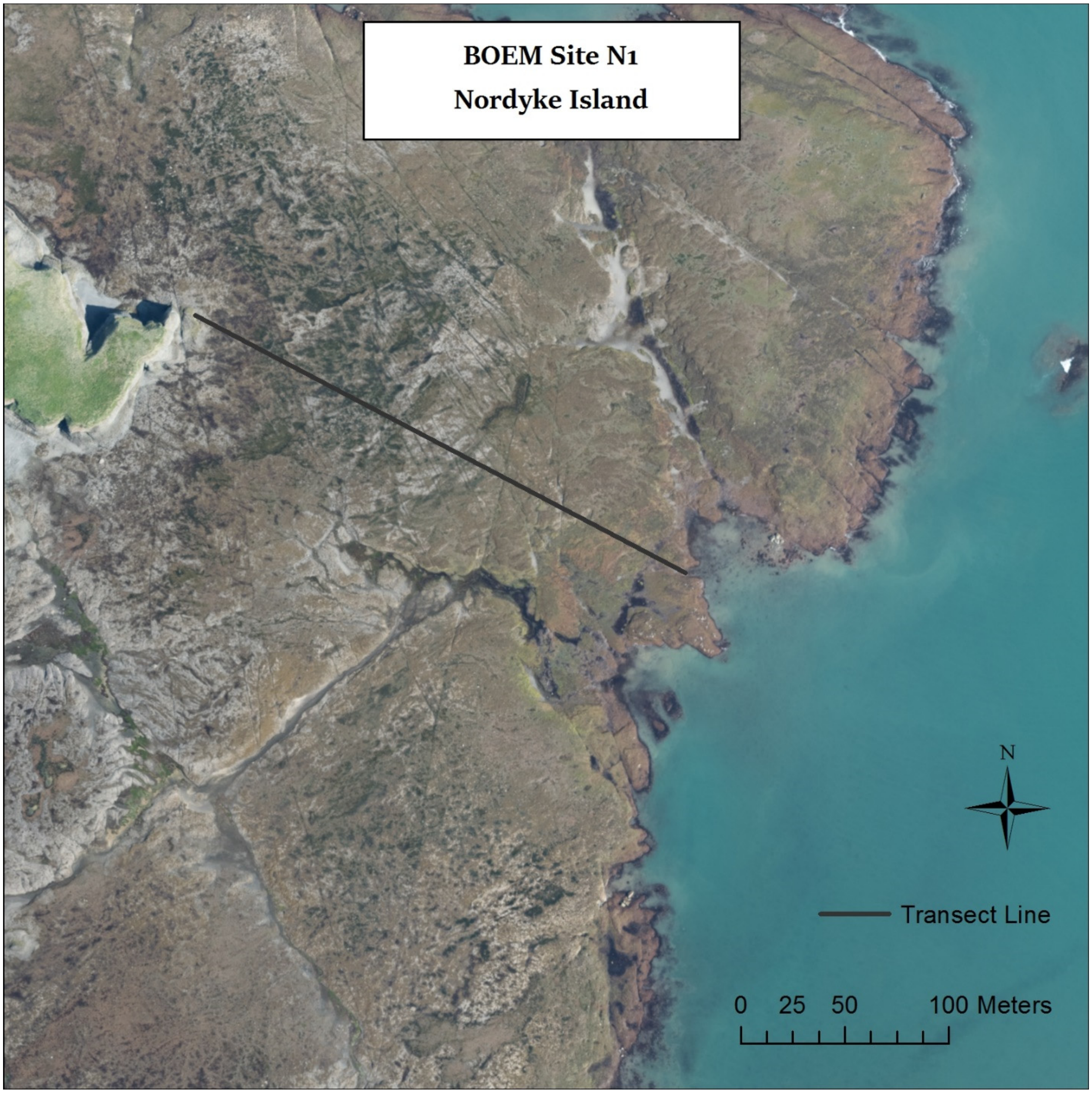


Figure 3.2.1.10.1. Aerial orthoimage of Site N1, Nordyke Island, showing location of survey transect line.

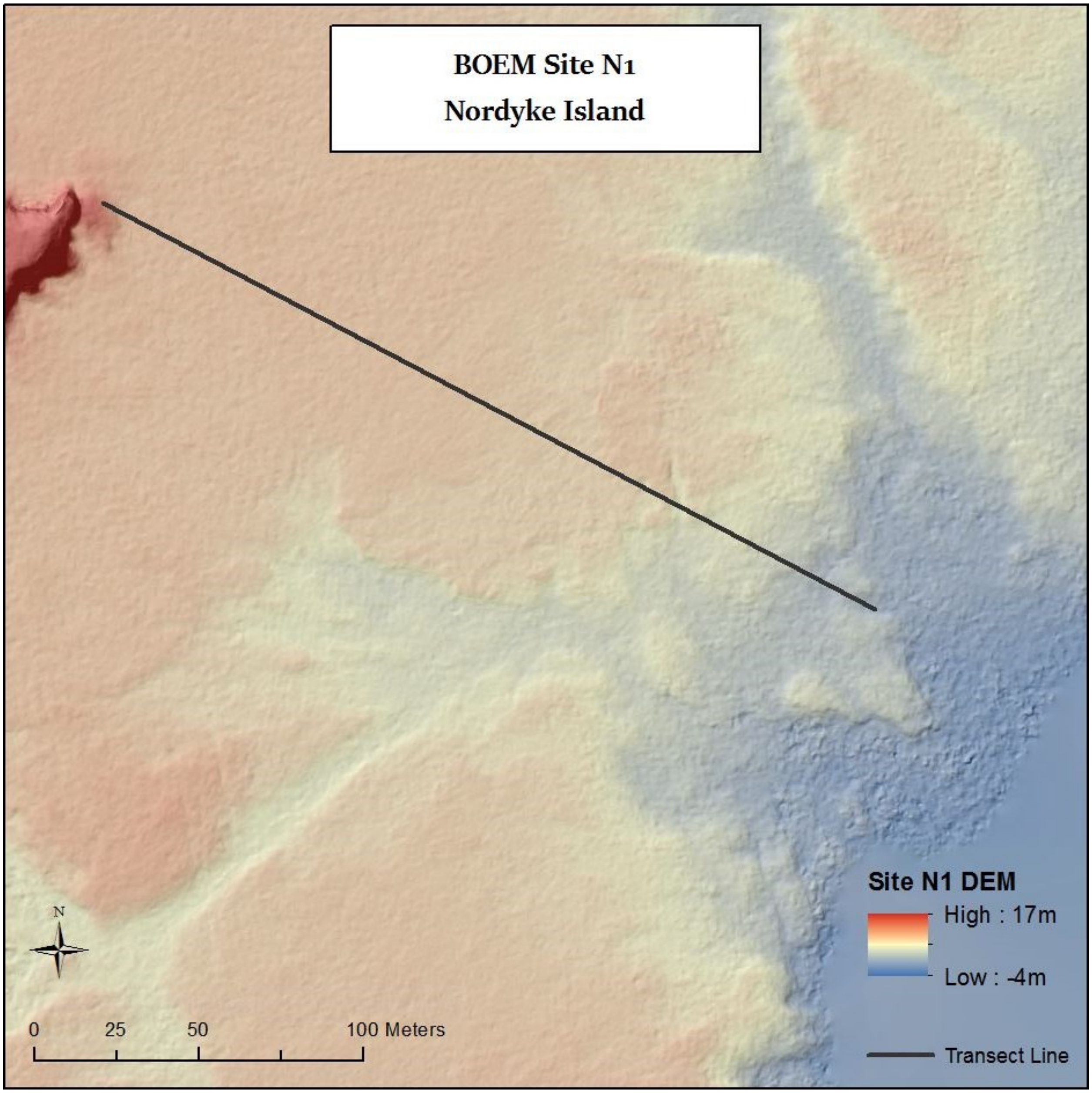


Figure 3.2.1.10.2. Digital surface model along transect of Site N1.
Digital surface model derived from aerial survey and survey-grade GPS control points. Height is orthometric (0= modeled MSL).

3.2.1.11 **Douglas Reef**

Douglas Reef covers the majority of the south side of Kamishak Bay. Douglas Reef is a wide broad reef at the northern end of the Alaska Peninsula approximately 4 miles wide and 24 miles long covering approximately 9,000 hectares. This broad system has several oceanic channels extending into the bay creating 3 distinct reef areas that are generally not connected to the mainland. The reef is intertidal in nature with a few small islands located throughout the reef area. The reef is subject to direct oceanic physical processes on the eastern portion of the reef, while the western portion of the reef is relatively protected. The northern edges of the reef are all exposed to physical forcing from Cook Inlet.

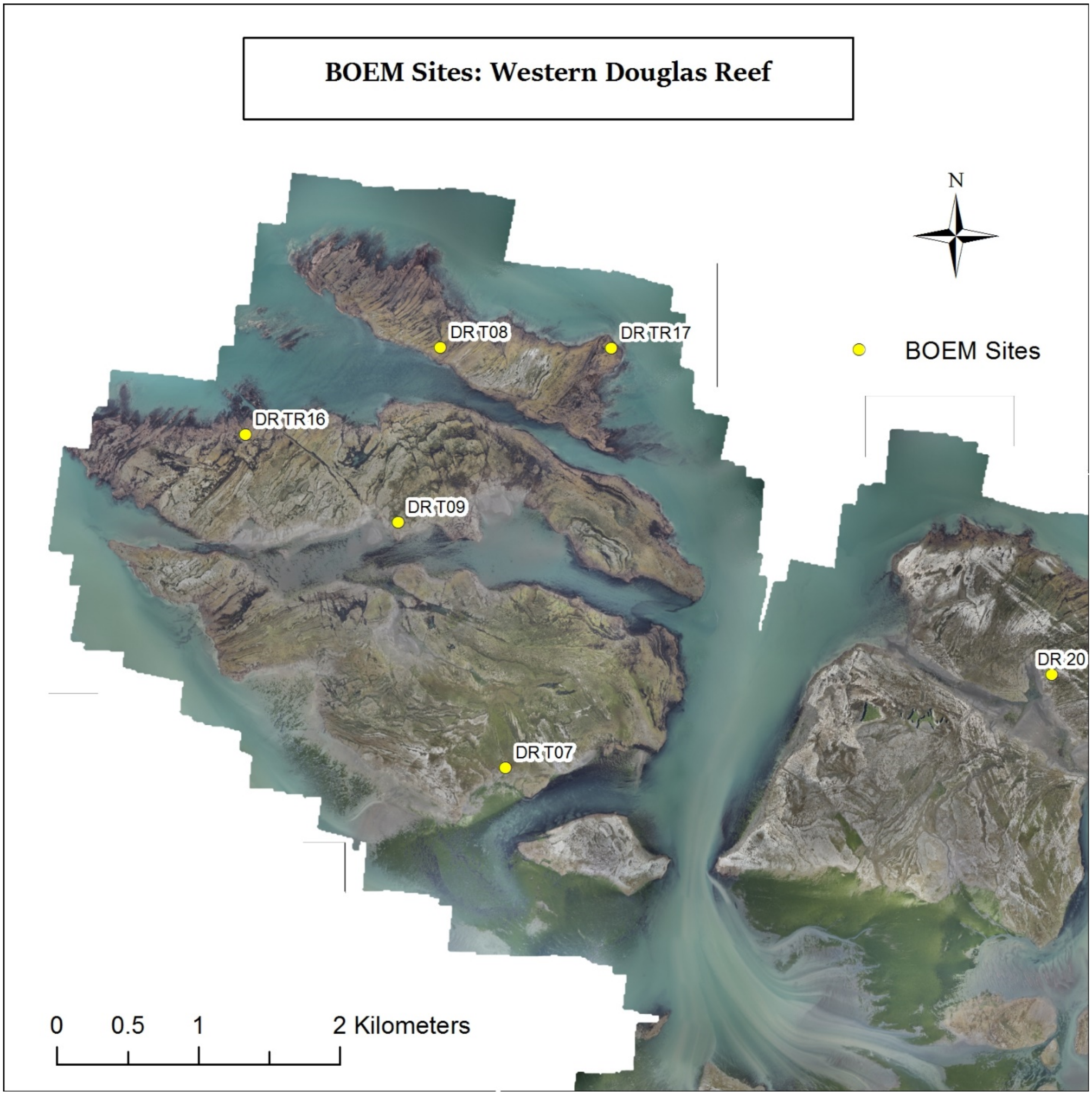


Figure 3.2.1.11.1. Aerial orthoimage of western Douglas Reef sites showing location of surveys.

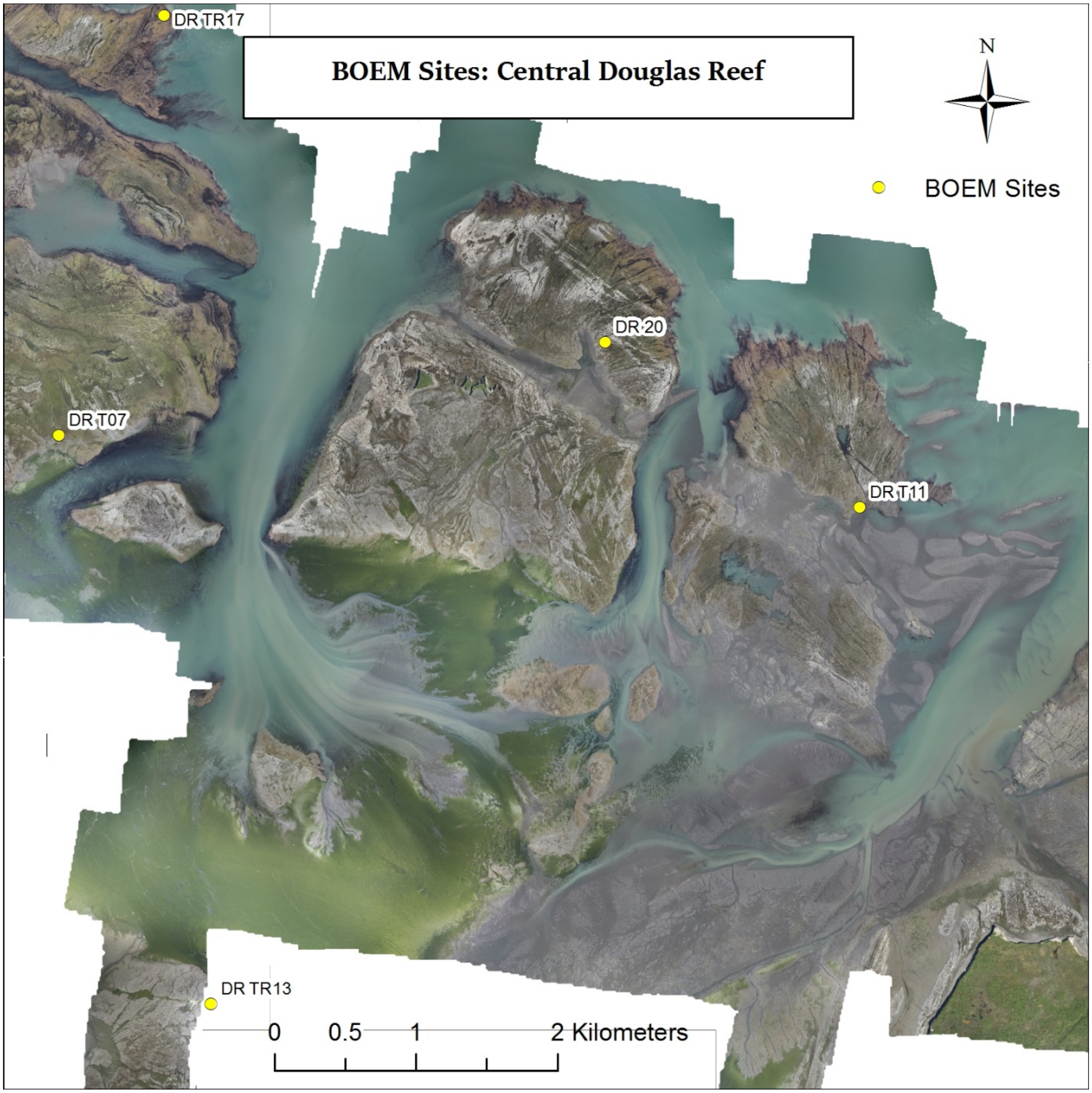


Figure 3.2.1.11.2. Aerial orthoimage of central Douglas Reef sites showing location of surveys.

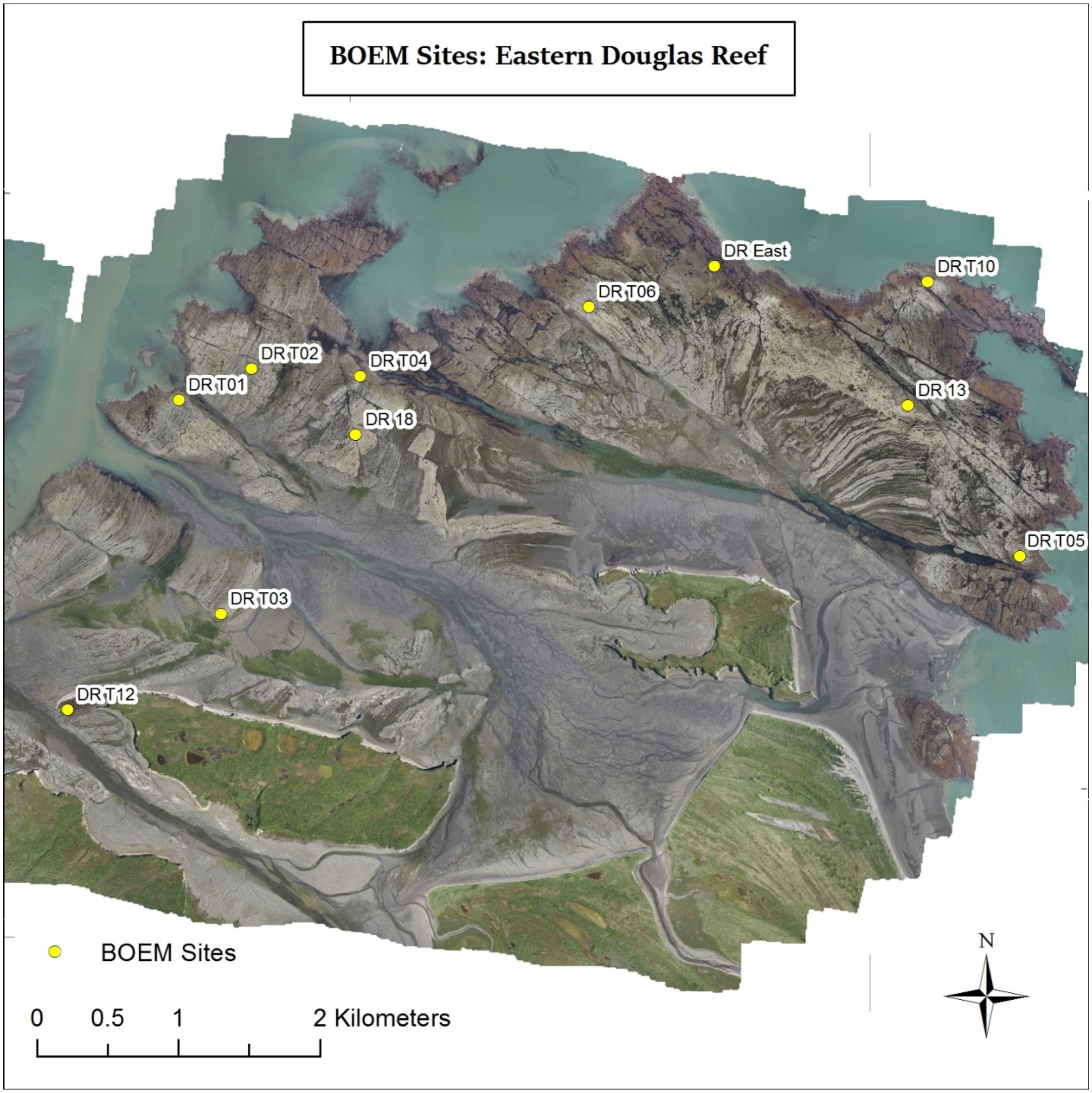


Figure 3.2.1.11.3. Aerial orthoimage of eastern Douglas Reef sites showing location of surveys.

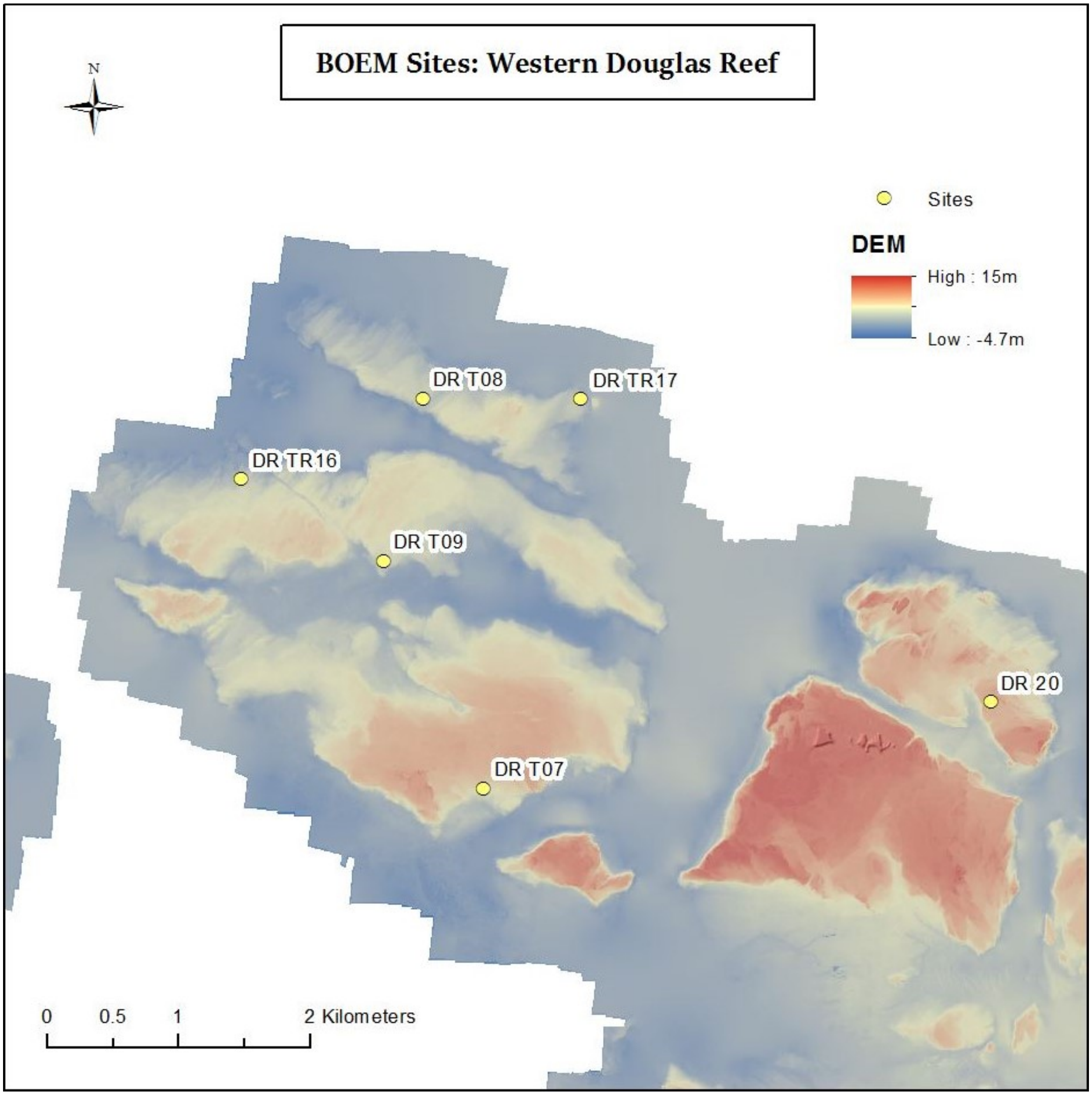


Figure 3.2.1.11.4. Digital surface model along transect of Western Douglas Reef.
Digital surface model derived from aerial survey and survey-grade GPS control points. Transect site locations indicated. Height is orthometric (0= modeled MSL).

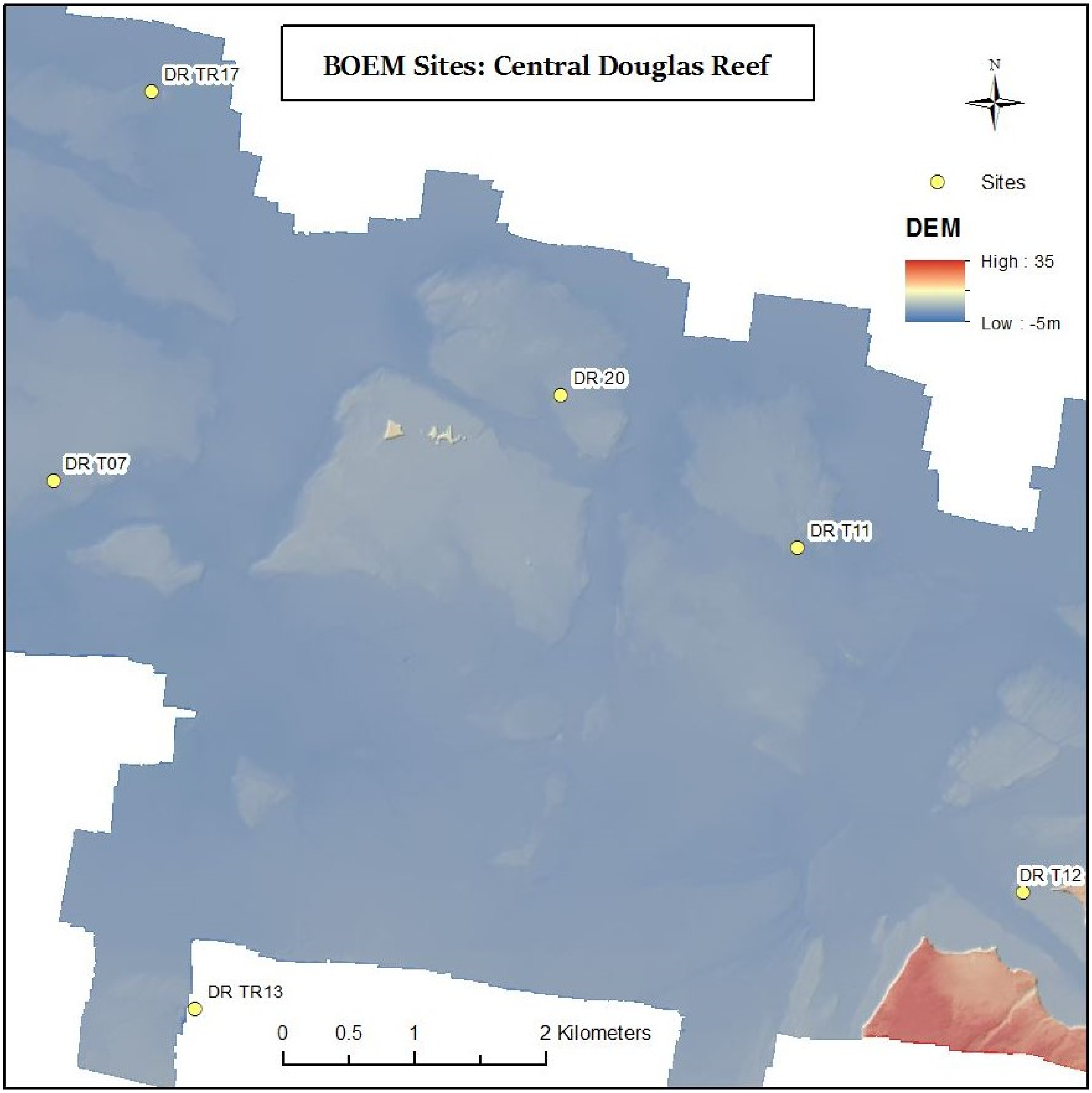


Figure 3.2.1.11.5. Digital surface model along transects of Central Douglas Reef.
Digital surface model derived from aerial survey and survey-grade GPS control points. Transect site locations indicated. Height is orthometric (0= modeled MSL).

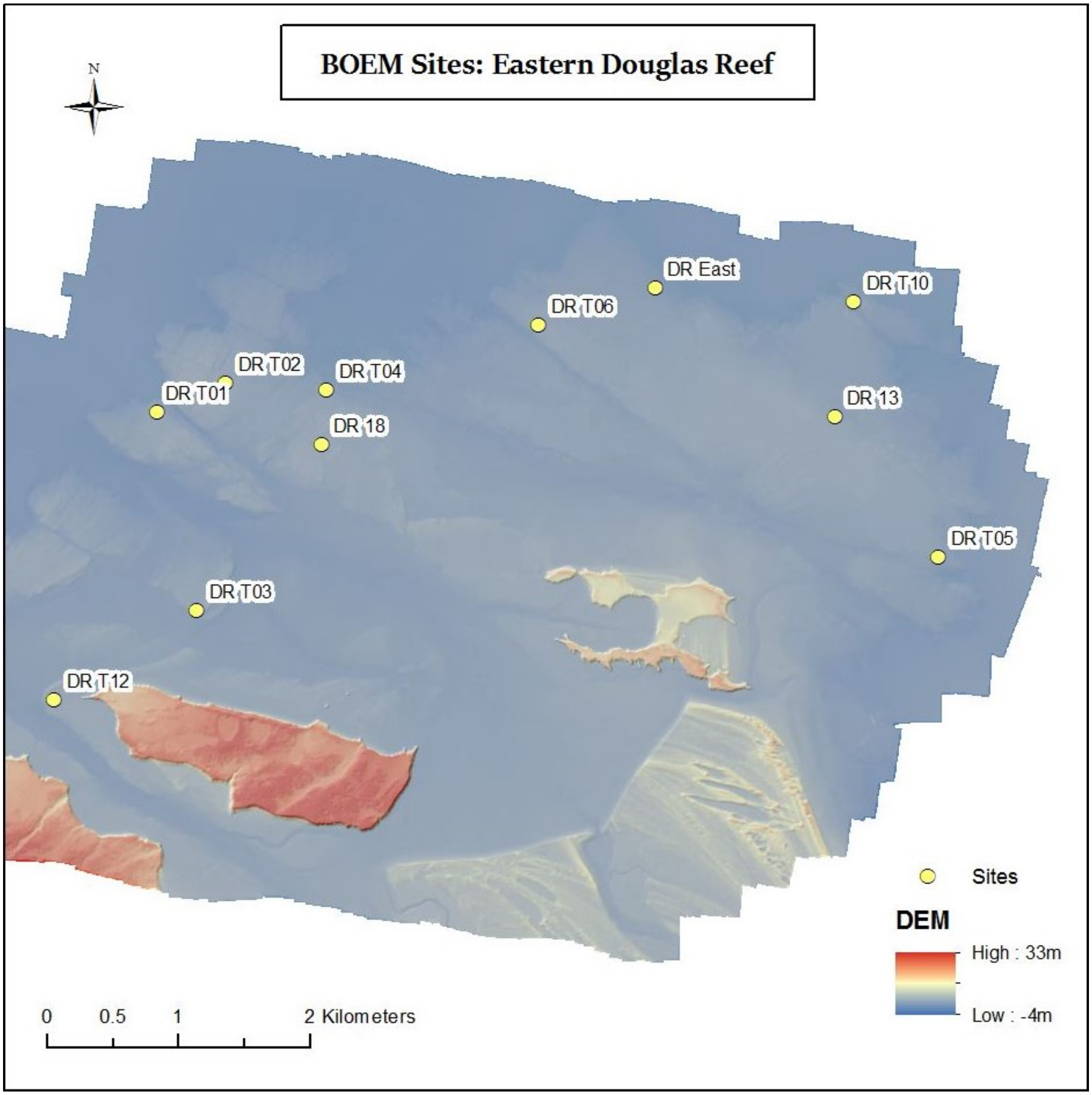


Figure 3.2.1.11.6. Digital surface model along transects of Eastern Douglas Reef.
Digital surface model derived from aerial survey and survey-grade GPS control points. Transect site locations indicated. Height is orthometric (0= modeled MSL).

3.2.2 Site Attributes and Topography

Key physical attributes were derived for each intertidal site (Table 3.2.2.1) and site profiles were examined in orthometric and MLLW elevations (Figures 3.2.2.1. and 3.2.2.2). Equivalent physical parameters were not derived for subtidal sites. Transect direction/azimuth indicates the direction of the transect line from beach face to low water. *ShoreZone* BioExposure expresses exposure to fetch. Definitions are available at the NOAA *ShoreZone* website (https://alaskafisheries.noaa.gov/mapping/DataDictionary/.) The *ShoreZone* shore type (BC Class) was initially used to identify rocky or mixed rock and sediment types for the purposes of random site selection. Some sites such as 3A and TR1 fall outside of these classes, yet were predominantly rock substrate, because *ShoreZone* BC class was mapped at minimal section lengths of 100 m, so BC class did not always correlate with observed substrate. Overall slope in degrees was calculated with a simple rise/run using the total length of the transect, the orthometric height of the top of each transect and the orthometric height of the end point of each transect.

Table 3.2.2.1. Table of physical intertidal site attributes.

Site Code	Site name	Transect Direction	Transect Azimuth (degrees)	*ShoreZone* BC Class	*ShoreZone* BioExposure	Overall Slope (Degrees)	Ramp Slope (Degrees)
2	Contact Point	SE	144	2	E	1	0.5
4	Pomeroy Island	SE	135	5	E	1.5	0.5
6	Iliamna Point	ESE	108	7	SE	3.5	2
10	Chinitna Bay	SSW	200	8	SE	3.3	3.3
19	Chenik Head	ESE	112	2	SE	1.1	0.5
41	Augustine East	E	83	8	SE	2.9	n/a
3A	Augustine Island	N	2	21	SE	0.8	0.4
BB1	Bruin Bay	ENE	65	12	SE	3.6	2.5
N1	Nordyke Island	ESE	118	2	SE	1	0.2
SI1	Scott Island	ENE	63	13	E	4	1
TR1	Turtle Reef	ENE	69	24	SE	1.6	0.3

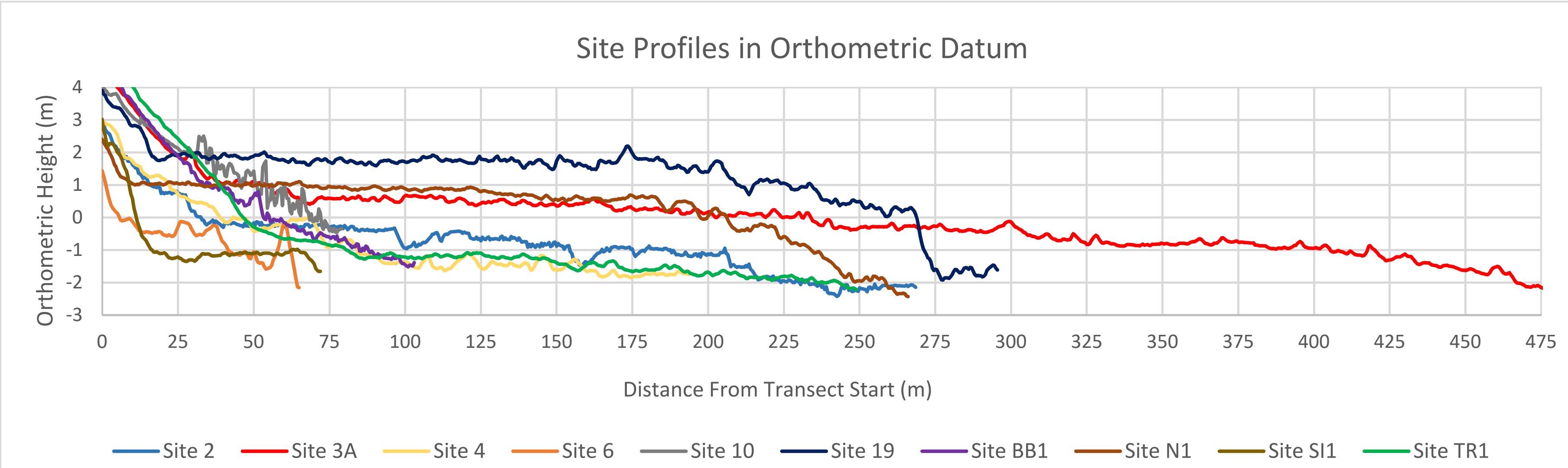


Figure 3.2.2.1. Vertical range and profile along intertidal transects at each of the 10 non-reef sites in orthometric datum.
Note the exaggerated vertical axis. Vertical measurements were taken to create a digital elevation model at each site and measurements often extended above the estimated Mean Higher High Water (MHHW). In the orthometric datum, 0 = modeled MSL.

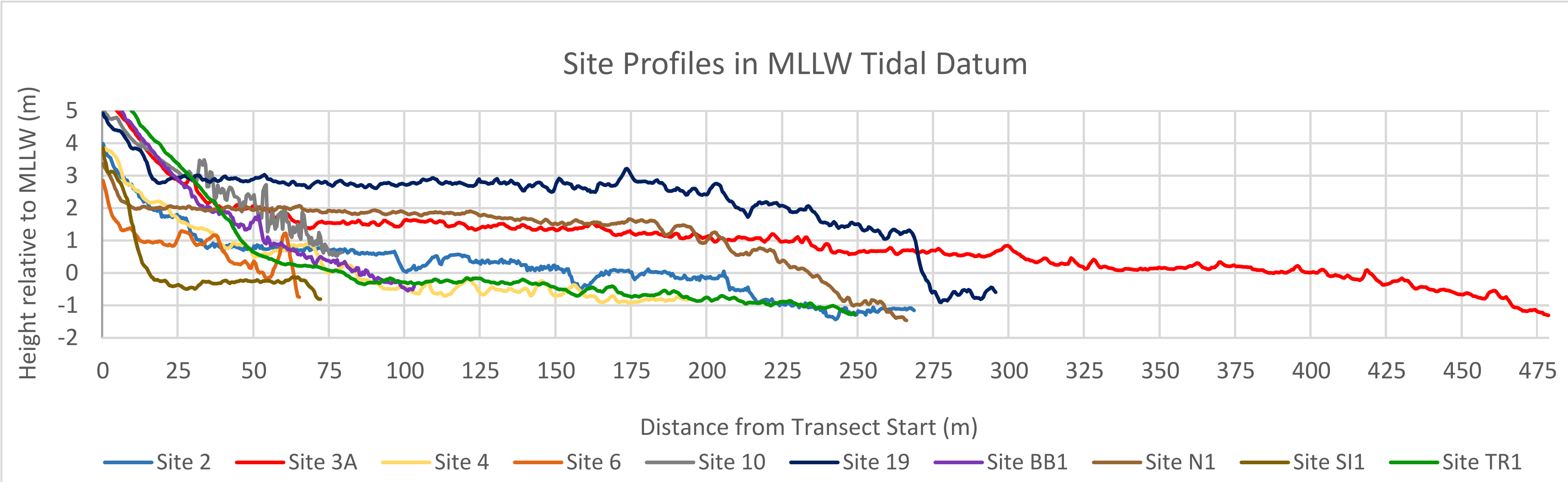


Figure 3.2.2.2. Vertical range and profile along intertidal transects at each of the 10 non-reef sites in MLLW tidal datum. Note the exaggerated vertical axis. Vertical measurements were taken to create a digital elevation model at each site and measurements often extended above the estimated Mean Higher High Water (MHHW). An unofficial tidal datum conversion factor was not available until after data analysis was conducted. This figure is provided to give additional context to each site relative to a datum used commonly by researchers in the intertidal zone.

3.3 Subtidal Quadrat Data

Seven sites were sampled in four years from 2015 – 2018, although several sites could only be visited in three years because of boating logistics and/or weather. When algal biomass per site was averaged over all years, the sites farthest into Kamishak Bay grouped close together (S_2, S_19S, S_3A). While S_NI2 is spatially close to S_19S, its algal composition was very distinct. Sites farther north (S_GI and S_4) and farther south (S_DP) in the study region were distinct from the inner Kamishak Bay sites and from each other (Figure 3.3.1).

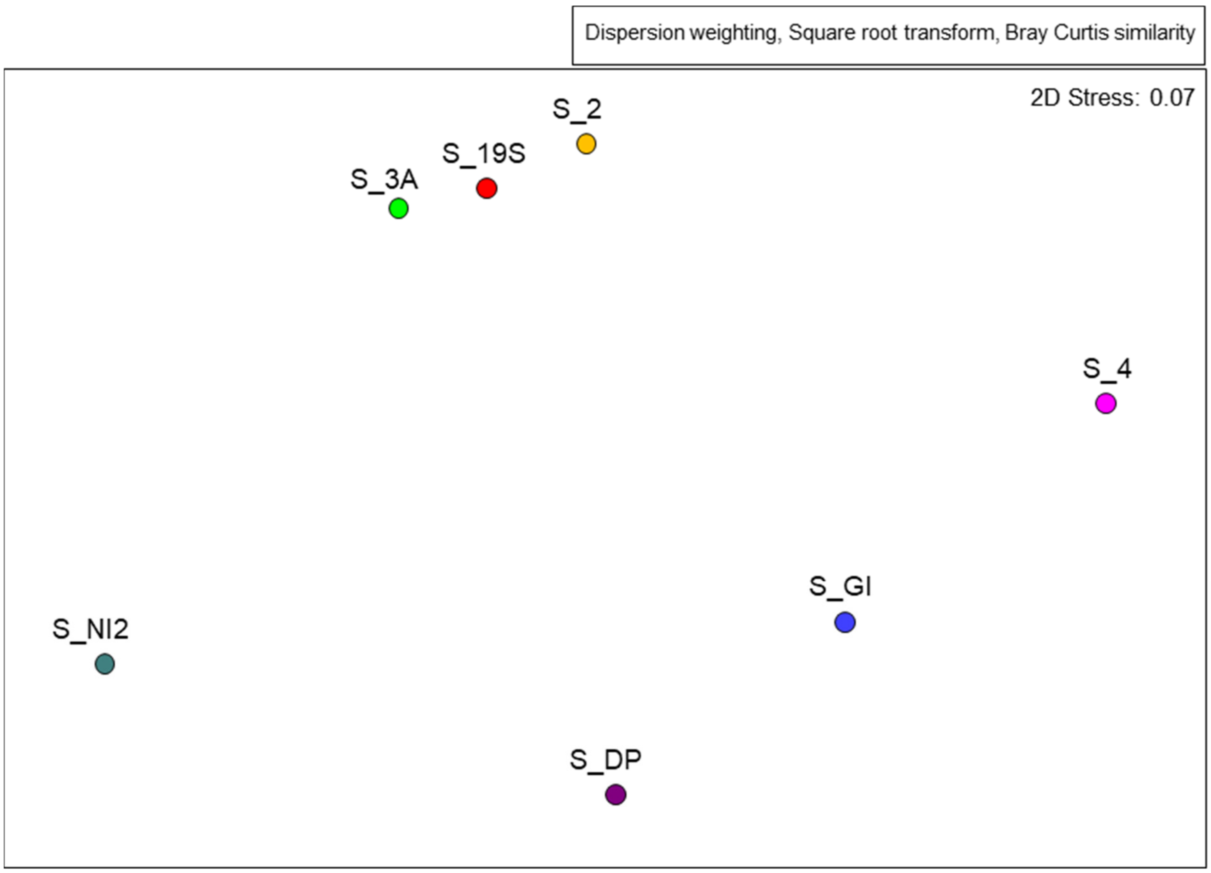


Figure 3.3.1. nMDS ordination of subtidal macroalgal biomass averaged across study years per site.
Sites farthest into Kamishak Bay build a tight cluster (S_2, S_19S, S_3A) except S_NI2, which is spatially located next to S_19S, but had a distinct algal community. Sites farther north (S_GI and S_4) and farther south (S_DP) were distinct from the inner Kamishak Bay group and from each other.

Averaged across years, some macroalgal taxa were common for most sites, specifically the red alga *Constantinea* spp. and some kelp species, either *Saccharina latissima* or *S. nigripes* (Figure 3.3.2). At most sites, both kelp species occurred, but there was no discernable spatial pattern of sites closer together featuring the same dominant kelp species. At the farthest south sites (S_NI2 and S_DP), *S. latissima* were absent. In general, combined algal biomass was highest at the more northern sites (Figure 3.3.2; S_GI, S_4, and S_3A) and lowest farther south (S_NI2). Both the maximum number of macoalgal taxa found at a site across all study years (Figure 3.3.3(a)) and the Shannon Wiener diversity index across years (Figure. 3.3.3(b)) showed a slight trend of higher values in the mid-study region, i.e., in central Kamishak Bay, with lower values farther north (towards the head of Cook Inlet) and father south (towards the Gulf of Alaska). Overall, maximum number of macroalgal species found ranged from 10 at S_GI to 46 at S_3A.

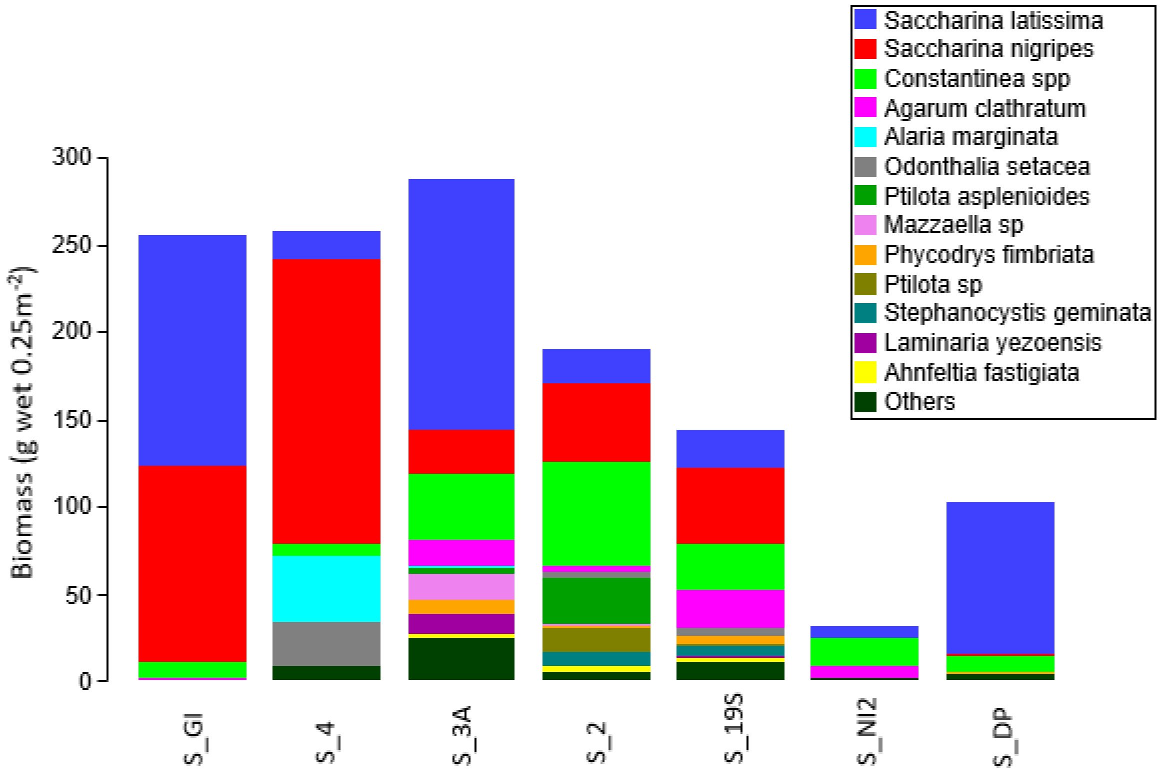


Figure 3.3.2. Composition of subtidal macroalgal biomass averaged across study years per site. A variable number of additional less common taxa per site are grouped under "others". Sites ordered from north to south by latitude.

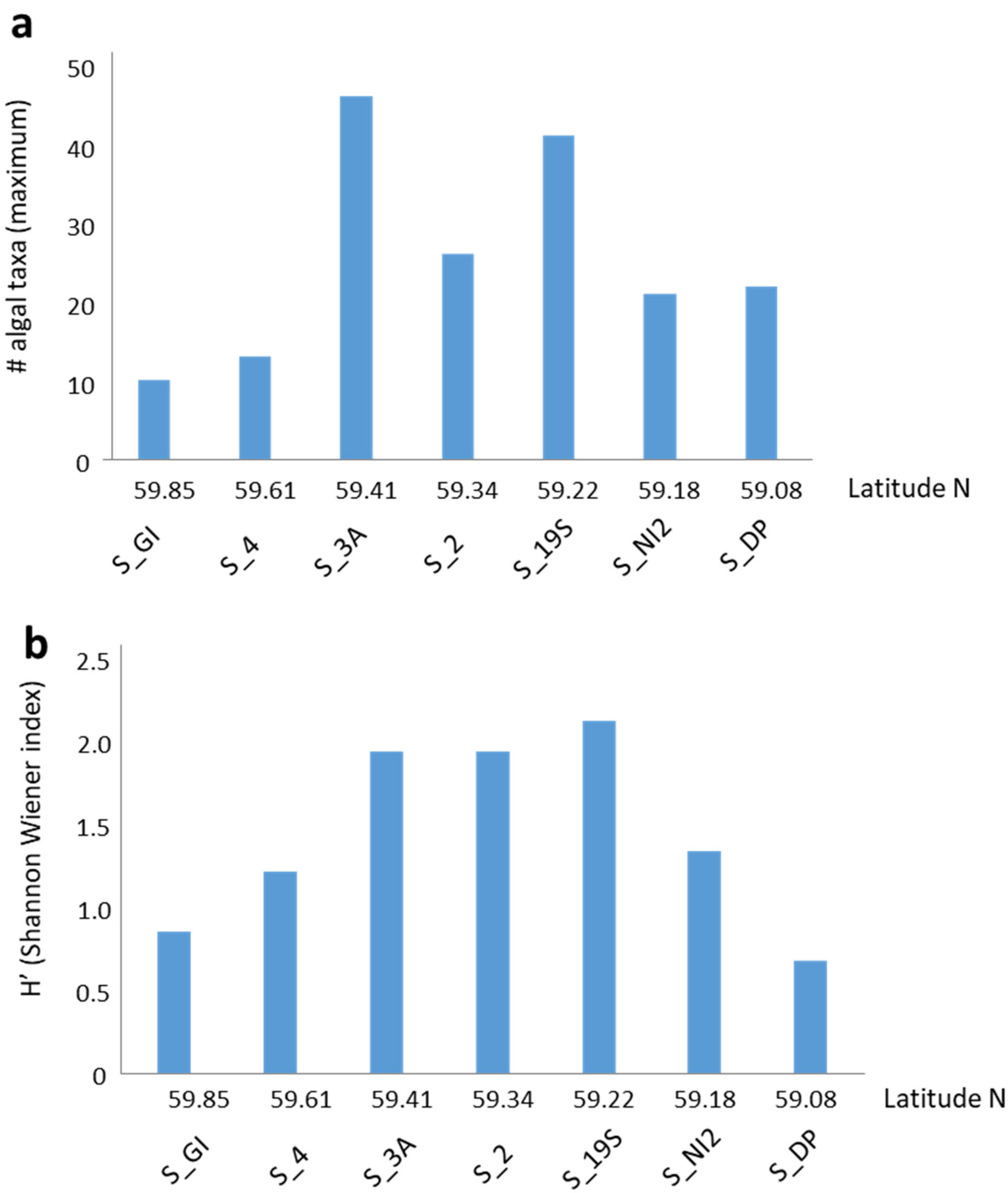


Figure 3.3.3. Maximum number of subtidal algal taxa per site combined across all years (a), and Shannon Wiener diversity index per site, with years per site averaged (b).
Data based on biomass collections. Sites ordered from north to south by latitude. For both taxon richness and Shannon diversity, there was a peak at mid-latitudes.

Figure 3.3.4. nMDS plot of subtidal algal assemblages at the subtidal study sites over four sampling years (not all sites were sampled in all years), based on biomass collections. While there was no clear distinction among sites, some moderate groupings could be detected (see text for details).

Annual macroalgal composition (based on biomass) per site was similar for some sites (years per site clustered within the nMDS ordination), but sites were not clearly distinct from each other (Figure 3.3.4). Annual samples at S_4 grouped together as well as those from S_GI. The S_3A years were spread out but also separated from the main cluster. Annual samples from S_2, S_19S, and S_NI2 grouped relatively closely but with much overlap among the sites, probably indicative of their proximity within the study region. Two years of the S_DP samples also fell within that grouping, while S_DP in 2017 fell far apart from all other samples. The lack of clear site distinction and consistency of macroalgal composition over the study years was also obvious when examining individual algal species per site over years (Figure 3.3.5).

While presence of major algal taxa was often consistent over years, biomass contribution of those taxa varied strongly among years. In some cases, composition changed drastically in one or more study years. For example, at S_4, *Saccharina nigripes* was a minor biomass contributor in years 2015 and 2016, while in 2017 it was the overwhelming biomass dominant (Figure 3.3.5). Similarly, a relatively large contribution to biomass by the kelp *Alaria marginata* at this site in 2015 was not detected in other sampling years. As another example, the noticeable presence of the red alga *Ptilota asplenioides* at site S_2 was only found in year 2016-2018 while the species was not observed at that site in 2015. As already mentioned, annual macroalgal composition at

S_DP was extremely variable. Here, biomass of *S. latissima* was very high in 2016 and was the primary contributor for the overall high biomass seen in that year, but it was not found in subsequent years (Figure 3.3.5).

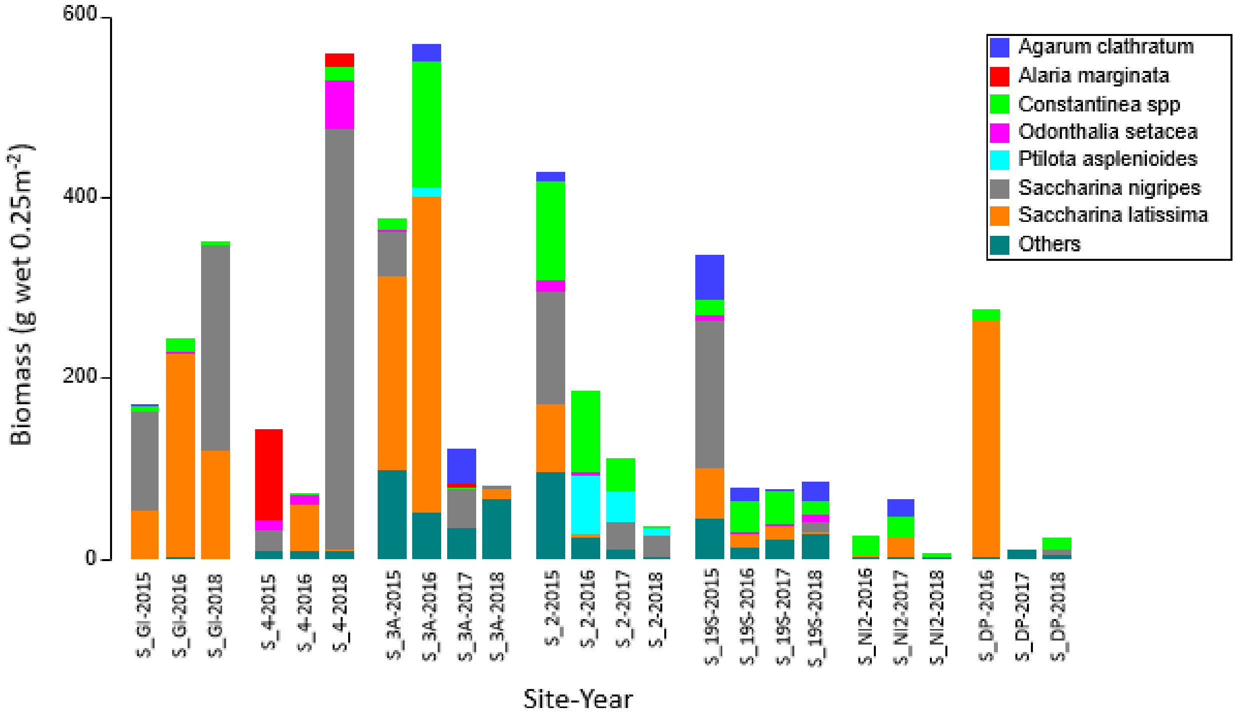


Figure 3.3.5. Subtidal algal biomass at subtidal study sites over time.
Seven algal species that overall contributed most to biomass are shown here. All other species are grouped as “others”. Sites are arranged in an approximate north-south fashion from left to right.

Table 3.3.1. PERMANOVA results for the effects of site (fixed factor) and year (random factor) on the subtidal macroalgal assemblages in Cook Inlet.
The significant interaction effect of site and year leaves the individual effects uninterpretable.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
site	6	1.26E+05	20947	1.9831	0.0001	9821
year	3	7.56E+04	25198	10.455	0.0001	9841
site x year	14	1.52E+05	10852	4.5028	0.0001	9604
Residual	191	4.60E+05	2410.1			
Total	214	8.26E+05				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	368.81	8.79
V(ye)	459.53	10.95
V(sixye)	957.87	22.83
V(Res)	2410.1	57.43

Table 3.3.2. PERMANOVA results for the effect of site (fixed factor) on subtidal macroalgal assemblages within each year.
Site always was a significant factor but with a large residual component that always exceeded the site effect.

2015

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
site	4	41102	10275	4.8831	0.0001	9856
Residual	20	42086	2104.3			
Total	24	83187				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	1634.2	43.71
V(Res)	2104.3	56.29

2016

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
site	6	96438	16073	7.7251	0.001	996
Residual	63	1.31E+05	2080.6			
Total	69	2.28E+05				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	1399.2	40.21
V(Res)	2080.6	59.79

2017

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
site	4	58339	14585	5.0301	0.001	993
Residual	45	1.30E+05	2899.5			
Total	49	1.89E+05				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	1168.5	28.72
V(Res)	2899.5	71.28

2018

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
site	6	90606	15101	6.0718	0.001	994
Residual	63	1.57E+05	2487.1			
Total	69	2.47E+05				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	1261.4	33.65
V(Res)	2487.1	66.35

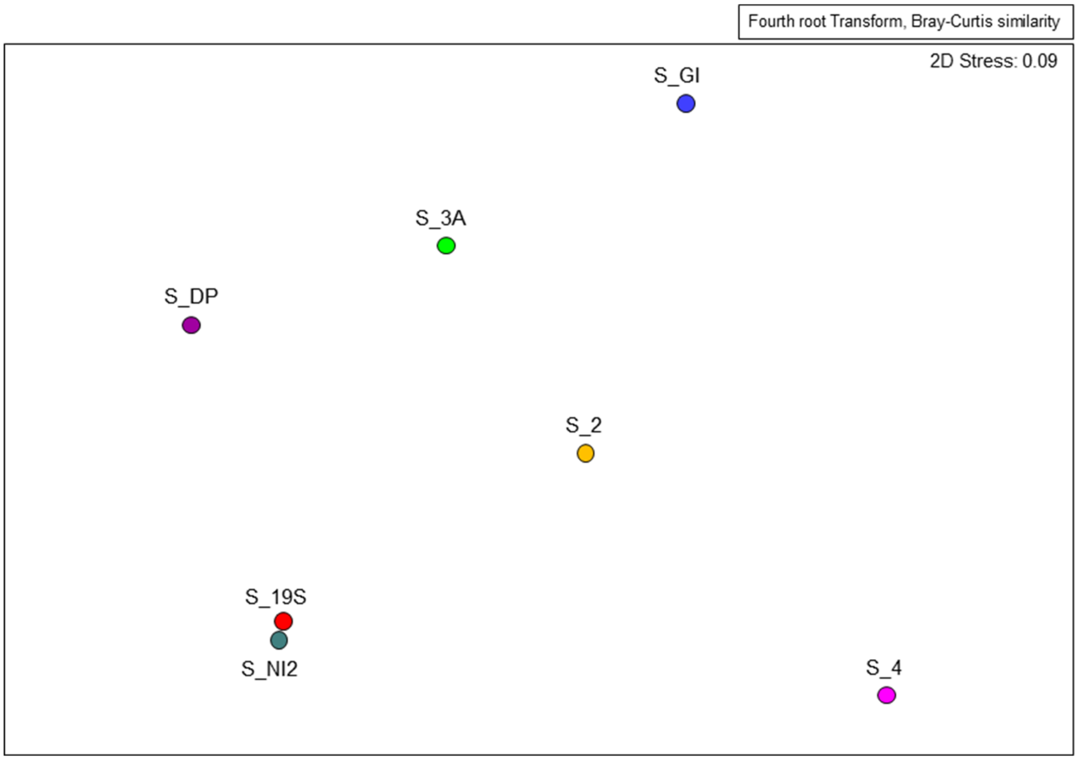


Figure 3.3.6. nMDS ordination of the subtidal invertebrate composition per study site based on biomass collections, averaged across sampling years.
Sites were distinct except for S_19S and S_NI2.

Most sites had lower biomass in 2017 and 2018 compared with earlier years, except for the more northern sites, S_GI and S_4. The influence of site and year on the macroalgal assemblage was further explored using PERMANOVA (Table 3.3.1). There was a significant year and site interaction term, explaining about 23% of the total variance; hence, site and year effects alone were not further interpreted. This matches the previous descriptive results that the algal assemblages had some characteristic taxa per site but that they were highly influenced by sampling year. The residual (unexplained) component of variance was high at 57%.

Biomass of the invertebrate assemblage was first aggregated on the phylum/class level and averaged over years. Invertebrate composition was distinct for all sites, except for the close clustering of sites S_19S and S_NI2, which were also the closest sites spatially (Figure 3.3.6). This is different from the year-averaged patterns in algae, where S_19S and S_NI2 were very different in their algal composition (compare Figure 3.3.6 with Figure 3.3.1). Invertebrate phyla/class biomass contributions averaged per site across years were highly variable. Some taxa occurred across all sites, although at low biomass (e.g., Gastropoda and Decapoda), while other taxa, such as Polychaeta and Ascidiacea, were particularly unevenly represented across sites, either being very prominent at some sites or very rare at others (Figure 3.3.7).

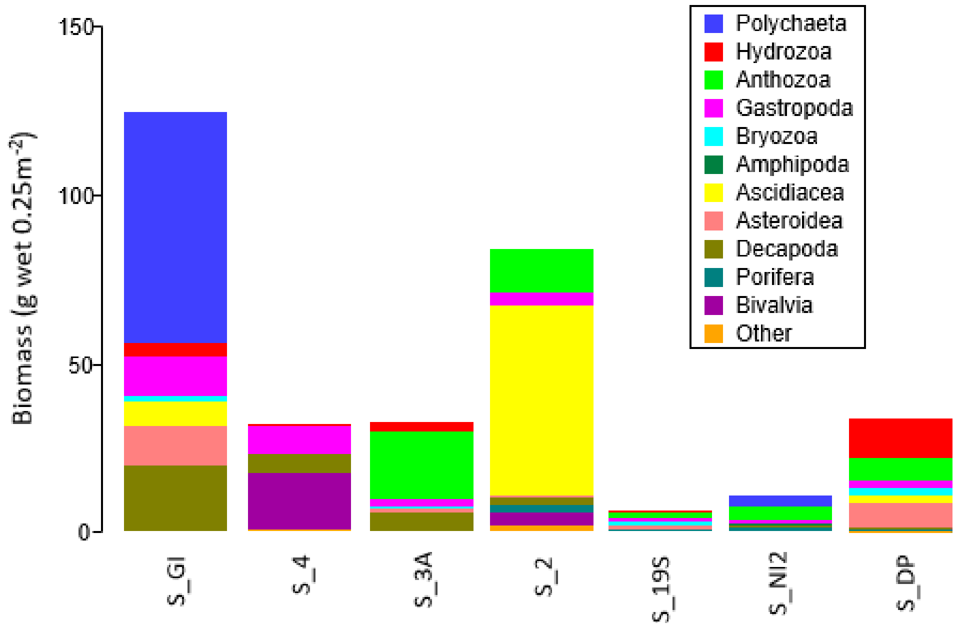


Figure 3.3.7. Subtidal biomass of invertebrate taxa (aggregated at the phylum/class level) averaged across sampling years per site.

When sites were combined across all years, both the maximum number of invertebrate species (Figure 3.3.8(a)) found at each site as well as the Shannon Wiener diversity index (Figure 3.3.8(b)) at each site did not show any discernible patterns among sites, especially in terms of north-south orientation along the eastern Cook Inlet coast. The maximum number of species ranged from 24 at S_2 to 37 at S_3A. Distribution of major taxa (aggregated on phylum/class level) was distinct for some sites (Figure 3.3.9). For example, Bivalvia were particularly common at S_4, at least at two out of the three study years. In other cases, single years were unique for a particular site such as the high biomass of Polychaeta at S_GI in 2015. While patchy in distribution, the occurrence of sea stars at several sites (especially S_GI) across years is noteworthy because of the prominent sea star wasting die-off along other regions of the Gulf Alaska in the same study period. At other sites, e.g., S_DP, asteroids were fairly abundant in 2016 but not in subsequent years. Generally, overall invertebrate biomass was consistently low across all years at S_19S and S_NI2, possibly contributing to the high similarity in multivariate ordination described above, while biomass was more variable across years at other sites.

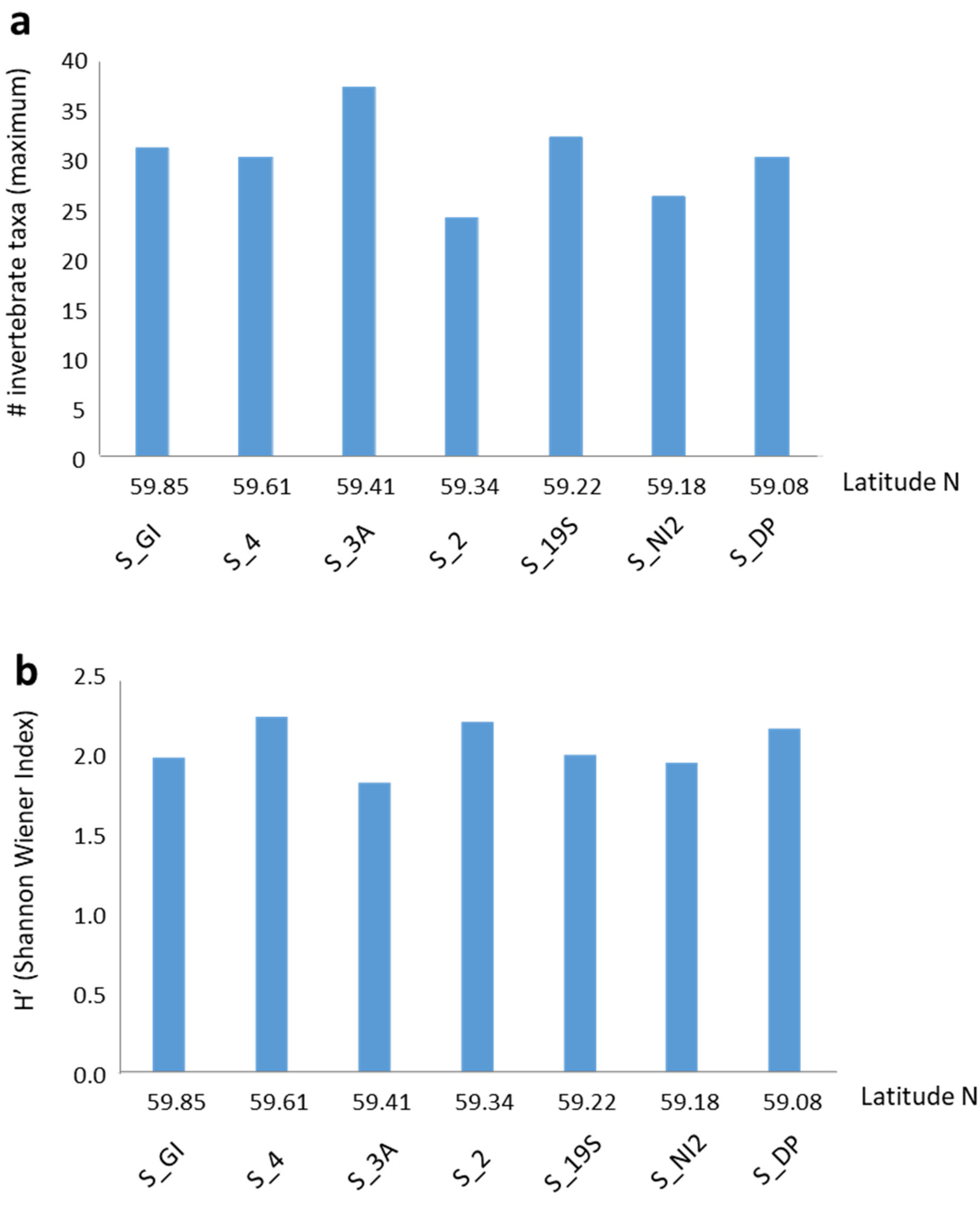


Figure 3.3.8. Maximum number of subtidal invertebrate phyla/class per site combined across all years (a), and Shannon Wiener diversity index for invertebrates per site (b), with years per site averaged for both measures.
Sites ordered from north to south by latitude. There was no distinct pattern in maximum taxa or diversity among sites.

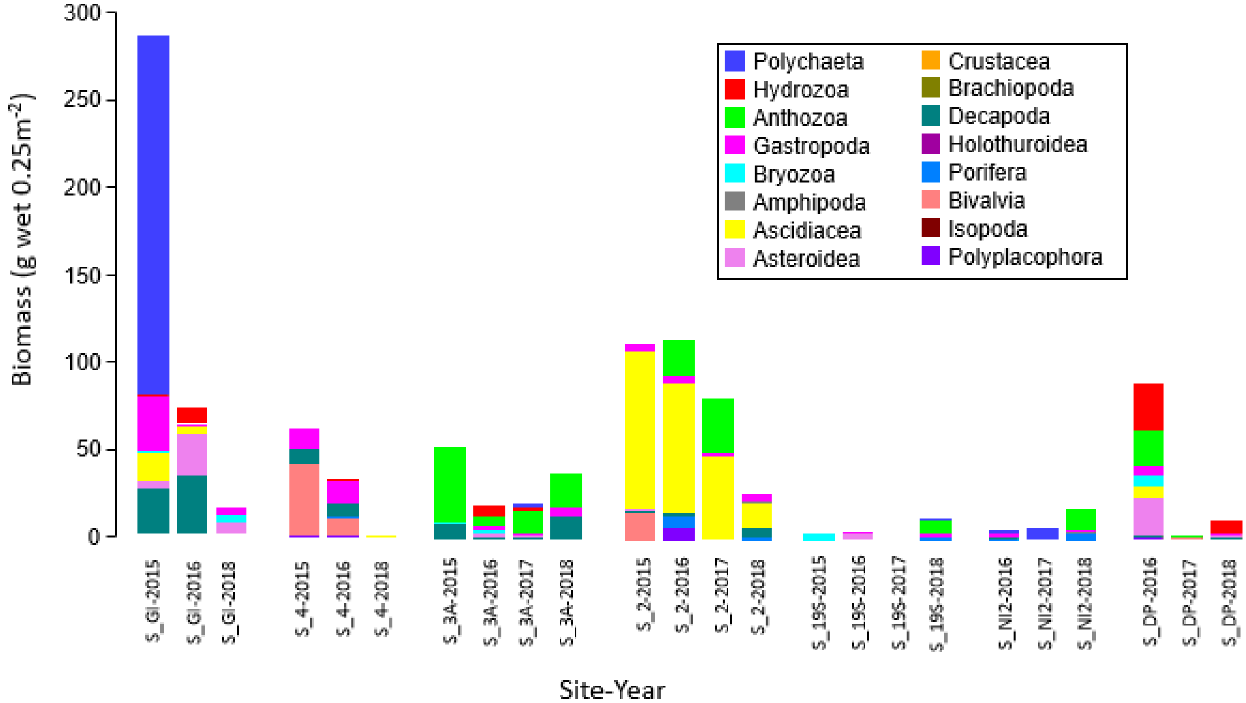


Figure 3.3.9. Subtidal invertebrate biomass at subtidal study sites over time.
Taxa were aggregated at the phylum/class level. Sites are arranged in an approximate north-south fashion from left to right.

Exploring invertebrate community composition in multivariate similarity space revealed strong overlap of all sites and years, regardless if invertebrates were aggregated at the phylum/class level or the lowest taxonomic level (Figure 3.3.10(a) and (b)). A very high stress level in the lowest taxonomic level ordination suggests that no reasonable representation of the relationships could be achieved for this dataset. Hence, PERMANOVA tests for the effects of site and year on the invertebrate assemblage structure were conducted on the aggregated phylum/class dataset (Table 3.3.2). There was a significant year and site interaction term, explaining about 20% of the variance. The residual component of variance was high at 63% (Table 3.3.2).

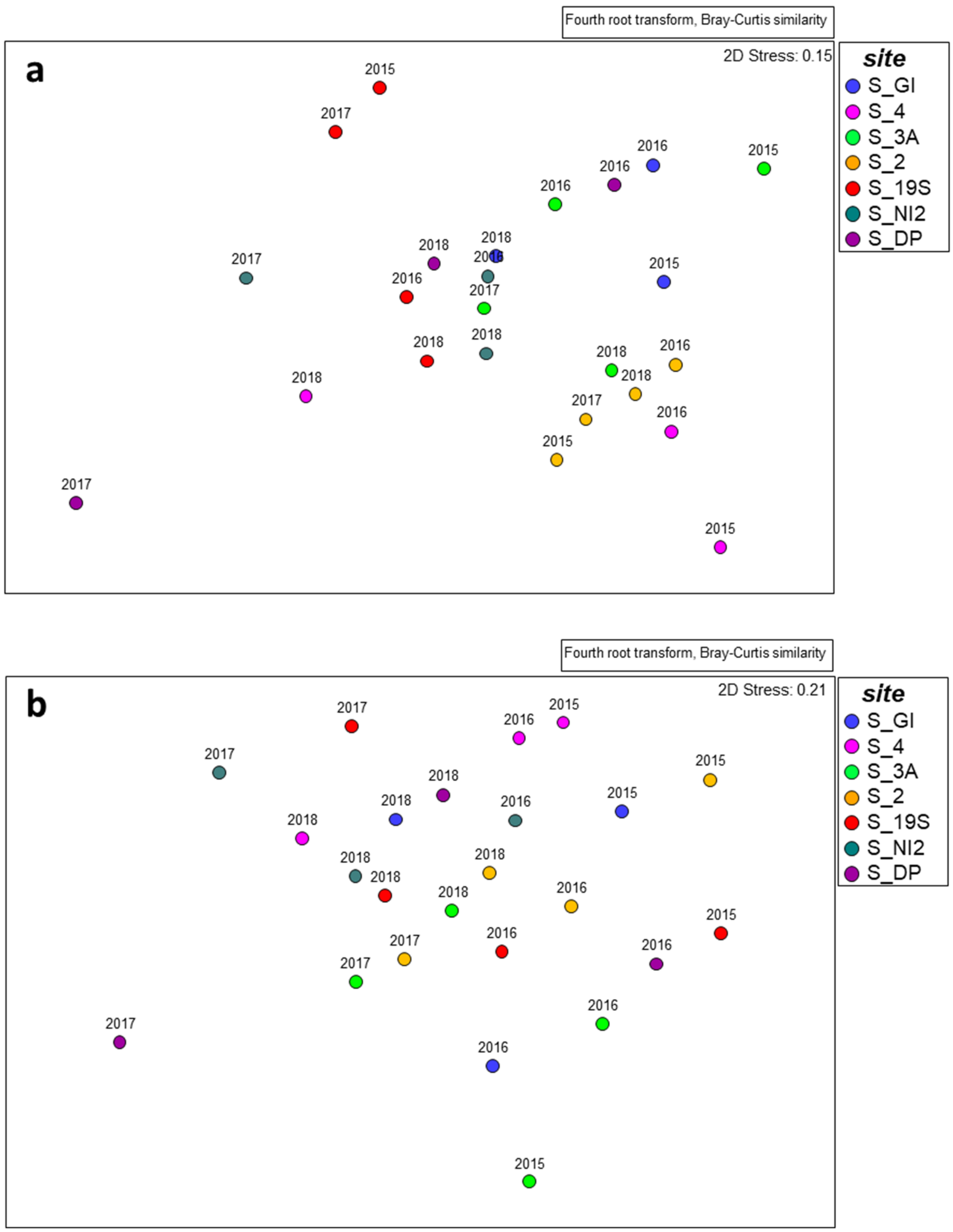


Figure 3.3.10. nMDS plot of subtidal invertebrate biomass aggregated at the phylum/class level (a) and at the lowest taxonomic resolution level (mostly species, genus or morphotype) (b).
The high stress level of the nMDS on lowest taxon resolution level indicates that the ordination is a weak representation of the relationships.

Table 3.3.2. PERMANOVA results for the effects of site (fixed factor) and year (random factor) on the subtidal invertebrate assemblage based on biomass in Cook Inlet.
The significant interaction effect of site and year leaves the individual effects uninterpretable.

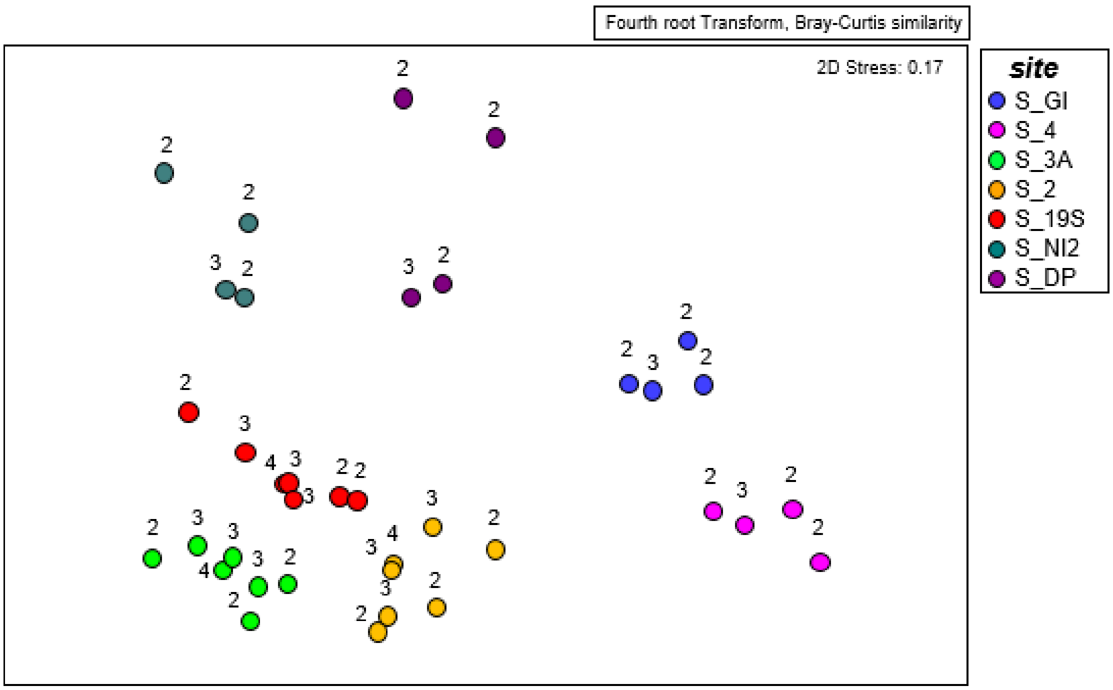
Source	df	SS	MS	Pseudo-F	P(perm)	unique perms
site	6	1.01E+05	16915	2.1431	0.0009	9873
year	3	43471	14490	6.8228	0.0001	9903
site x year	14	1.13E+05	8097.7	3.8128	0.0001	9819
Residual	191	4.06E+05	2123.8			
Total	214	6.69E+05				

Estimates of components of variation

Source	Estimate	% variance explained
S(si)	320.45	9.50
V(ye)	249.38	7.40
V(sixye)	677.83	20.10
V(Res)	2123.8	62.99

These combined results suggest that sites could not be reliably characterized for either macroalgal or invertebrate assemblages with a single year of sampling (see Figure 3.3.4 and 3.3.5 for macroalgae and Figure 3.3.9 and 3.3.10 for invertebrates). Although within-year variability was relatively low at most sites, between-year variability was high. However, when multiple sampling years were averaged, sites separated well for both assemblages. Multi-year sampling scenarios were assessed by averaging two or more years of sampling data per site to explore if sampling more years improved site characterization and separation (Figure 3.3.11). When sites were averaged over two or more years, community composition became more similar (compare Figure 3.3.4 and Figure 3.3.10).

Percent cover data of subtidal communities were dominated at all sites (including main and satellite sites) by the categories Rhodophyta (various species of red algae), open substrate, and overstory kelp (Figure 3.3.12). The open substrate category is not obtained from the biomass collections, but it is an important ecological indicator of disturbance or space competition in subtidal communities. The overall PERMANOVA had a significant three-way interaction term (Table 3.3.3) of sites within regions by year. Community composition derived from biomass collections and percent cover assessments differed (Figure 3.3.13); while this is not surprising, it reaffirms that the two sampling approaches produce different data that, in combination, are useful for a more holistic description of the subtidal communities in western Cook Inlet.



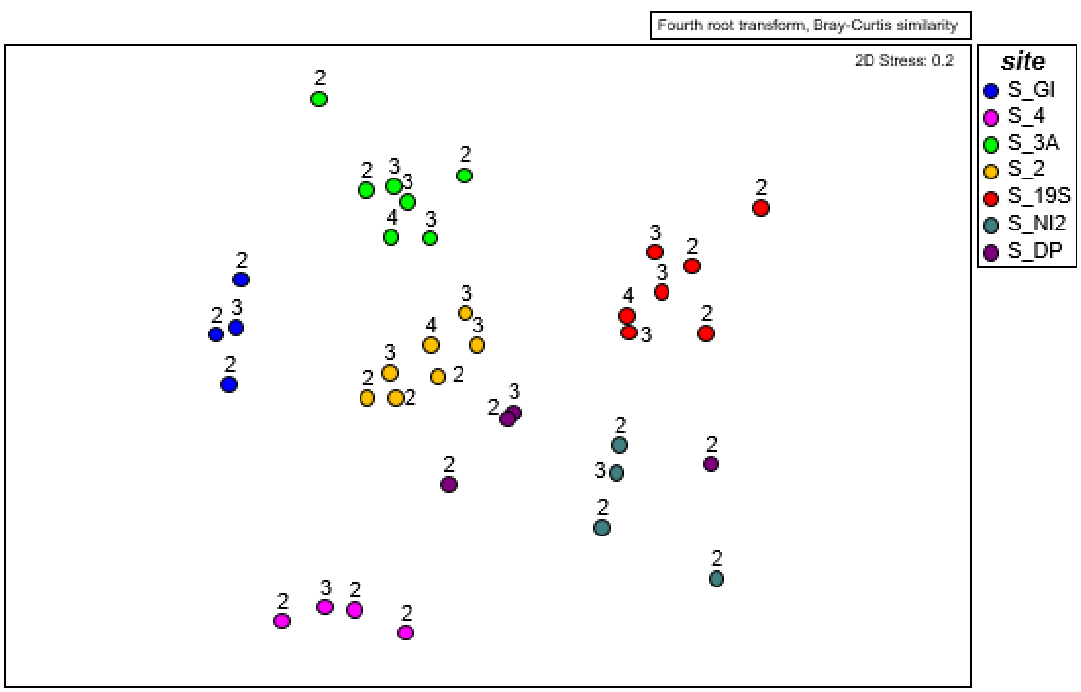


Figure 3.3.11. nMDS ordination of subtidal macroalgal composition (top) and invertebrate composition (bottom) based on biomass per study site, averaged across different combinations of sampling years. Numbers above points denote the number of years that were averaged. Sites were distinct from each other if at least two sampling years were averaged (compare spread of sites when only one year was sampled as seen in Fig. 3.3.4 (macroalgae) and Fig. 3.3.10 (invertebrates) to averaged communities over multiple years as seen in Fig. 3.3.11). Site averages where two or more years per site were sampled grouped closer (Fig 3.3.11) than when only one sampling year was included (Fig. 3.3.4 and 3.3.10).

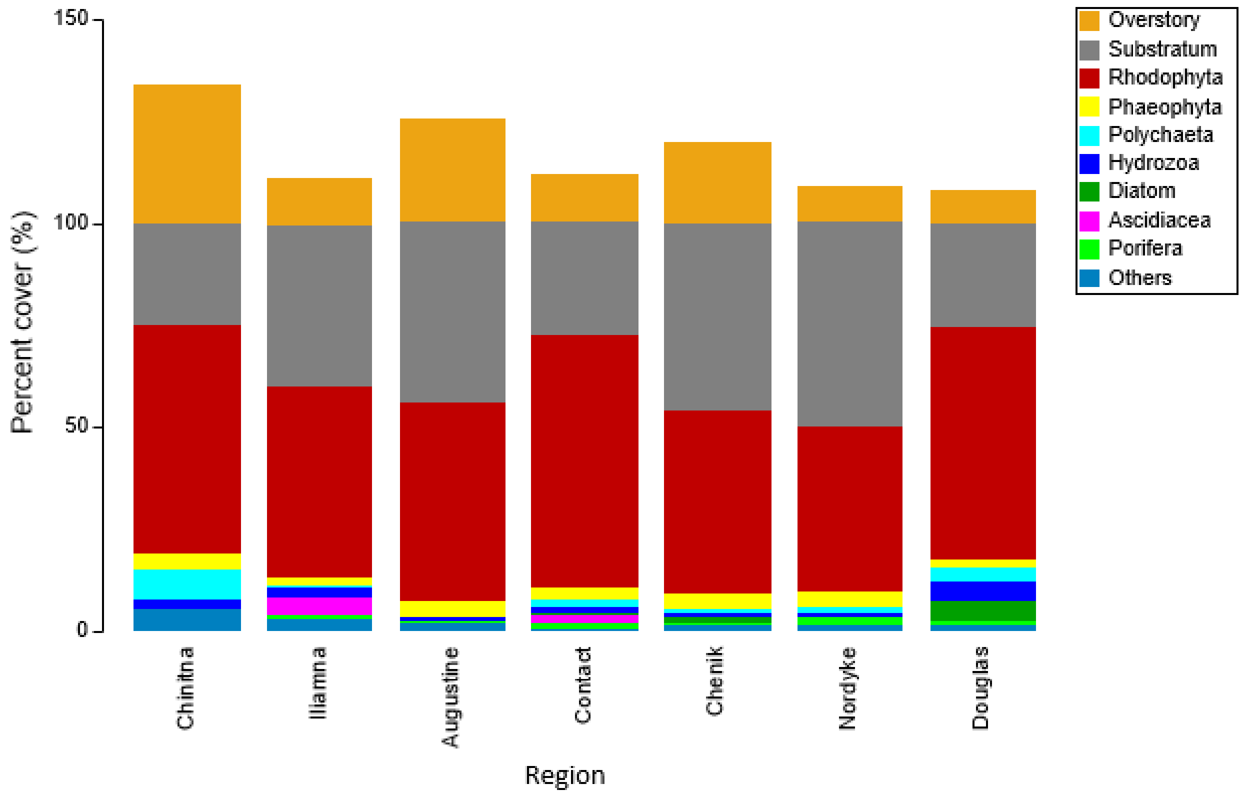


Figure 3.3.12. Percent-cover composition of macroalgae and invertebrates, averaged for all sites (main and satellite) per region (see text for details) and across all years.
Regions are ordered from north to south.

Table 3.3.3. PERMANOVA results on subtidal percent-cover data (region is a fixed factor, year is a random factor, site is nested in region).
There was a significant three-way interaction term.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Region	6	1.28E+05	21326	1.3122	0.045	997
Year	3	83576	27859	5.0536	0.001	997
Site(Region)	22	2.73E+05	12427	2.2543	0.001	998
Region x Year	15	1.57E+05	10458	1.8971	0.001	997
Site(Region) x Year	24	1.32E+05	5512.6	9.367	0.001	998
Residual	639	3.76E+05	588.51			
Total	709	1.23E+06				

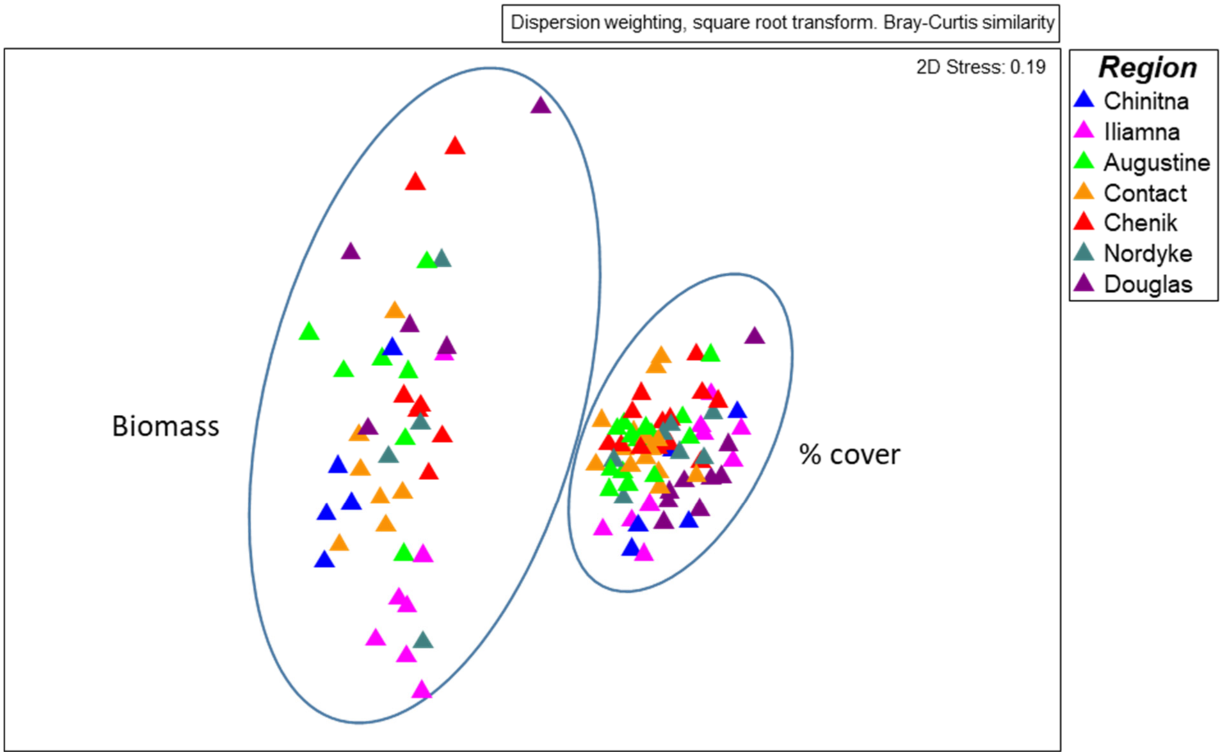


Figure 3.3.13. Community data obtained from subtidal biomass collections and from percent-cover assessments differ.
The tighter grouping of percent-cover data indicates that this method is less appropriate to differentiate various regions within western Cook Inlet.

3.4 Intertidal Quadrat Data

Some of the presentations below include data from the entire vertical sampling range for each site. Other analyses and data presentations incorporate the high-resolution tidal-height data collected for each quadrat and analyzed data within specific vertical ranges.

3.4.1 **Qualitative Assessment of Methods**

A required deliverable of this project was to provide recommendations for potential future monitoring in the study area. To accomplish this, various monitoring methods were employed and evaluated, each requiring different sampling effort on-site or for post-field analysis. One of the challenges of sampling the expansive rocky habitat exposed at low tide is the limited time available for sampling during any one low tide and the limited number of minus tides during a spring tide series. With little knowledge of the complexity of species assemblages or their temporal and spatial variability throughout the study area, the initial sampling was designed to strike a balance between (1) detailed data collections made *in situ* by samplers with expertise in Alaska seaweeds and invertebrates and (2) information that can be collected quickly in the field by non-taxonomists. The former provides more detail at fewer sites and can be limited by the availability of experts during field sampling. The latter can be done opportunistically, taking advantage of leveraging opportunities on shorter-notice. There are trade-offs in effort, necessary expertise, and time in the field (limited by tide and logistics) between the quality of data collected and the quantity.

Two quadrat-sampling methods were compared for measuring invertebrate and algae abundances: point-contact and photo-quadrat sampling. Specifically, we compared percent cover as measured by each method for representative overstory and understory organisms.

Point-contact quadrat collections require taxonomic expertise and more time on-site, so fewer can be collected per site. In contrast, photo-quadrats require little time on-site, allowing higher numbers of replicates to be collected, but they require more time to process after leaving the field.

3.4.1.1 **Quantitative Assessment of Methods: Species Detection**

Percent cover from photo-quadrats that only “see” the surface layer underestimated algae densities compared to point-count measurements that record data through all layers (Figure 3.4.1.1.1). The greatest differences between the two methods occur when comparing understory organisms (e.g. coralline algae) to the overstory kelps.

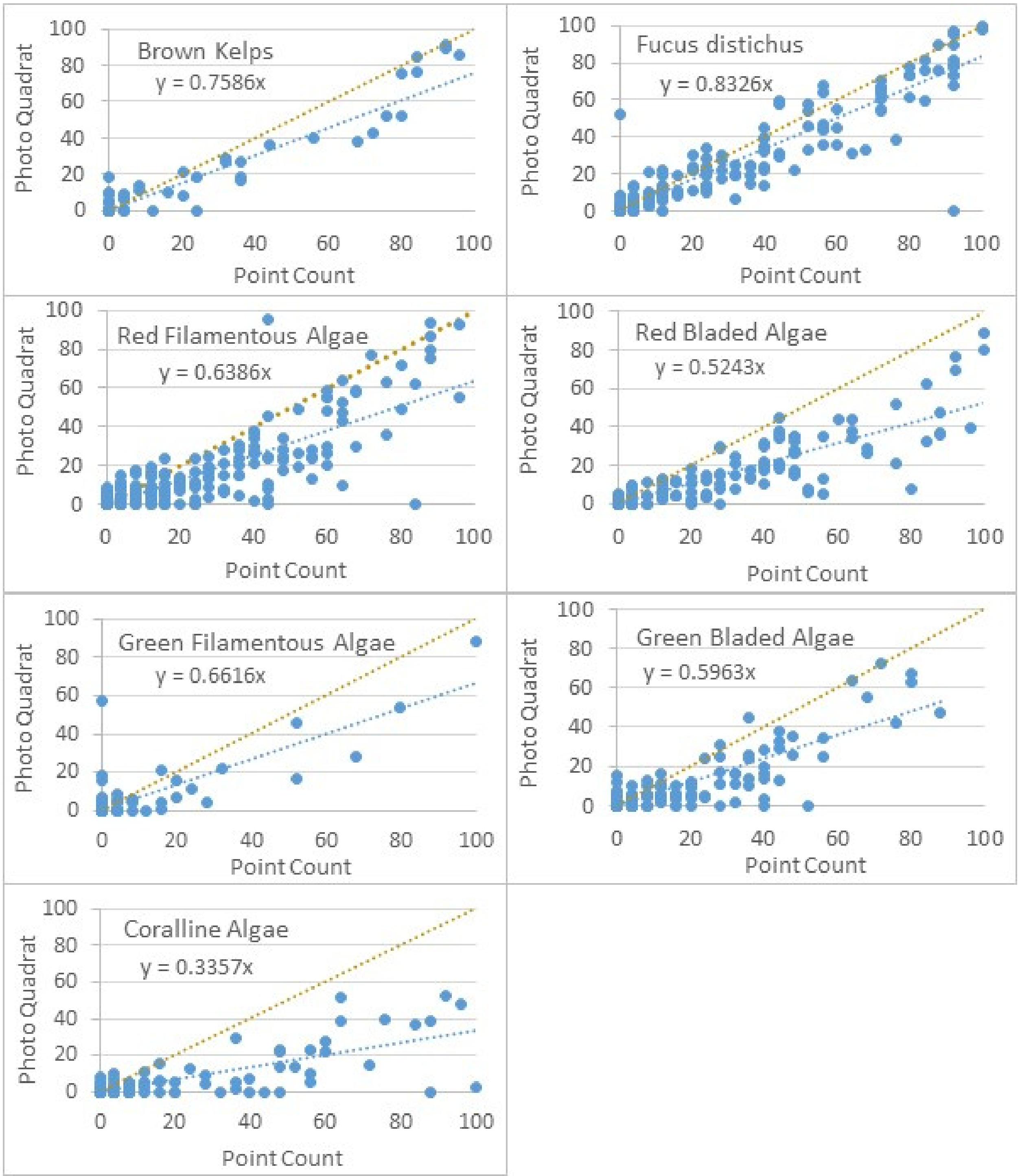


Figure 3.4.1.1.1. Intertidal photo-quadrat data compared to point-count quadrat data for direct quadrat comparisons of two methods, photo-quadrat interpretation and on-site point-count quadrats through all layers.
The closer the slope is to 1, the more similar the results between the two methods. Data is % cover.

3.4.1.2 **Quantitative Assessment of Methods: Site Richness**

The next series of figures refers to the specific method comparisons outlines in Section 2.2.5.1 of the Methods where species richness is compared among the various intertidal sampling methods. For the comparisons, the taxonomic data include all taxonomic levels recorded. So, for example, a filamentous red alga was identified to species in one quadrat photo from a site and in another lower-quality quadrat photo a "filamentous red algae" was not identified to species, they were both included as taxon in the analyses. Thus, the data presented in the following methods comparisons represent "inclusive" or "liberal," interpretations of taxonomic richness.

The first comparisons are made for "paired quadrats," where both photo-quadrats and point-count quadrat methods were applied to each quadrat. These comparisons are followed by comparisons where data from all photo-quadrats and all point-count quadrats are included in the analyses. The comparisons described below are for:

(i) Photo-quadrat identification of attached epibiota for only those quadrats where point-count quadrat data were also collected,

(ii) Point-count identification of attached epibiota for only the "top layer,"

(iii) Point-count identification of attached epibiota through all layers,

(iv) Photo-quadrat identification of attached epibiota for all photo quadrats (a sample size 4 times that of the point-count quadrats),

(v) Photo-quadrat identification of attached epibiota and mobile invertebrates (includes all photo-quadrats),

(vi) Point-count identification of attached epibiota and mobile invertebrates through all layers,

(vii) Point-count identification of attached epibiota through all layers, plus mobile invertebrates and species observed by unconstrained expert search within each site that included taxa that may not have landed within any quadrats.

Paired Quadrats: Photo-Quadrat Interpretation vs Top Layer of Point-Counts (methods (i) and (ii), respectively): In terms of epibiota richness calculated from just the quadrats where both photo-interpretation and point-count methods were applied (methods (i) and (ii) above), in most cases the top layer results of the point-count method resulted in higher site richness than the photo-quadrat method (Figure 3.4.1.2.1). The cases where this did not hold were mainly from 2015 (except for Turtle Reef and 2017 Bruin Bay); 2015 was the first year of applying the photo methods and produced the lowest quality photos of all the years due to the absence of standardization and other refinements (common camera models, etc.) employed in later years. Thus the 2015 photo interpretation samples have the highest chance of sometimes allowing for identification to species and sometimes only allowing identification to higher taxon levels, leading to a 'falsely' inflated total richness under the liberal assumptions used here.

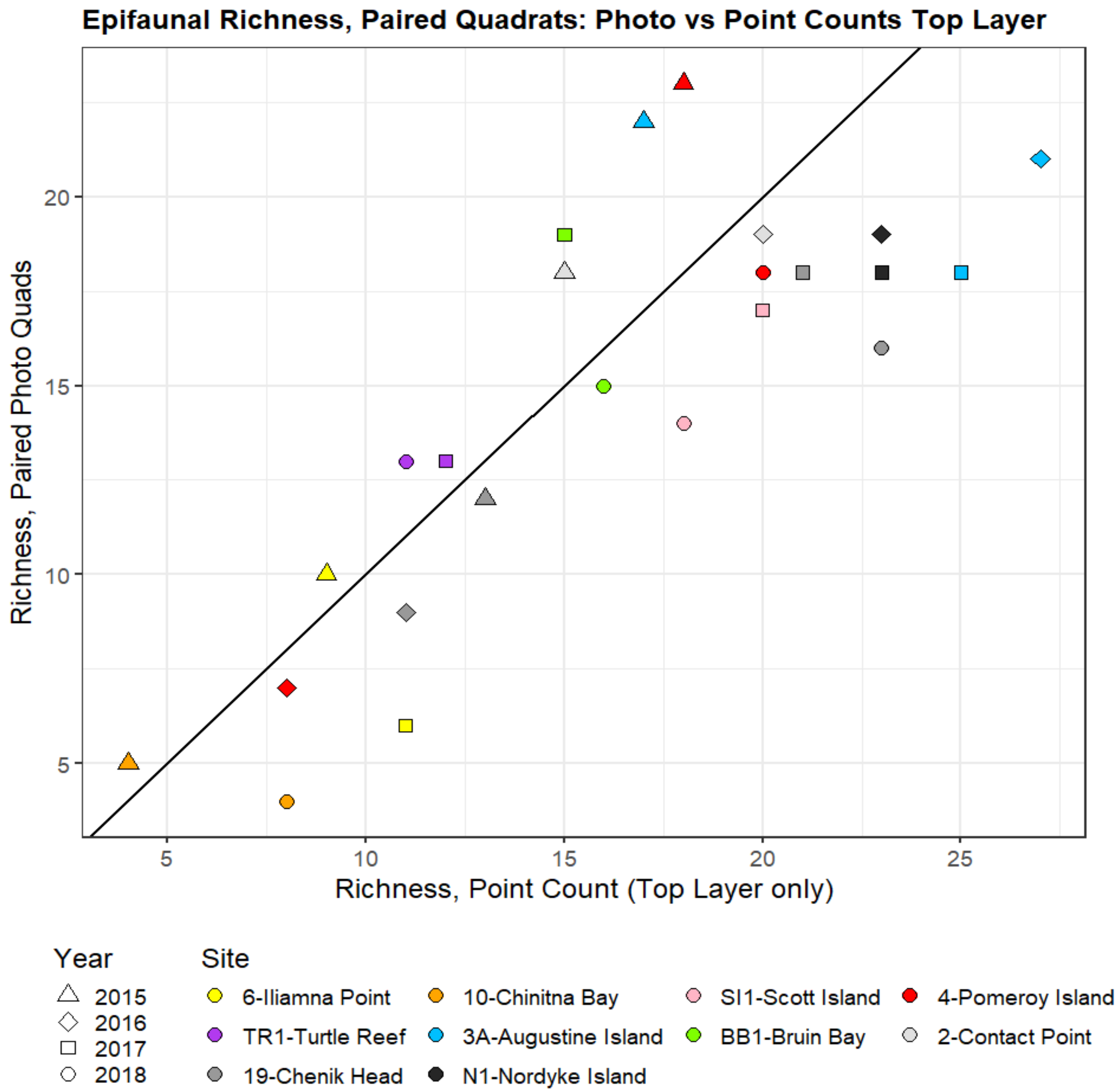


Figure 3.4.1.2.1. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epibiota data (using only photo quadrats where point-count quadrat data were also collected, i.e. "paired") and the "top layer" data from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

Paired Quadrats: Photo Interpretation vs All Layers of Point Count ((i) and (iii), respectively): Continuing to focus just on quadrats where both photo-interpretation and point-count methods were applied, epibiota richness for point-count quadrat data collected through all layers is higher than for photo-quadrats in almost all cases (Figure 3.4.1.2.2 for all site and year combinations for both methods ((i) and (iii)).

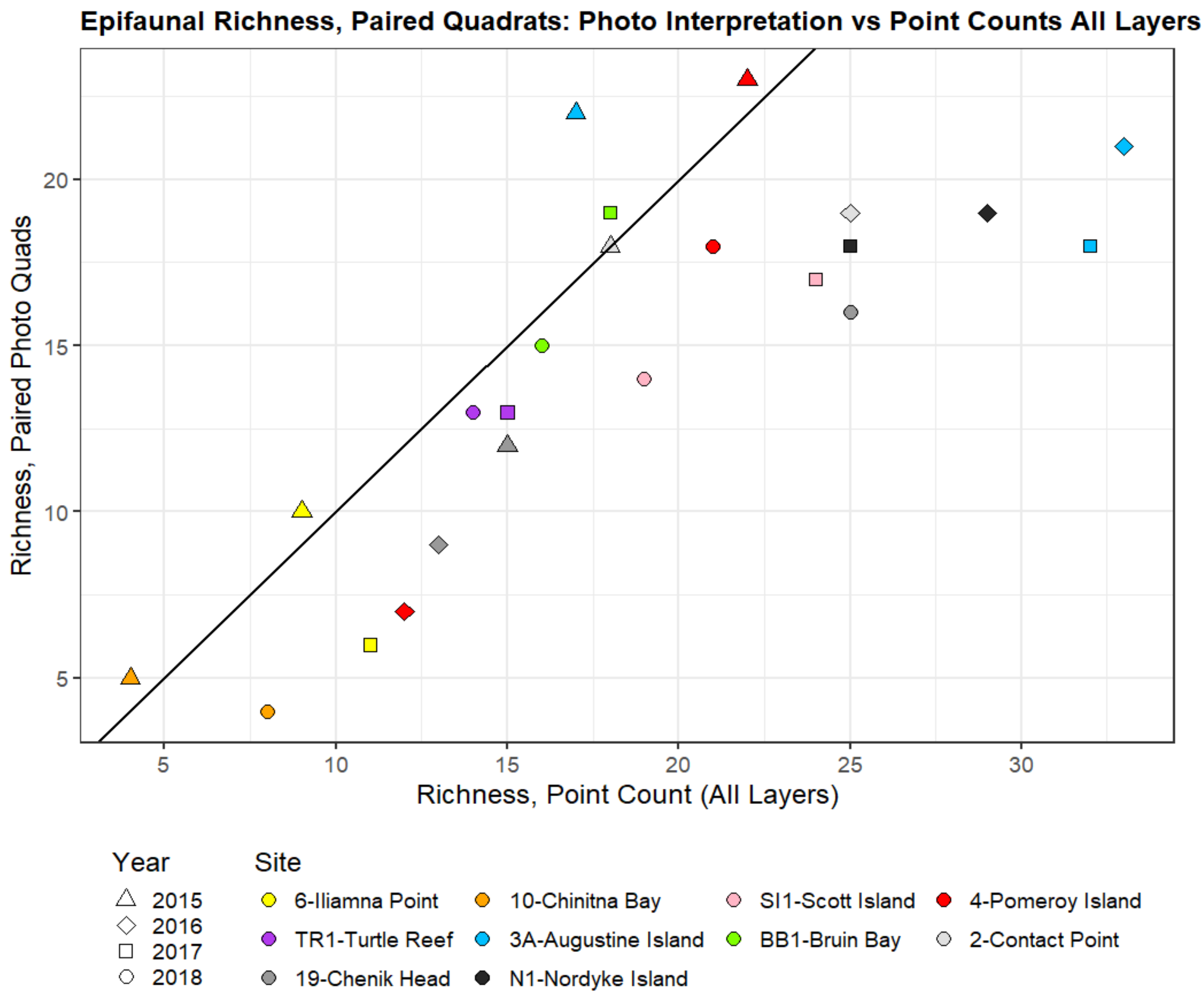


Figure 3.4.1.2.2. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epifloral data (using only photo quadrats where point-count quadrat data were also collected) and data for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

All Quadrats: Photo Interpretation vs All Layers of Point Count ((iv) vs. (iii), respectively): The photo-quadrat method's increased samples sizes (generally 4x as many quadrats at a site) compared to the point-count method led to higher epibiota richness for most sites and most years (Figure 3.4.1.2.3). Compared to Figure 3.4.1.2.2, there is an increase in the number of taxon for photo quadrats when including data from all photo quadrats, as opposed to just those photo quadrats where point-count data were collected.

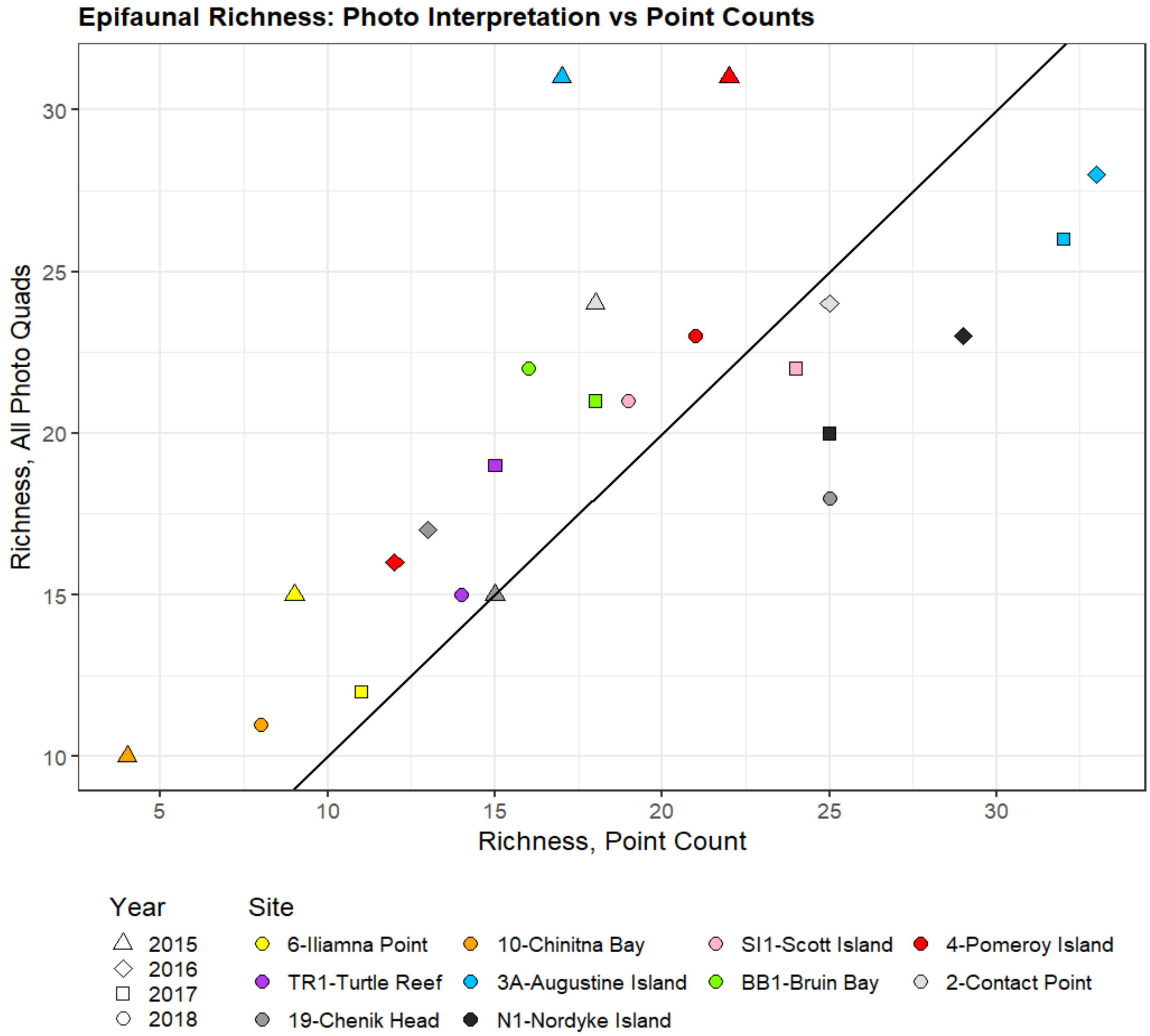


Figure 3.4.1.2.3. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epibiota data (using all photo-quadrat data) and data for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

All Quadrats: Photo Interpretation vs All Layers of Point Count for mobile invertebrates only ((vi minus iii) vs. (v minus iv), respectively): For visualizations in Figure 3.4.1.2.4, data include only mobile invertebrates to emphasize the differences in the ability to detect these organisms for the two methods. Thus, the combined epbiota + mobile invertebrate data are not shown together here. In terms of mobile invertebrate richness, on-site counts associated with the point-count data collections consistently detected more taxon than did the photo-interpretation method (Figure 3.4.1.2.4).

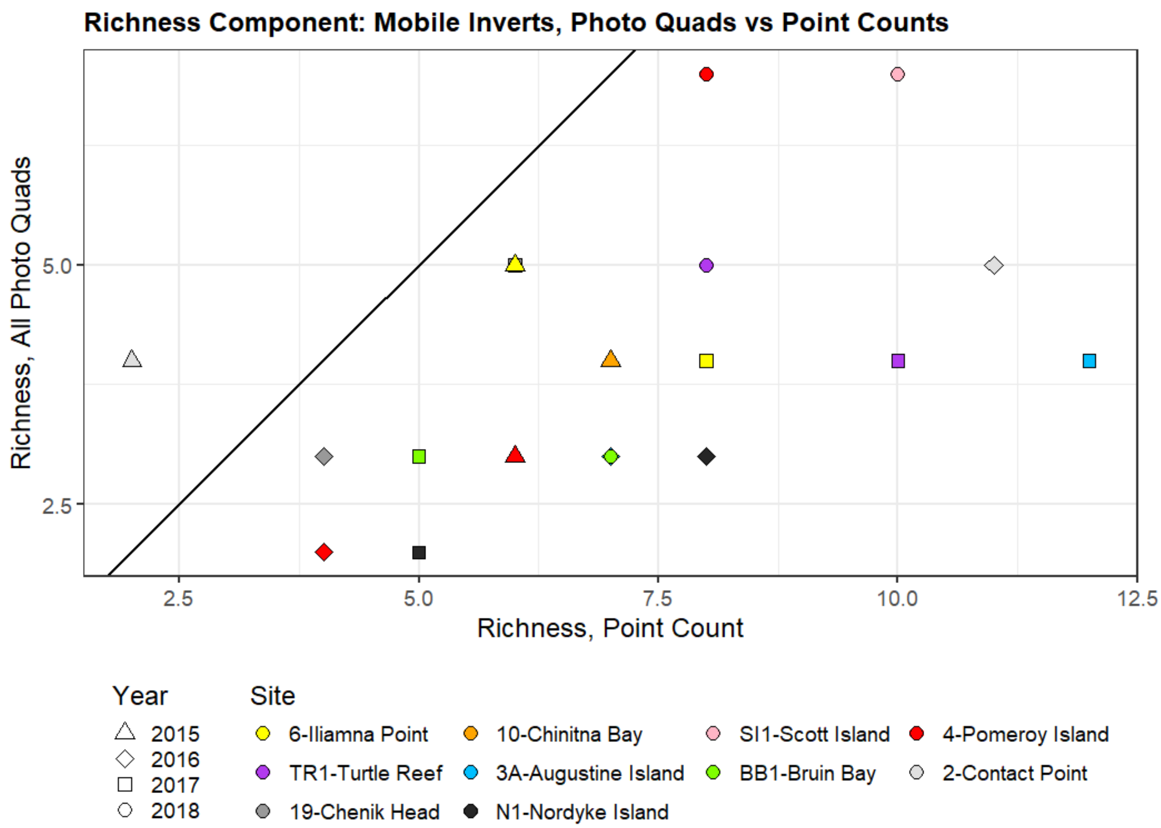


Figure 3.4.1.2.4. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat mobile invertebrates (using all photo-quadrat data) and mobile invertebrates for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

Except for the 2015 survey at site 2, Contact Point, mobile invertebrate richness was higher for the point-count quadrats than for photo quadrats and there does not appear to be a consistent gain in mobile invertebrate richness over time (i.e. due to improved photographic standards after 2015).

The seven methods were compared quantitatively for differences in their total richness estimates (Figure 3.4.1.2.5). Comparing site richness by year for all methods listed above showed a general trend of increased richness from methods (i) to (vii). The highest richness measured per site was for identifying taxon through all layers via point-count quadrat methods combined with expert identification of non-contacted taxon within quadrats, mobile invertebrates within quadrats, and non-quadrat species occurring within the transect swath (method vii). One parameter that was not measured was the sampling intensity (i.e. man-hours) per site. This varied depending on how much total time within a tide and total man-hours were available for sampling, which depended on logistics, tidal range, equipment difficulties, number of personnel on-site, and, in 2018, reduced quadrat sampling time due to the need to vacate the transect swatch to allow collections of drone-imagery at the lowest tide. These factors all impacted the amount of time spent available to search for site species that may not have landed within the quadrats and are discussed when interpreting results.

Systematic differences in total site richness among methods (v), (vi) and (vii) were quantitatively assessed using a generalized linear mixed model using a Poisson distribution family to accommodate the discrete nature of richness; Site and Year were treated as random effects, in line with the data collection design (Pinheiro & Bates 2000). This approach was analogous to a mixed effects ANOVA, but for count data rather than continuous response data. Analyses were conducted in R (R Core Team 2019) mainly using the packages lme4 (Bates et al. 2015) and ggplot2 (Wickham 2016). The generalized linear mixed-effects model provided an adequate summary of the observations with various diagnostics revealing no noteworthy departures from the modelling assumptions regarding model fit or normality of random effect estimates, etc.

Table 3.4.1.2.1. Effect estimates from the generalized linear mixed model analysis characterizing the differences among the top three measurement methods.

Effects	Source	Estimate			
Random		Variance	Std. Deviation	Number of realizations	
	Site (Intercept)	0.078	0.279	10	
	Year (Intercept)	0.031	0.177	4	
Fixed		Mean	Std. Error	z value	Pr(>|z|)
	‘Photo, All Quadrats, + mobile invertebrates’	3.120	0.132	23.6	<2e-16
	‘Point, All Layers, + mobile invertebrates’ - ‘Photo, All Quadrats, + mobile invertebrates’	0.070	0.058	1.21	0.225
	‘Point, All Layers, + mobile invertebrates + Expert Search’ - ‘Photo, All Quadrats, + mobile invertebrates’	0.677	0.051	13.27	<2e-16

For the random effects estimates, the variation across sites in Total Richness was more than double that across years: 0.078 vs 0.031 (Table 3.4.1.2.1). Relative to the background spatial variation within a site, there was no systematically distinguishable difference in total site richness estimates between the photo interpretation (w/ larger sample sizes) and the point-count method (w/ more detailed observation); however, the inclusion of a taxonomic expert search consistently and significantly increased the resulting total site richness by approximately 22% (Table 3.4.1.2.1).

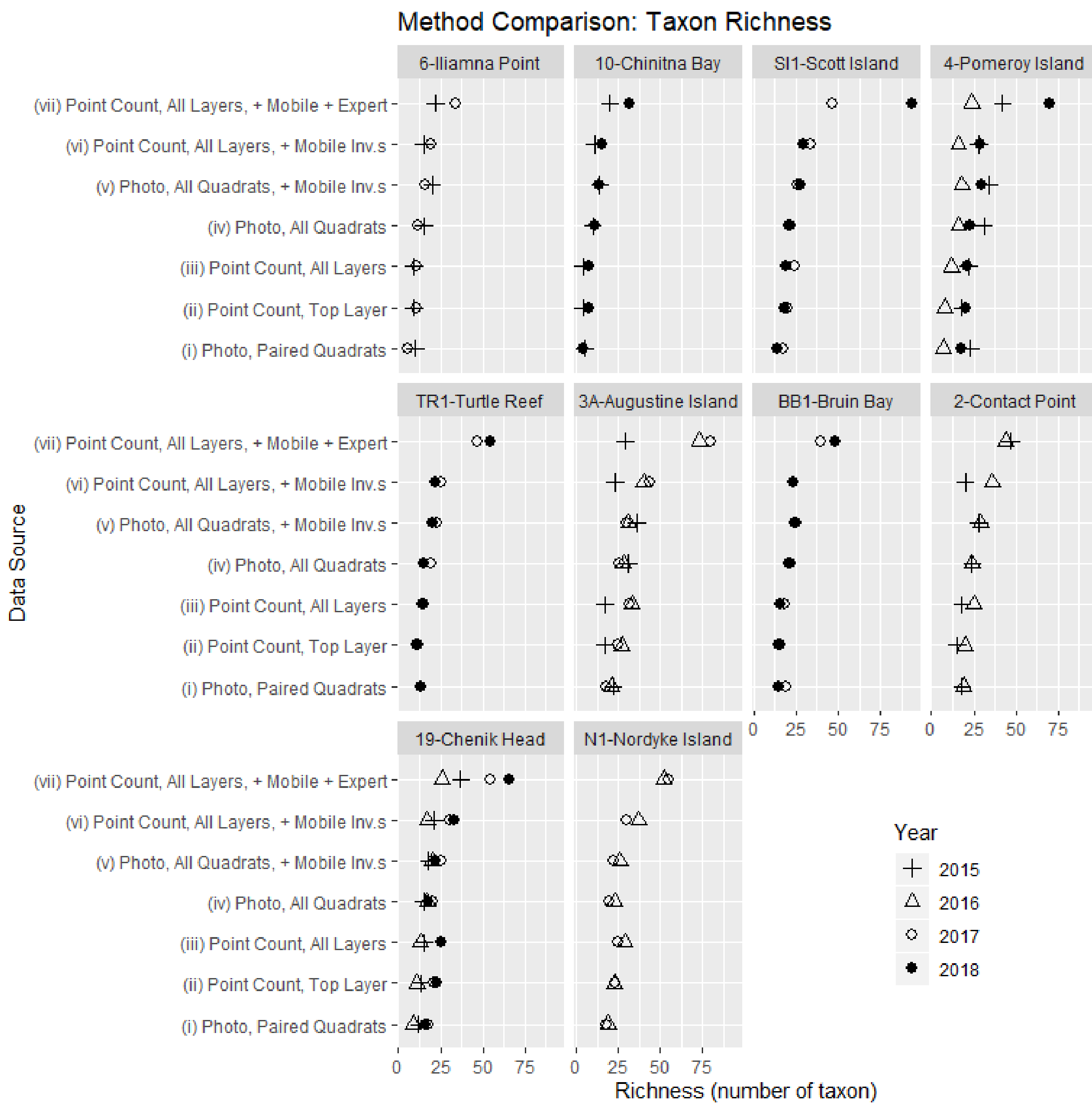


Figure 3.4.1.2.5. Graphic representation of intertidal site richness by year for each of the seven richness comparisons (methods i through vii).

The taxonomic precisions of the photo-quadrat and point-count quadrat methods are shown by illustrating the number of taxa identified for each taxonomic level (Figure 3.4.1.2.6). The data show that, even with a smaller sample size, point-count quadrat methods identified more taxon and at higher precision (Figure 3.4.1.2.6).

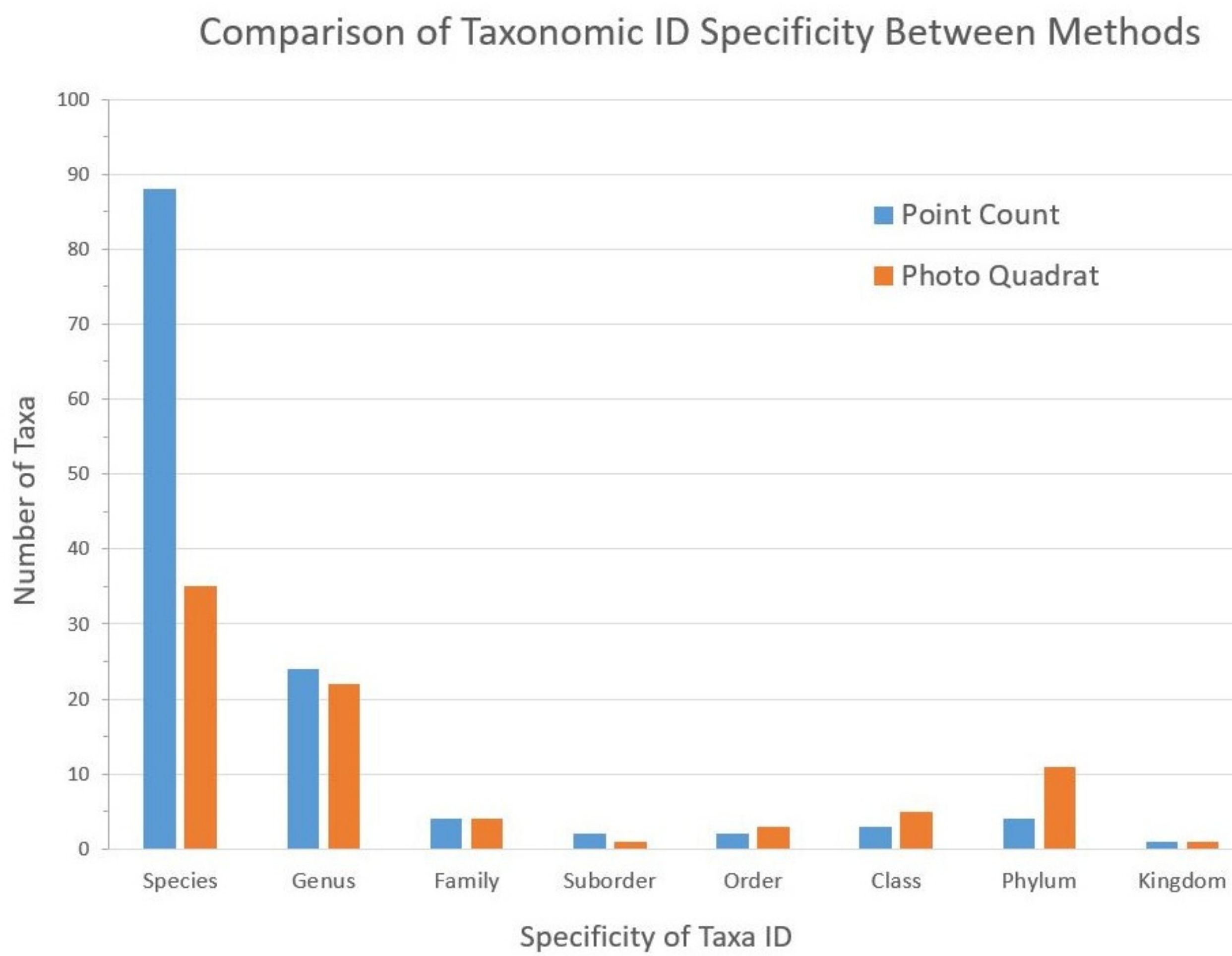


Figure 3.4.1.2.6. Graph comparing precision of identification of taxa between methods (v) and (vi). The degree of precision to which each unique organism was identified (to the most specific taxonomic level possible) decreases from left to right, from most precise (Species) to least precise (Kingdom). The Y axis indicates the number of taxa identified in each taxonomic level. For example, a filamentous green algae might have been identified to a particular species (e.g. *Acrosiphonia arcta*, to the genus level, or, in photo-quadrats, it may have only been identified morphologically (e.g. fine filamentous green algae). In the latter case, the lowest taxonomic level that could be reported would be the phylum for green alga (i.e. Chlorophyta).

3.4.1.3 **Site Richness Comparisons**

Species lists were compiled for each site across all years and are included as presence/absence data grouped by phyla (Appendix Tables A.1.1-A.1.11). Based on data presented in the methods comparisons above, the richness data presented here are for the most comprehensive taxonomic lists and include point-count quadrat data recorded through all layers (i.e. all sessile seaweeds and invertebrates) plus mobile invertebrates and non-quadrat site species. The lists include all taxonomic levels recorded. For example, if a site includes a specific species recorded and a separate record recorded for an organism with a shared higher taxonomic level (e.g. genus, family), both records are included unless it is known that there is only one possible species for that taxon. This is the most "generous" interpretation of data richness. A later discussion describes differences in this "generous" calculation of species richness compared to "conservative" estimates of richness for a low and a high richness site.

Species richness data area were plotted geographically as pie diagrams scaled to total species richness for each site (Figure 3.4.1.3.1). The left pie in each paired set of pie figures includes the seaweed phyla Rhodophyta, Ochrophyta, and Chlorophyta. There were three sites that had eelgrass (Magnoliophyta) on-site, but that phyla is not represented in the pie diagrams (Figure 3.4.1.3.1).

The two sites with the lowest total species richness are the two northernmost sites, Site 6 at Iliamna Point north of Chinitna Bay and Site 10 on the north side of Chinitna Bay. These two sites had the lowest number of seaweed taxon and relatively low numbers of invertebrates compared to the sites further south. Sites 3A and SI1 had the highest species richness and were both relatively protected sites; Site 3A is on the N side of Augustine Island and is protected by Burr Point, while Site SI1 is semi-protected by Scott Island and the mainland. Both sites also had more boulders scattered across the site compared to many of the other sites, providing protection for many invertebrate species.

"Effort" (man-hours) spent searching for additional species while on each site was not tracked. Additional sampling time and man-power was available on Scott Island in 2018, which is reflected in the higher number of non-quadrat species found that year.

Algae dominated the species lists at sites with the longest and flattest ramp profiles. These sites – Sites 19 at Chenik Head, N1 on Nordyke Island, 3A on Augustine, BB1 in Bruin Bay, and 2 at Contact Point – are all in the southern portion of the study area and reflected a range of wave exposures. All sites except Site 3A on Augustine were predominantly bedrock substrate.

At all sites, there were 2 to 3 times as many taxa of Rhodophytes as there were of Chlorophytes or Ochrophytes; overall, Rhodophytes accounted for more than half of all seaweed taxon. For invertebrates, Mollusca (mainly grazing gastropods) and Arthropoda (mainly barnacles) had the most species at all sites.

The relative contributions of seaweed and lumped invertebrates remained largely the same across years within each site (Figures 3.4.1.3.2 and Figure 3.4.1.3.3). The most abundant invertebrate phyla were generally consistent across time. The three sites that were added in 2017 (SI1, TR1, and BB1) had more phyla represented than most other sites, especially compared to the two northern most sites (sites 6 and 10); however, Site 3A was an exception. Sites SI1, TR1, and

BB1 were added to the study in 2017 to capture a wider range of wave exposure categories. In addition, two of these sites (TR1 and SI1) were more similar to Site 3A in that there was more boulder habitat in the low intertidal.

Site 4 on Pomeroy Island had few invertebrate phyla in 2016. This site was sampled very early in the tide series when the lowest tide was substantially less than when sampled in 2015 and 2018. There was also a storm surge that raised the water level, which complicated access to the site. The total sampleable habitat while on-site that year was limited to MLLW and higher, thus missing all invertebrates below MLLW. In some later community assemblage analyses, these tidal height differences will be accounted for. Echinodermata were represented almost wholly by sea stars which can be highly variable as they move onshore and offshore and appear or disappear from taxon lists (e.g. 2015 to 2016 at sites 2 and 19).

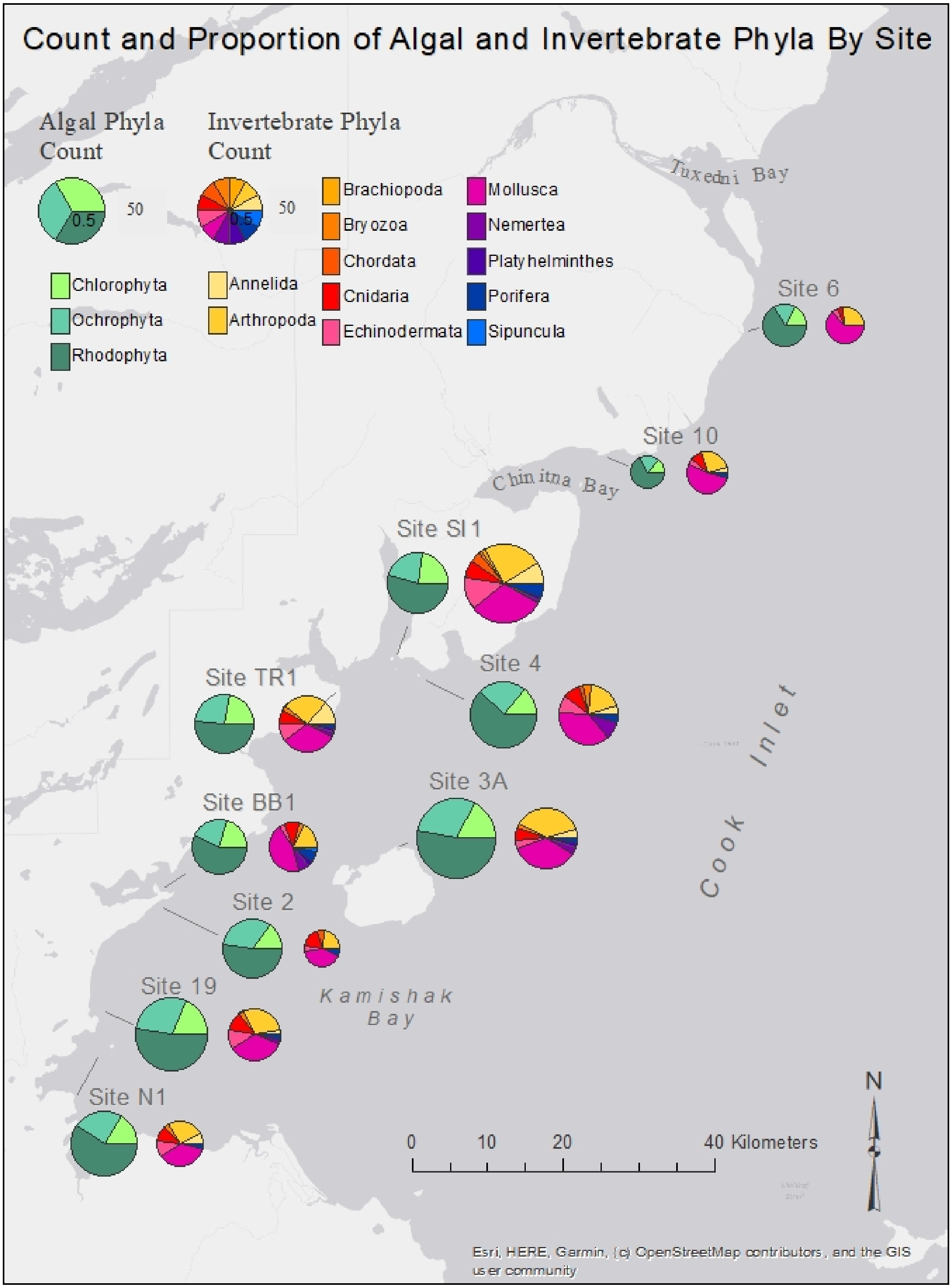


Figure 3.4.1.3.1 Count and proportion of number of taxa per phyla by intertidal site.

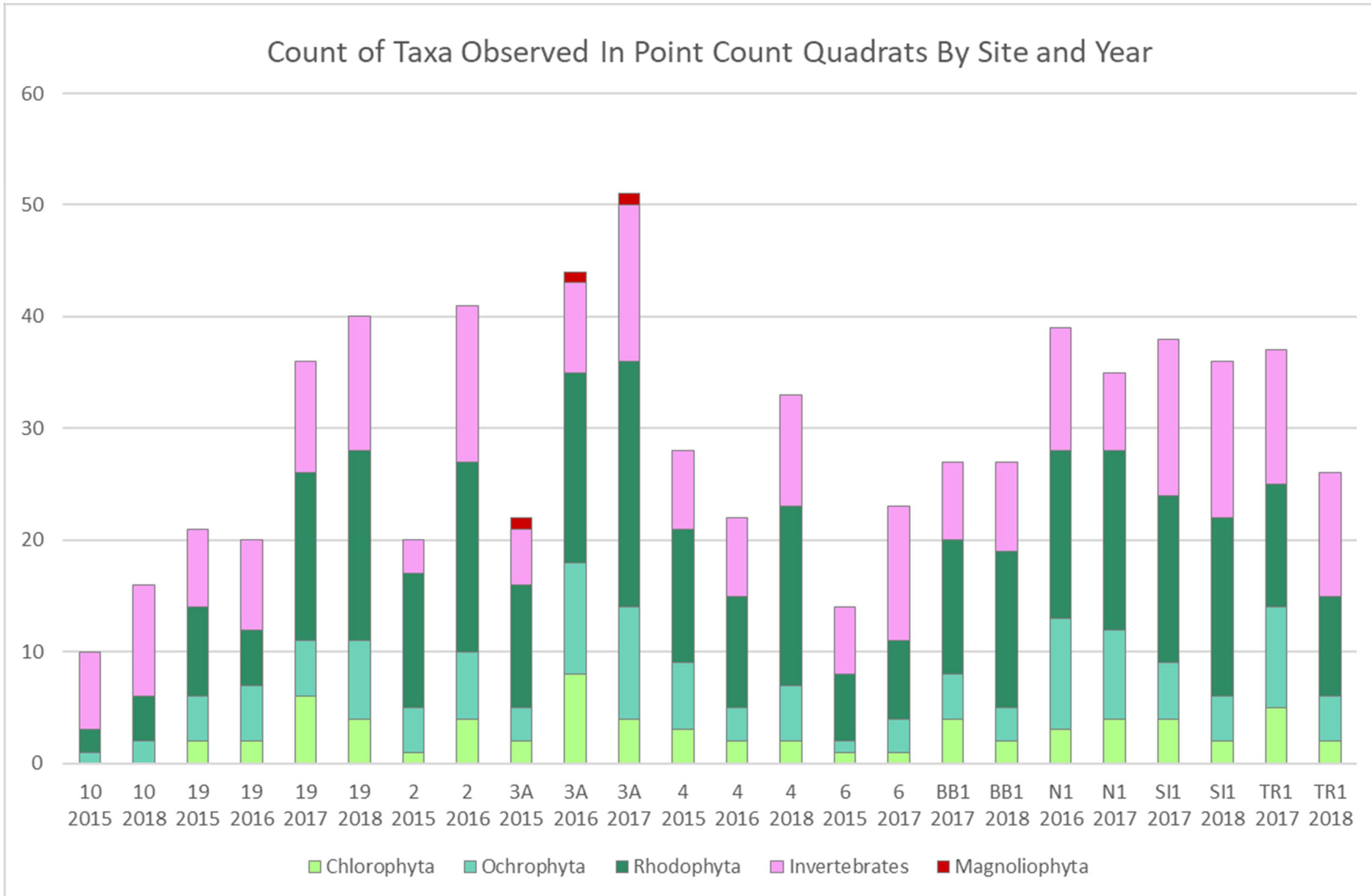


Figure 3.4.1.3.2. Proportional taxonomic abundance of all taxa identified at all intertidal sites in all years using point-count quadrats and expert walk around identification aggregated to phylum level.

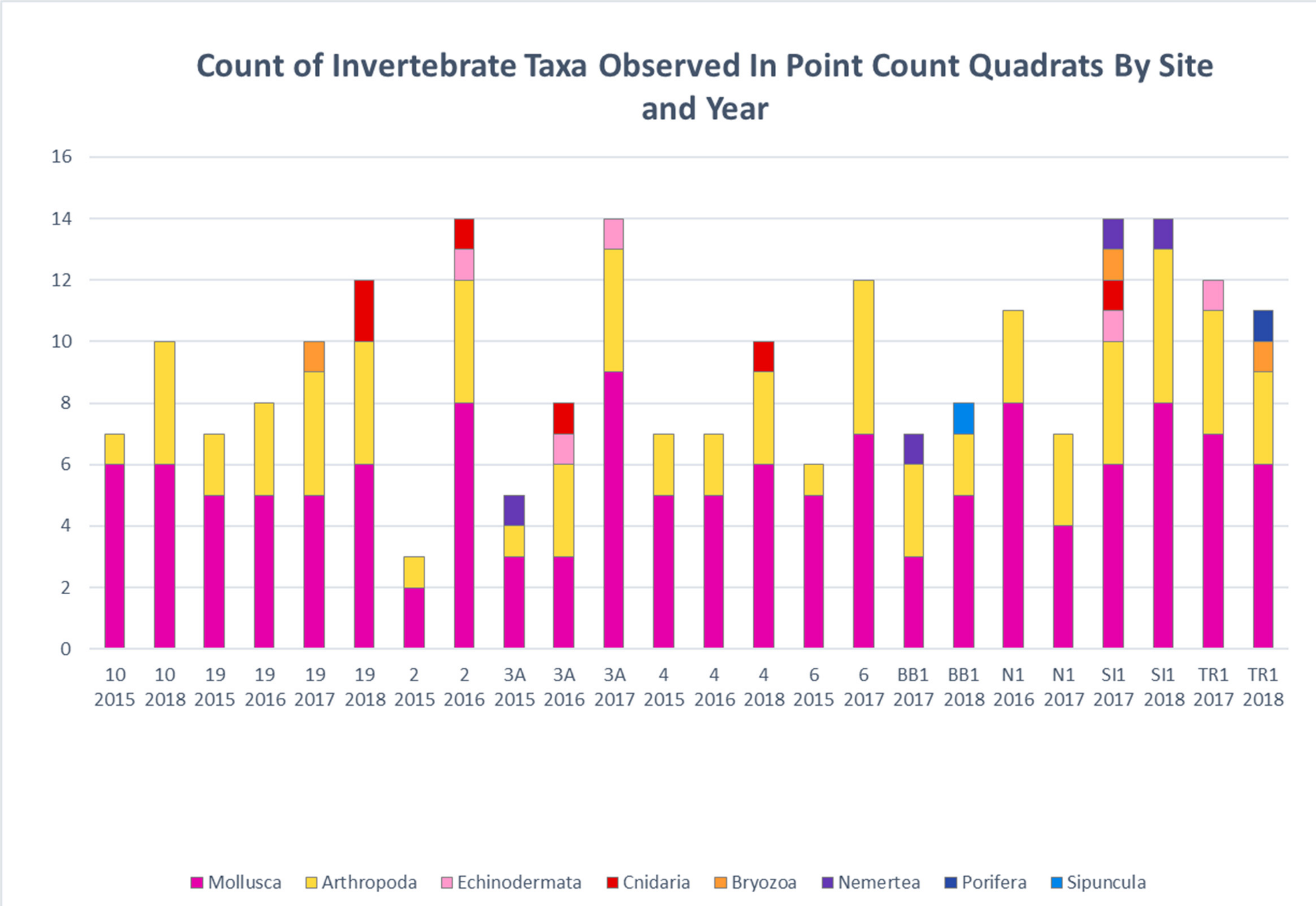


Figure 3.4.1.3.3. Proportional taxonomic abundance of all invertebrate taxa identified at all intertidal sites in all years using point-count quadrats and expert walk around identification.

3.4.2 **Intertidal Assemblage Analyses**

3.4.2.1 **Tidal Ranges of Intertidal Species**

Intertidal zonation determines which species dominate the intertidal communities across the vertical intertidal range. The observed elevation range of some of the most abundant organisms within the study area demonstrated the strong zonation patterns for some species that impact community assemblages within and among sites in the study area (Figure 3.4.2.1.1). Some taxa are tolerant of a range of tidal zones, while others are restricted to narrow vertical ranges (e.g. *Devaleria callophylloides* forma *devaleria*, *Halosaccion glandiforme*, *Palmaria hecatensis*). Kelps, including the most dominant kelp in the study area, *Saccharina latissima,* are restricted to the lowest intertidal zones. The upper vertical limits for these species correlated with tide pools or channels. The dominant barnacles in the study area were *Chthamalus dalli* and *Balanus glandula*, which are typically found in the upper to mid tidal elevations. In this study area, however, upper intertidal substrate (sandy beach face at top of the transect) at several sites precludes attachment of sessile invertebrates and the physical environment at most sites (ice and sediment scour) preclude over-winter survival of most organisms. Thus, few species are found at the highest tidal ranges.

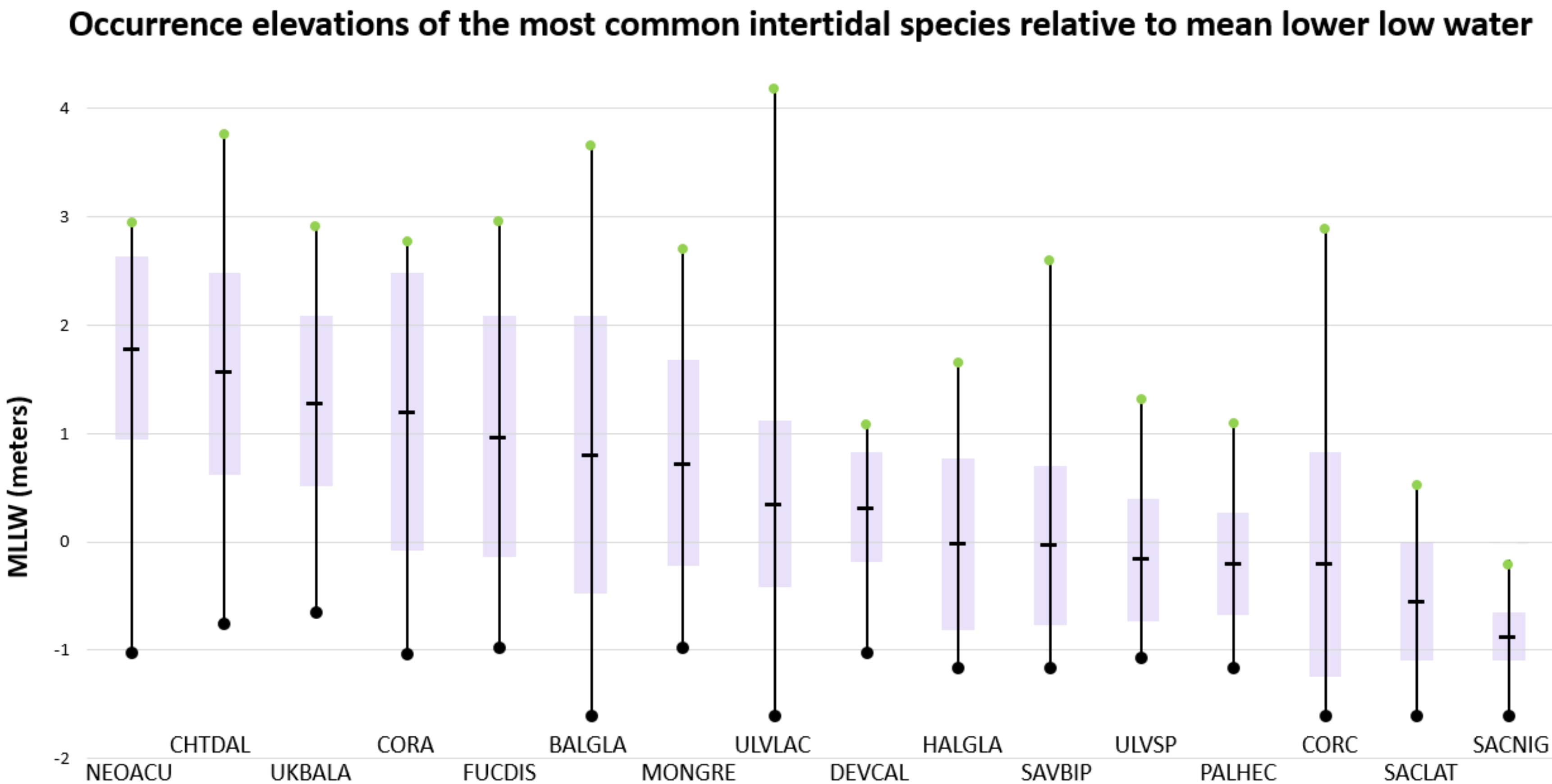


Figure 3.4.2.1.1. Occurrence elevations of the most common intertidal species relative to unofficial MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. This figure includes all species that occurred in more than 100 point-count locations. NEOACU = *Neorhodomela aculeate*, CHTHDAL = *Chthamalus dalli*, UKBALA = Unknown Balanamorpha, CORA = Articulate coralline algae, FUCDIS = *Fucus distichus*, BALGLA = *Balanus glandula*, MONGRE = *Monostroma grevillei*, ULVLAC = *Ulva lactuca*, DEVCAL = *Devaleria callophylloides* f. *devaleria*, HALGLA = *Halosaccion glandiforme*, SAVBIP = *Savoiea bipinnata*, ULVSP = *Ulva* spp., PALHEC = *Palmaria hecatensis*, CORC = Crustose Coralline algae, SACLAT = *Saccharina latissima*, and SACNIG = *Saccharina nigripes*. Horizontal bar is tidal elevation, circles on vertical bar indicate the measured maximum and minimum range (green and black), shaded gray vertical box 1 standard deviation above and below the mean tidal elevation.

Zonation patterns of percent cover for several groups of organisms varied by site and year (Figures 3.4.2.1.2 - 3.4.2.1.7). These graphics show only percent-cover data for species at point-count quadrats (through the layers), but do not reflect species found outside of quadrats when completing site-species lists. Thus, the species lists in Appendix Tables A.1.1-A.1.11 may list taxa that are not reflected in these graphics that reflect only percent-cover data collected through quadrat sampling. For example, several species of Chlorophyta occurred at Site 10 in Chinitna Bay, but were either found outside of quadrats or were trace within quadrats (Table A.1.2). At all sites, Chlorophyta were highest in the mid to lower intertidal and were composed mainly of thin bladed greens *Ulva* spp. and *Monostroma grevillei*. At Site 4 on Pomeroy Island, Chlorophyta had a higher percent cover in the upper intertidal compared to the low intertidal and were composed of relatively dense band of the fine filamentous algae *Rosenvingiella polyrhiza*. Site 6 at Iliamna Point also had a band of *R. polyrhiza* in the high intertidal, although it was less dense than the band at Site 4. This species can be a marker of MHHW on bedrock substrate.

The eelgrass *Zostera marina* only occurred in quadrat data at Site 3A on Augustine Island in 2015 and 2016 (Figure 3.4.2.1.3) in an area of sand habitat between the beach face and the lower intertidal boulder/cobble habitat. Relative to the 450 m long transect at this site, *Z. marina* was patchy and was missed in quadrats in 2017, but was recorded as present. Z. *marina* was observed at two other sites – BB1 in Bruin Bay and TR1 on Turtle Reef at the mouth of Iliamna Bay, as well as at the Douglas Reefs (described in section 3.4.2.2); however, it did not occur in quadrats.

Non-kelp Ochrophyta were dominated by *Fucus distichus* and were variable in their tidal range among sites (Figure 3.4.2.1.4). For example, *F. distichus* was relatively abundant on Site 2 (Chenik Head) and N1 (Nordyke Island) but were concentrated at different vertical ranges. These two sites are spatially close together, but the *F. distichus* concentrations were at lower elevations on Site N1, which is more exposed to winter storms. Another common non-kelp Ochrophyta is *Melanosiphon intestinalis*, a mid-intertidal species that occurred at most sites.

Although abundant subtidally, most kelp species were not abundant at most sites in the study area (Figure 3.4.2.1.5), and when they were detected in the quadrats, they were found in the lowest intertidal zones. Kelps were absent intertidally at the two most northerly sites, Sites 6 and 10. At Site 4 on Pomeroy Island, *Alaria marginata* was abundant in the lowest tidal zones in 2015 but was absent in 2018, likely due to seasonal differences for this annual species. Sampling in 2018 was earlier in the spring than in 2015. When comparing drone SfM imagery taken in May 2018 to fixed-wing SfM imagery collected in June, there is a substantial difference in observable *A. marginata*, with little observed in May but long flat blades dominating the lower intertidal in the June imagery.

Non-coralline Rhodophyta were ubiquitous throughout the study area (Figure 3.4.2.1.6*)*. This phylum is represented through a wide tidal range, with *Neorhodomela* spp. (mainly *N. aculeata*) most abundant in the mid-intertidal and *Savoiea bipinnata*, *Palmaria hecatensis*, and *Devaleria* spp. most abundant in the lower intertidal zones. Coralline algae were present (at low percent cover) at all sites with little variability across time (Figure 3.4.2.1.7). Site 4 on Pomeroy Island was an exception with coralline algae abundant in the low intertidal zone (Figure 3.4.2.1.7).

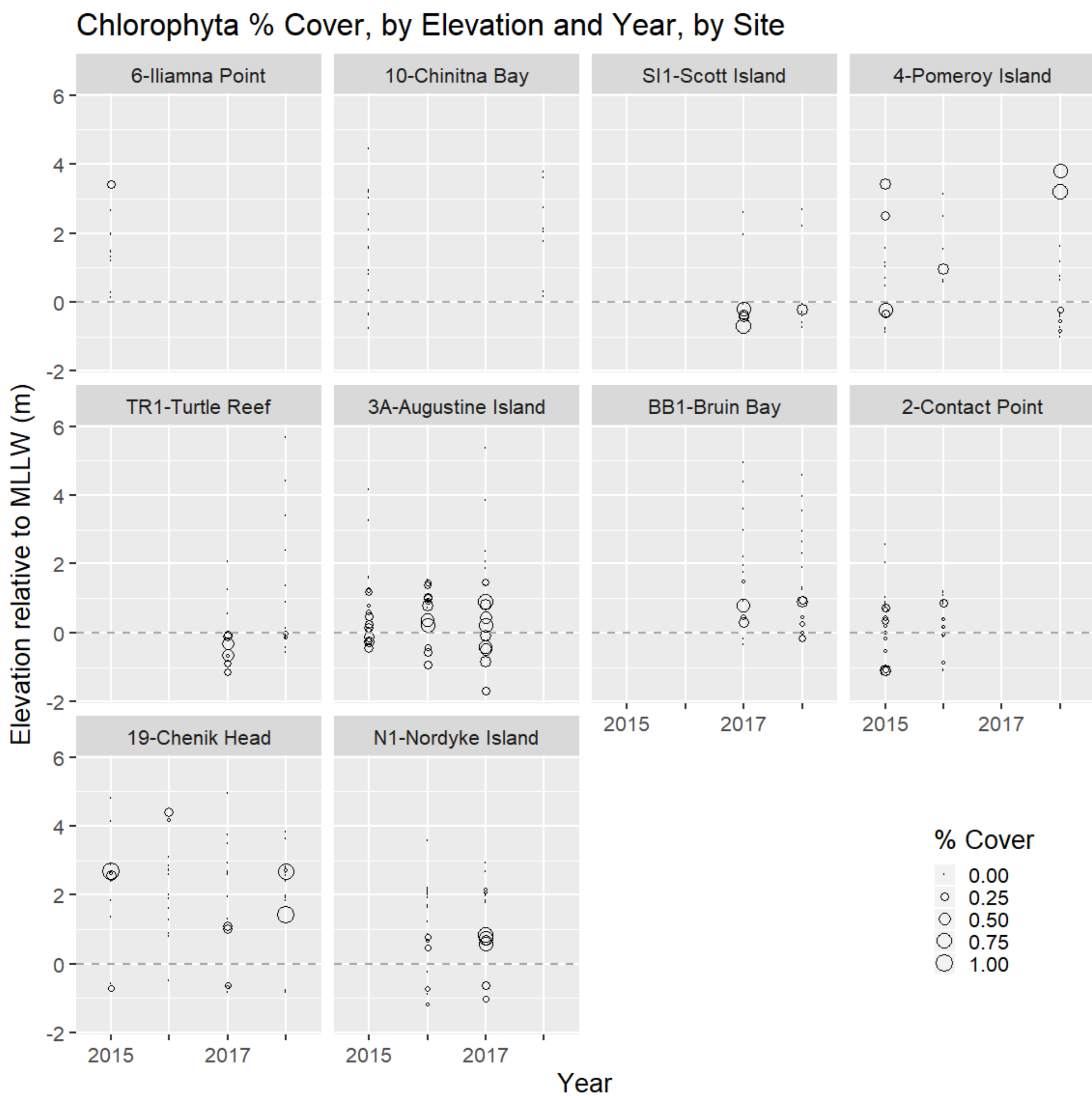


Figure 3.4.2.1.2. Occurrence elevations of Chlorophyta relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

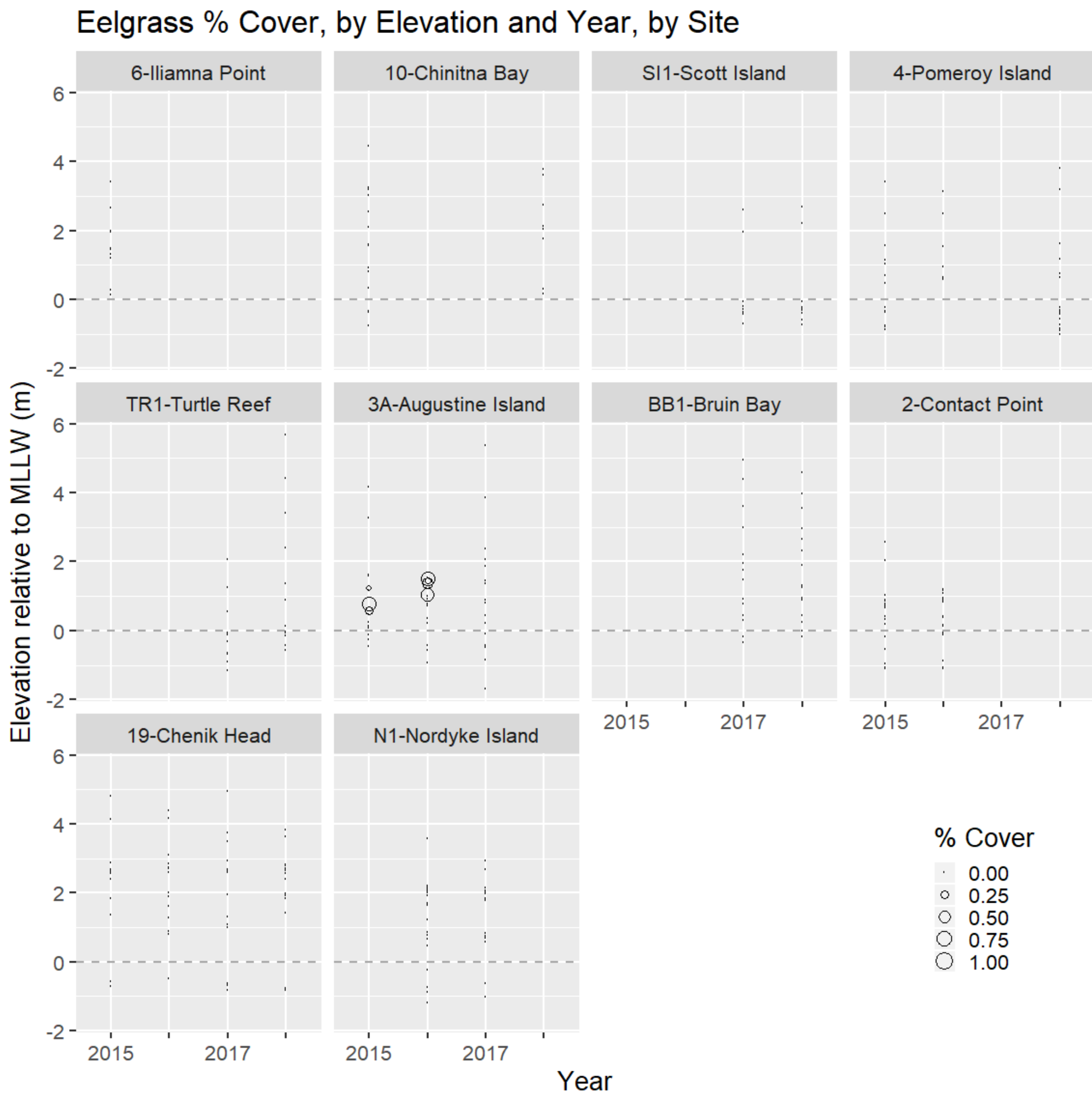


Figure 3.4.2.1.3. Occurrence elevations of Eelgrass relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

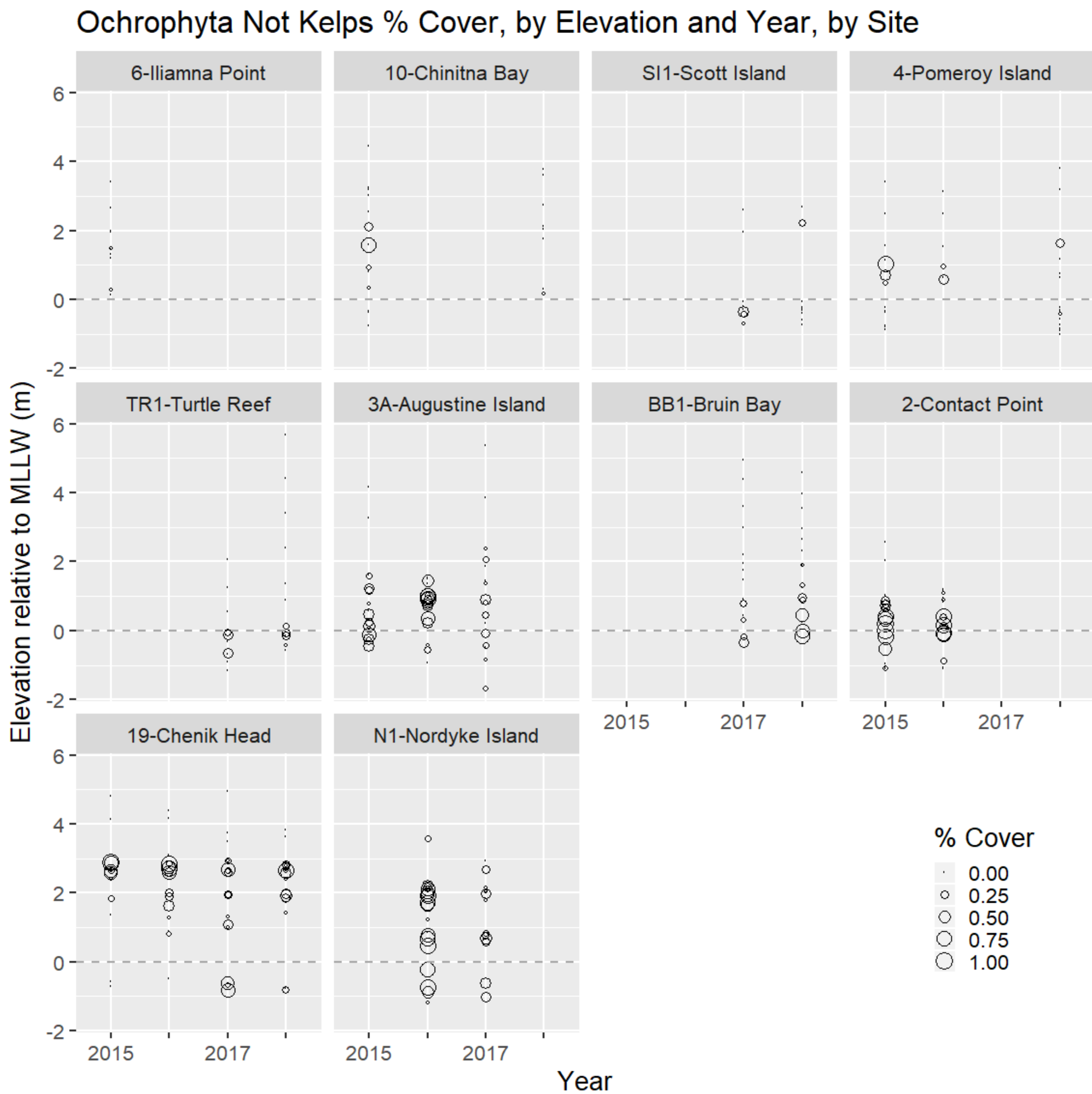


Figure 3.4.2.1.4. Occurrence elevations of non-kelp Ochrophyta relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

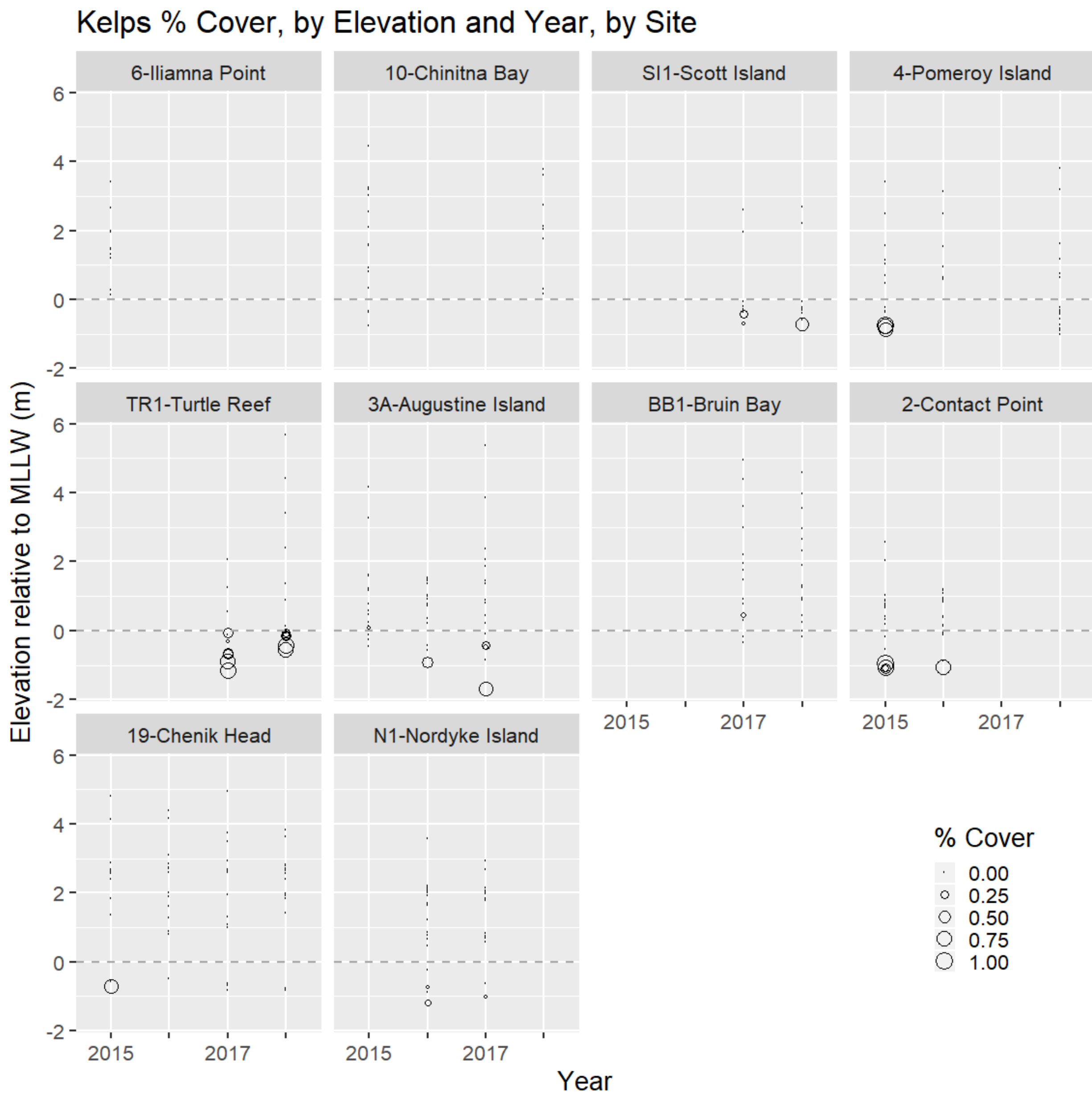


Figure 3.4.2.1.5. Occurrence elevations of kelps relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

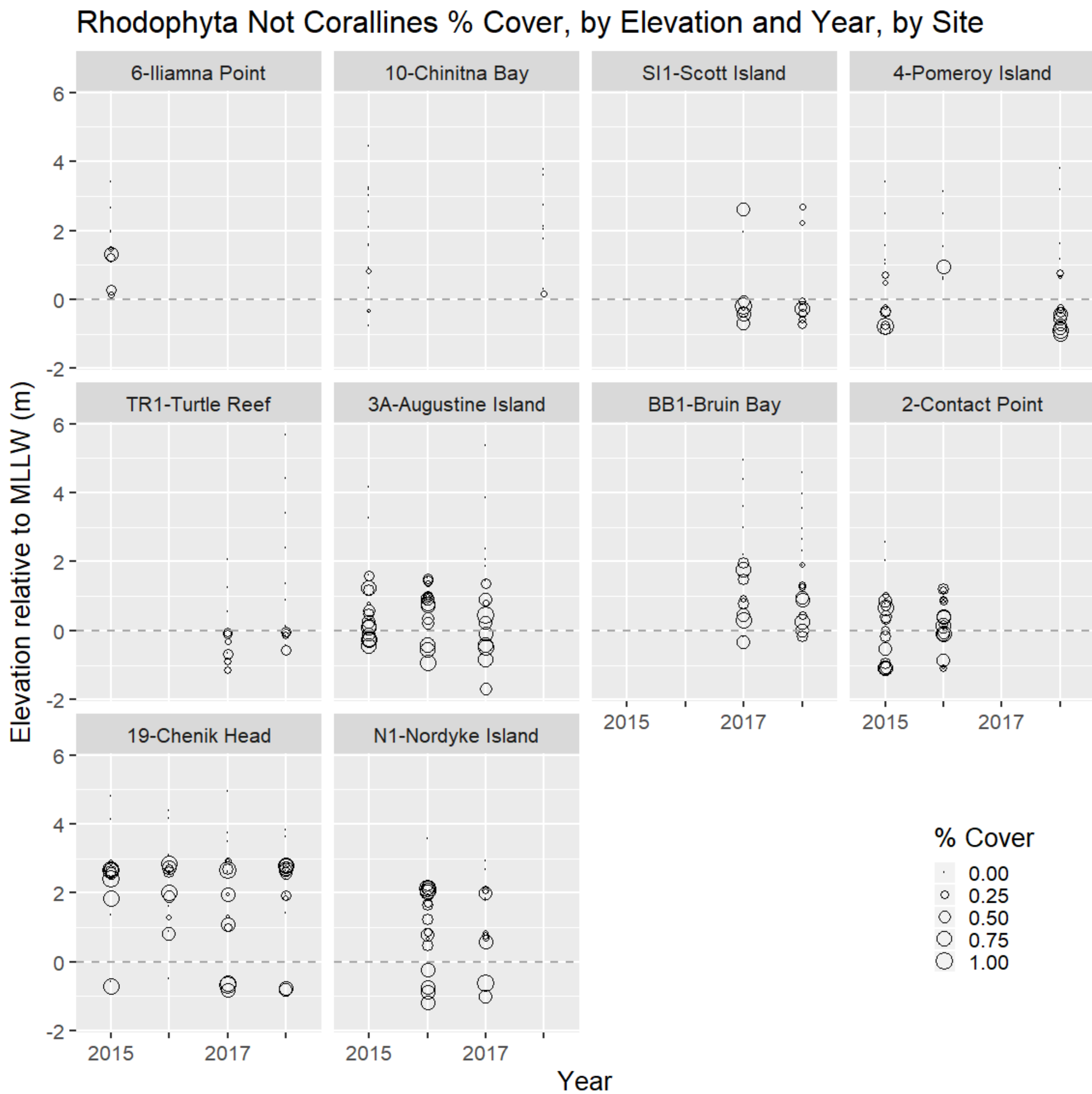


Figure 3.4.2.1.6. Occurrence elevations of non-coralline Rhodophyta relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

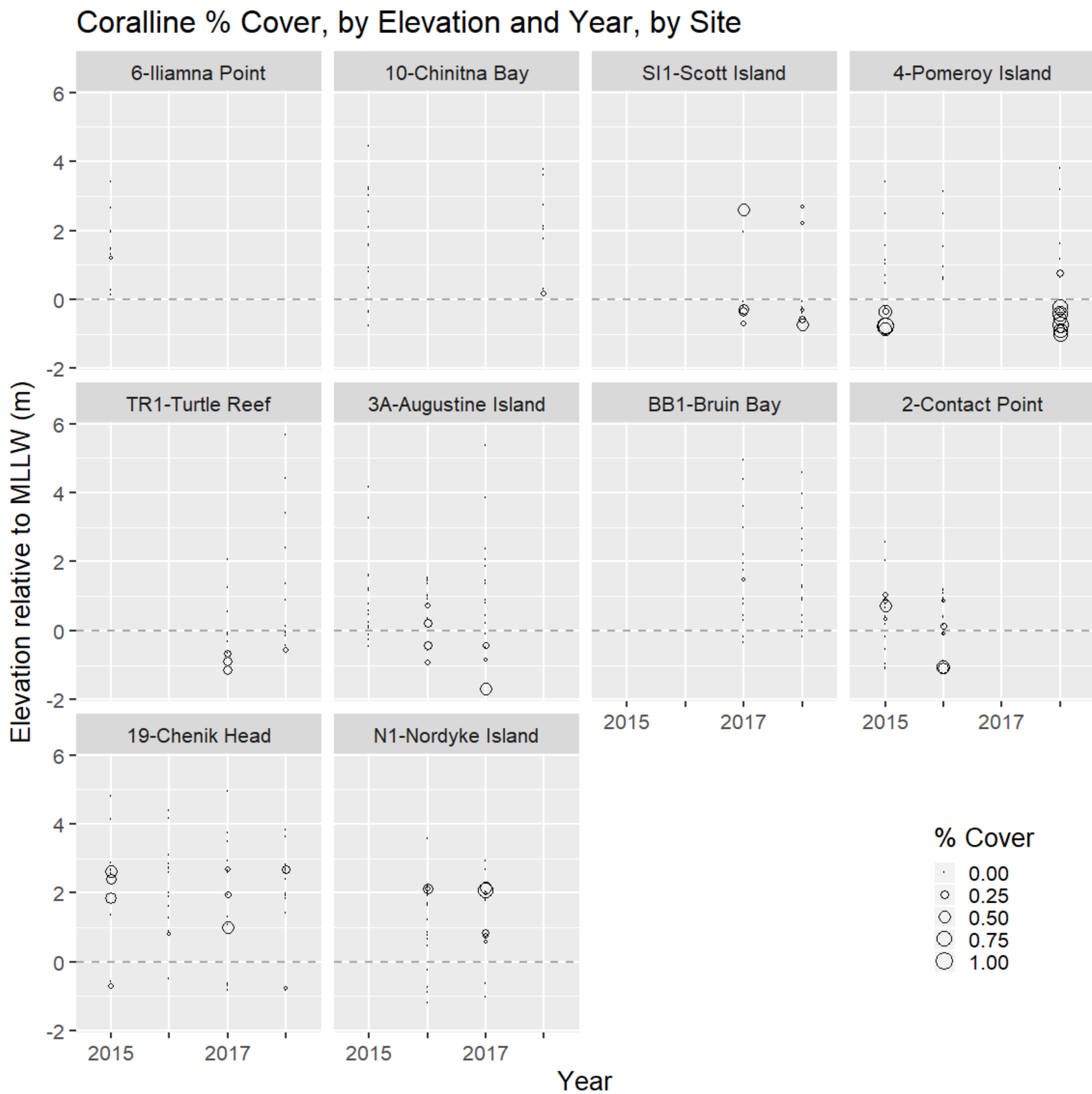


Figure 3.4.2.1.7. Occurrence elevations of coralline algae relative to MLLW.
This figure illustrates the tidal heights of the most commonly occurring species within the intertidal surveys as determined from the point-count assessments. Note that zero percent cover at a quadrat is depicted by a dot. The area of the circle represents percent cover.

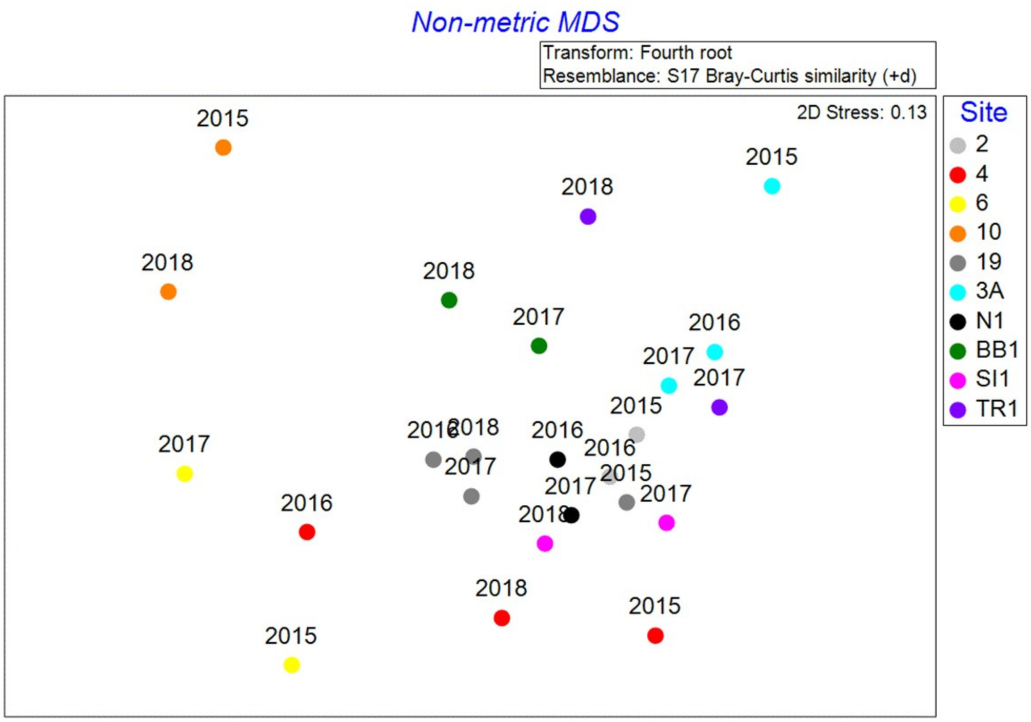
3.4.2.2 **Multivariate Analyses of Intertidal Data**

The phyla-level data presented in Figures 3.4.1.3.1 and 3.4.1.3.2 were divided further into Chlorophyta (all), Rhodophyta-not Corallines, Rhodophyta-Corallines, Ochrophyta-not kelps, Ochrophyta-kelps, sessile invertebrates (all species combined), and bare substrate. The variation among sites and years in the site-level average percent covers for these groups were visualized using nMDS plots (Figure 3.4.2.2.1).

The nMDS ordinations show that for somes sites the year-to-year variation at a site was as big or bigger than the 'distance' between sites (e.g., Sites 3A or 4) while others were relatively similar across years compared to the 'distance' between sites (e.g., Sites 10, N1 or BB1). Averaging each site across years shows that, even at this high taxonomic level, sites 6 and 10 (the furthest north sites) ordinate away from the other sites and from each other. Sites 19 and N1 are geographically close and ordinate together. Sites 4 and SI1 are also geographically close and ordinate together. At these taxonomic levels, the sites in the central and southern study area ordinate within a greater than 80% (but < 90%) similarity cluster (turquoise line). Chlorophyta (lack of) and higher contribution of sessile invertebrates (Balanamorpha) drove the differences among Sites 6 and 10 compared to the other sites. Overlaying the percent-cover data onto the sample (site) data shows these large differences for the northern sites compared to all other sites (Figure 3.4.2.2.2).

The data were further considered at the level of each of the 82 taxon of interest (Appendix B). The Bray-Curtis distance between the site-level and year-specific mean percent-cover data for each of the 82 taxon of interest was used to develop nMDS projections using all the years of observations from the 10 "core" (non-reef sites, 24 total collections) (Figure 3.4.2.2.3). At the broad-scale, the two-dimensional projection appeared to do a generally adequate job capturing the relative 'distances' among observations of community assemblages from different sites or years (stress = 0.1618). The nMDS suggests greater variation in assemblages across years for the more northerly sites (e.g., 6-Iliamna Point, 10-Chinitna Bay, and 4-Pomeroy Island), a possible distinction of the 2015 collections from the other year's collections, and a potential separation between northerly vs southerly sites, though the differences among sites in terms of which years they were sampled somewhat limits simple interpretation of relative magnitudes of spatial versus temporal variation.

Given the visual complexity of the single nMDS ordination plot that includes ordination of site-year community assemblages, the next set of plots (Figure 3.4.2.2.4) repeats the nMDS plot, but highlights the points associated with each site from multiple years to allow easier tracking of changes across time in community assemblages at a site. Two sites that ordinate very near each other, Sites 19 and N1, are highlighted on the same plot in order to fit 9 figures on one page.



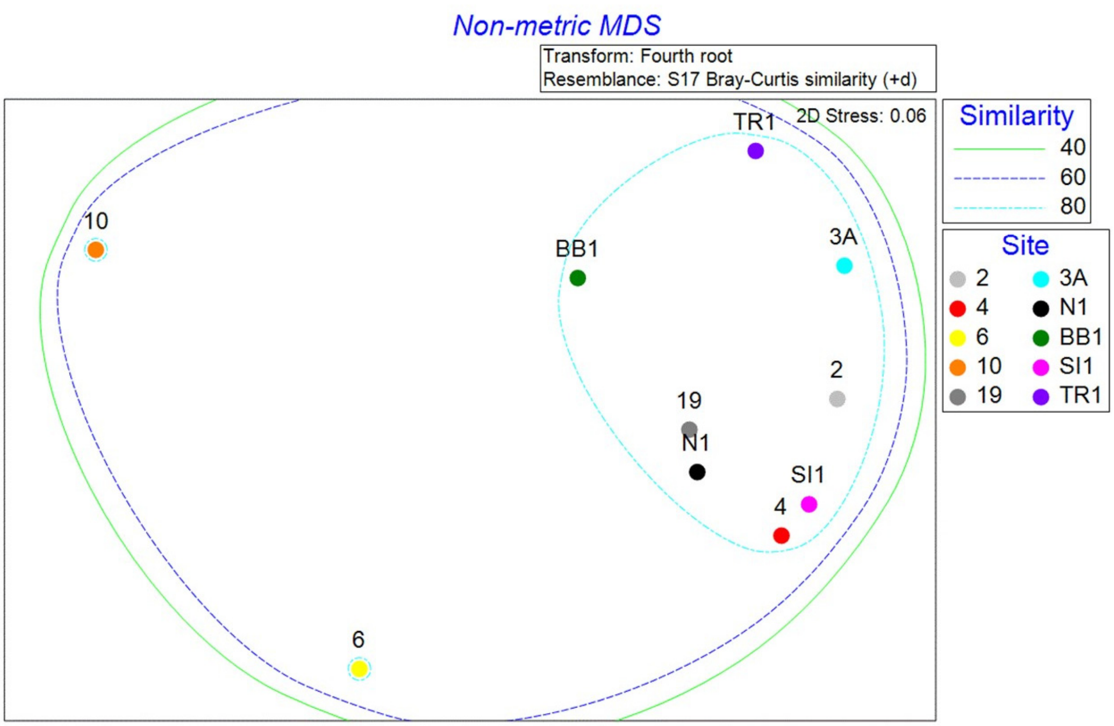


Figure 3.4.2.2.1. nMDS ordination of intertidal macroalgal and assemblage percent cover at various higher taxonomic levels (Chlorophyta (all), Rhodophyta-not Corallines, Rhodophyta-Corallines, Ochrophyta-not kelps, Ochrophyta-kelps, sessile invertebrates (all), and bare substrate) averaged by site-year (top) and by site averaged across all years sampled (bottom). The northern most sites (Sites 6 and 10) ordinate furthest from all other sites and from each other. At these taxonomic levels, the sites in the central and southern study area ordinate within a greater than 80% (but < 90%) similarity cluster (turquoise line).

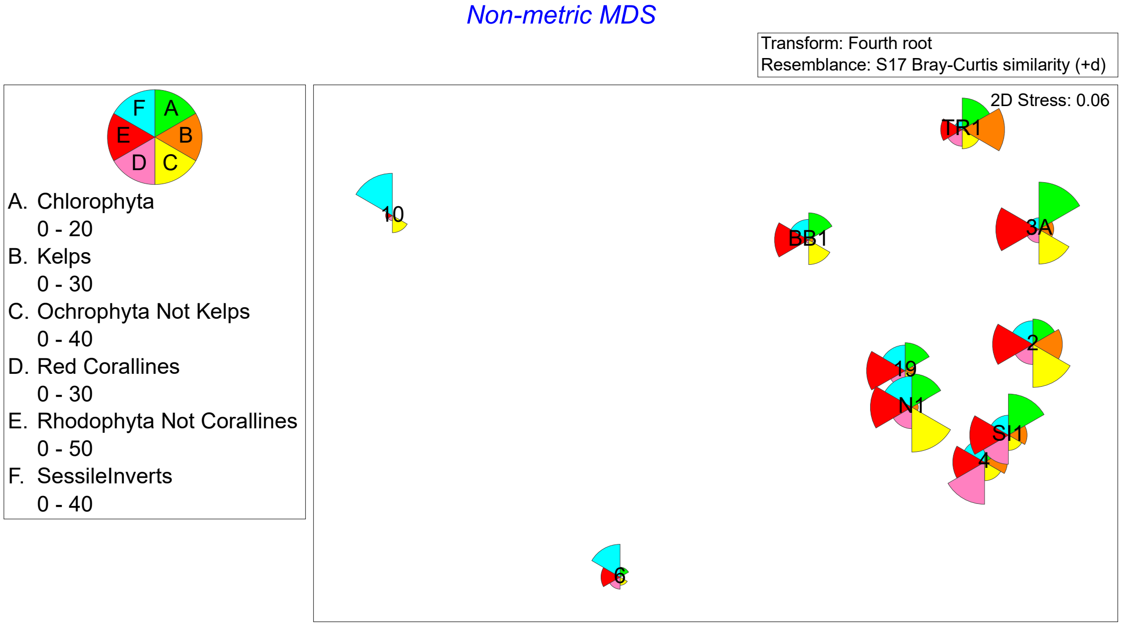


Figure 3.4.2.2.2. Bubble plot with taxon contributions overlain on nMDS ordination plot of intertidal site percent-cover data averaged across all sampling years.

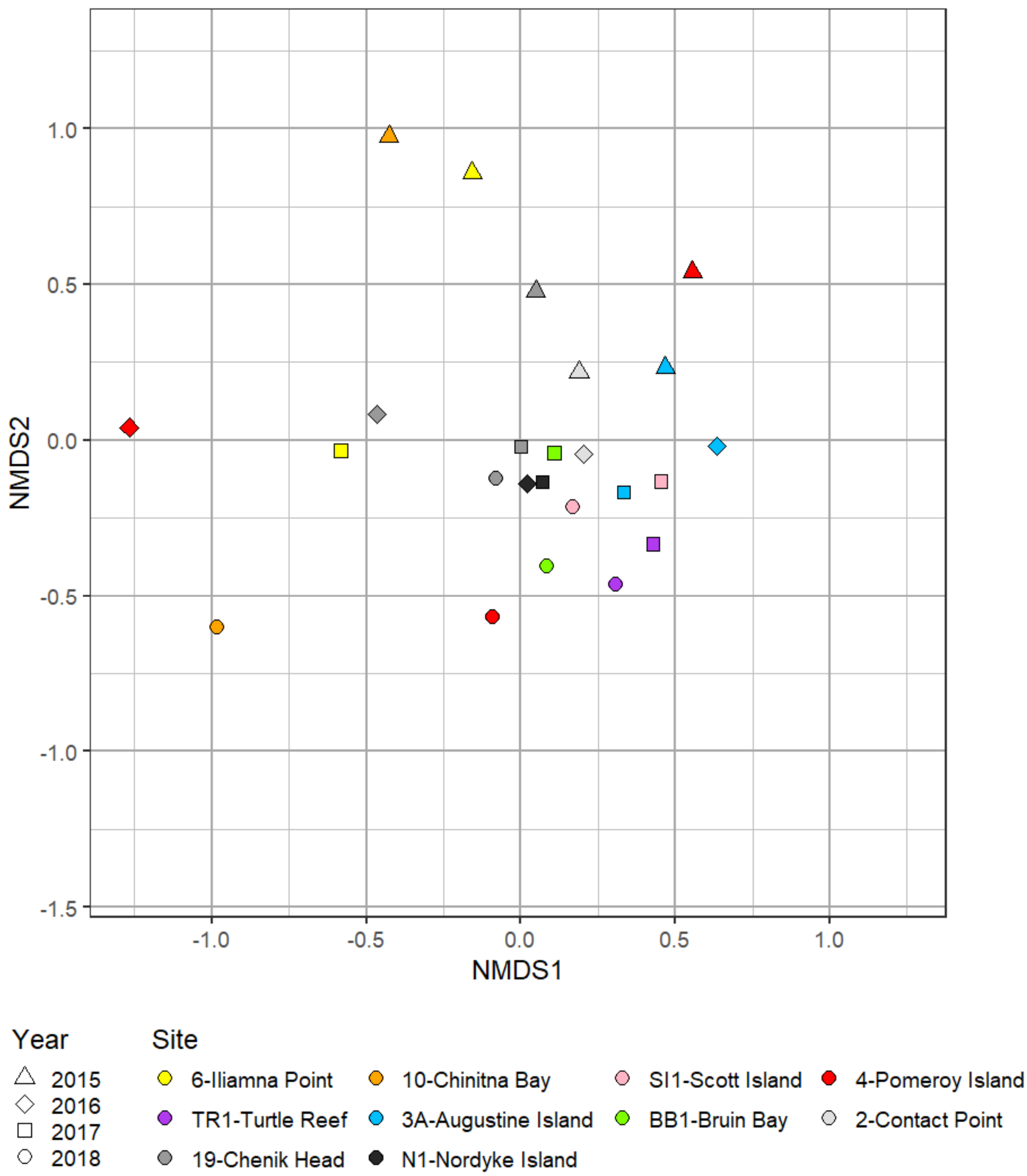


Figure 3.4.2.2.3. nMDS plot of community assemblage data (site-level estimated mean percent cover for each of 82 taxon, see text) from ten intertidal non-reef sites and all years of collection. The final nMDS stress was 0.1618.

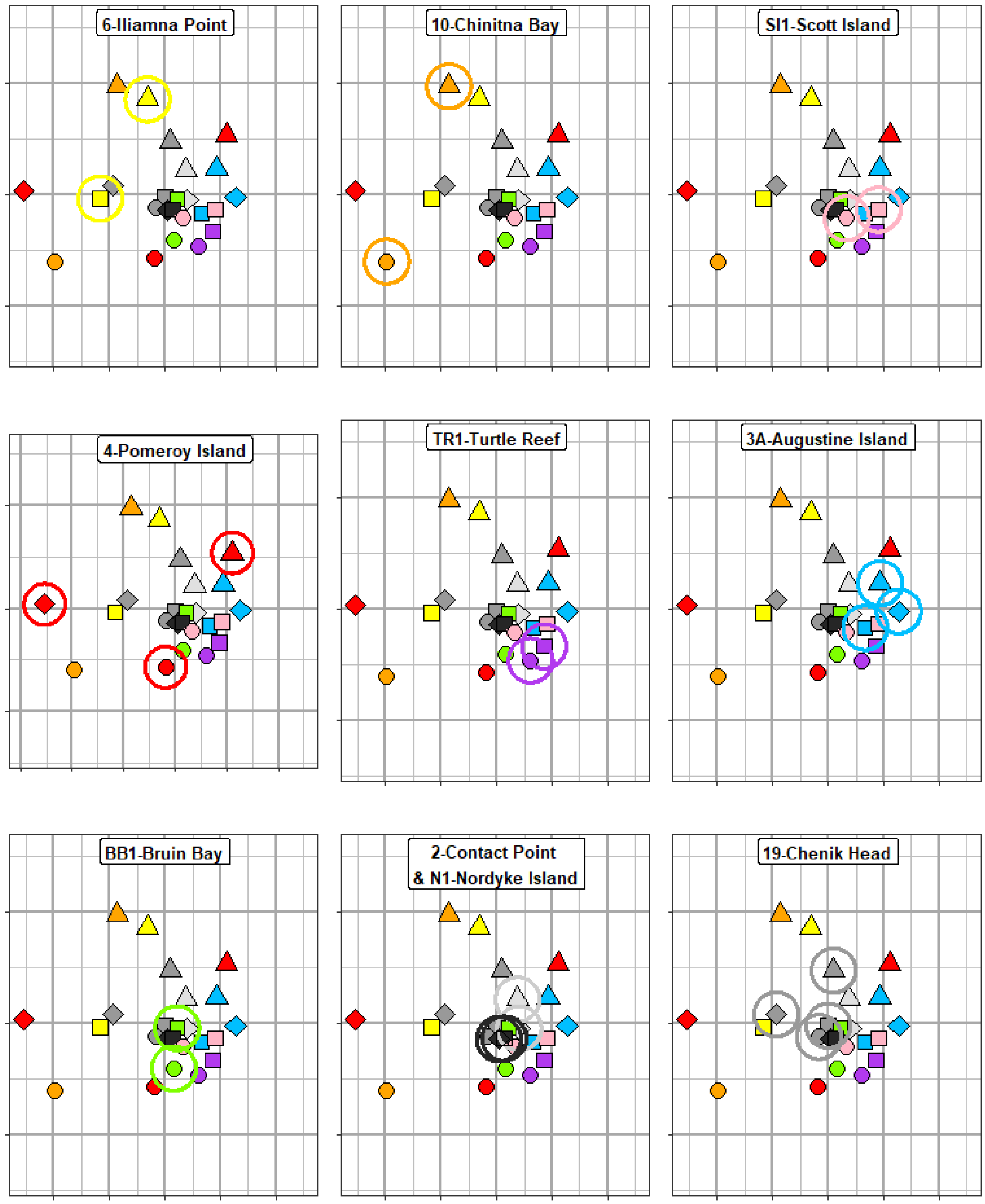


Figure 3.4.2.2.4. The collections from each intertidal site are highlighted with circles in that site's plot so one can more easily see the relative changes in composition across years at that site. Sites are ordered, from left to right, top row to bottom, from north to south. N1-Nordyke Island is shown in blue with Contact Point to allow all 10 sites to be displayed on one page.

The full species assemblages averaged across all sampling years at each site were estimated using the lowest taxonomic level data from point-count quadrat data (Figure 3.4.2.2.5). Similar to the nMDS analyses at the higher taxonomic levels (Figure 3.4.2.2.1), the northernmost sites, Sites 6 and 10, ordinate furthest from other sites, though Site 4 now ordinates further from Site

S1 than it did with higher taxon-level assemblages. Sites TR1, SI1, and 4 are all in the Iniskin/Iliamna Bay area and ordinate further from the more southern stations in Kamishak Bay proper. Bubble plots illustrate contributions of several epifloral taxon onto the nMDS plot and show that common rockweed, *Fucus distichus*, was ubiquitous across the study area, though contributed more to the species assemblages of sites in the southern study area in Kamishak Bay (Figure 3.4.2.2.6). *Neorhodomela aculeata* also contributed much more to assemblages in the southern study area, and contributed far less further north (Figure 3.4.2.2.6). *Palmaria hecatensis* was also ubiquitous across the study area, but contributed most to total site community assemblages at nearby sites TR1 and SI1 (Figure 3.4.2.2.6). Encrusting coralline algae had higher cover at the central study area sites, as did the kelps *Saccharina latissima*, *S. nigripes*, and *Alaria marginata* (Figure 3.4.2.2.7).

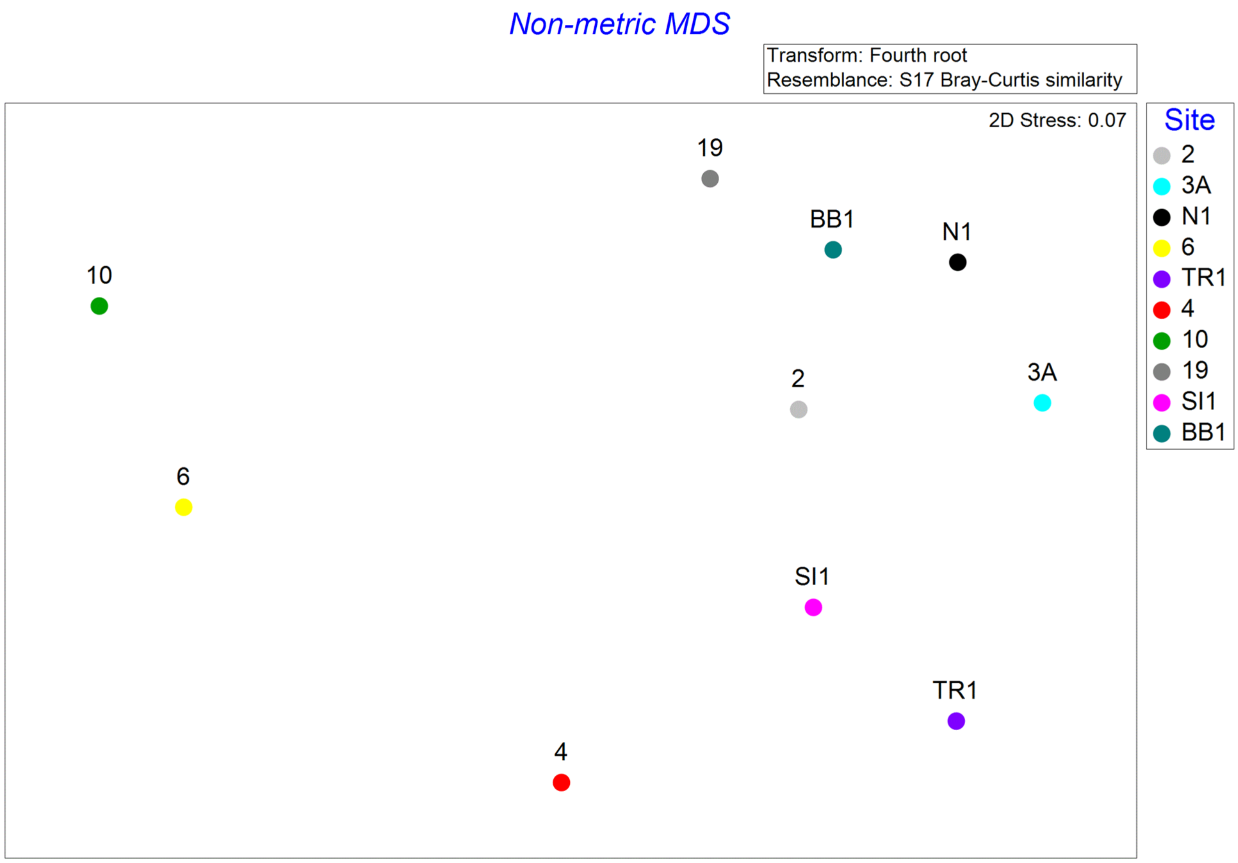


Figure 3.4.2.2.5. nMDS ordination of intertidal macroalgal and assemblage percent cover at lowest recorded taxonomic levels averaged by site across all sampling years.
The northernmost sites (Sites 6 and 10) ordinate furthest from all other sites and from each other.

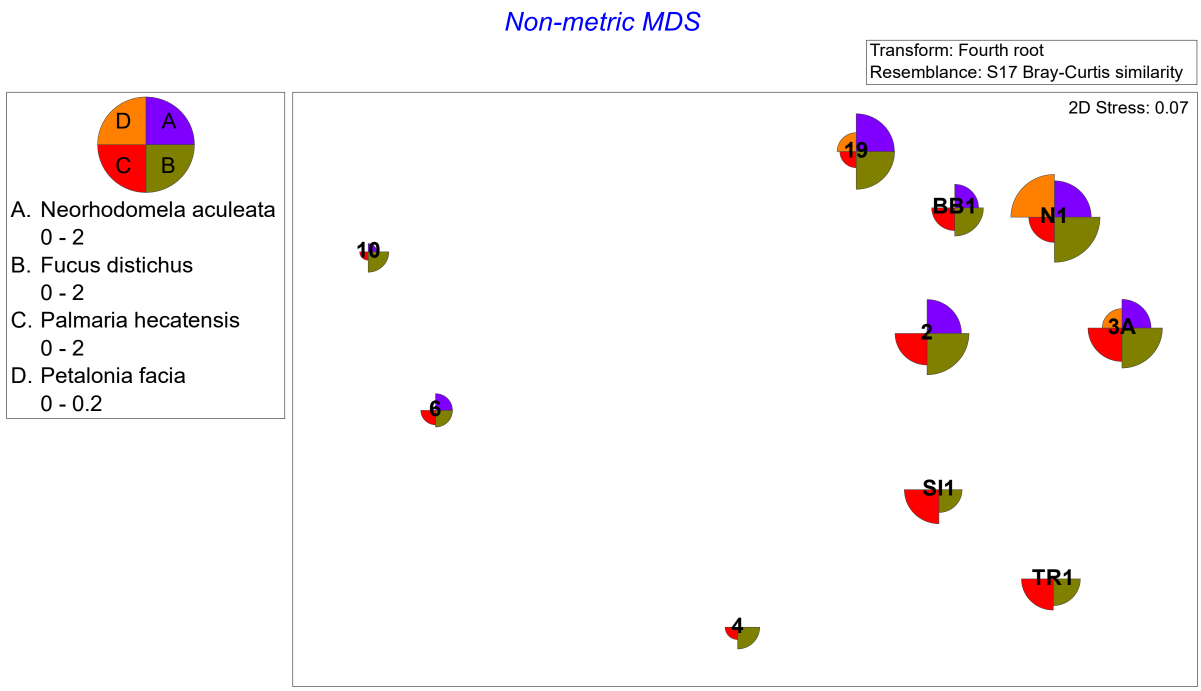


Figure 3.4.2.2.6. Bubble plot with taxon contributions of several common macroalgae overlain on nMDS ordination plot of intertidal site percent-cover data averaged across all sampling years.

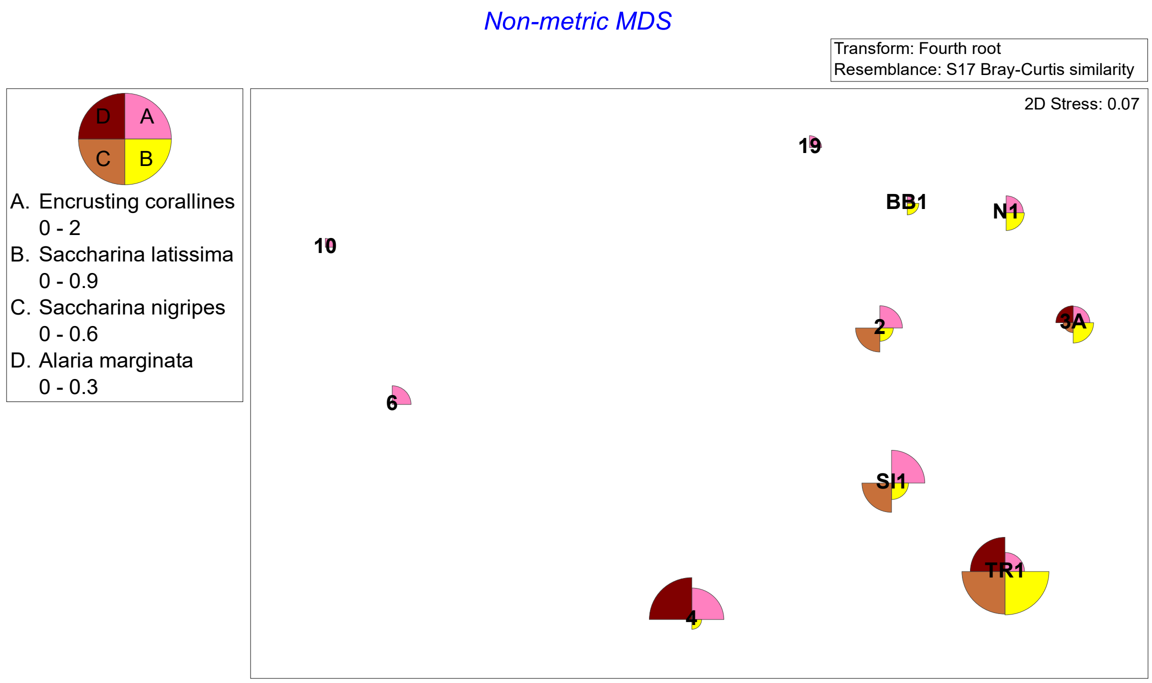


Figure 3.4.2.2.7. Bubble plot with taxon contributions of coralline algae and kelp species overlain on nMDS ordination plot of intertidal site percent-cover data averaged across all sampling years.

As discussed above, many intertidal species are limited to much narrower vertical ranges than are others. By analyzing community assemblages for entire sites, the differences in community assemblages at various tidal heights among sites may be obscured. Most sites in the study had a steeper beach face in the high intertidal zone with a lower angle ramp in the middle intertidal zones. Several also had a shorter steeper intertidal zone between Mean Higher High Water and the lowest tide during sampling. Percent-cover data from point-count quadrats was ordinated at "binned" vertical tidal heights averaged by site across all sampling years (Figure 3.4.2.2.8).

Larger distances among site assemblages were seen at the highest tidal range (Figure 3.4.2.2.8). These are typically mostly bare beach faces with scattered sessile invertebrates (mainly Balanamorpha). Among sites, the lowest tidal ranges ordinate the closest, indicating less variability than higher on the site. When group-averaged cluster similarities are overlaid on the nMDS plot, there is no clear grouping by the vertical height categories. It is clear that the most abundant habitat (elevational bin) on a site differ widely across sites (Figure 3.2.2.2). For example, the most abundant vertical height at sites TR1, 2, and 4 are similar and much lower than at Sites 19, N1, and 3A, with the long low-angle ramp on Site 19 higher in the intertidal zone than the other sites. To compare community assemblages based on "ramp" vs "non-ramp" habitat at each site, an nMDS plot was created for site categories "high" – or vertically higher than the dominant ramp habitat, "ramp" – reflecting the lowest-angle habitat, and "low" – for habitat at lower elevations than the ramp (Figure 3.4.2.2.9).

Community assemblages at the highest vertical elevations (category "high") are typically mostly bare rock or sediment and show disparate species assemblages. These relatively barren habitats would provide little useful information for monitoring change, and are removed from the nMDS ordination (Figure 3.4.2.2.10). Again, Sites 6 and 10 ordinate furthest from the other sites. Sites with the least vertical differentiation between their "ramp" and habitat at lower elevations ordinate relatively close to each other (Sites 2, 4, TR1, and SI1). Sites 19 and N1, the furthest south sites ordinate very near to each other for similar ramp categories, and the assemblages for the two ramp categories on each site are more dissimilar to each other than they are to the other site. Note these two sites have a major vertical elevational change between the ramp elevation and the lowest elevation assemblages.

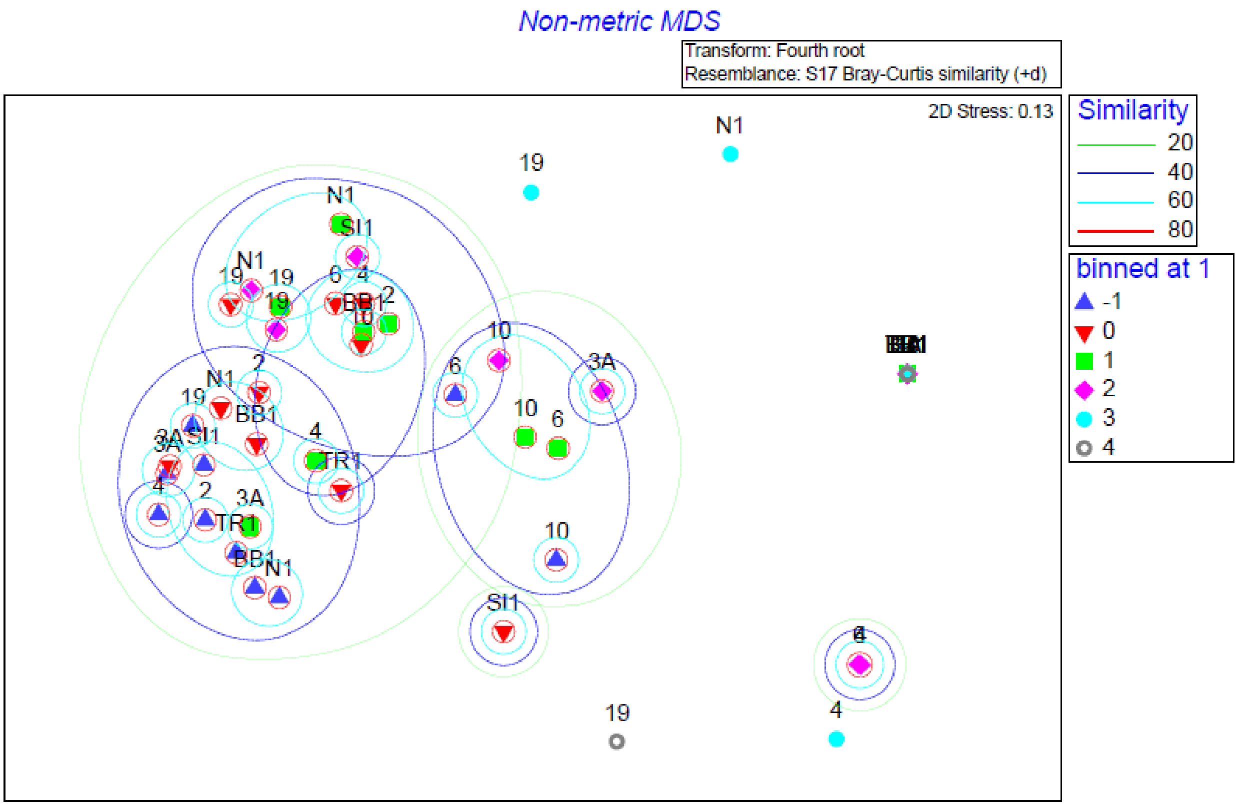


Figure 3.4.2.2.8. nMDS plot of community assemblage percent-cover data "binned" by vertical height and averaged for site across sampling years at ten intertidal non-reef sites and all years of collection.

Group-averaged Cluster similarities are overlain and indicated by the colored lines. The vertical heights are relative to MLLW and are binned into the categories: < -1.0 m; > -1 and < 0 m; > 0 and < +1 m; > 1 and < 2 m; > 2 and < 3 m; >3 and < 4m.

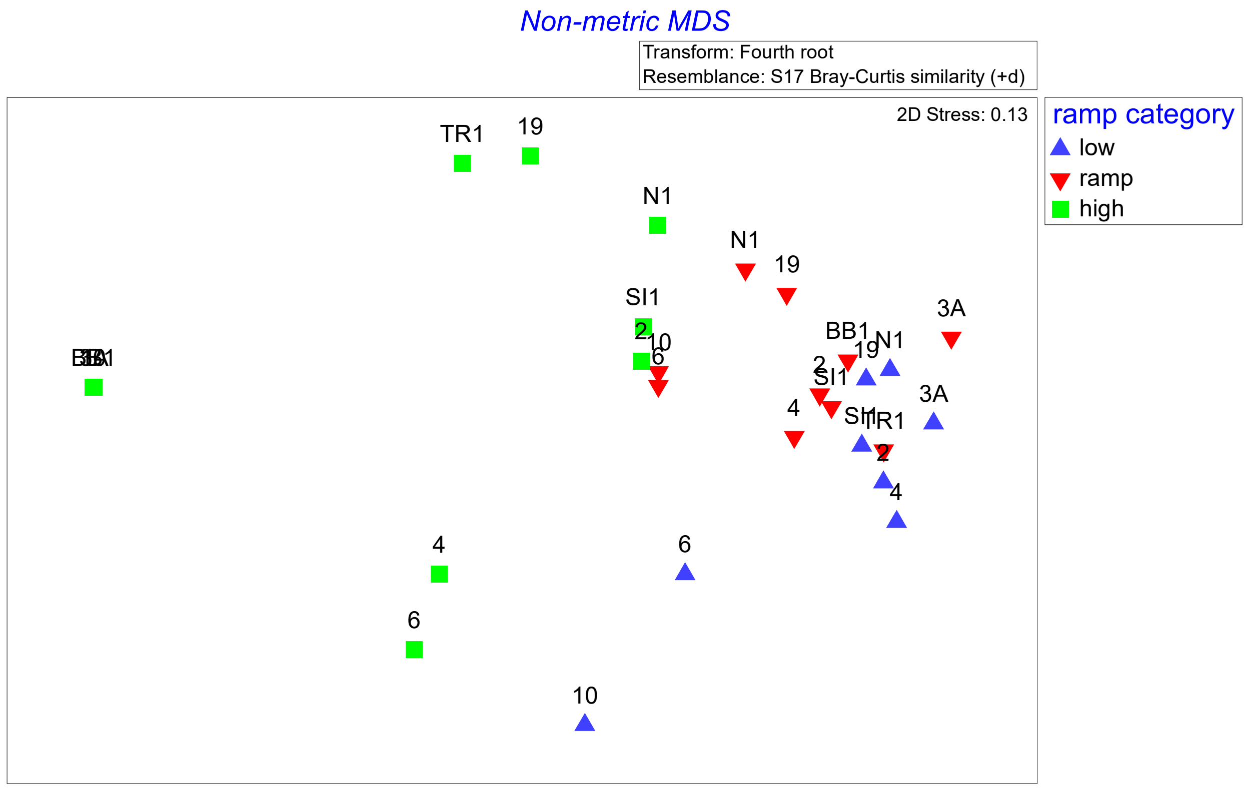


Figure 3.4.2.2.9. nMDS plot of community assemblage percent-cover data “binned” relative to “ramp” habitat and averaged for site across sampling years at ten intertidal non-reef sites and all years of collection.
High = data collected at quadrats at higher elevations than the dominant “ramp” habitat on a site; typically a relatively steep bedrock or sediment beach face at the top of the transect. Ramp = the dominant, lower-angle habitat along each transect. Low = habitat sampled at lower elevations than the dominant “ramp” habitat that typically occurred below estimated Mean Lower Low Water.

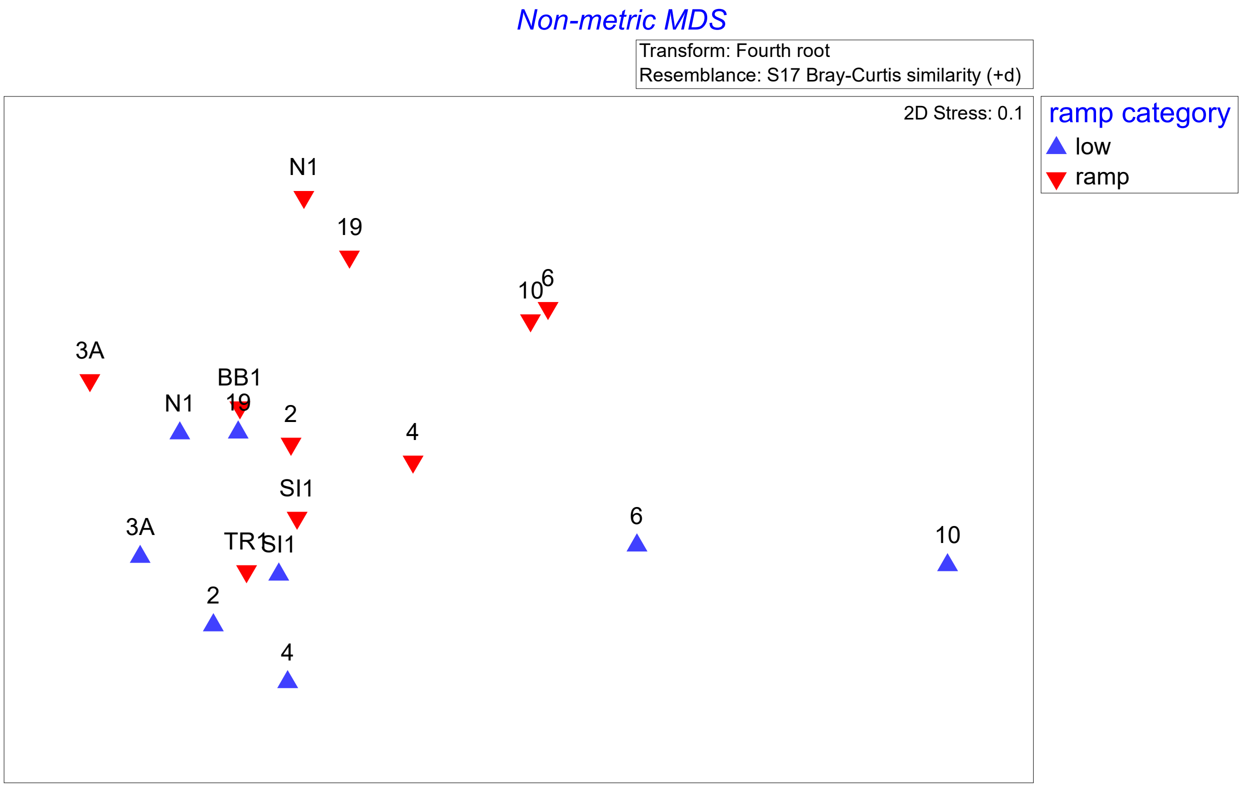


Figure 3.4.2.2.10. nMDS plot of community assemblage percent-cover data "binned" relative to "ramp" habitat and averaged for site across sampling years at ten intertidal non-reef sites and all years of collection.
Ramp = the dominant, lower-angle habitat along each transect. Low = habitat sampled at lower elevations than the dominant "ramp" habitat that typically occurred below estimated Mean Lower Low Water.

An nMDS ordination of species assemblage percent-cover data was constructed for the Douglas Reef complex in southeastern Kamishak Bay (Figure 3.4.2.2.11). This complex of offshore reefs and rock ramps was sampled by both photo and point-count quadrats to provide species-level data for defining community assemblages of the large habitat polygons that are visible in the Structure from Motion imagery of the area. The sampling design differed from that on the core sites described above in that transects could not be sampled from a shoreline beach to the waterline. Instead, samples were collected throughout the reef system to represent a wide range of habitats (Table A.1.11).

The Douglas Reef data were analyzed by vertical elevation categories across the entire reef complex (Figure 3.4.2.2.11). Although the stress is 0.1 indicating the ordination is a reasonable approximation of the true similarities among sites in 2-d space, the true similarities among species assemblages are low among all sites. The lowest elevation (< -1.5 m) ordinated the furthest from all other sites. Simpler analyses show the presence of *Saccharina latissima* at this elevation was the major contributor to the ordination of Site 2 relative to all other sites. The higher elevation assemblages differed from the low elevations, and each other, mainly from differences in the barnacle *Chthamalus dalli*. A unique form of *Devaleria callophylloides (D. callophylloides f. devaleria)*, that we observed only in Kamishak Bay, was the main contributor for differences among the <0.5 and <0.0 m elevation assemblages, with its range seeming to be restricted to that narrow tidal elevation. There were too few quadrat samples distributed at all elevations throughout the entire reef system to determine differences by latitude or longitude or by protected vs. exposed sections of the reef.

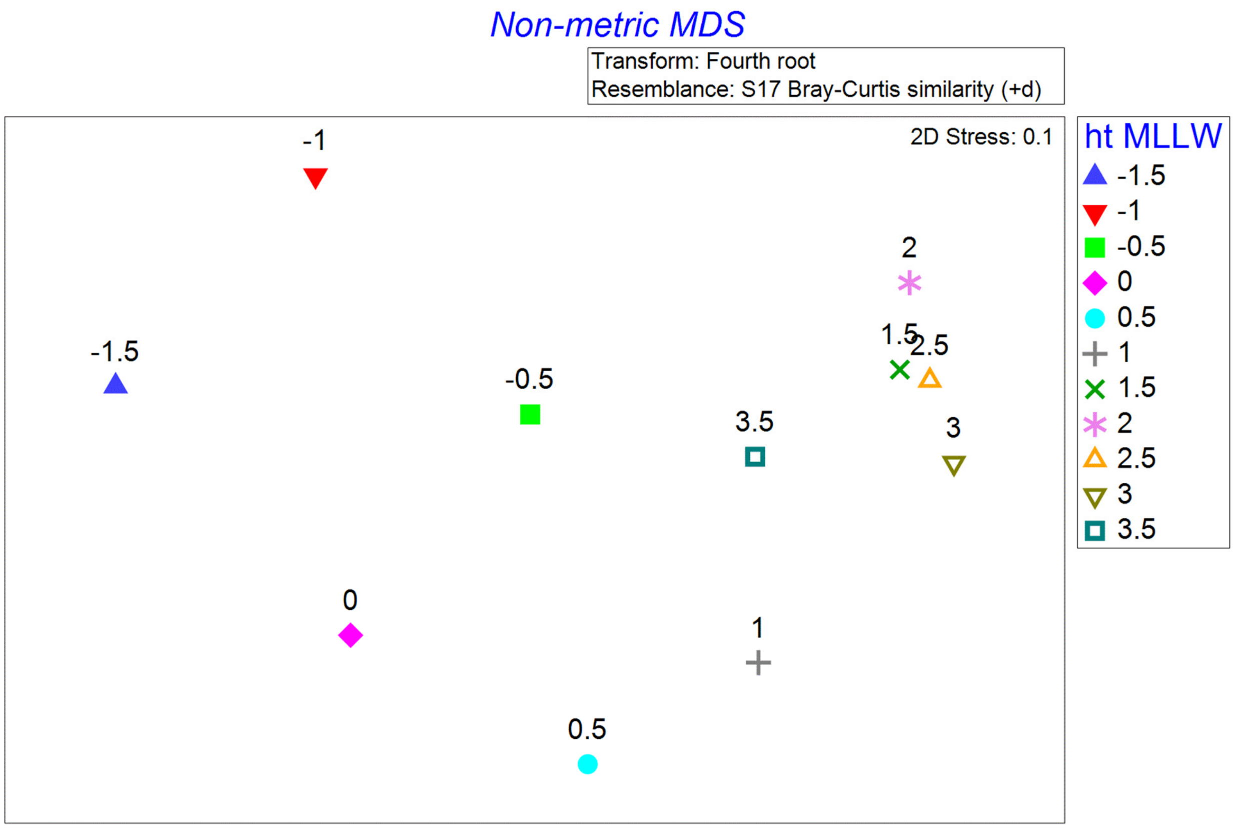


Figure 3.4.2.2.11. nMDS plot of community assemblage percent-cover data from the Douglas River reef complex "binned" into 0.5 m vertical elevation categories relative to MLLW.
The number on the legend represents the tidal elevation (m) below which the data were averaged. So, for example, -1.5 represents data at lower elevation than -1.5 m tidal height relative to MLLW and -1.0 m represents data between -1.0 and -1.5 m relative to MLLW.

To increase the replication for the Douglas Reef complex for comparison to all other sites, the photo-quadrat data were used since there were four times as many photo quadrats as there were point-count quadrats used in the above analysis. The Douglas Reef (DR) assemblage data ordinated with all other sites and averaged for each site across all sampling years showed that the DR site ordinated closer to sites further north (e.g. 3A and 4) than it did to the nearest Sites 19 and N1 (Figure 3.4.2.2.12). Contributions to the dissimilarities between DR and most other sites were driven by the presence of *D. callophylloides f. devaleria* and the eelgrass *Zostera marina* at Site DR, as well as the absence of *Fucus gardneri.*

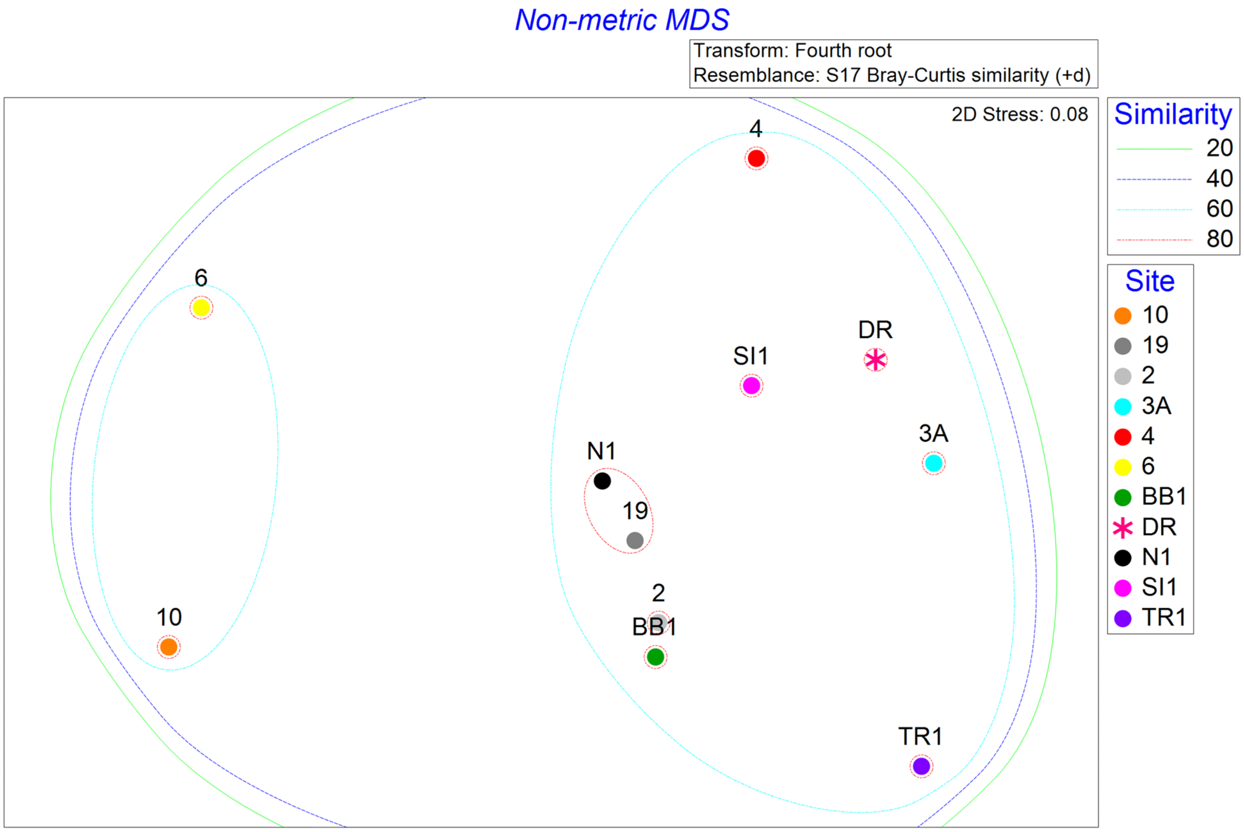


Figure 3.4.2.2.12. nMDS plot of community assemblage percent-cover data from the Douglas River reef complex compared to all other sites.
Data were averaged by site over all years. Colored lines show group-averaged cluster similarities.

3.4.3 Site Species and Voucher Collections

Voucher Collections

Efforts to collect, identify, and archive benthic marine algae for this project have resulted in a comprehensive voucher collection. A complete inventory of hundreds of voucher specimens with select *in situ* photographs has been compiled into an image-rich, digital catalog for western lower Cook Inlet (Figure 3.4.3.1). This type of compilation is not a traditional product from these surveys, but it is a valuable effort that highlights the diversity and unusual morphologies for species in the region. Cumbersome documentation of voucher specimens and photographs are often left out of reporting and remain unseen. Publishing the catalog as a NOAA Technical Memorandum will ensure wide distribution of this unique baseline information and virtual curation of the collection.

Figure 3.4.3.1. Sample pages from the western lower Cook Inlet Benthic Marine Algae Digital Catalog.
These pages show digital images of a voucher pressing (left panel) and *in situ* photo (right panel) of the red alga, *Constantinea subulifera*. Each image is annotated with key metadata: scientific name, life-history observations, habitat information, unique specimen number, collection location, collection date, project site code, and GPS waypoint.

3.5 SfM

3.5.1 Manned aircraft habitat mapping – Douglas Reef Example

Results of the habitat segmentation (Figure 3.5.1.1) tests indicated that high levels of segmentation were needed along with a considerable degree of merging where edges may indicate similar habitat types. Segmentation and merge tests were conducted using only the red, green, blue, near infrared, and elevation bands within the image in the data layer segmentation settings.

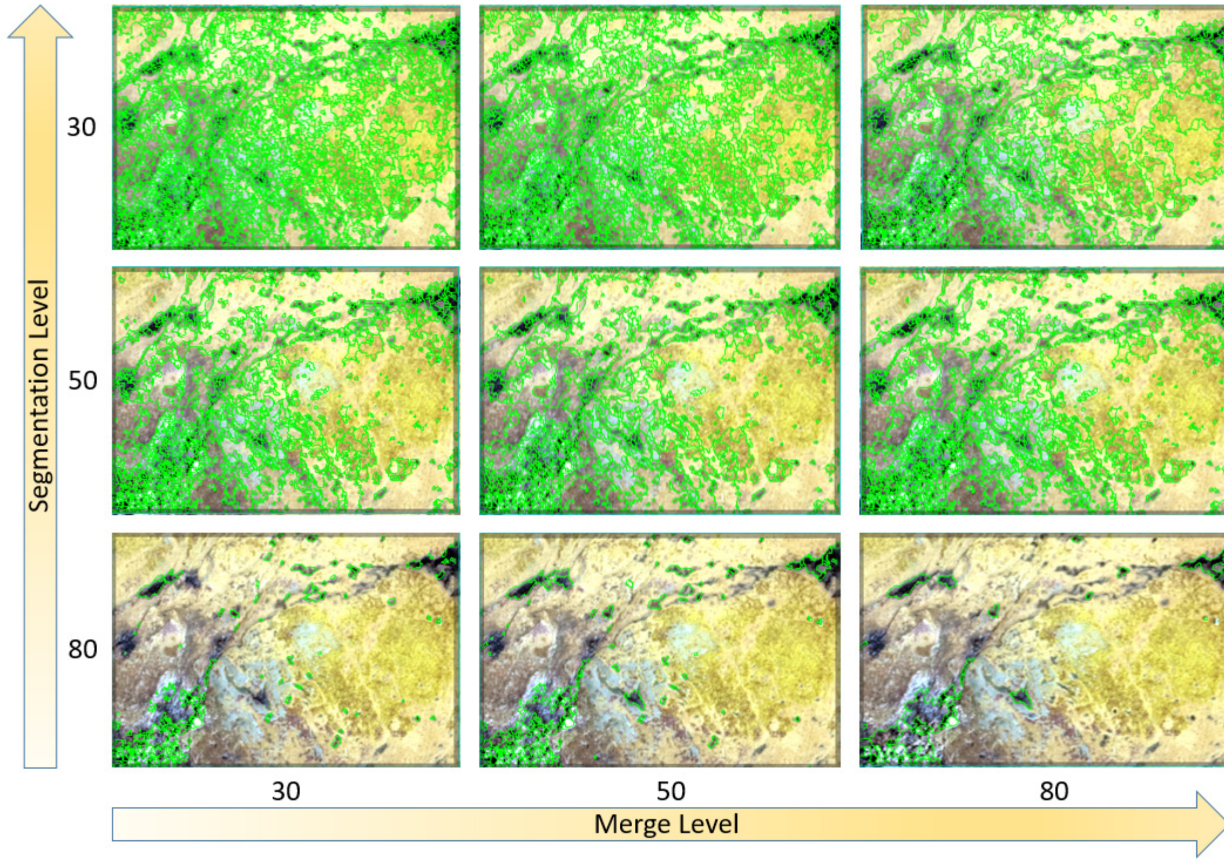


Figure 3.5.1.1. Habitat segmentation grid. Amount of segmentation increases towards the top of the graph, and merging of segments increases towards the right of the graph.
Ultimately, the segmentation level needed to be higher than indicated in the habitat segmentation grid shown.

The final segmentation that yielded best results had an edge segmentation algorithm at a scale of 10 and a full lambda schedule merge algorithm with a scale of 80 (Figure 3.5.1.2). This was determined to be the best because it yielded obvious segmentation at color breaks within the image at a scale that did not overly segment areas of similarities. Segmentation is particularly important because habitat type extraction can only occur on the scale of a segment. If an area is overly segmented, processing time in greatly increased, and if the area is not segmented enough, then areas of different habitat will be classified identically. These segmentation parameters were attempted at several sites to ensure that segmentation would work broadly across the region using the same methodology. Tests of segmentation across sites indicated these segmentation parameters would work well in many areas for feature extraction.

Following the determination of the segmentation parameters, example-based feature extraction (habitat typing) was initiated. Site 19 (Figure 3.5.1.3) was chosen because this site included both manned aerial imagery and imagery collected from unmanned aerial vehicles for the purpose of creating site-specific digital surface models.

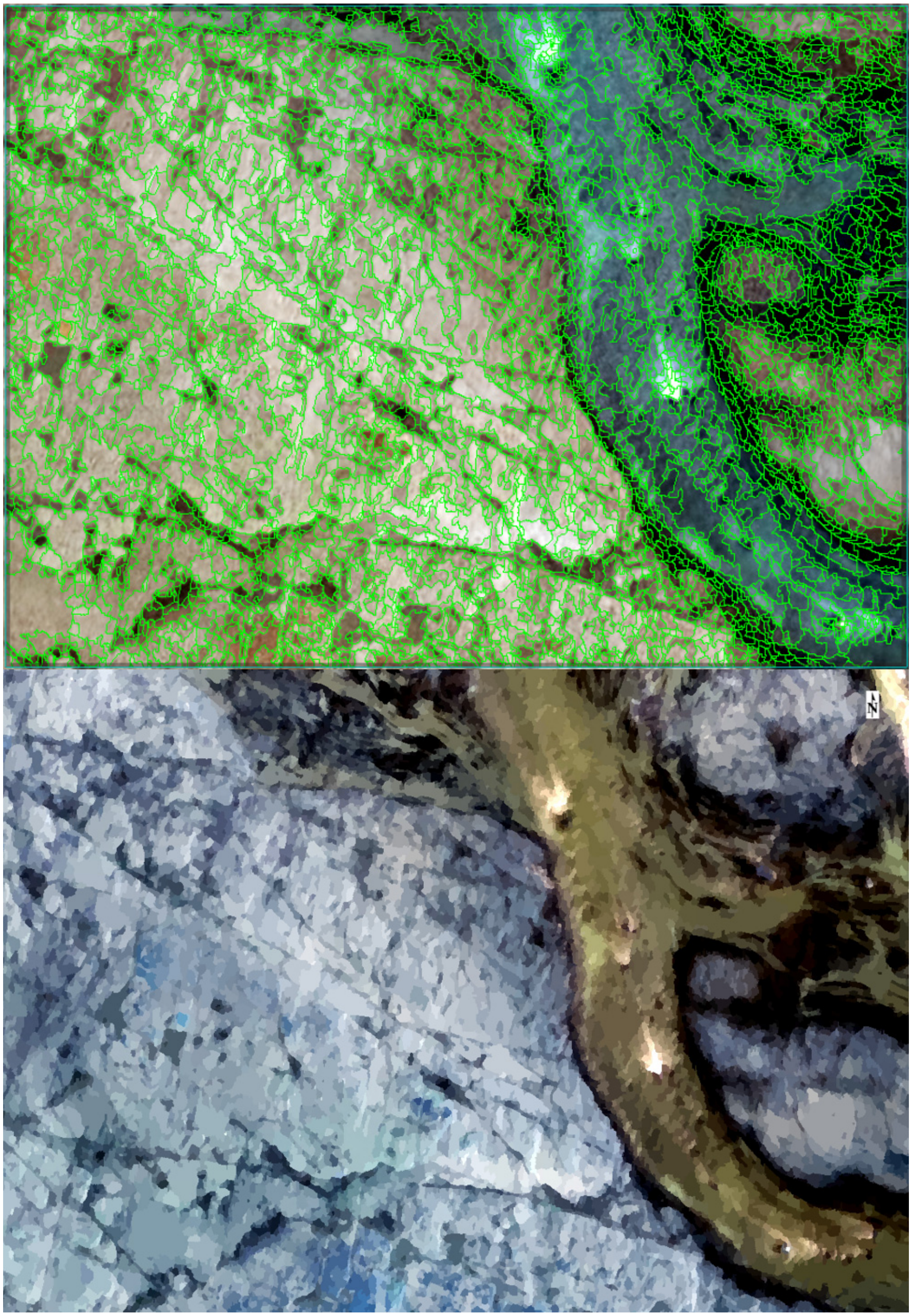


Figure 3.5.1.2. Final habitat segmentation selection showing segment determination in a selected location using spectral data (upper image) and the interpreted segmentation for feature extraction (lower image).
Segmentation was determined in ENVI using edge segmentation algorithm at a scale of 10 and a full lambda schedule merge algorithm with a scale of 80.

Figure 3.5.1.3. Site 19 blended orthomosaic from which habitat assessments were conducted.

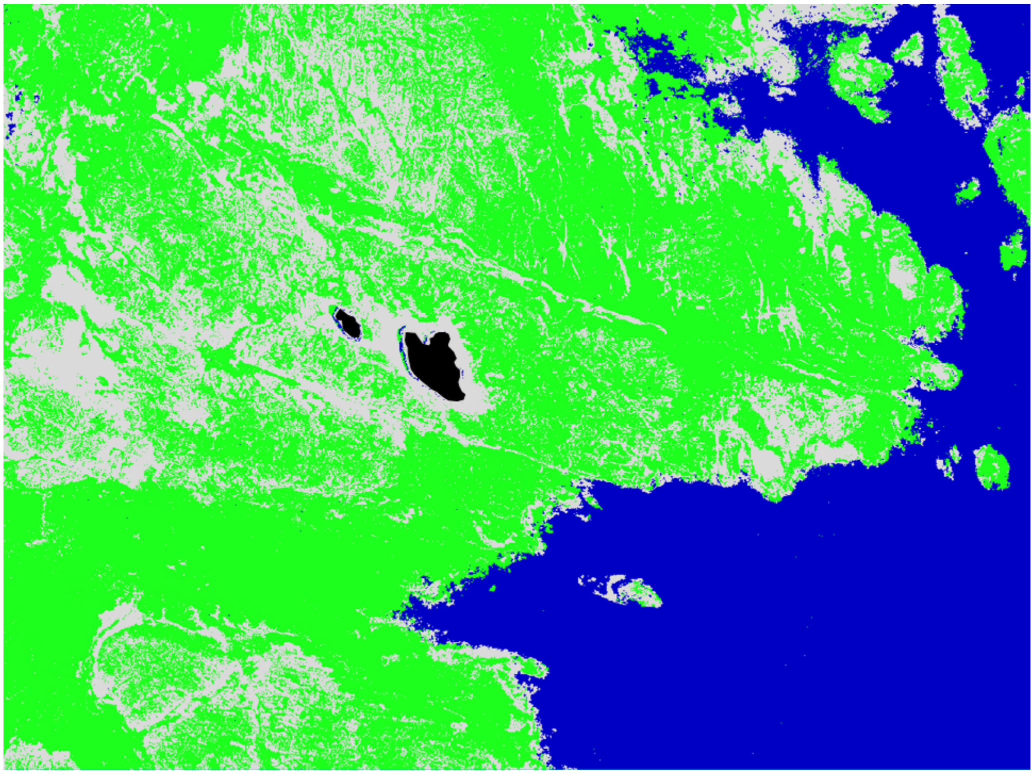


Figure 3.5.1.4. Site 19 feature extraction results of water (blue), non-vegetated (grey), and vegetated areas (green).
The terrestrial vegetation was masked (black) on the two islands in the image.

Using the assessment criteria outlined in Figure 2.4.4.2, the first attempt at classification focused on determining the difference between water, vegetated, and non-vegetated areas. This classification (Assessment Level 1, Figure 2.4.4.2) was extremely successful in habitat classification at a gross level (Figure 3.5.1.4). There were some smaller questionable areas near the edges of the water, but the vast majority of the area in the image appeared to be classified appropriately. Assessment Level 2, differentiating kelp from other algae, was successfully attempted next. Assessment Level 3, differentiating water, non-vegetated, eelgrass, kelp, and other algae, was also successfully implemented (Figure 3.5.1.5).

Assessment Level 4 (Figure 2.4.4.2), which further differentiates algae into brown algae other than kelp, green algae, and red algae, is technically achievable. However, the low quantity of ground-truthed test data and lack of "pure" ground samples of swaths of each type of habitat needed by ENVI to train the classification system were a limiting factor in achieving this level of classification.

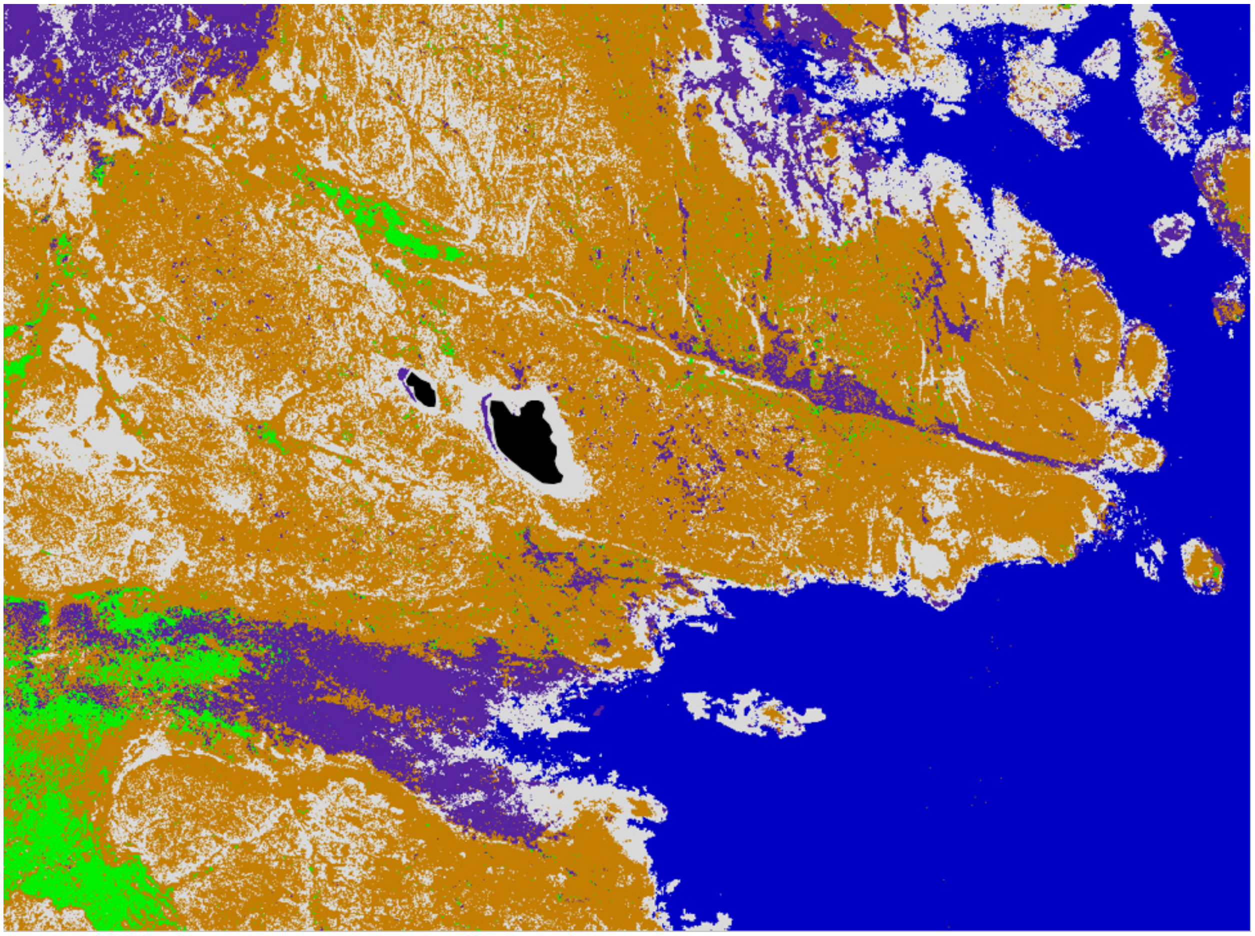


Figure 3.5.1.5. Site 19 feature extraction results of water (blue), non-vegetated (grey), seagrass (green), kelp (purple), and vegetated areas (brown).
The terrestrial vegetation was masked (black) on the two islands in the image.

3.5.2 **High-resolution imagery of sites and study area collected at low tide**

In addition to elevational data, high-resolution imagery (pixel size of 9 to 12 cm) was collected during low tide for much of the study area using fixed-wing aircraft and survey-grade GPS that were deployed during intertidal surveys. In contrast, the previous best available imagery had resolution of between 0.5 m and 1 m, and much of this imagery was not collected at low tide. This imagery has been acquired for all sites except Site BB1 and the southwest portion of Douglas Reef (transects DR_TR13-DR_TR15, DR_TR18, DR W, and DR 84).

Comparisons of UAS imagery at different scales enables one to distinguish readily the differences between the two types of data (Figure 3.5.2.1).

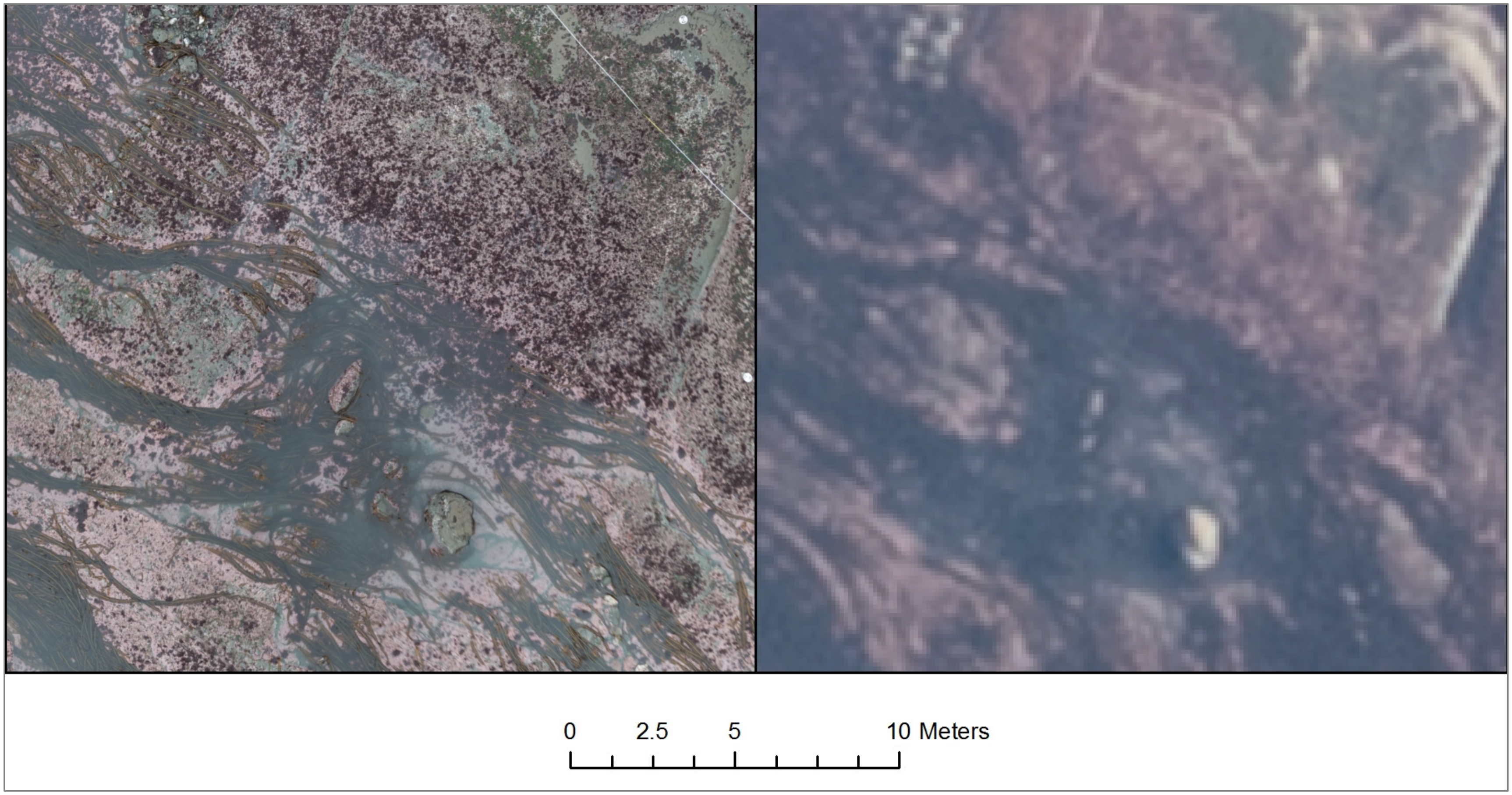


Figure 3.5.2.1. UAS imagery (left) juxtaposed next to fixed-wing SfM imagery (right) on Site 4, Pomeroy Island.
Images are of the same area and demonstrate the high-definition capabilities of UAS imagery. The image on the left has sub-cm pixel resolution while the image on the right has 12cm pixel resolution. These images were taken 4 weeks apart and the site experienced some visible changes in algal cover during that time.

UAS used as a platform is effective at collecting high-resolution imagery at an extremely small scale; however, the current available platforms have limitations in extent that can be collected during a tidal cycle. In addition, the existing platforms are subject to blurry images in gusting conditions and have difficulty maintaining tracks in windy conditions. It is also important to recognize the UAS platform has difficulty maintaining spacing and speed when transiting different directions in windy conditions. This leads to blurry images, and overlap constraints required for DEM derivation from photogrammetric techniques.

4 Discussion

This section includes recommendations for a long-term monitoring program (e.g., habitats, sites, and methods) based on our sampling design, quadrat sampling methods, intertidal and subtidal data, and habitat modeling tests.

Also discussed are spatial and temporal trends and interpretations in the context of known physical parameters – such as known circulations patterns, Cook Inlet suspended sediment data by north-south gradient, ice scour, freshwater, etc. These data do not exist for each individual site, but a knowledge of general physical differences within the study area was used to inform recommendations for future sampling and added measurements.

Included is a discussion of the unique reef habitats and their potential importance in the area as habitat. The value of high-resolution digital elevation models and imagery for developing habitat models for sites and the larger study area SfM data (and even old Landsat imagery) will provide great information on some of the major assemblages compared to what was seen on the ground, especially for eelgrass.

4.1 Subtidal

Interannual differences in macroalgal and invertebrate assemblages at each site were very large based on assemblage ordinations and the significant year x site interaction term in all analyses. This makes reliable site characterization based on a single year of sampling difficult despite the site-specific prominence of some taxa at certain sites. The results and interannual sampling frequency analyses conducted here suggest that because of the high interannual variability, sampling a site more than once may be beneficial in providing a more reliable characterization of a site. It seems that three years of sampling provided a good assessment in most cases, while four years changed this characterization only marginally. For sites that had high variability among the quadrats in one year, increasing the sampling intensity (i.e., sampling more quadrats) may assist in decreasing within site variability. Optimally, future subtidal sampling to monitor western Cook Inlet should include several years of repetitive sampling at the same sites, even if these years are not consecutive, and include more quadrats sampled per site in any given year. By sampling both in multiple years and increasing sampling effort, the amount of within-year versus among-year variability could be better determined.

There were moderate differences in algal assemblages along the western Cook Inlet side, mostly with a peak in diversity at inner Kamishak Bay sites, but less so for invertebrate assemblages. Some of the sites within Kamishak Bay (S_3A, S_2, S_19S) shared some similar species assemblages, especially among the macroalgae, such as a prominence of *Constantinea* spp. Sites farther north (S_GI) and south (S_DP) were more distinct, although these groupings were less obvious for the invertebrate assemblage. For impact assessment, choosing sites that span the latitudinal extent of the current study would, therefore, be important, although a subset of sites within Kamishak Bay could be chosen if the number of sites were a limitation for future work. Within Kamishak Bay, a site that would be suggested to be discontinued is S_NI2, which was among the more variable sites with relatively low diversity and low biomass. Even for practical reasons such as exposure to inclement weather, this site may be among the less suitable for future impact assessments.

Biological drivers may be playing a role in structuring western Cook Inlet communities. Sea otters are known keystone predators in coastal subtidal systems in Alaska and have been shown to control both macroalgal and invertebrate communities through their strong top-down role. Sea otters are currently very abundant in Cook Inlet. A recent survey in western lower Cook Inlet (southwest Alaska stock) estimated 10,737 (SE = 2,323) sea otters (Garlich-Miller et al. 2018). During this survey, sea otters were not uniformly distributed across western lower Cook Inlet. The highest sea otter densities (up to 8 sea otter/km^2) occurred within Kamishak Bay to the west and north of Augustine Island. Sea otter densities were relatively low north of Kamishak Bay Inlet (Garlich-Miller et al. 2018). Since sea otters are abundant in this region and are known to control community structure, any changes to sea otter populations could be used as a biological indicator to initiate a re-survey of the western Lower Cook Inlet subtidal benthic communities. This suggests that biological factors such as abundance and distribution of key predators should be taken into account when interpreting the characteristics and potential changes in shallow subtidal community composition.

Environmental conditions are known to influence coastal benthic communities both on long-term time scales, influencing site-specific community structure, as well as shorter-term, driving changes in communities. We were unable to obtain reliable environmental records for the study sites during this project but a future goal should be to obtain temperature and salinity records at selected study sites. For this study, we tried to use anchors into the sand/cobble substrate to secure temperature data-loggers at some selected sites. Most loggers could not be retrieved the following year, likely because of the strong exposure to inclement weather of these sites. In the future, we suggest finding large rocks and drilling anchors into the rocks to better secure the loggers. This has been successfully done in the Gulf Watch Alaska program in the intertidal and could be done subtidally (using an underwater drill). Understanding the role that environmental drivers play in shaping the subtidal communities would be useful to be able to separate environmental impacts from others, e.g., anthropogenic influences from oil and gas development. Sampling in this study coincided with the occurrence of an unprecedented warming anomaly in the Gulf of Alaska, also referred to as the “blob”. Warmer waters by 2-3 °C above normal have been linked to a number of biological responses across all ecosystem components, from plankton to whales. It is possible that waters in western Cook Inlet also experienced warming, influencing shallow subtidal communities. This could lead to greater homogenization of these communities across sites, possibly linked to external effects like temperature increases. Similarly, macroalgal biomass seemed to decrease at most sites in the later study years, which could be tied to the same change in temperature. Establishing environmental records for select study sites in western Cook Inlet could help provide more solid correlations for such effects.

One of the effects that has been suggested to be linked to the warming waters in the Gulf of Alaska is the outbreak in sea star wasting disease, as evidenced by results from the Gulf Watch Alaska program. Sea stars have practically disappeared in Prince William Sound, Kenai Fjords, Kachemak Bay, and Katmai National Park and Preserve between 2014 and 2016 (Konar et al. 2019). In contrast, we observed sea stars in western Cook Inlet during these same study years, particularly at the most northern site S_GI. However, at the most southern site, S_DP, we did observe a decline is sea stars when comparing 2016 to 2017 and 2018. Whether this was a true decline or simply site variability cannot be confirmed without additional sampling years. While the warm temperatures in the northern Gulf of Alaska could have contributed to a lessening of differences in subtidal site characteristics, the generally colder conditions that place western Cook Inlet biogeographically in the subpolar Beringian Province rather than the Aleutian Province (Foster et al. 2010), could have contributed to this region being a refuge for sea stars in the northern Gulf of Alaska. Both the isolation as well as its potential as a refuge emphasize the ecological importance of western Cook Inlet for the overall Gulf of Alaska marine ecosystem and the need to monitor this system in a time of climatic and anthropogenic changes.

The subtidal sampling design included several satellite sites around the main study sites to increase data coverage in the sub regions of the overall western Cook Inlet study area. There was little cohesion among main and respective satellite sites, suggesting that there are little actual regional differences but more site specific differences. Regional differences could have been assumed because of the effects that stronger tidal currents and greater influence of glacial meltwater and river drainage in more northern regions may have on subtidal communities. While we did not detect distinct regions, subtidal communities varied somewhat along the latitudinal extent of the study area. Unsurprisingly, the percent-cover data produced community descriptions that were distinct from those obtained with biomass collections. While biomass collections capture even small and inconspicuous species, the percent-cover data capture major taxa and also the amount of bare substrate. This is an important measure that can serve as an indicator of disturbance in a system or if competitive interactions among sessile species are a structuring factor in these communities. Hence, collecting both biomass and percent cover at a site is important and is recommended to be continued for any future subtidal monitoring. In addition, the efficiency of the percent-cover data collection makes it a very useful addition to the biomass collections. However, the value of additional satellite sites is questionable, and a better strategy might be to sample additional sites with both biomass and percent cover. Our current data indicate that there may not be distinct regions, but a general north-south gradient in at least some community elements was detected. It might be useful to add more sites to this gradient for future monitoring.

4.2 Intertidal

4.2.1 Long-term Monitoring, Habitat and Integration

The west side of Cook Inlet is a “gap” for long-term monitoring; other areas of Cook Inlet such as inner and outer Kachemak Bay currently have, and historically had, monitoring programs such as the Natural Geography in Shore Areas (NaGISA) project that documented latitudinal and longitudinal biodiversity gradients in nearshore habitats and how they change over time. The Gulf Watch Alaska program currently operating from Prince William Sound to the Shelikof Strait includes annual long-term (decadal scale) monitoring of nearshore areas, including rocky habitats. Given the gaps in data for rocky habitats on the west side of Cook Inlet, the uniqueness of these habitats, their importance to nearshore fish (e.g. spawning herring) and other organisms, and risks from upstream and adjacent oil industry activities, this work focused on these lower Cook Inlet nearshore areas.

The methods used to select sites ensured that this assessment program incorporated a statistically representative range of rock to mixed-rocky intertidal substrates (from 100% immobile bedrock to mixed gravel and boulder/cobble) in the study area. Although the sites were randomly chosen with all potential sites grouped as a single strata, future long-term monitoring should consider a site selection criteria to be inclusive of substrate type, exposure, and/or other physical characteristic combinations.

The site selection process used in this study included more sites on outer coastlines because those sites dominated the overall targeted habitats. The results appear to demonstrate that the more-protected coastlines support greater biodiversity than the more exposed rocky coastal sites. Complicating this was that although all sites had ample hard substrate for attached macroflora and mobile macrofauna, they differed in the amount of interstices, crevices, and general rugosity associated with providing sheltering habitat. Differences among sites appeared related to both physical exposure to wave action and substrate type, but there were not enough sites to state conclusively that substrate differences drove species richness. The inclusion of a classification system for site characteristic data is important for sampling efforts.

This study focused on sampling across the entire tidal range, capturing high to low intertidal habitats, with low slope mid-intertidal rock ramps and reefs dominating the sampling sites. Current broad scale Gulf of Alaska and North Pacific rocky intertidal monitoring focuses on specific elevations within the intertidal. By modifying the sampling approach from those more broadly in use, major portions of the vertical habitat were able to be sampled in this assessment. While the assessment was unable to identify high priority monitoring considerations in the upper intertidal — since it is a highly mobile substrate (e.g. sand beach face) or is relatively bare (likely from ice scour and winter freezing conditions) — the same is not true for the more biodiverse lower intertidal. There are numerous species occurring in the lower intertidal that are important components of the ecosystem (e.g. herring spawn). This is relevant when considering other intertidal monitoring efforts in the western Gulf of Alaska. While not explicitly a part of this assessment, a quick comparison to data from other coastal monitoring areas in western Gulf of Alaska shows this study captures more species of kelp because we include sampling below MLLW, as well as subtidal sampling, which other monitoring programs do not. Thus, the importance of having a broader elevational range beyond the standard used in wide-scale regional sampling in lower Cook Inlet, particularly mid and lower intertidal components, is an important element of long-term monitoring.

This assessment demonstrated that both photo quadrats and point counts have value in a monitoring program, particularly when combined together. One of the biggest differences between the two methods was that point-contact data collections are enhanced by the sampler's ability to feel textures and look at additional specimens outside of the quadrat frame. This increases the accuracy and resolution of the data collected. Typically, on-site identifications can be made to lower taxonomic levels than identifications made through photo interpretations. Another major difference is that photographs only provide information on organisms visible in the photo, meaning organisms underneath other organisms are not visible and would not be recorded during photo-interpretation. Point-contact methods allow for a more thorough data record by sampling through all layers. Kelps typically overlay other algae and invertebrates and show up as the top layer in photographs and match fairly closely with point-count percent cover;

however, kelp cover was still under-represented in photo-quadrat data due to kelp that might overlay a different kelp species within a quadrat. Mid-story and under-story seaweeds such as the filamentous and bladed red algae that dominate much of the study area (e.g. the filamentous *Pterosiphonia bipinnata* and *Neorhodomela aculeata* and the bladed *Palmaria* spp.) are somewhat under-represented by photo-quadrat methods. Understory species such as coralline red algae are not captured well by photo-quadrat methods. These comparisons highlight the value of point-count quadrat methods as a more accurate reflection of both two-dimensional and three-dimensional cover of intertidal communities.

The 2015 field season was the first application of the photo methods, and it produced the lowest quality photos of all the years due to the absence of standardization and other refinements (common camera models, etc.) employed in later years. Thus, the 2015 photo-interpretation samples have the highest chance of allowing for identification to species as well as allowing identification to higher taxonomic levels, leading to a 'falsely' inflated total richness under the liberal assumptions used (when all taxonomic levels were used in richness calculations). This may explain why the 2015 photo-quadrats show the highest epibiota richness among the multiple years of sampling for Iliamna, Pomeroy Island, and Augustine Island. One of the benefits of photo-quadrat methods, however, is that a larger number of quadrats can be collected within a low-tide sampling window. For intertidal organisms with patchy distributions within a site, an increased sample size through photo-quadrat collections increases the likelihood that additional species would be detected. In 2015 at Site 2, the increased mobile invertebrates reported for photo quadrats was due to the increased sampling size (when including all photo quadrats) and the associated increased change of encountering additional species.

The increased sample size of photo-quadrats did not compensate, though, for the ability to look under the layers of macroalgae or the ability to identify organisms on-site. While mobile invertebrates account for relatively fewer taxon compared to the number of macroalgae taxon, they can be abundant and potentially exert substantial grazing pressure and/or structuring influences on macroalgal assemblages.

Ultimately, there were only small differences between photo-quadrat data and point-count data species richness when comparing number of taxa. This is due to the greater number of photo quadrats that can be taken at a site versus collecting only point-count data. Incorporating photo-quadrat percent cover data in habitat classification of aerial based imagery is particularly valuable because only surface communities would be identified. Quantification of three-dimensional composition of all species within a quadrat is not possible using a photo-quadrat methodology, which yields only surface percent cover on a site (e.g. occupied vs. unoccupied surface space). There is high value in placing personnel with biological and taxonomic expertise on the ground in a sampling effort to identify species external to quadrats through targeted identification efforts. When these data are included it is possible to capture a more complete picture of site species richness than quadrat information of either type yields.

Looking at intertidal community assemblages, the results of data analysis showed most sites were more similar within site over years than they were to other sites. There was also a geographical distribution of algal community similarities. Southerly sites were more similar to each other than they were to the northerly sites, with the dividing line being the Iniskin Peninsula. In addition, the more southerly sites varied less across years than the more northerly sites which were not similar spatially (compared to each other), temporally (same site across years), or geographically (compared to southern sites). Thus, geographical strata may be important in considering future monitoring. However, temporal differences can only be addressed through long-term monitoring, and because this assessment was not a long-term monitoring program, limited statistical analyses could be made for temporal variability.

By analyzing community assemblages for entire sites, the differences in community assemblages at various tidal heights among sites may be obscured. Most sites in the study had a steeper beach face in the high intertidal zone with a lower angle ramp in the middle intertidal zones. Several also had a shorter, steeper intertidal zone between MLLW and the lowest tide during sampling. Ordinations of multi-species data benefited by "binning" data into vertical tidal heights and accurate tidal elevation data associated with quadrat data is an important component of intertidal monitoring on the wide rocky habitats in the lower Inlet.

There was more overlap in species assemblages among intertidal sites than subtidal sites; subtidal assemblages were less homogenous than intertidal sites. A simple explanation may be because sites were selected based on intertidal habitat data and not subtidal data, so subtidal sites may represent a different subset of habitats. Another consideration is that at intertidal sites, even at the same tidal height, the quadrats closer to shore might experience less "net" energy caused by wave energy dissipating over a reef that extends shoreward beyond the quadrat. This would lead to more stable conditions for intertidal species assemblages to develop. It is also possible that intertidal ice scouring could lead to intertidal species assemblages being in a more regular "regeneration" phase while subtidal habitats may have had more time to mature into an "old growth" phase more representative of localized environmental conditions.

4.2.2 **Seasonality and Temporal Scale**

This assessment was limited in its ability to discuss seasonality on rocky nearshore habitats in western lower Cook Inlet. However, it was possible to identify seasonal differences based on limited imagery collections a month apart at a few sites. Phenological changes to macroalgal communities are an important consideration when trying to establish long-term monitoring involving macroalgal assemblages. Senescence and growth in this region vary by species and will notably affect the results of photo-based assessments regardless of a terrestrial or aerial platform. However, annual sampling has provided valueblae data in other long-term monitoring programs. The Gulf Watch Alaska Program samples once per year using ground-based expertise, with sampling occurring at the same time of year in each region. The nearshore component of GWA has been able to detect changes in coastal biological communities at a variety of spatial scales with annual sampling (Bodkin et al. 2017; Coletti et al. 2016, 2018 and 2019; Konar et al. 2016 and 2019). Although the lower western Cook Inlet rocky habits differ from most rocky habitats across the entire GWA program, the monitoring approach used in this study will capture annual patterns if sampling occurs consistently across time.

Additional limitations were specifically related to temporal assessments. There was a limited number of years over which this study was conducted, and long-term monitoring by necessity covers a much larger temporal scale. Individual studies covering short temporal scales can be highly influenced by transient environmental conditions. This sampling study was initiated during the middle of the first North Pacific long-term high sea surface temperature anomaly (the

“Blob”). No pre-anomaly data was included in this study. However, this study was of sufficient length that sampling also included post-anomaly years, and for the few sites that span 2015 – 2018 there were no substantial shifts with time within site. However, a long-term monitoring program would allow monitoring across time and correlate observations to environmental drivers.

4.2.3 **Physical Data**

Environmental drivers, particularly oceanographic conditions, are particularly relevant for intertidal assemblages. Because this study was focused on biological assemblage change over time, and not on environmental correlates, the efforts that were placed in collecting physical data were not sufficient to fully understand the broader environmental conditions over time at the individual sites. While there is some broad scale knowledge of the environmental conditions, there are limited long-term physical data collections in the region. Satellite data, while useful, is infrequent, and often not at the appropriate scale for physical assessment of the nearshore.

However, even with limitations, it was possible to show that western lower Cook Inlet sites differed from other rocky coastal habitats in the western Gulf of Alaska and arguably, anywhere in the world. Establishing a long-term monitoring program in the area could incorporate annual visits to a subset of assessment sites. Thus, any monitoring program using sites established from this study would automatically start with four years of data.

4.2.4 **Remote Sensing**

Photographic imagery is a particularly powerful tool in habitat assessments broadly speaking and would be extremely valuable in this region for intertidal habitat assessments. The ability to rapidly collect photographs considerably adds to the ability of a monitoring and assessment program to be able to document habitat changes with an established quality assurance plan and backup quality control measures. In addition, the incorporation of a high-resolution aerial-based platform allows for the collection of imagery over broad scale areas from which to make inferences for habitat mapping purposes. Manned aerial imagery collection is great for large-scale assessments, while unmanned aerial vehicles are valuable for extremely high-resolution data collection over smaller targeted site areas. While not incorporated until late in this assessment effort, these tools can be used in a long-term monitoring program to effectively integrate and correlate ground based sampling results with aerial imagery for habitat mapping purposes. While this program was only able to effectively get to Assessment level 4 of the habitat mapping design using aerial imagery, this was a noteworthy accomplishment considering that the assessment was not designed for aerial imagery based habitat mapping when initiated.

This study demonstrated the use of aerial photography and incorporation of SfM photogrammetry techniques to assess elevation and habitat that, with refinement, could potentially monitor dominant species assemblages or morphological categories of macro-algae and invertebrates across wide polygon areas of intertidal habitat that dominate lower western Cook Inlet, as well as geomorphological changes to soft sediments coastlines. However, future work should include a greater number of sites to capture variability across the entire area at risk. Based on our initial analyses and lessons learned from sampling, we developed a list of recommendations for moving forward.

4.3 Recommendations

The following recommendations apply to long-term monitoring in the rocky habitats of western lower Cook Inlet. Kachemak Bay Research Reserve (KBRR), the Alaska Department of Fish and Game, and Gulf Watch Alaska have existing intertidal and subtidal monitoring and research efforts in place in and around Kachemak Bay, on the eastern side of Cook Inlet. Therefore a decision was made to focus on the relatively understudied western Cook Inlet. The western region also supports subsistence and commercial endeavors as well as a growing tourist industry. As noted in Section 1.2, there are other habitat types within the area, but this study focused on the rocky intertidal areas of the region. Recognizing the importance of mixed sediment and soft sand beaches that support infaunal invertebrates it is recommended that BOEM consider assessments in these habitats as well.

Recommendations for a future monitoring program rely on the successful assessment sampling from 2015-2018 in lower western Cook Inlet. This nearshore assessment produced an extensive database of intertidal and shallow subtidal habitat information for an area at risk from potential oil development and production activities in the OCS Cook Inlet Planning Area. The data are unique in this area by incorporating invertebrate and algae abundance and diversity across the entire tidal range as opposed to only a few specific tidal heights as in prior studies. The focus of the nearshore assessments was on lower western Cook Inlet for several reasons: (1) the area is adjacent to the OCS Lease Sale 244 for the Cook Inlet Planning Area, (2) the area is "downstream" of existing and potential oil industry activities relative to the roughly "net" north to south movement of Cook Inlet's western boundary current, (3) the area contains wide rock ramp and reef habitats that have previously been poorly studied and yet are ubiquitous in the region, and (4) the area is important for higher trophic levels, such as providing habitat for spawning herring. Specific considerations are described below.

Through a statistical selection process, the study focused on filling data gaps for rocky habitats and identified an initial core set of 6 study sites sampled in 2015. During subsequent sampling years from 2015-2018, storm and residual waves precluded access to some sites during the limited sampling windows each year and, thus, alternate sites were added to the study. For example, sites were added within the more-protected waters of Bruin, Iniskin, and Iliamna bays in 2017 and 2018, when storm and residual waves precluded sampling at sites 2, 4, N1, and 3A on one or both field trips. The additional sites provide insight into a wider range of rocky habitats by including more substrate-exposure categories into the overall nearshore assessment.

4.3.1 Long-term Monitoring, Habitat, and Integration

Recommendation:

We recommend BOEM implement a monitoring program in lower Cook Inlet. With proposed development, documentation of the composition, distribution, and abundance of species over time is important not only to meet agency needs for compliance but also as a way for management agencies to document change with increasing power over time. A monitoring program in this area should take into consideration existing long-term monitoring programs to ensure trends occurring at Gulf-wide scales can be examined concurrently. The spatial scale in which trends vary may provide insight as to the driver of that change, whether it be local (e.g. localized contamination) or region wide (e.g. warming surface waters in the Gulf of Alaska). However, we recognize the uniqueness of the study area, which requires field methods be structured specific to the large, rocky reef systems present along the west side of lower Cook Inlet. Whether implementing existing, new or some combination of field methods, BOEM should consider funding decadal-scale long-term studies.

Justification:

There exists a precedence for BOEM to support long-term monitoring. BOEM currently supports efforts in other regions including the Arctic Marine Biodiversity Observing Network (AMBON), the Multi-Agency Rocky Intertidal Network (MARINe) and the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO). These partnerships include universities, federal and state agencies as well as private entities. Currently, in the Gulf of Alaska, the Exxon Valdez Oil Spill Trustee Council supports an on-going long-term monitoring program, Gulf Watch Alaska (GWA). GWA includes a nearshore component that examines various community trends across coastal habitats, including rocky intertidal, spanning the Gulf of Alaska.

Similarities and differences exist between these LTM programs. For this study, we implemented existing methods from site selection to field sampling protocols when feasible, but also paired sampling in some cases to make comparisons across different methods (random point contact vs. photo quadrat). As with GWA, a random site selection component was used in this study which allows for statistical inferences across similar habitats. This is a distinction from the MARINe program. Another distinction between this current study and MARINe is the frequency of sampling. Due to the remoteness of these sites, access is difficult and costly, therefore sampling has been completed on an annual basis. Sampling frequency for GWA is also annual, in most cases. We recommend annual sampling at a minimum. Annual sampling limits our ability to detect within year variation, but can detect changes across years. To facilitate comparisons between methods such as random point contact (RPC, a method employed by GWA) and photo quadrats (a method employed by MARINe), paired sampling was conducted. We have provided analyses that allow for the consideration of a paired sampling design.

Recommendation:

We recommend that a monitoring program continue to include rocky habitat in western lower Cook Inlet. Monitoring sites should include a range of rocky substrates, from 100% bedrock to mixed boulder and cobble in order to capture variations in hard, immobile substrate available for attached flora and fauna compared to highly rugose or partially mobile substrate that provides additional micro-habitats for other organisms.

Justification:

The study area is unique compared to many other areas of coastal Alaska in its combination of low-angle intertidal and shallow subtidal habitats, high tidal ranges, and winter shore-fast ice.

Our understanding of the natural patterns and recovery after disturbance in rocky habitats along other Gulf of Alaska rocky shorelines may not apply to the study area, and area-specific monitoring of temporal and spatial trends is recommended to detect potential impacts from activities within the OCS Cook Inlet Planning Area. Natural cyclical patterns, patchiness, sensitivity to and recovery from disturbance, and response to changing oceanographic conditions may differ from what is seen in other rocky areas of Gulf of Alaska, such as the Kenai Fjords, Katmai coast, Prince William Sound, and Kachemak Bay study areas of the Gulf Watch Alaska program.

Furthermore, it is prudent to ensure that a monitoring program include both outer coast and protected rocky habitats. Given that spilled oil can migrate into protected areas, it is important to consider monitoring areas with less wave energy. To remove oil from low-energy beaches and their crevices and interstices where oil may strand is difficult. With stranded oil potentially leading to long-term contamination stress to the biology of the system, monitoring sites in these habitats is potentially valuable.

The OCS Cook Inlet Planning Area is only one of two areas in BOEM's current Alaska lease sale plans, with continued interest by industry after the successful purchase of leases during Lease Sale 244. For this reason, a focus should be on long-term monitoring of the rocky sites for this study. Rocky habitat is a major emphasis of the GWA program for other rocky areas of the western Gulf of Alaska. The GWA program encompasses multiple sampling methods to account for differences among their study region, as well as to ensure continuity with prior sampling in specific areas. Similarly, monitoring in the BOEM study area should incorporate the sampling methods used for the BOEM lower Cook Inlet habitat assessment to provide continuity and to extend the temporal timeline of any future monitoring data set.

The sites sampled during the assessment program showed variability among sites, so a monitoring program should include sites that represent a geographical range, as well as combinations of substrate, exposure, and other physical characteristics. Because the assessment program focused on sampling multiple times at each site (from 2 to 4 visits to each site during the four-year sampling program), a limited number of sites were sampled.

Recommendation:

We recommend BOEM utilize an existing data sharing structure similar to GWA to facilitate the public dissemination of data.

Justification:

GWA has been successful in creating a structure for data management and dissemination. A BOEM-supported long-term monitoring (LTM) program could integrate with GWA in terms of data sharing and publishing. This would allow for consistent and streamlined public access of data. Data sharing also allows for across-program collaboration to examine trends in biological communities over space and time. GWA as well as AMBON have partnered with the Alaska Ocean Observing System (AOOS) to act as the central data node for access.

4.3.2 **Physical Data**

Recommendation:

We recommend that detailed physical data be collected during a monitoring program, including substrate rugosity and oceanographic conditions including temperature, salinity, currents, suspended sediments, and ice. Temperature loggers ought to be deployed along rocky shorelines using methods currently employed by Gulf Watch Alaska, preferably in close proximity to sampling sites.

Justification:

Some of these data exist broadly in the area, but it is important to obtain finer resolution oceanographic data at or near the surveyed sites (i.e. temperature and salinity). Broad scale models are not a fine enough resolution to understand the dynamic interactions at the scale necessary for integrated interpretation of data. In the Gulf of Alaska, changing offshore temperatures due to the 2014-2017 marine heatwave ("Blob") were reflected in observed broad ecosystem changes (Coletti et al. 2019). Some temperature loggers were deployed for this study in soft sediment in the low intertidal and shallow subtidal, anchored by sediment screws. Many were not recovered, likely due to the effects of ice scour.

Successful retrieval of loggers might also be improved for the collection of data for at least part of the year if loggers were deployed over the summer months and collected and replaced in the fall. Regardless of how successful the over-wintering data collections were, the summer collections would provide a finer-scale understanding of temperatures and salinities throughout the study than are available now. By comparing data collected over the summer months to that collected during the same time period by the GWA program further offshore, potential extrapolation of the GWA winter data to nearshore environments might be possible.

Recommendation:

We recommend that BOEM acquires high-resolution intertidal topographic maps of lower Cook Inlet.

Justification:

Much of western lower Cook Inlet has large portions of the intertidal zone with extremely low slope topography ≤ 1% and overall topographic relief of ≤2%. This low topographic relief can lead to horizontal water line location errors of ≥ 11.45 m (38 ft) for every 20 cm (0.66 ft) of tidal height. The accuracy of the highest-resolution existing topographic elevational maps, developed through IfSAR, is approximately 1.85 m (6.07 ft). For an intertidal zone like a reef or mud flat with a slope of 1 degree, a 1.85 m vertical uncertainty creates a potential horizontal water line location error of 106 meters (348 ft). DEMs produced from SfM often contain a downward vertical shift of uncertain magnitude, and require ground control to correct for the approximately 0.5 m (1.64 ft) uncertainty. Ground control was collected with the SfM effort in several places to address this challenge at our site locations, bringing the elevational accuracy to ~±20 cm.

However, there are additional areas that were not surveyed, and need additional work. The most important reason for high accuracy elevation information is to understand oil stranding potential and habitat exposure to stranding during the high tidal inundation cycles present within Cook Inlet. This information would be particularly relevant to an unintentional oil release of substantial enough quantity to impact coastal habitats from a lease sale site or operations.

Recommendation:

We recommend BOEM support the installation of public tidal gauges in the region. Public Tidal datums from the area are critical to understanding the biology in relation to tidal exposure. These will be important data in a long-term monitoring program.

Justification:

Western lower Cook Inlet is a noted NOAA National Water Level Observation Network (NWLON) gap (multiple functional areas), and lacks tidal datums throughout the region. Without tidal datums it is impossible to know where the surveyed ellipsoid or orthometric heights are relative to MSL, MLLW, MHW or any other portion of a tidal datum. The conversion table from orthometric to MLLW datum at each site (Table 2.3.1) is unofficial and should not be used as anything other than an estimate of MLLW relative to orthometric 0 elevation at each of this project's intertidal sites. Table 2.3.1 suggests that the offset between orthometric 0 elevation and MLLW may vary by over 0.5 m across the study area. The calculated standard deviation of the difference between orthometric and MLLW for the intertidal sites is 15 cm.

4.3.3 Seasonality

Recommendation:

We recommend that timing of field surveys should be kept as consistent as possible. We recommend the low tide series that occur in late May to early June annually.

Justification:

Algal phenology greatly impacts the capacity for assessing intertidal and subtidal species richness and abundance since annual cycles of growth and senescence vary between alga species. For instance, by late summer the growth of red alga species dominate the intertidal zone causing the sampling of other species to become difficult, especially for photo-quadrat sampling or habitat analysis of aerial imagery. This seasonal variability was seen within the assessment program when UAS-based SfM imagery captured in May 2018 was compared to manned aircraft SfM imagery of the same area captured four weeks later. The intervening time between images represented a growth period for kelp which was evident in the later set of imagery. Percent-cover data between the two images, if analyzed, would vary substantially.

Annual variation in environmental conditions such as water temperature and air temperature can impact the phenology of alga species. Tracking these phenological shifts requires temporal comparison of richness and abundance between years, which is only appropriate if sample timing is consistent across years for the duration of the long-term monitoring program. However, due to logistical considerations and the timing of low-tide windows, it may be necessary for site sampling to vary by several weeks between years.

4.3.4 Remote Sensing

Recommendation:

We recommend the use of aerial photography to assess broad-scale changes in habitats over time.

Justification:

Aerial imagery collected in a systematic way in conjunction with in-flight survey-grade GPS is a relatively inexpensive but highly accurate way to provide large scale data collection on habitat change. This data can be particularly relevant to soft sediment coastal geomorphological changes. The vertical resolution of a surface model is approximately twice that of the pixel size of the aerial images used to create the elevation model. Thus, if aerial images with 10 cm pixels are acquired, the resulting elevation model may be precise to 20 cm.

Satellite data is not as reliably available as planned fixed-wing-based aerial acquisitions due to time constraints. These include the need to collect images during crucial early-summer low-tide windows, increased effects of high cloud cover on satellites relative to fixed-wing aircraft, and timing of low tide relative to fixed satellite orbits. Satellite imagery is also lower-resolution as compared with 10-15 cm aerial photography, although sub-meter satellite imagery collected at low tide could be a useful tool in habitat classification.

Use of remotely sensed images to thematically map habitat depends upon field design. To successfully classify the imagery into habitat types, future field surveys should be timed closely to aerial image acquisition. Ideally the acquisitions should happen in the same low-tide cycle. Based upon 2018 results at Site 4, a 4-week time difference is too great. A difference of one tide cycle between a field survey and aerial image acquisition may prove to be acceptable. The quadrats sampled in this project were collected according to the project's protocol to sample intertidal biota, and were not collected in a manner ideal for use in providing training data to a supervised vegetation classification process. For future survey efforts focused on habitat mapping, field biologists should refer to established protocols for collecting training and validation data for habitat classification workflows. At a minimum, mapping-grade or survey-grade GPS will need to be used to delineate multiple areas of relatively homogenous vegetation for each ground cover class. Referencing the best available imagery in the study area while in the planning phase will help determine the ground cover classes to be surveyed in the field.

4.3.5 Taxonomic Expertise

Recommendation:

Field sampling teams should continue to include coastal ecology experts who have extensive experience in coastal Alaska, preferably with experience in Cook Inlet, and who are trained in identifying intertidal invertebrates and algae.

Justification:

Our data indicates the value of knowing species richness on sites and, in combination with quantitative data, diversity measures at each location can be invaluable to a monitoring program. From a biological point of view the morphologies of many species are highly unique in western lower Cook Inlet. Western lower Cook Inlet produces challenges of identifying species because their morphologies differ greatly from standard morphologies making taxonomic expertise critical in this area.

Additional field personnel can be non-experts who work closely with the coastal ecologists to conduct many of the field tasks, such as collecting photo quadrats and site photos, recording data, collecting, pressing, and preserving voucher specimens, data entry, collecting physical data, field gear maintenance, and learning taxonomic species identifications for future field work.

4.3.6 **Sampling Design**

Recommendation:

Monitoring of rocky habitats should include sampling across all tidal heights.

Justification:

Most intertidal rocky habitat monitoring programs focus on a limited number of tidal heights, replicating sampling quadrats along shore-line parallel transects. However, those methods could potentially miss large swaths of habitat across the extensive intertidal polygons found in the study area. While continuing to sample along vertical transects, future discussions could consider incorporating limited horizontal transects to assess variability and compare to studies conducted by other entities in the study area. If considered, at least one horizontal transect should be placed below MLLW (e.g. at -1m) and one at a tidal height corresponding to the GWA program (e.g. at +0.5 m).

With detailed RTK and SfM data now available for most of the shorelines in the study area, pre-stratification could take place to ensure replication within strata on each site to capture the variability of community assemblages across the entire tidal range.

For rocky habitat in the western lower Cook Inlet area, it is not recommended that “permanent” quadrats be established. Based on experiences with other monitoring programs, considerable time can be lost on-site searching for quadrat markers. It is expected that this would be worse where quadrats are spaced further apart, as they are across the expansive rocky habitat in the study area and where ice scour and boulder movement could compromise quadrat markers.

Recommendation:

Monitoring should continue to incorporate both photo and point-count quadrats.

Justification:

RPC quadrats require more time on-site, but provide detailed species lists and quantify organisms throughout over- and under-story layers, as opposed to photo quadrats. However, photo-quadrat methods allow the collection of a higher number of quadrats quickly while on-site. Also, photo quadrats can be collected by less experienced field personnel, potentially increasing opportunistic sampling at more sites. Photo quadrats require substantial post-field processing that can take a lot of time and funding to complete and a two-tiered approach to analyzing photo quadrats could include (1) interpretation of the imagery by a non-expert at high taxonomic levels or morphological categories and (2) assessment by taxonomic experts following major changes shown by (1) or in the event of an oil spill. In this way, the photographs would support analyses of easily identifiable categories, with some at species level (e.g. *Fucus distichus*), but most at lumped higher categories such as kelps, corallines, bladed reds, filamentous reds, filamentous greens, bladed greens, and so on. The high-resolution photographs would provide a mechanism for archiving detailed species-level information by allowing experts to subsequently view them over time or in the event of a disturbance to the area. To be effective, detailed methods for collecting photo quadrats must be prepared, ensuring the highest possible image resolution. Site photography should always include a specific list of general site photographs that would provide context for the more detailed quadrat-level photographs.

4.3.7 **Sampling Locations**

Recommendation:

Monitoring sites should include a range of rocky substrates, from 100% bedrock to mixed boulder and cobble in order to capture variations in hard, immobile substrate available for attached flora and fauna compared to highly rugose or partially mobile substrate that provides additional micro-habitats for other organisms.

Justification:

The sites sampled during the assessment program showed variability among sites, so a monitoring program should include sites that represent a geographical range, as well as combinations of substrate, exposure, and other physical characteristics while concurrently allowing for replication. Because the assessment program focused on sampling each site over multiple years (from 2 to 4 visits to each site during the four-year sampling program), a limited number of sites was sampled.

Recommendation:

A future monitoring program should continue repeated sampling at the assessment sites – taking into consideration recommendations below – while also extending the number of different sites to capture information along physical gradients.

Justification:

Data collected at each site over multiple years will allow comparisons to changing ocean conditions and to potential disturbances from future lease sale activities.

In anticipation of funding and logistical limitations for a long-term monitoring program, we recommend a combination of repeated sampling at a few sites, rotating repeated sampling at the other assessment sites, and one-time sampling at new sites. For example, sites 19, 3A, and SI - representing a range of substrates, exposure, and geographic range – could take place each year to provide fine-scale temporal trends that can be compared to changing oceanographic conditions or disturbances, and could capture cyclical patterns. A rotating schedule of the other assessment sites could include sampling at one or two sites per year, which would allow some measure of temporal changes that might correlate with longer-term changes in physical conditions, but might miss year-to-year variability. One-time sampling of one to three additional sites each year would expand the geographic coverage to capture the range of existing rocky habitat in the study area.

The multivariate data analyses showed several sites that were very similar to each other, including sites 19 and N1 and sites BB1 and 2. A long-term monitoring program could consider removing one of each of these pairs. If so, given that site 19 has 4 years of data collections from 2015-2018, we recommend retaining that site and dropping site N1. The percent cover and richness data show low richness and cover at sites 6 and 10 in the northern study area, and for intertidal sampling this portion of the study area could be given lower priority – especially since it is “upstream” of net currents relative to the lease sale area in lower Cook Inlet.

4.4 Other Considerations

If an understanding of seasonal phenological change by site is desired, additional sampling could be done at select sites to look at differences between seasons. One option would be to acquire on-the-ground sampling data using consistent subtidal or intertidal methods. Another option would be to conduct periodic SfM surveys in conjunction with ground-truthing surveys to acquire classification training and validation data for habitat mapping (see section 4.3.4). Although these options would not be part of a long-term monitoring plan, it could be useful to assess and understand effects of an oil spill on algal communities in different seasons.

There is a considerable lack of benthic habitat data regarding extent and distribution of marine species. Nearshore benthic habitat mapping is required to understand the distribution and extent of marine habitat types serving as nursery grounds and foraging grounds for coastal marine species of the region. The results identified in this report indicated intertidal macroalgal species were surprisingly different from those of the subtidal communities in variability and distribution. Reference conditions from which to base change detection – an essential aspect of monitoring – is an important consideration given the current limited information on subtidal benthic habitat extent and distribution in the area. Additional benthic subtidal marine flora distribution information is critical when considering changes in habitat for fishes and other important marine species of the region. Therefore, while not directly related to the implementation of a long-term monitoring program, it is an important consideration for future work that would be necessary in understanding both natural changes to the nearshore coastal habitats and the potential for oil and gas leases to impact those same environs.

In addition to benthic habitat sampling, a detailed oceanographic study should be conducted at the initiation of a long-term monitoring program to better characterize the nearshore area's currents, suspended sediments, and ice.

Higher-resolution oceanographic data (compared to offshore data currently collected by other entities) might capture differences between exposed oceanic sites and more-protected sites inside of bays and along the SW to NE Cook Inlet axis. The nearshore data would be interpreted in the context of oceanographic data collected for the rest of Cook Inlet during the "environmental drivers" component of the Gulf Watch Alaska program. A towed ADCP designed for shallow, nearshore waters could be deployed to identify gross differences in tidal currents for each site.

Another gradient observed in Cook Inlet is winter ice cover. Though the highest concentrations in winter are typically observed in the upper Inlet as mobile, broken ice, nearshore (and even landfast) ice is reported highest in the very southern portion of Kamishak Bay. Ice gouge marks were still evident in summer months during the assessment program for portions of the Douglas River reef complex and some denuded patchy areas of other sites are suspected to be from winter ice. Periodic winter overflights from Homer to the study area during the coldest winter months could provide imagery to develop a localized "ice index" as a potential environmental driver explaining differences in species assemblages and cover among sites.

5 References

Alaska *ShoreZone* Program Partnership website (www.*ShoreZone*.org)

AlgaeBase (http://www.algaebase.org/)

Biblio R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Bodkin, J.L., H.A. Coletti, B.E. Ballachey, D. Monson, D. Esler, and T.A. Dean. 2017. Spatial and temporal variation in Pacific blue mussel, *Mytilus trossulus*, abundance in the northern Gulf of Alaska, 2006-2015. Deep Sea Research Part II: https://doi.org/10.1016/j.dsr2.2017.04.008Boehm, P.D. (editor). 2001. Sediment Quality in Depositional Areas of Shelikof Strait and Outermost Cook Inlet. OCS Study, MMS 2000-024. Submitted by Arthur D. Little, Inc., Cambridge, MA to Anchorage, AK: USDOI, MMS, Alaska OCS Region. 69 pp. http://www.boem.gov/BOEMNewsroom/Library/Publications/2000/2000_024.aspx.

Burbank, D.C., 1977. Circulation studies in Kachemak Bay and lower Cook Inlet, Vol III of Environmental Studies of Kachemak Bay and Lower Cook Inlet, ed. by L.L. Trasky, et.al. Marine Coastal Habitat Management Report, Alaska Dept. of Fish and Game, Anchorage, AK.

Clarke, K.R., Gorley, R.N., Somerfield, P.J., Warwick, R.M. (2014) Change in marine communities: an approach to statistical analysis and interpretation, 3nd edition. PRIMER-E: Plymouth.

Cochran, W.G. 1977. Sampling Techniques. 3rd Edition, John Wiley & Sons, New York.

Coletti, H., K. Iken, T. Jones, B. Konar, M. Lindeberg, S. Saupe and S. Venator. 2017. Evaluation of nearshore communities and habitats in lower Cook Inlet, Alaska. US Dept. of the Interior, Bureau of Ocean Energy Management, Anchorage, AK. OCS Study BOEM 2017-045. 48 pp.

Coletti, H., D. Esler, B. Konar, K. Iken, K. Kloecker, D. Monson, B. Weitzman, B. Ballachey, J. Bodkin, T. Dean, G. Esslinger, B. Robinson, and M. Lindeberg. 2019. Gulf Watch Alaska: Nearshore Ecosystems in the Gulf of Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 18120114-H), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Coletti, H., J. Bodkin, T. Dean, K. Iken, B. Konar, D. Monson, D. Esler, M. Lindeberg, R. Suryan. 2018 Intertidal Ecosystem Indicators in the Northern Gulf of Alaska *in* Zador, S. G., and E. M. Yasumiishi. 2018. Ecosystem Status Report 2018: Gulf of Alaska. Report to the

North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99301. https://www.fisheries.noaa.gov/resource/data/2018-status-gulf-alaska-ecosystem

Coletti, H. A., J. L. Bodkin, D. H. Monson, B. E. Ballachey, and T. A. Dean. 2016. Detecting and inferring cause of change in an Alaska nearshore marine ecosystem. Ecosphere 7(10):e01489. 10.1002/ecs2.1489.Danielson, S. L., K. S. Hedstrom, E. Curchitser, 2016. Cook Inlet Model Calculations, Final Report to Bureau of Ocean Energy Management, M14AC00014, OCS Study BOEM 2015---050, University of Alaska Fairbanks, Fairbanks, AK, 149 pp.

Dean, T. A., J. L. Bodkin, H.A. Coletti. 2014. Protocol narrative for marine nearshore ecosystem monitoring in the Gulf of Alaska: Version 1.1. Natural Resource Report NPS/SWAN/NRR—2014/756. National Park Service, Fort Collins, Colorado.

Dean, T.A. and J.L. Bodkin. 2006. Sampling protocol for the nearshore restoration and ecosystem monitoring (N-REM) program. Exxon Valdez Restoration Project //0750. Draft Final Report. Exxon Valdez Restoration Office, Anchorage, AK.

Douglas Bates, Martin Maechler, Ben Bolker, Steve Walker (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Foster NR, Lees D, Lindstrom SC, Saupe S. 2010. Evaluating a Potential Relict Arctic Invertebrate and Algal Community on the West Side of Cook Inlet. Coastal Marine Institute, Final Report OCS Study MMS 2010-005. University of Alaska Fairbanks, 79 pp.

Garlich-Miller J, Esslinger G, Weitzman B. 2018. Aerial surveys of sea otters (*Enhydra lutris*) in lower Cook Inlet Alaska, May 2017, Technical Report MMM 2018-01, Marine Mammals Management, Fish and Wildlife Service, Region 7 Alaska.

Irvine, G. 2001. Development of Coastal Monitoring Protocols and Process-Based Studies to Address Landscape-Scale Variation in Coastal Communities of Glacier Bay National Park and Preserve. USGS Final Annual Report. Anchorage, AK. 121 pp.

Konar B, Mitchell TJ, Iken K, Coletti H, Dean T, Esler D, Lindeberg M, Pister B, Weitzman B. 2019. Wasting disease and environmental variables drive sea star assemblages in the northern Gulf of Alaska. *Journal of Experimental Marine Biology and Ecology* 520. https://doi.org/10.1016/j.jembe.2019.151209

Konar, B., K. Iken, H. A. Coletti, D. H. Monson and B. P. Weitzman. 2016. Influence of static habitat attributes on local and regional intertidal community structure. Estuaries and Coasts 39: 1735. doi:10.1007/s12237-016-0114-0.

Krzanowski, W.J. 1993. Principles of Multivariate Analysis: a user's perspective. Oxford University Press, Oxford, England.

Lindeberg, M. R. and S. C. Lindstrom. 2015. Field Guide to Seaweeds of Alaska. Fairbanks, Alaska: Alaska Sea Grant College Program. University of Alaska Fairbanks. 188 p. ISBN 978-1-56612-156-9. doi.org/10.4027/fgsa.2010.

NOAA Fisheries Alaska *ShoreZone* Coastal Mapping and Imagery website (https://alaskafisheries.noaa.gov/mapping/szflex/)

Rigby R, Iken K, Shirayama, Y. 2007. Sampling biodiversity in coastal communities. Kyoto University Press. pp. 145

Shelden, K. E. W., D. J. Rugh, K. T. Goetz, C. L. Sims, L. Vate Brattström, J. A. Mocklin, B. A. Mahoney, B. K. Smith, and R. C. Hobbs. 2013. Aerial surveys of beluga whales, Delphinapterus leucas, in Cook Inlet, Alaska, June 2005 to 2012. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-263, 122 p.

The Seaweeds of Alaska website (http://www.seaweedsofalaska.com)

The World Register of Marine Species (http://www.marinespecies.org/index.php)

Zimmermann, M., and M. M. Prescott. 2014. Smooth sheet bathymetry of Cook Inlet, Alaska. U.S. Dep. Commerce, NOAA Tech. Memo. NMFSAFC-275, 32 p.

6 Appendix A: Site Species Lists

Table A.1.1 – Table A.1.11 list species observed at each intertidal site for all years combined and reflect only presence/absence and not relative abundances within a site. These lists are derived from method vii in section 3.4.1.2. Taxa are listed by phyla. Note that if a site includes a specific species as well as a record of its higher taxonomic level (e.g., genus, family), both records are included unless it is known that there is only one species possible. The Tables are generally in the order of sites from north to south.

Table A.2.1 — A.2.11 list species observed at each site for all years from independent photo-quadrat analysis, derived from method v in section 3.4.1.2.

Table A.1.1. Taxa observed at Site 6 at Iliamna Point north of Chinitna Bay for all years combined. Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 6, Iliamna Point			
Algae		**Invertebrates**	
Chlorophyta	*Rosenvingiella polyrhiza*	Arthropoda	*Balanus glandula*
	Ulva lactuca		*Chthamalus dalli*
	Ulva sp		*Pagurus sp*
	Ulvaria obscura		*Semibalanus cariosus*
Ochrophyta	Filamentous diatoms		Unknown Balanomorpha
	Fucus distichus	Cnidaria	*Urticina crassicornis*
	Ralphsia phase	Echinodermata	*Leptasterias sp*
	Saccharina latissima	Mollusca	*Hiatella arctica*
Rhodophyta	*Ahnfeltia fastigiata*		*Littorina scutulata*
	Articulated coralline		*Littorina sitkana*
	Cryptosiphonia woodii		*Lottia pelta*
	Devaleraea callophylloides		*Lottia persona*
	Encrusting corallines		*Lottia scutum*
	Gloiopeltis furcata		*Lottiidae*
	Mastocarpus alaskensis		*Mytilus trossulus*
	Mastocarpus spp		*Nucella emarginata*
	Neorhodomela aculeata		*Nucella lima*
	Neorhodomela sp		*Nucella sp*
	Odonthalia floccosa		*Tonicella lineata*
	Palmaria hecatensis		
	Petrocelis Form		
	Polysiphonia pacifica		
	Pyropia sp		
	Savoiea bipinnata		

Table A.1.2. Taxa observed at Site 10 in Chinitna Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 10, Chinitna Bay			
Algae		**Invertebrates**	
Chlorophyta	*Prasiola borealis*	Annelida	*Dodecaceria sp*
	Rosenvingiella polyrhiza	Arthropoda	*Balanus glandula*
Ochrophyta	*Fucus distichus*		*Chthamalus dalli*
	Melanosiphon intestinalis		*Pagurus hirsutiusculus*
	Ralfsia fungiformis		*Semibalanus balanoides*
Rhodophyta	*Ahnfeltia fastigiata*		*Semibalanus cariosus*
	Bangia spp		Unknown Balanomorpha
	Encrusting corallines	Cnidaria	*Anthopleura artemisia*
	Halosaccion firmum		*Urticina crassicornis*
	Mastocarpus spp	Echinodermata	*Leptasterias hexactis*
	Neorhodomela aculeata	Mollusca	*Cyanoplax dentiens*
	Palmaria hecatensis		*Littorina scutulata*
	Petrocelis Form		*Littorina sitkana*
	Ptilota asplenioides		*Lottia pelta*
	Savoiea bipinnata		*Lottia persona*
			Lottia scutum
			Lottiidae
			Mopalia sp
			Mytilus trossulus
			Nucella canaliculata
			Nucella emarginata
			Nucella lima
		Porifera	*Halichondria panicea*

Table A.1.3. Taxa observed at Site 4 on Pomeroy Island for all years combined. Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 4, Pomeroy Island

Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia duriuscula*	Annelida	*Nereis sp*
	Acrosiphonia sp		*Serpula vermicularis*
	Prasiola borealis	Arthropoda	*Balanus glandula*
	Rosenvingiella polyrhiza		*Chthamalus dalli*
	Ulva lactuca		*Elassochirus gilli*
	Ulva sp		*Pagurus beringanus*
	Ulvaria obscura		*Pagurus hirsutiusculus*
Ochrophyta	*Alaria marginata*		*Semibalanus balanoides*
	Colpomenia bullosa		*Semibalanus cariosus*
	Filamentous diatoms		Unknown Balanomorpha
	Fucus distichus	Bryozoa	*Bryozoa*
	Melanosiphon intestinalis		*Primavelans insculpta*
	Petalonia facia	Chordata	*Aplidium californicum*
	Ralfsia fungiformis	Cnidaria	*Abietinaria sp*
	Ralphsia phase		*Anthopleura artemisia*
	Saccharina latissima		*Metridium senile*
	Saccharina nigripes		*Urticina crassicornis*
	Saccharina sp	Echinodermata	*Henricia leviuscula*
	Scytosiphon lomentaria		*Henricia sp*
Rhodophyta	*Ahnfeltia fastigiata*		*Leptasterias hexactis*
	Antithamnionella pacifica		*Solaster stimpsoni*
	Articulated coralline	Mollusca	*Cryptochiton stelleri*
	Bangia spp		*Katharina tunicata*
	Bossiella frondescens		*Lacuna variegata*
	Constantinea sp		*Littorina scutulata*
	Corallina officinalis		*Littorina sitkana*
	Cryptosiphonia woodii		*Lottia pelta*
	Devaleraea callophylloides		*Lottia persona*
	Encrusting corallines		*Lottia scutum*
	Halosaccion glandiforme		*Margarites pupillus*
	Halosaccion sp nov.		*Mopalia sp*
	Mastocarpus spp		*Mytilus trossulus*
	Mazzaella parvula		*Nucella lamellosa*
	Mazzaella phyllocarpa		*Nucella spp*
	Mazzaella sp		*Onchidoris bilamellata*
	Mikamiella ruprechtiana		*Tonicella lineata*

Rhodophyta	*Neopolyporolithon reclinatum*	Mollusca	*Trichotropis cancellata*
	Neorhodomela aculeata	Nemertea	*Amphiporus sp*
	Odonthalia floccosa f. comosa		*Emplectonema buergeri*
	Odonthalia setacea		*Emplectonema gracile*
	Palmaria hecatensis		*Tubulanus polymorphus*
	Petrocelis Form	Porifera	*Ophlitaspongia pennata*
	Phycodrys fimbriata		*Suberites domuncula*
	Ptilota asplenioides		
	Pyropia fucicola		
	Pyropia sp		
	Pyropia spp		
	Pyropia taeniata		
	Savoiea bipinnata		
	Tokidadendron bullatum		

Table A.1.4. Taxa observed at Site SI1 on Scott Island at the mouth of Iniskin Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site SI1, Scott Island

Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia coalita*	Annelida	*Arctonoe vittata (Grube, 1855)*
	Acrosiphonia duriuscula		*Harmothoe imbricata*
	Chaetomorpha sp		*Ophelina acuminata*
	Monostroma grevillei		*Ophelina sp*
	Rosenvingiella polyrhiza		*Polychaeta*
	Ulva lactuca		*Spirorbis sp.*
	Ulva prolifera	Arthropoda	*Balanus glandula*
	Ulva sp		*Cancer oregonensis*
	Ulvaria obscura		*Chthamalus dalli*
	Urospora sp		*Elassochirus tenuimanus*
Ochrophyta	*Alaria marginata*		*Hapalogaster mertensii*
	Desmarestia aculeata		*Idotea sp*
	Filamentous diatoms		*Maera danae*
	Fucus distichus		*Oregonia gracilis*
	Melanosiphon intestinalis		*Pagurus beringanus*
	Petalonia facia		*Pagurus hirsutiusculus*
	Ralphsia phase		*Pagurus sp*
	Saccharina latissima		*Pugettia gracilis*
	Saccharina nigripes		*Semibalanus balanoides*
Ochrophyta	*Saccharina sp*	Arthropoda	*Semibalanus cariosus*
Rhodophyta	*Antithamnionella pacifica*		*Telmessus cheiragonus*
	Articulated coralline		Unidentified Shrimp
	Bossiella frondescens		Unknown Balanomorpha
	Constantinea sp	Brachiopoda	*Terebratalia transversa*
	Cryptosiphonia woodii	Bryozoa	*Bryozoa*
	Devaleraea callophylloides	Chordata	*Aplidium californicum*
	Dumontia alaskana		*Ascidiacea*
	Dumontia simplex		*Ascidiacea sp. 2*
	Encrusting corallines	Cnidaria	*Abietinaria sp*
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria		*Anthopleura artemisia*
	Halosaccion glandiforme		*Grammaria sp*
	Hildenbrandia rubra		*Metridium senile*
	Mastocarpus spp		*Urticina crassicornis*
	Mazzaella phyllocarpa	Echinodermata	*Cucumaria sp*

Rhodophyta	*Neorhodomela oregona*
	Odonthalia floccosa
	Odonthalia setacea
	Palmaria hecatensis
	Petrocelis Form
	Phycodrys fimbriata
	Polysiphonia pacifica
	Savoiea bipinnata
	Sparlingia pertusa
	Turnerella mertensiana

Echinodermata	*Eupentacta pseudoquinquesemita*
	Evasterias troschelii
	Henricia leviuscula
	Henricia sanguinolenta
	Henricia sp
	Leptasterias hexactis
	Leptasterias sp
	Solaster stimpsoni
Mollusca	*Clinocardium nuttallii*
	Lacuna sp
	Lacuna vincta
	Littorina scutulata
	Littorina sitkana
	Lottia pelta
	Lottia persona
	Lottia scutum
	Margarites pupillus
	Modiolus sp
	Mopalia muscosa
	Mopalia sp
	Mya sp
	Mytilus trossulus
	Nucella emarginata
	Nucella lamellosa
	Nucella spp
	Onchidoris bilamellata
	Tonicella insignis
	Tonicella lineata
	Tripoplax trifida
Nemertea	*Emplectonema buergeri*
Platyhelminthes	*Polycladida*
Porifera	*Halichondria panicea*
	Polymastia sp
	Porifera
	Suberites domuncula

Table A.1.5. Taxa observed at Site TR1 on Turtle Reef at the mouth of Iliamna Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site TR1, Turtle Reef

Algae		**Invertebrates**	
Chlorophyta	Acrosiphonia duriuscula	Annelida	*Eudistylia vancouveri*
	Monostroma grevillei		*Eudistylia sp*
	Pseudothrix borealis		*Polychaeta*
	Rosenvingiella polyrhiza		*Polynoidae*
	Ulothrix flacca		Serpulid worm
	Ulva lactuca	Arthropoda	*Atylus collingi*
	Ulva linza		*Balanus glandula*
	Ulva sp		*Chthamalus dalli*
	Urospora sp		*Maera danae*
Ochrophyta	*Alaria marginata*		*Oregonia gracilis*
	Filamentous diatoms		*Pagurus beringanus*
	Fucus distichus		*Pagurus hirsutiusculus*
	Leathesia marina		*Semibalanus balanoides*
	Petalonia facia		*Telmessus cheiragonus*
	Ralfsia fungiformis		Unknown Balanomorpha
	Ralphsia phase	Bryozoa	*Bryozoa*
	Saccharina latissima	Cnidaria	*Anthopleura artemisia*
	Saccharina nigripes		*Anthozoa*
	Saccharina sp		*Urticina crassicornis*
	Scytosiphon lomentaria	Echinodermata	*Chiridota discolor*
Rhodophyta	*Antithamnionella pacifica*		*Henricia leviuscula*
	Articulated coralline		*Leptasterias hexactis*
	Constantinea sp		*Solaster stimpsoni*
	Cryptosiphonia woodii	Mollusca	*Bivalvia*
	Devaleraea callophylloides		*Cryptonatica affinis*
	Devaleraea mollis		*Hiatella arctica*
	Encrusting corallines		*Littorina sitkana*
	Halosaccion glandiforme		*Lottia pelta*
	Mastocarpus spp		*Lottia persona*
	Mazzaella parvula		*Lottia scutum*
	Mazzaella phyllocarpa		*Mopalia sp*
	Neorhodomela aculeata		*Mytilus trossulus*
	Odonthalia setacea		*Nucella spp*
	Palmaria hecatensis		*Onchidoris bilamellata*
	Palmaria sp NOV.		*Tonicella lineata*

Rhodophyta	*Petrocelis Form*	Nemertea	*Amphiporus angulatus*
	Polysiphonia sp	Platyhelminthes	*Polycladida*
	Pyropia spp	Porifera	*Halichondria panicea*
	Savoiea bipinnata		
	Sparlingia pertusa		
	Turnerella mertensiana		

Table A.1.6. Taxa observed at Site 3A on Augustine Island for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 3A, Augustine Island

Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia arcta*	Annelida	*Nereis sp*
	Acrosiphonia duriuscula		*Spirorbis sp.*
	Acrosiphonia sp	Arthropoda	*Amphipoda*
	Blindingia minima		*Balanus glandula*
	Filamentous green algae cf *Acrosiphonia/Cladophora/Urospora*		*Cancer oregonensis*
	Kornmannia leptoderma		*Chromopleustes oculatus*
	Monostroma grevillei		*Chthamalus dalli*
	Pseudothrix borealis		*Gammaridea*
	Ulva lactuca		*Hyas lyratus*
	Ulva linza		*Idotea sp*
	Ulva sp		*Oregonia gracilis*
	Ulva spp		*Pagurus beringanus*
Ochrophyta	*Agarum clathratum*		*Pagurus hirsutiusculus*
	Alaria marginata		*Pagurus sp*
	Coilodesme bulligera		*Pugettia gracilis*
	Coilodesme californica		*Semibalanus balanoides*
	Desmarestia aculeata		*Spinulogammarus subcarinatus*
	Dictyosiphon foeniculaceus		*Telmessus cheiragonus*
	Ecotocarpus sp		Unknown Balanomorpha
	Elachista fucicola	Bryozoa	*Bryozoa*
	Filamentous diatoms	Cnidaria	*Hydrozoa*
	Fucus distichus		*Metridium senile*
	Laminaria yezoensis		*Urticina crassicornis*
	Melanosiphon intestinalis	Echinodermata	*Henricia sp*

	Petalonia facia
Ochrophyta	*Pylaiella littoralis*
	Ralfsia fungiformis
	Ralphsia phase
	Saccharina latissima
	Saccharina nigripes
	Saccharina sp
	Scytosiphon lomentaria
	Soranthera ulvoidea
Rhodophyta	*Ahnfeltia fastigiata*
	Antithamnionella pacifica
	Articulated coralline
	Bossiella frondescens
	Ceramium pacificum
	Clathromorphum spp
	Constantinea sp
	Cryptosiphonia woodii
	Devaleraea callophylloides
	Devaleraea mollis
	Dumontia alaskana
	Encrusting corallines
	Euthora cristata
	Filamentous red algae cf *Endocladia/Microcladia/ Odonthalia/Neorhodomela*
	Halosaccion firmum
	Halosaccion glandiforme
	Hildenbrandia sp
	Mastocarpus spp
	Mazzaella phyllocarpa
	Mazzaella sp
	Mazzaella spp
	Mikamiella ruprechtiana
	Neorhodomela aculeata
	Neorhodomela oregona
	Odonthalia floccosa
	Odonthalia setacea
	Palmaria hecatensis
	Petrocelis Form
	Phycodrys fimbriata

	Leptasterias hexactis
Mollusca	*Enteroctopus dofleini*
	Katharina tunicata
	Lacuna sp
	Lacuna vincta
	Littorina sitkana
	Lottia pelta
	Lottia persona
	Lottia scutum
Mollusca	*Lottia sp*
	Macoma balthica
	Mopalia sp
	Mytilus trossulus
	Nucella lima
	Onchidoris bilamellata
	Peltodoris nobilis
	Tonicella lineata
Nemertea	*Emplectonema gracile*
	Paranemertes peregrina
Platyhelminthes	*Polycladida*
Porifera	*Halichondria panicea*

Vertebrates	
Chordata	*Clupea harengus* eggs

Plants	
Magnoliophyta	*Zostera marina*

	Pyropia sp
Rhodophyta	*Pyropia spp*
	Savoiea bipinnata
	Scagelia occidentale
	Schizymenia pacifica
	Sparlingia pertusa
	Tokidadendron bullatum
	Wildemania cuneiformis
Unknown	Encrusting brown cf *Ralphsia/ Petrocelis*

Table A.1.7. Taxa observed at Site BB1 in Bruin Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia arcta*	Arthropoda	*Balanus glandula*
	Monostroma grevillei		*Chthamalus dalli*
	Pseudothrix borealis		*Pagurus hirsutiusculus*
	Rosenvingiella polyrhiza		*Pentidotea wosnesenskii*
	Ulva lactuca		Unknown Balanomorpha
	Ulva spp	Bryozoa	*Bryozoa*
	Urospora sp	Cnidaria	*Anthopleura artemisia*
Ochrophyta	*Desmarestia aculeata*		*Anthopleura elegantissima*
	Filamentous diatoms		*Urticina crassicornis*
	Fucus distichus	Echinodermata	*Leptasterias hexactis*
	Melanosiphon intestinalis	Mollusca	*Chitonida*
	Petalonia facia		*Cyanoplax dentiens*
	Pylaiella littoralis		*Lacuna vincta*
	Ralphsia phase		*Littorina scutulata*
	Saccharina latissima		*Littorina sitkana*
Rhodophyta	*Ahnfeltia fastigiata*		*Lottia pelta*
	Antithamnionella pacifica		*Lottia persona*
	Constantinea sp		*Lottia scutum*
	Cryptosiphonia woodii		*Lottiidae*
	Devaleraea callophylloides		*Mytilus trossulus*
	Devaleraea callophylloides forma Devaleraea		*Nucella sp*
	Dumontia alaskana		*Nucella spp*
	Encrusting corallines		*Onchidoris bilamellata*
	Halosaccion firmum	Nemertea	*Emplectonema gracile*

	Halosaccion glandiforme		*Paranemertes peregrina*
Rhodophyta	*Halosaccion sp nov.*	Platyhelminthes	*Polycladida*
	Mastocarpus spp	Porifera	*Halichondria panicea*
	Neorhodomela aculeata		*Porifera*
	Neorhodomela oregona	Sipuncula	*Phascolosoma agassizii*
	Odonthalia floccosa		
	Odonthalia floccosa f. comosa	**Plants**	
	Odonthalia setacea	Magnoliophyta	*Zostera marina*
	Palmaria hecatensis		
	Petrocelis Form	**Vertebrates**	
	Savoiea bipinnata	Chordata	*Pholis laeta*

Table A.1.8. Taxa observed at Site 2 at Contact Point just south of Bruin Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 2, Contact Point			
Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia arcta*	Arthropoda	*Balanus glandula*
	Acrosiphonia duriuscula		*Chthamalus dalli*
	Kornmannia leptoderma		*Pagurus hirsutiusculus*
	Monostroma grevillei		Unknown Balanomorpha
	Ulva lactuca	Chordata	*Ascidiacea*
	Ulva sp	Cnidaria	*Anthopleura artemisia*
Ochrophyta	*Chordaria chordaeformis*		*Hydrozoa*
	Desmarestia aculeata		*Urticina crassicornis*
	Dictyosiphon foeniculaceus	Echinodermata	*Henricia sp*
	Filamentous diatoms	Mollusca	*Littorina sitkana*
	Fucus distichus		*Lottia pelta*
	Melanosiphon intestinalis		*Lottia persona*
	Pylaiella littoralis		*Mopalia ciliata*
	Ralfsia fungiformis		*Mytilus trossulus*
	Saccharina latissima		*Nucella emarginata*
	Saccharina nigripes		*Tonicella lineata*
	Saccharina sp	Porifera	*Halichondria panicea*
	Scytosiphon lomentaria		
	Soranthera ulvoidea		
	Stephanocystis geminata		
Rhodophyta	*Ahnfeltia fastigiata*		
	Articulated coralline		
	Bossiella frondescens		
	Constantinea sp		
	Cryptosiphonia woodii		
	Devaleraea callophylloides		
	Dumontia alaskana		
	Encrusting corallines		
	Halosaccion firmum		
	Halosaccion glandiforme		
	Halosaccion sp nov.		
	Hildenbrandia sp		
	Mastocarpus spp		
	Mazzaella sp		
	Neorhodomela aculeata		

Rhodophyta	*Neorhodomela oregona*		
	Palmaria hecatensis		
	Petrocelis Form		
	Phycodrys fimbriata		
	Ptilota asplenioides		
	Savoiea bipinnata		
	Tokidadendron bullatum		

Table A.1.9. Taxa observed at Site N1 on Nordyke Island in western Kamishak Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site N1, Nordyke Island			
Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia arcta*	Annelida	*Polychaeta*
	Acrosiphonia duriuscula		*Sedentaria*
	Monostroma grevillei	Arthropoda	*Amphipoda*
	Pseudothrix borealis		*Balanus glandula*
	Ulothrix flacca		*Chthamalus dalli*
	Ulva lactuca		*Pagurus hirsutiusculus*
	Ulva spp		*Semibalanus balanoides*
	Ulvaria obscura		*Telmessus cheiragonus*
Ochrophyta	*Ecotocarpus sp*		*Unknown Balanomorpha*
	Elachista fucicola	Bryozoa	*Bryozoa*
	Filamentous diatoms	Cnidaria	*Anthopleura artemisia*
	Fucus distichus		*Anthopleura elegantissima*
	Melanosiphon intestinalis		*Urticina crassicornis*
	Petalonia facia	Echinodermata	*Crossaster papposus*
	Pylaiella littoralis		*Henricia leviuscula*
	Ralfsia fungiformis		*Leptasterias hexactis*
	Ralphsia phase	Mollusca	*Chitonida*
	Saccharina latissima		*Littorina sitkana*
	Scytosiphon lomentaria		*Lottia pelta*
	Soranthera ulvoidea		*Lottia persona*
Rhodophyta	*Ahnfeltia fastigiata*		*Lottiidae*
	Antithamnionella pacifica		*Margarites pupillus*
	Articulated coralline		*Mopalia sp*
	Bossiella frondescens		*Mytilus trossulus*
	Constantinea sp		*Nucella lima*
	Corallina officinalis		*Tonicella lineata*
	Corallina vancouveriensis	Porifera	*Halichondria panicea*
	Cryptosiphonia woodii		
	Devaleraea callophylloides		
	Devaleraea mollis		
	Dumontia alaskana		
	Encrusting corallines		
	Halosaccion firmum		
	Halosaccion glandiforme		
	Hildenbrandia rubra		

Rhodophyta	*Hildenbrandia sp*		
	Mastocarpus spp		
	Mazzaella spp		
	Neopolyporolithon reclinatum		
	Neorhodomela aculeata		
	Neorhodomela oregona		
	Palmaria hecatensis		
	Petrocelis Form		
	Phycodrys fimbriata		
	Polysiphonia pacifica		
	Polysiphonia sp		
	Pyropia sp		
	Savoiea bipinnata		
	Scagelia occidentale		
Plants			
Magnoliophyta	*Zostera marina*		

Table A.1.10. Taxa observed at Site 19 at Chenik Head in western Kamishak Bay for all years combined.
Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Site 19, Chenik Head			
Algae		**Invertebrates**	
Chlorophyta	*Acrosiphonia arcta*	Annelida	*Sedentaria*
	Blindingia minima	Arthropoda	*Balanus glandula*
	Chaetomorpha sp		*Chthamalus dalli*
	Monostroma grevillei		*Gammaridea*
	Prasiola borealis		*Hyas lyratus*
	Pseudothrix borealis		*Oregonia gracilis*
	Rosenvingiella polyrhiza		*Pagurus hirsutiusculus*
	Ulothrix flacca		*Semibalanus balanoides*
	Ulva lactuca		*Semibalanus cariosus*
	Ulva sp		*Telmessus cheiragonus*
	Ulva spp		Unknown Balanomorpha
Ochrophyta	*Agarum clathratum*	Bryozoa	*Bryozoa*
	Chordaria chordaeformis	Cnidaria	*Anthopleura artemisia*
	Chordaria flagelliformis		*Epiactis prolifera*
	Dictyosiphon foeniculaceus		*Metridium senile*
	Filamentous diatoms		*Urticina crassicornis*
	Fucus distichus	Echinodermata	*Henricia leviuscula*
	Melanosiphon intestinalis		*Henricia sp*
	Melanosiphon intestinalis crust		*Leptasterias hexactis*
	Petalonia facia		*Solaster sp*
	Pylaiella littoralis	Mollusca	*Lacuna vincta*
	Ralfsia fungiformis		*Littorina sitkana*
	Ralphsia phase		*Lottia pelta*
	Saccharina latissima		*Lottia persona*
	Saccharina nigripes		*Lottia scutum*
	Saccharina sp		*Margarites pupillus*
	Scytosiphon lomentaria		*Mytilus trossulus*
	Soranthera ulvoidea		*Nucella emarginata*
Rhodophyta	*Ahnfeltia fastigiata*		*Nucella lima*
	Antithamnionella pacifica		*Nucella spp*
	Articulated coralline		*Onchidoris bilamellata*
	Bossiella frondescens		*Trichotropis cancellata*
	Constantinea sp	Nemertea	*Emplectonema buergeri*

Rhodophyta	*Corallina officinalis*	Porifera	*Halichondria panicea*
	Cryptosiphonia woodii		
	Devaleraea callophylloides		
	Devaleraea mollis		
	Dumontia alaskana		
	Encrusting corallines		
	Halosaccion firmum		
	Halosaccion glandiforme		
	Hildenbrandia rubra		
	Mastocarpus spp		
	Mazzaella phyllocarpa		
	Neorhodomela aculeata		
	Neorhodomela oregona		
	Neorhodomela sp		
	Odonthalia floccosa		
	Odonthalia sp		
	Palmaria hecatensis		
	Petrocelis Form		
	Phycodrys fimbriata		
	Ptilota asplenioides		
	Ptilota serrata		
	Pyropia fucicola		
	Pyropia sp		
	Pyropia spp		
	Savoiea bipinnata		
	Sparlingia pertusa		

Table A.1.11. Taxa observed at Douglas Reefs in Kamishak Bay for all years combined. Observations reported here include those from quadrats (point contacts, non-contacted species, and mobile invertebrates) and species observed on site but not found in quadrats.

Douglas Reefs, transects DR_T01-DR_TR19			
Algae & Seagrasses			
Chlorophyta	*Acrosiphonia duriuscula*	Rhodophyta	*Ahnfeltia fastigiata*
	Acrosiphonia sp		*Antithamnionella pacifica*
	Blidingia minima		Articulated coralline
	Chaetomorpha sp		*Bossiella frondescens*
	Cladophora sericea		*Constantinea sp*
	Monostroma grevillei		*Corallina officinalis*
	Pseudothrix borealis		*Cryptosiphonia woodii*
	Rosenvingiella polyrhiza		*Devaleraea callophylloides*
	Ulothrix/Urospora spp		*Devaleraea callophylloides forma Devaleraea*
	Ulva lactuca		*Devaleraea callophylloides forma novel*
	Ulva linza		*Devaleraea mollis*
	Ulva sp		Encrusting corallines
Ochrophyta	*Alaria marginata*		*Halosaccion firmum*
	Chordaria chordaeformis		*Halosaccion glandiforme*
	Chordaria flagelliformis		*Hildenbrandia rubra*
	Dictyosiphon foeniculaceus		*Hildenbrandia sp*
	Filamentous diatoms		*Mastocarpus spp*
	Fucus distichus		*Neopolyporolithon reclinatum*
	Laminaria sp. nov.		*Neorhodomela aculeata*
	Melanosiphon intestinalis		*Neorhodomela oregona*
	Petalonia facia		*Palmaria hecatensis*
	Pylaiella littoralis		Petrocelis Form
	Ralfsia fungiformis		*Phycodrys fimbriata*
	Saccharina latissima		*Pyropia sp*
	Scytosiphon lomentaria		*Pyropia taeniata*
	Small foliose brown blade cf Petalonia		*Savoiea bipinnata*
	Stephanocystis geminata		*Scagelia occidentale*
Plants		**Invertebrates**	
Magnoliophyta	*Zostera marina*	Annelida	*Spirorbis sp.*
		Arthropoda	*Chthamalus dalli*
			Semibalanus balanoides
			Unknown Balanomorpha
		Cnidaria	*Anthopleura artemisia*
		Echinodermata	*Henricia sp*
		Mollusca	*Lacuna sp*
			Mytilus trossulus

The following tables were derived from an independent expert's photo analysis of all quadrats, including mobile invertebrates.

Table A.2.1. Taxa observed at Site 6 at Iliamna Point in western Cook Inlet for all years combined. Observations reported here include those from all quadrats.

Site 6, Iliamna Point				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	*Semibalanus cariosus*
	Foliose green algae cf Ulva/Monostroma/Ulvaria			Unknown Balanomorpha
	Urospora sp		Echinodermata	*Asterina miniata*
Ochrophyta	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus		Mollusca	*Lirabuccinum dirum*
	Fucus distichus			*Littorina sp*
Rhodophyta	Articulated coralline			*Lottia digitalis*
	Cryptosiphonia woodii			*Lottiidae*
	Encrusting corallines			*Mytilus trossulus*
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			*Nucella sp*
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Mastocarpus spp			
	Neorhodomela sp			
	Odonthalia sp			
	Petrocelis Form			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			

Table A.2.2. Taxa observed at Site 10 in Chinitna Bay in western Cook Inlet for all years combined. Observations reported here include those from all quadrats.

Site 10, Chinitna Bay				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	*Semibalanus cariosus*
	Foliose green algae cf Ulva/Monostroma/Ulvaria			Unknown Balanomorpha
Ochrophyta	Filamentous diatoms		Cnidaria	*Anthozoa*
	Fucus distichus		Mollusca	*Littorina sp*
	Saccharina latissima			*Lottiidae*
	Scytosiphon lomentaria			*Mytilus trossulus*
Rhodophyta	*Ahnfeltia sp*			*Nucella sp*
	Cryptosiphonia woodii		Porifera	*Halichondria sp*
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Neorhodomela sp			

Table A.2.3. Taxa observed at Site 4 at Pomeroy Island in western Cook Inlet for all years combined.
Observations reported here include those from all quadrats.

Site 4, Pomeroy Island				
Algae			**Invertebrates**	
Chlorophyta	*Acrosiphonia spp*		Arthropoda	*Semibalanus cariosus*
	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora			Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Bryozoa	*Bryozoa*
	Urospora sp		Cnidaria	*Anthozoa*
Ochrophyta	*Agarum sp*			*Urticina sp*
	Alaria marginata		Mollusca	*Calliostoma sp.*
	Filamentous diatoms			*Katharina tunicata*
	Fucus distichus			*Littorina sp*
	Saccharina latissima			*Lottiidae*
	Saccharina sp			*Mytilus trossulus*
	Scytosiphon lomentaria			*Nucella sp*
Rhodophyta	Articulated coralline			*Tonicella sp*
	Constantinea sp			Unknown gastropod
	Cryptosiphonia woodii		Porifera	*Porifera*
	Dumontia sp			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Hildenbrandia sp			
	Mastocarpus spp			
	Mazzaella phyllocarpa			
	Mazzaella sp			
	Neorhodomela sp			
	Odonthalia setacea			
	Palmaria sp NOV.			
	Petrocelis Form			
	Ptilota sp			
	Pyropia sp			
	Tokidadendron bullatum			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			

Table A.2.4. Taxa observed at Site SI1 at Scott Island in western Cook Inlet for all years combined. Observations reported here include those from all quadrats.

Site SI1, Scott Island				
Algae			**Invertebrates**	
Chlorophyta	*Acrosiphonia spp*		Arthropoda	Unknown Balanomorpha
	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Mollusca	*Calliostoma sp.*
	Foliose green algae cf Ulva/Monostroma/Ulvaria			*Fusitriton oregonensis*
Ochrophyta	*Alaria marginata*			*Littorina sp*
	Filamentous diatoms			*Lottiidae*
	Fucus distichus			*Mytilus trossulus*
	Melanosiphon intestinalis			*Nucella sp*
	Saccharina latissima			*Tonicella sp*
	Saccharina sp			*Unknown gastropod*
	Unknown Ochrophyta			*Unknown nudibranch*
Rhodophyta	Articulated coralline			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Dumontia sp			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Mastocarpus spp			
	Mazzaella sp			
	Neorhodomela sp			
	Odonthalia sp			
	Palmaria sp NOV.			
	Petrocelis Form			
	Pyropia sp			
	Tokidadendron bullatum			

Table A.2.5. Taxa observed at Site TR1 at Turtle Reef in western Cook Inlet for all years combined. Observations reported here include those from all quadrats.

Site TR1, Turtle Reef				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Chordata	*Ascidiacea*
Ochrophyta	*Alaria marginata*		Mollusca	*Calliostoma sp.*
	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus			*Littorina sp*
	Fucus distichus			*Lottiidae*
	Melanosiphon intestinalis			*Nucella sp*
	Saccharina latissima			*Tonicella sp*
	Saccharina sp			Unknown gastropod
	Small foliose brown blade cf Petalonia		Porifera	*Halichondria sp*
	Unknown Ochrophyta			
Rhodophyta	Articulated coralline			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			

Table A.2.6. Taxa observed at Site 3A on Augustine Island in western Cook Inlet for all years combined.
Observations reported here include those from all quadrats.

Site 3A, Augustine Island				
Algae			**Invertebrates**	
Chlorophyta	Acrosiphonia spp		Arthropoda	*Telmessus cheiragonus*
	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora			Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Mollusca	*Littorina sp*
Ochrophyta	*Agarum sp*			*Lottia sp*
	Alaria marginata			*Lottiidae*
	Dictyosiphon sp			*Nucella sp*
	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus			*Tonicella sp*
	Filamentous diatoms		Porifera	*Halichondria sp*
	Fucus distichus		**Plants**	
	Saccharina latissima		Magnoliophyta	*Zostera marina*
	Saccharina nigripes			
	Scytosiphon lomentaria			
	Small foliose brown blade cf Petalonia			
	Unknown Ochrophyta			
Rhodophyta	Articulated coralline			
	Constantinea sp			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Dumontia sp			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Hildenbrandia sp			
	Mastocarpus spp			
	Mazzaella sp			
	Neorhodomela sp			
	Odonthalia floccosa f. comosa			
	Odonthalia sp			
	Palmaria sp NOV.			
	Petrocelis Form			
	Phycodrys fimbriata			
	Pyropia sp			
	Tokidadendron bullatum			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			

Table A.2.7. Taxa observed at Site BB1 in Bruin Bay for all years combined.
Observations reported here include those from all quadrats.

Site BB1, Bruin Bay				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Mollusca	*Littorina sp*
Ochrophyta	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus			*Lottiidae*
	Filamentous diatoms			*Nucella sp*
	Fucus distichus			
	Leathesia marina			
	Saccharina latissima			
	Saccharina sp			
	Scytosiphon lomentaria			
Rhodophyta	*Ahnfeltia sp*			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Dumontia sp			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Neorhodomela sp			
	Odonthalia sp			
	Palmaria sp NOV.			

Table A.2.8. Taxa observed at Site 2 near Contact Point for all years combined. Observations reported here include those from all quadrats.

Site 2, Contact Point				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Cnidaria	Unknown Sertulariidae hydroid
Ochrophyta	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus		Echinodermata	*Henricia sp*
	Filamentous diatoms		Mollusca	*Littorina sp*
	Fucus distichus			*Lottiidae*
	Saccharina latissima			*Mytilus trossulus*
	Scytosiphon lomentaria			*Nucella sp*
	Stephanocystis geminata			Unknown gastropod
Rhodophyta	*Ahnfeltia sp*		Nemertea	Unknown Nemertea
	Articulated coralline		Porifera	*Halichondria sp*
	Constantinea sp			*Porifera*
	Cryptosiphonia woodii			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Hildenbrandia sp			
	Neorhodomela sp			
	Odonthalia floccosa f. comosa			
	Odonthalia sp			
	Palmaria sp NOV.			
	Tokidadendron bullatum			

Table A.2.9. Taxa observed at Site at Site N1 on Nordyke Island in western Kamishak Bay for all years combined.
Observations reported here include those from all quadrats.

Site N1, Nordyke Island				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	Unknown Balanomorpha
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Mollusca	*Littorina sp*
Ochrophyta	*Colpomenia bullosa*			*Lottiidae*
	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus			*Mytilus trossulus*
	Filamentous diatoms			*Nucella sp*
	Fucus distichus		Porifera	*Halichondria sp*
	Saccharina latissima			
	Scytosiphon lomentaria			
Rhodophyta	Articulated coralline			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Neorhodomela sp			
	Odonthalia sp			
	Palmaria sp NOV.			
	Petrocelis Form			
	Pyropia sp			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			

Table A.2.10. Taxa observed at Site 19 at Chenik Head in western Kamishak Bay for all years combined.
Observations reported here include those from all quadrats.

Site 19, Chenik Head				
Algae			**Invertebrates**	
Chlorophyta	Filamentous green algae cf Acrosiphonia/Cladophora/Urospora		Arthropoda	Unidentified decapod
	Foliose green algae cf Ulva/Monostroma/Ulvaria			Unknown Balanomorpha
Ochrophyta	*Colpomenia bullosa*		Chordata	*Ascidiacea*
	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus		Cnidaria	*Anthopleura artemisia*
	Filamentous diatoms		Mollusca	*Littorina sp*
	Fucus distichus			*Lottiidae*
	Melanosiphon intestinalis			*Margarites sp*
	Saccharina latissima			*Mytilus trossulus*
	Saccharina sp			*Nucella sp*
	Scytosiphon lomentaria			Unknown gastropod
	Small foliose brown blade cf Petalonia			
Rhodophyta	Articulated coralline			
	Cryptosiphonia woodii			
	Dumontia sp			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Neorhodomela sp			
	Odonthalia sp			
	Palmaria sp NOV.			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			

Table A.2.11. Taxa observed at the Douglas Reefs in southern Kamishak Bay for all years combined.
Observations reported here include those from all quadrats.

Douglas Reef transects 1-19				
Algae & Sea Grasses			**Invertebrates**	
Chlorophyta	*Acrosiphonia spp*		Arthropoda	Unknown Balanomorpha
	Filamentous green algae cf Acrosyphonia/Cladophora/Urospora		Cnidaria	*Anthopleura artemisia*
	Foliose green algae cf Ulva/Monostroma/Ulvaria		Mollusca	*Bivalvia*
Ochrophyta	*Alaria marginata*			*Littorina sp*
	Filamentous brown algae cf Pyliella/Dictyosiphon/Ectocarpus			*Lottiidae*
	Filamentous diatoms			*Mytilus trossulus*
	Fucus distichus			*Nucella sp*
	Melanosiphon intestinalis			
	Saccharina latissima			
	Small foliose brown blade cf Petalonia			
Rhodophyta	Articulated coralline			
	Constantinea sp			
	Cryptosiphonia woodii			
	Devaleraea callophylloides			
	Devaleraea callophylloides forma Devaleraea			
	Encrusting corallines			
	Filamentous red algae cf Endocladia/Microcladia/Odonthalia/Neorhodomela			
	Fine filamentous red algae			
	Foliose red algae cf Mazzaella/Mastocarpus/Palmaria			
	Halosaccion firmum			
	Halosaccion glandiforme			
	Halosaccion sp			
	Neorhodomela sp			
	Odonthalia sp			
	Palmaria sp NOV.			
	Petrocelis Form			
	Phycodrys fimbriata			
	Ptilota asplenioides			
	Pyropia sp			
Unknown	Encrusting brown cf Ralphsia/Petrocelis			
Magnoliophyta	*Zostera marina*			

7 Appendix B: List of Taxon Included in Community Assemblage Analyses

Table B.1. List of taxon included in the community assemblage analyses.
The following 82 'taxon' were included in the community assemblage analyses. These were all of the taxon ID'd in the point-count quadrat data, which was the basis for this analysis. Substrates and mobile invertebrates were not included in the 'community' summaries.

Algae & Seagrasses				
Chlorophyta	*Acrosiphonia arcta*		Rhodophyta	*Ahnfeltia fastigiata*
	Acrosiphonia coalita			*Antithamnionella pacifica*
	Acrosiphonia duriuscula			Articulated coralline
	Acrosiphonia sp			*Bossiella frondescens*
	Chaetomorpha sp			*Clathromorphum spp*
	Kornmannia leptoderma			*Constantinea sp*
	Monostroma grevillei			*Cryptosiphonia woodii*
	Pseudothrix borealis			*Devaleraea callophylloides*
	Rosenvingiella polyrhiza			*Devaleraea mollis*
	Ulothrix flacca			*Dumontia alaskana*
	Ulva lactuca			Encrusting corallines
	Ulva sp			Filamentous red algae cf Endocladia/Microcladia/ Odonthalia/Neorhodomela
	Ulva spp			*Halosaccion firmum*
	Ulvaria obscura			*Halosaccion glandiforme*
Ochrophyta	*Agarum clathratum*			*Halosaccion sp nov.*
	Alaria marginata			*Hildenbrandia rubra*
	Coilodesme bulligera			*Hildenbrandia sp*
	Desmarestia aculeata			*Mastocarpus spp*
	Ecotocarpus sp			*Mazzaella parvula*
	Elachista fucicola			*Mazzaella phyllocarpa*
	Filamentous diatoms			*Mazzaella sp*
	Fucus distichus			*Mikamiella ruprechtiana*
	Melanosiphon intestinalis			*Neopolyporolithon reclinatum*
	Melanosiphon intestinalis crust			*Neorhodomela aculeata*
	Petalonia facia			*Neorhodomela oregona*
	Pylaiella littoralis			*Neorhodomela sp*
	Ralfsia fungiformis			*Odonthalia floccosa*
	Ralphsia phase			*Odonthalia floccosa f. comosa*
	Saccharina latissima			*Odonthalia setacea*
	Saccharina nigripes			*Palmaria hecatensis*
	Saccharina sp			*Petrocelis* Form
	Scytosiphon lomentaria			*Phycodrys fimbriata*
	Soranthera ulvoidea			*Ptilota asplenioides*

				Pyropia sp
				Pyropia spp
				Savoiea bipinnata
				Scagelia occidentale
				Tokidadendron bullatum
				Wildemania cuneiformis
			Unknown Algae	Encrusting brown cf Ralphsia/Petrocelis
			Magnoliophyta	*Zostera marina*
Invertebrates				
Arthropoda	*Balanus glandula*		Bryozoa	*Bryozoa*
	Chthamalus dalli		Cnidaria	*Anthopleura artemisia*
	Semibalanus balanoides		Porifera	*Halichondria panicea*
	Semibalanus cariosus			
	Unknown Balanomorpha			

8 Appendix C: Site Strata Maps By Year

The site strata maps by year show field-assigned strata divisions used in the field when determining sampling interval, as per Section 2.2.2. These maps also illustrate the variations in the area exposed by lowest tide at each site during successive visits.

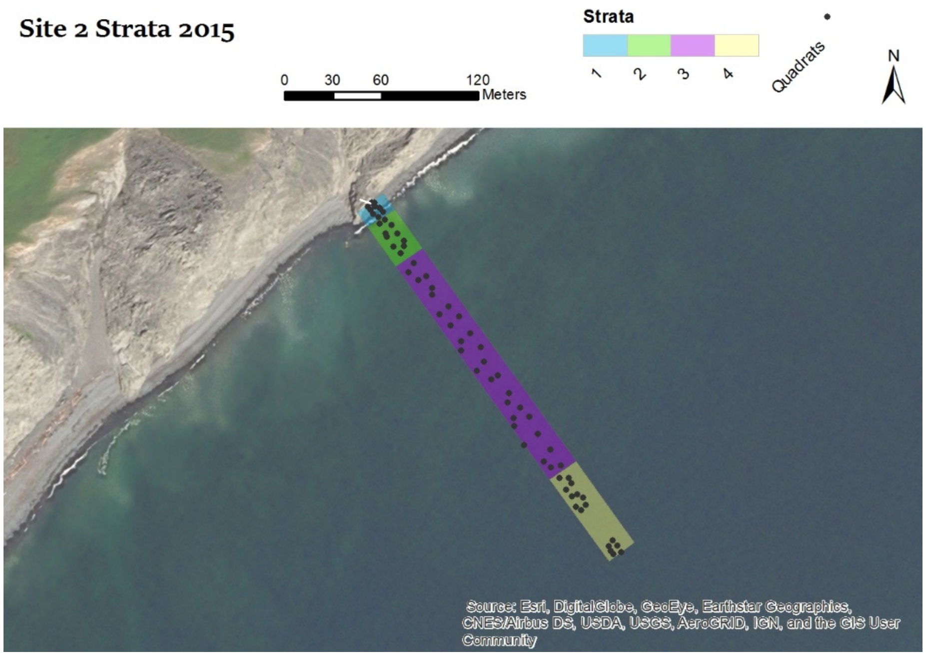


Figure C.1. Site 2 survey layout in 2015 illustrating strata divisions and quadrat placement.

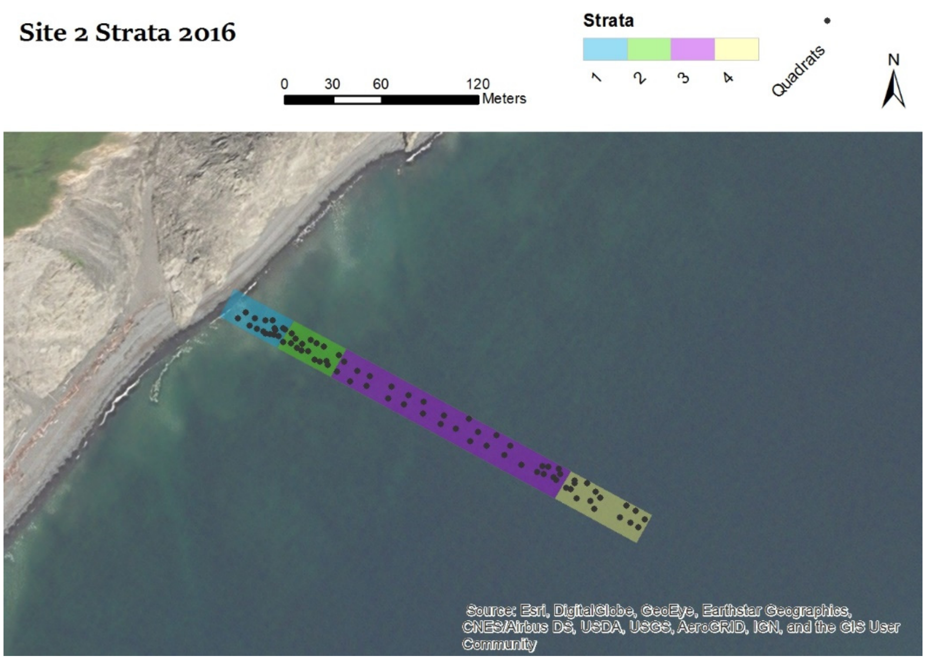


Figure C.2. Site 2 survey layout in 2016 illustrating strata divisions and quadrat placement.

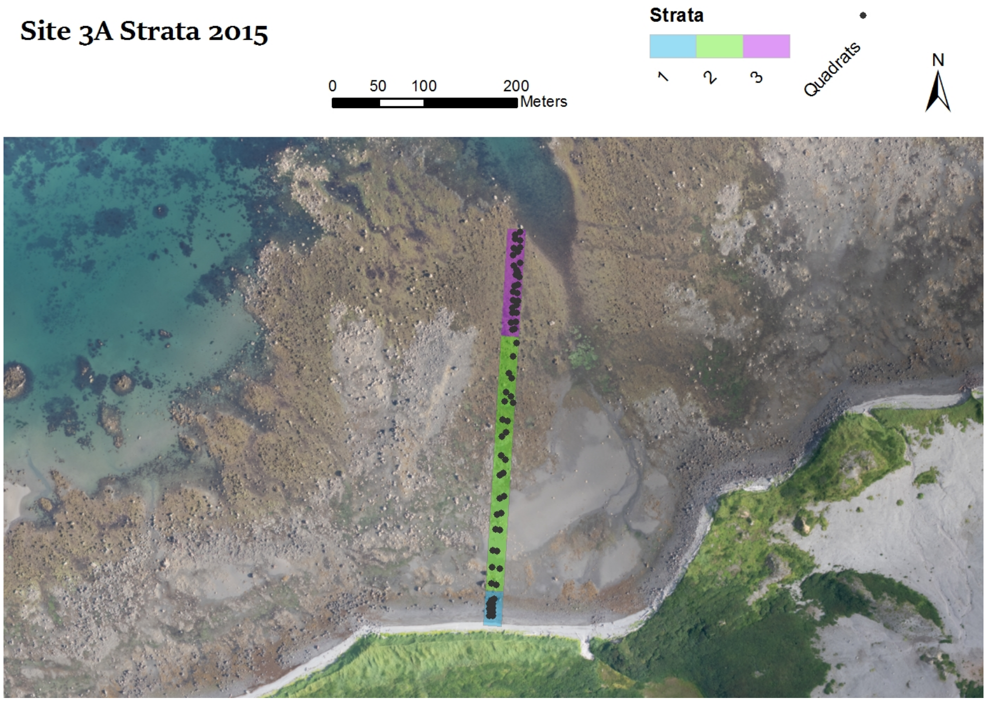


Figure C.3. Site 3A survey layout in 2015 illustrating strata divisions and quadrat placement.

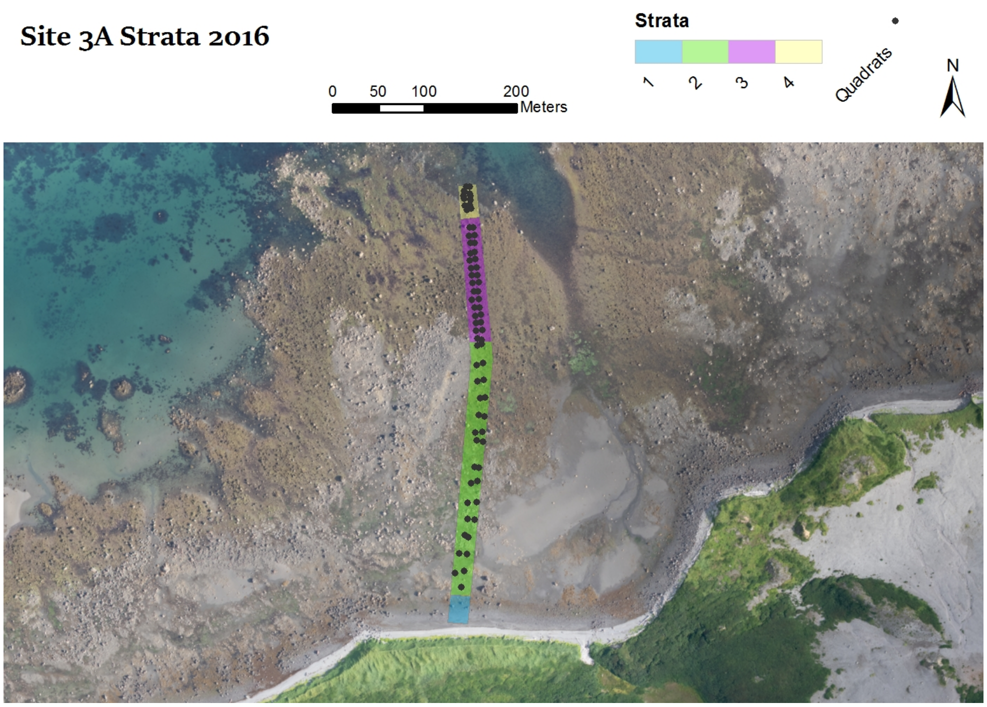


Figure C.4. Site 3A survey layout in 2016 illustrating strata divisions and quadrat placement.

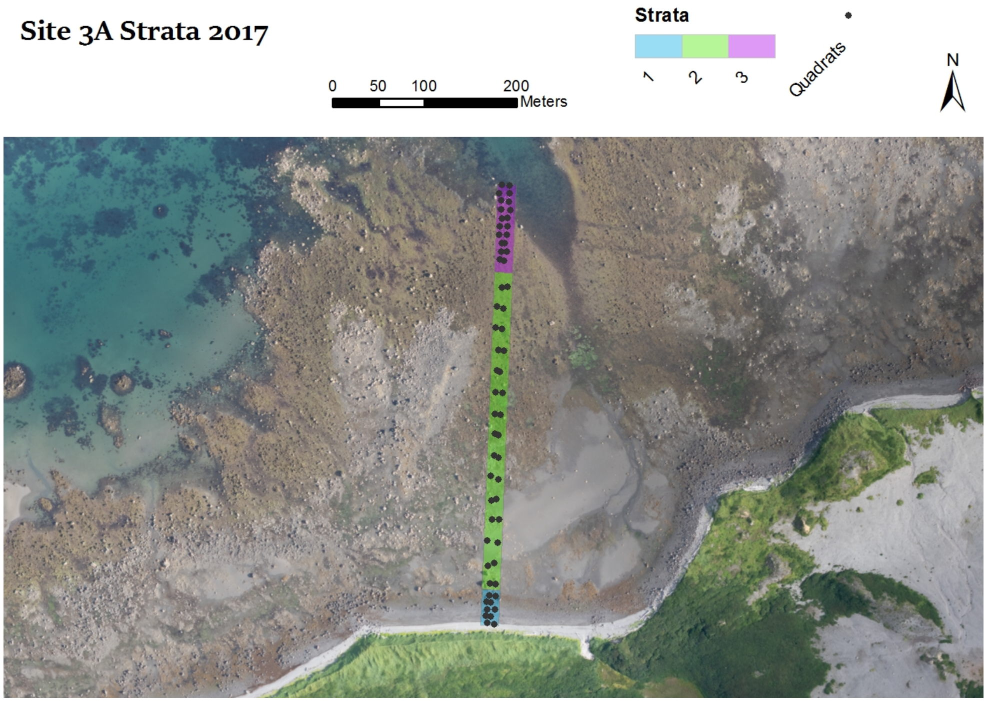


Figure C.5. Site 3A survey layout in 2017 illustrating strata divisions and quadrat placement.

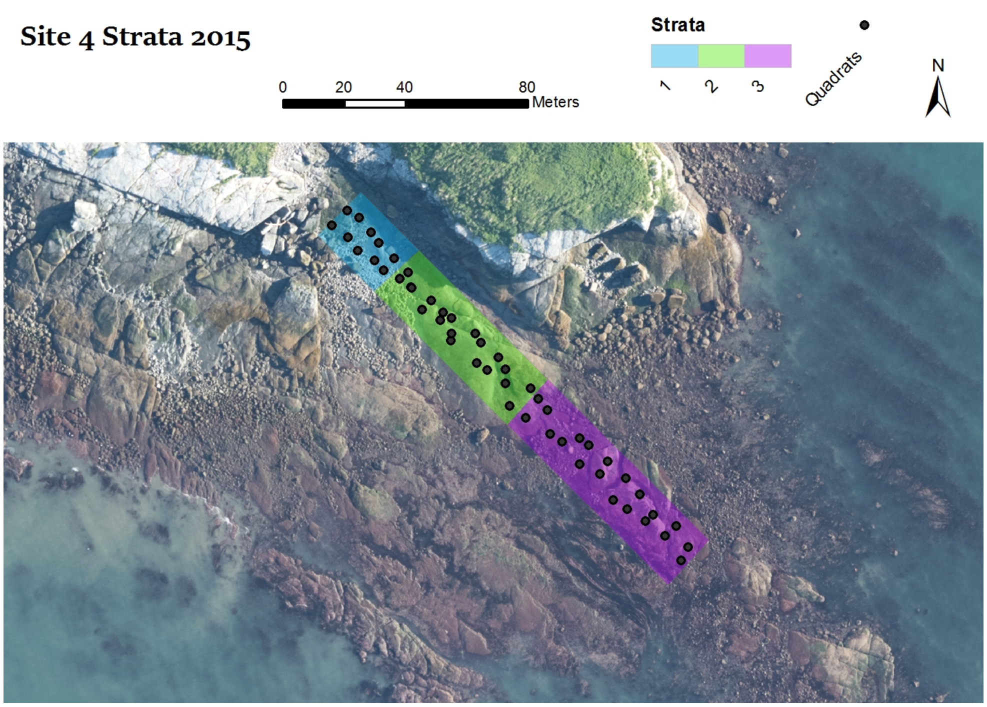


Figure C.6. Site 4 survey layout in 2015 illustrating strata divisions and quadrat placement.

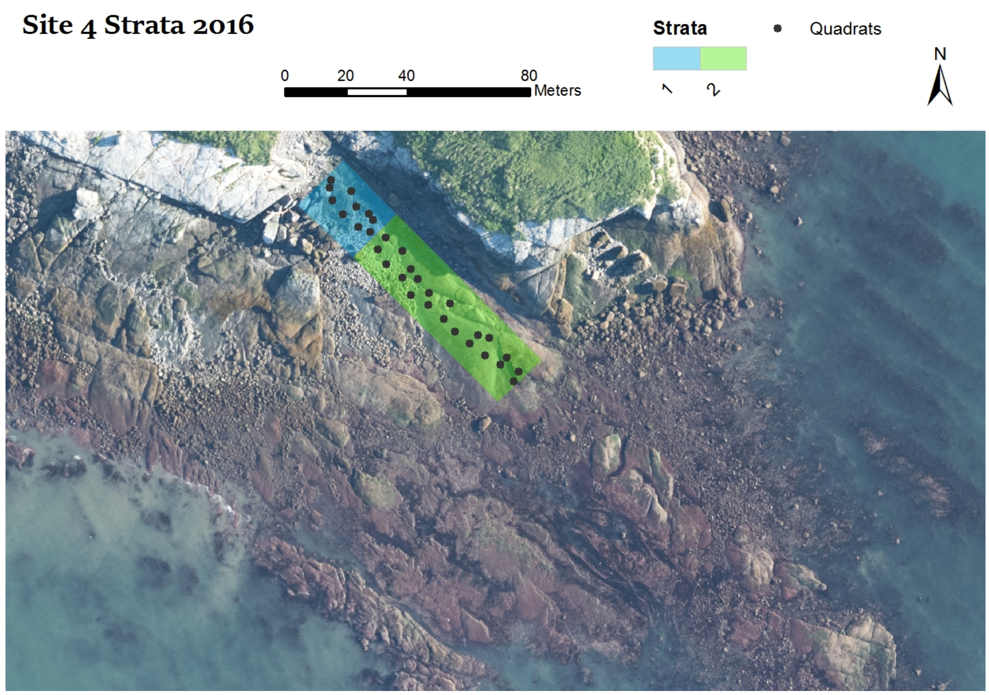


Figure C.7. Site 4 survey layout in 2016 illustrating strata divisions and quadrat placement.

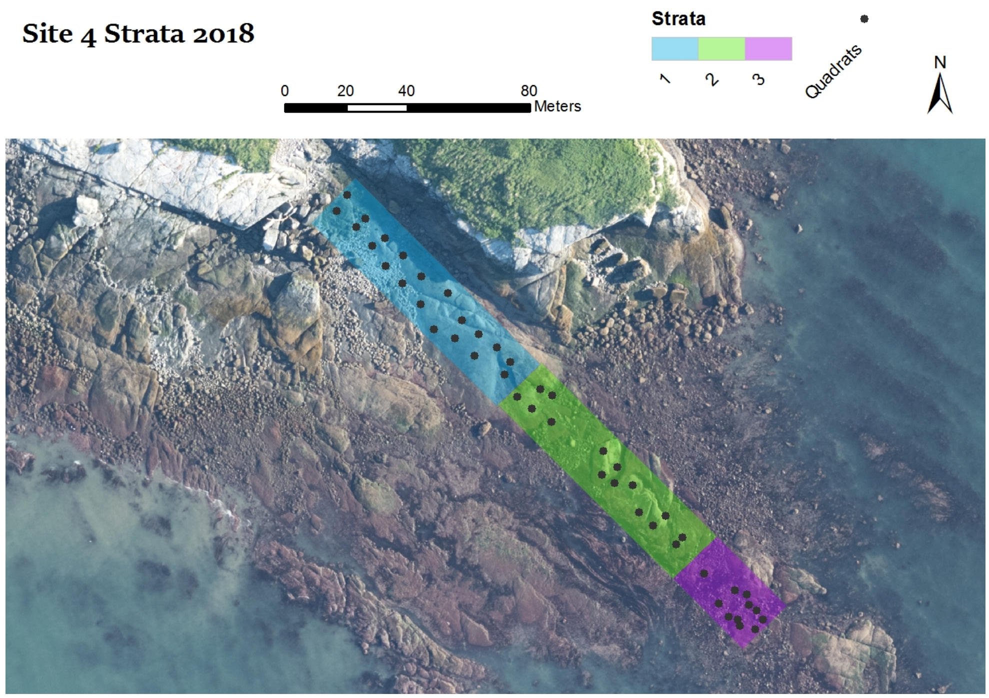


Figure C.8. Site 4 survey layout in 2018 illustrating strata divisions and quadrat placement.

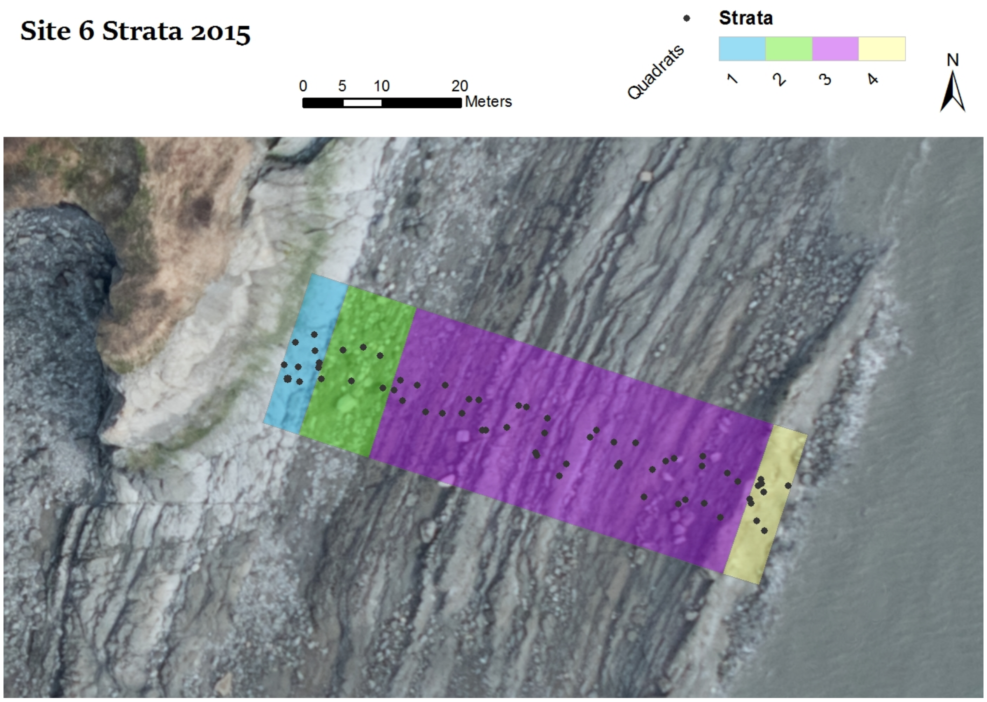


Figure C.9. Site 6 survey layout in 2015 illustrating strata divisions and quadrat placement.

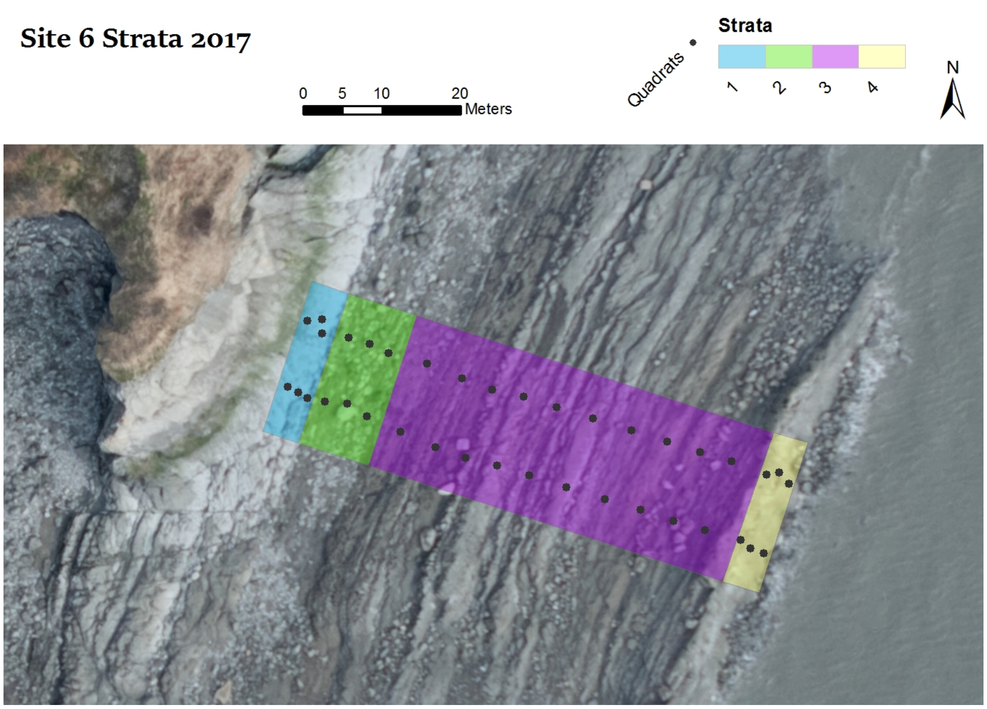


Figure C.10. Site 6 survey layout in 2017 illustrating strata divisions and quadrat placement.

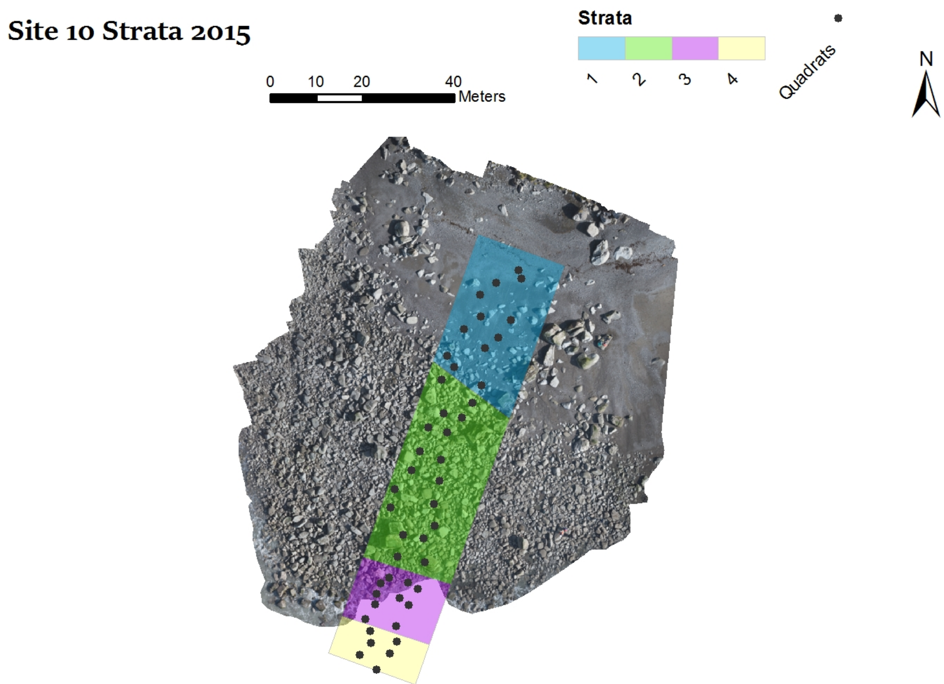


Figure C.11. Site 10 survey layout in 2015 illustrating strata divisions and quadrat placement.

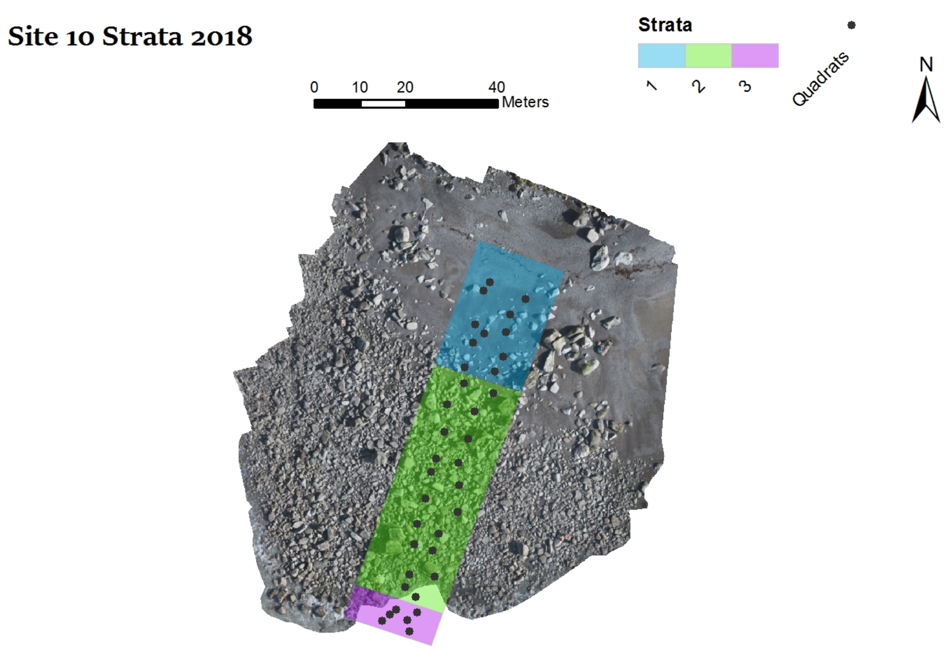


Figure C.12. Site 10 survey layout in 2018 illustrating strata divisions and quadrat placement.

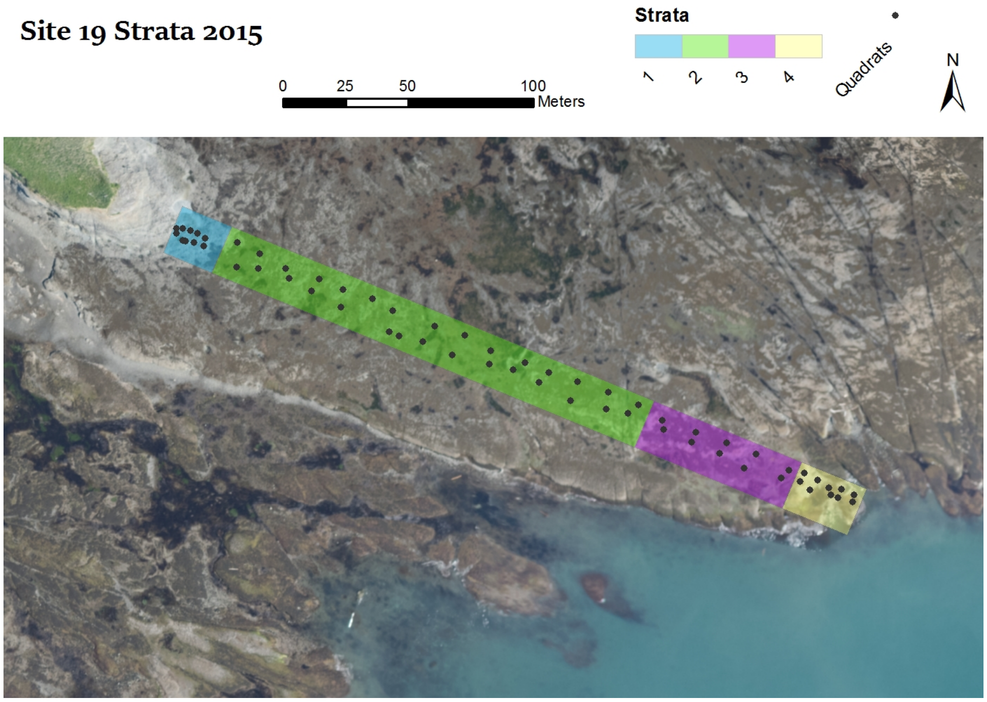


Figure C.13. Site 19 survey layout in 2015 illustrating strata divisions and quadrat placement.

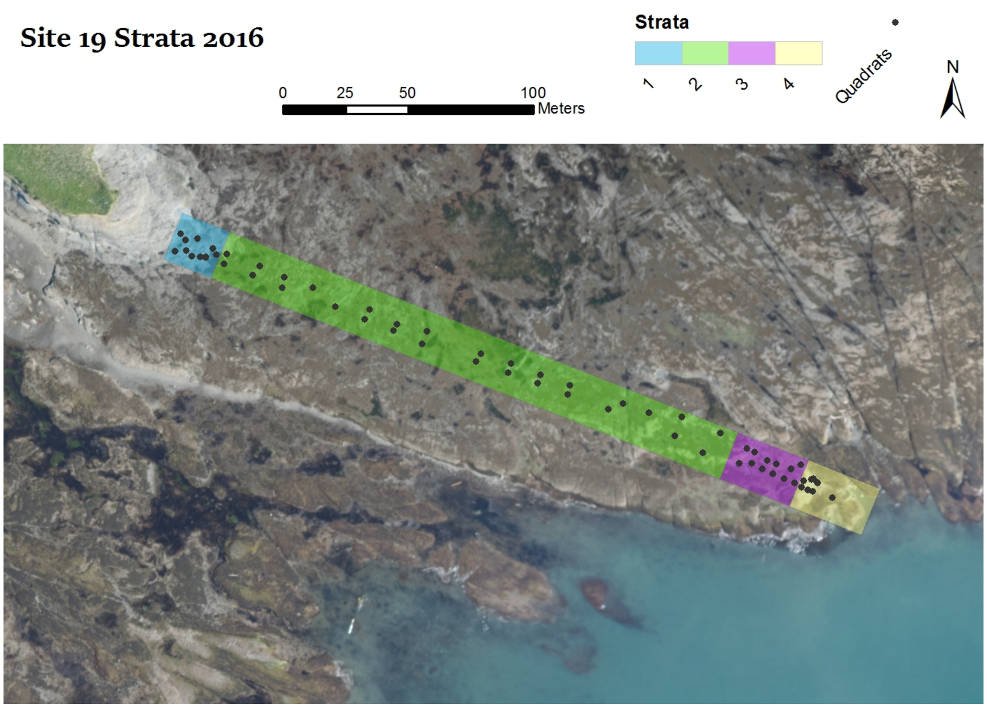


Figure C.14. Site 19 survey layout in 2016 illustrating strata divisions and quadrat placement.

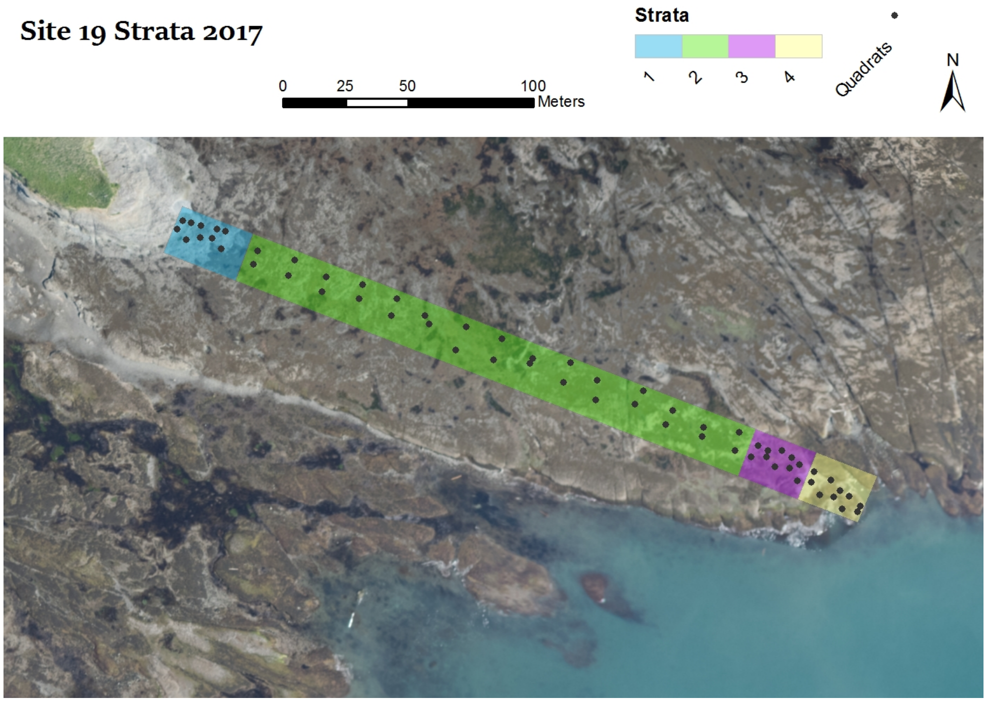


Figure C.15. Site 19 survey layout in 2017 illustrating strata divisions and quadrat placement.

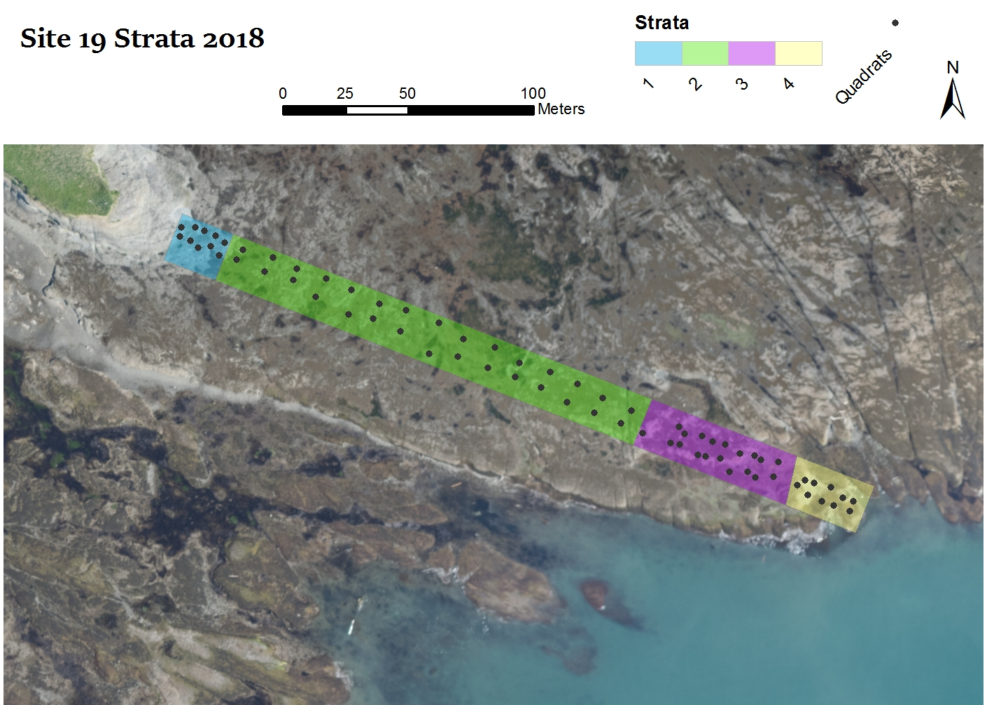


Figure C.16. Site 19 survey layout in 2018 illustrating strata divisions and quadrat placement.

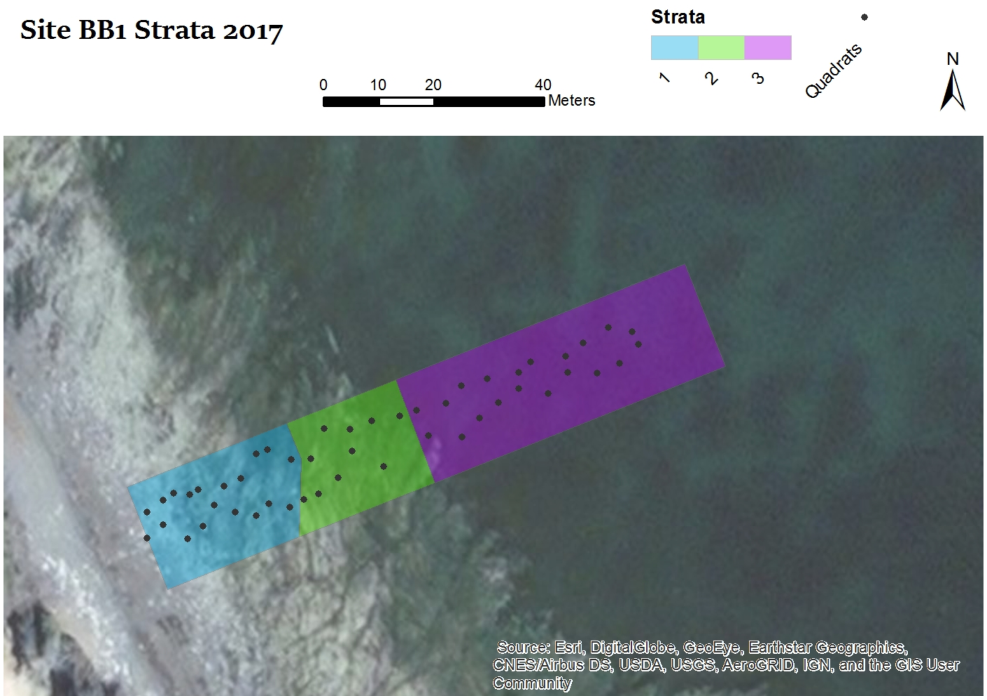


Figure C.17. Site BB1 survey layout in 2017 illustrating strata divisions and quadrat placement.

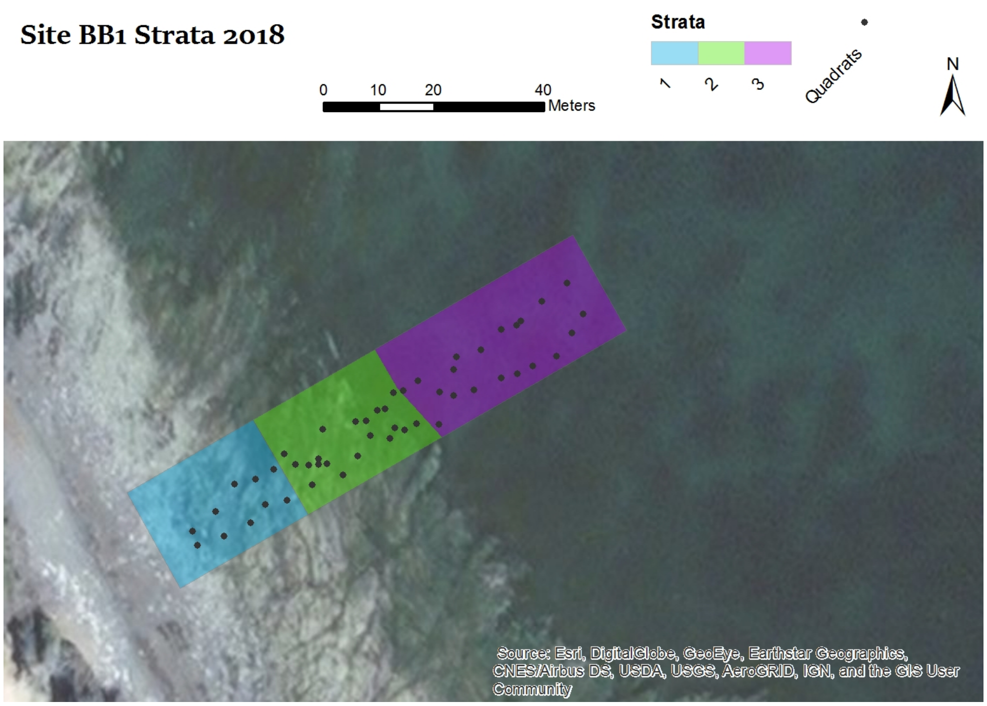


Figure C.18. Site BB1 survey layout in 2018 illustrating strata divisions and quadrat placement.

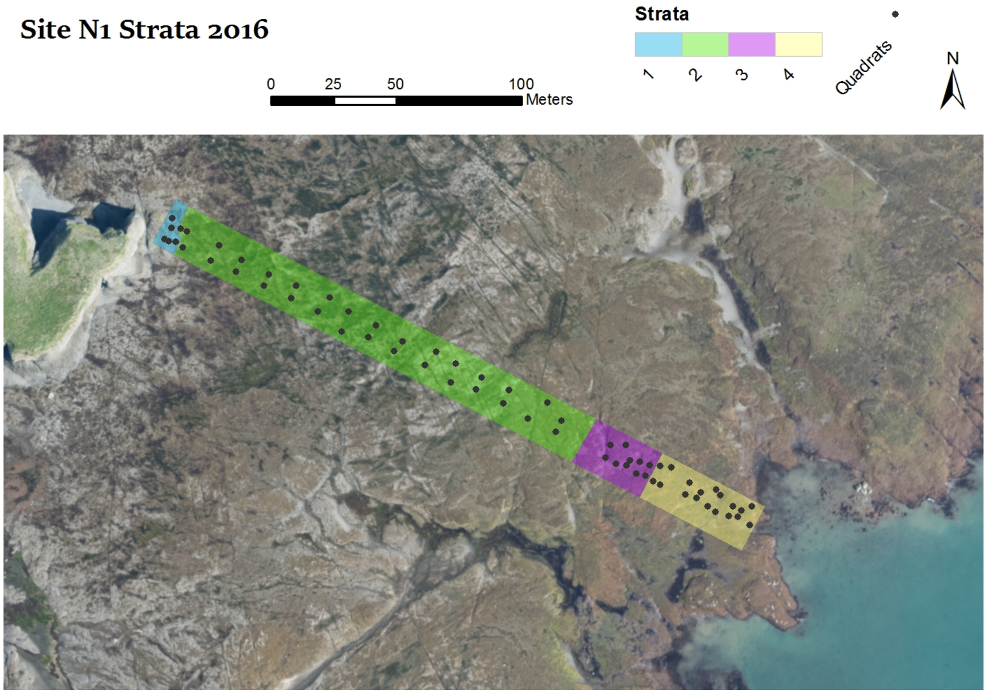


Figure C.19. Site N1 survey layout in 2016 illustrating strata divisions and quadrat placement.

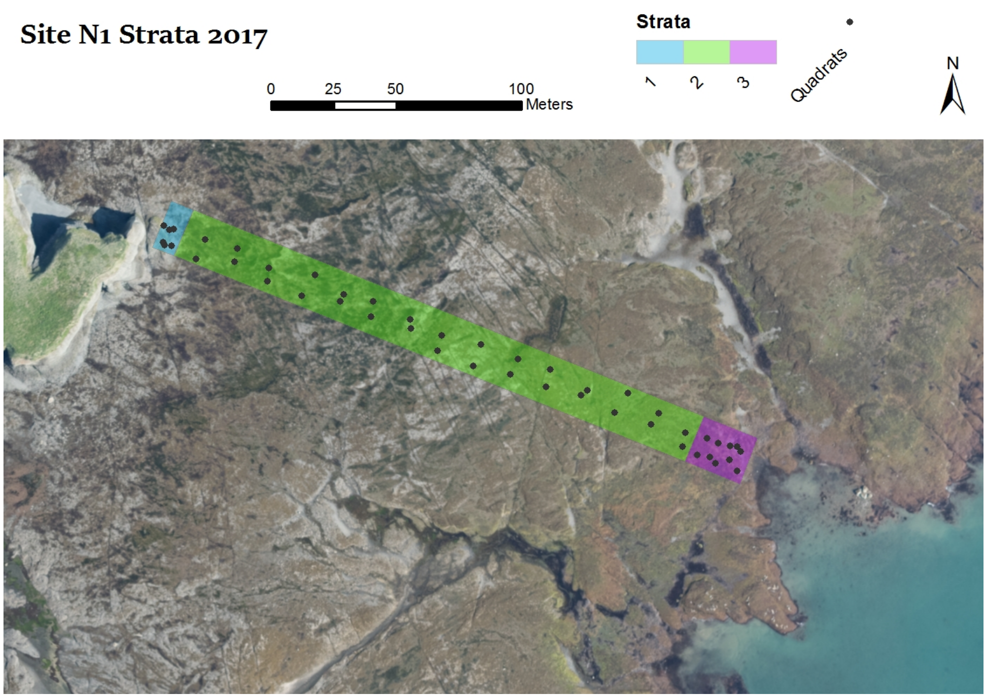


Figure C.20. Site N1 survey layout in 2017 illustrating strata divisions and quadrat placement.

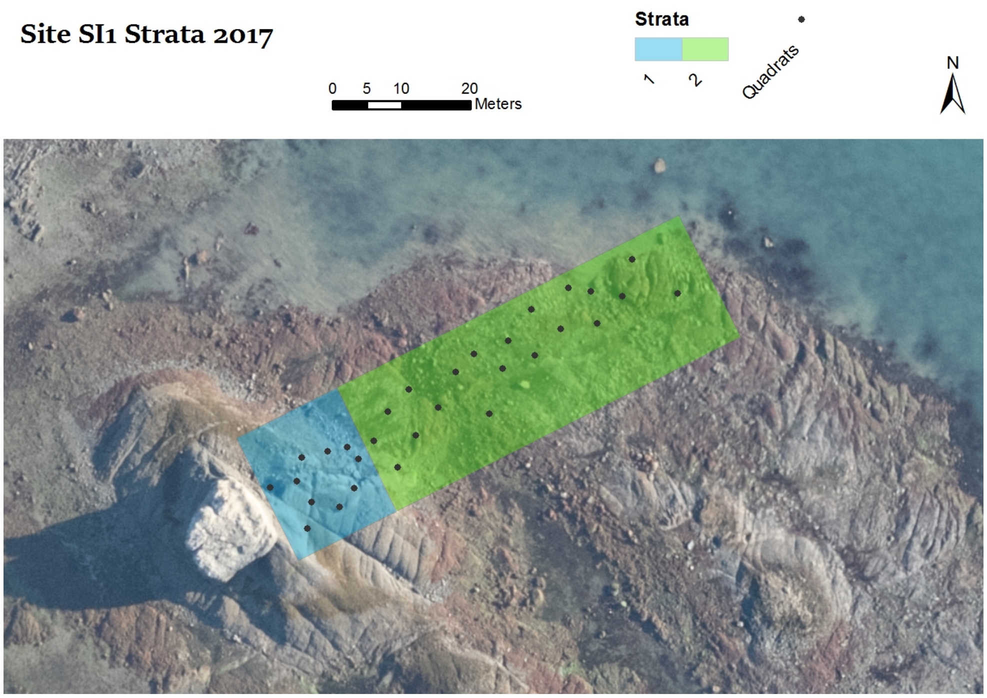


Figure C.21. Site SI1 survey layout in 2017 illustrating strata divisions and quadrat placement.

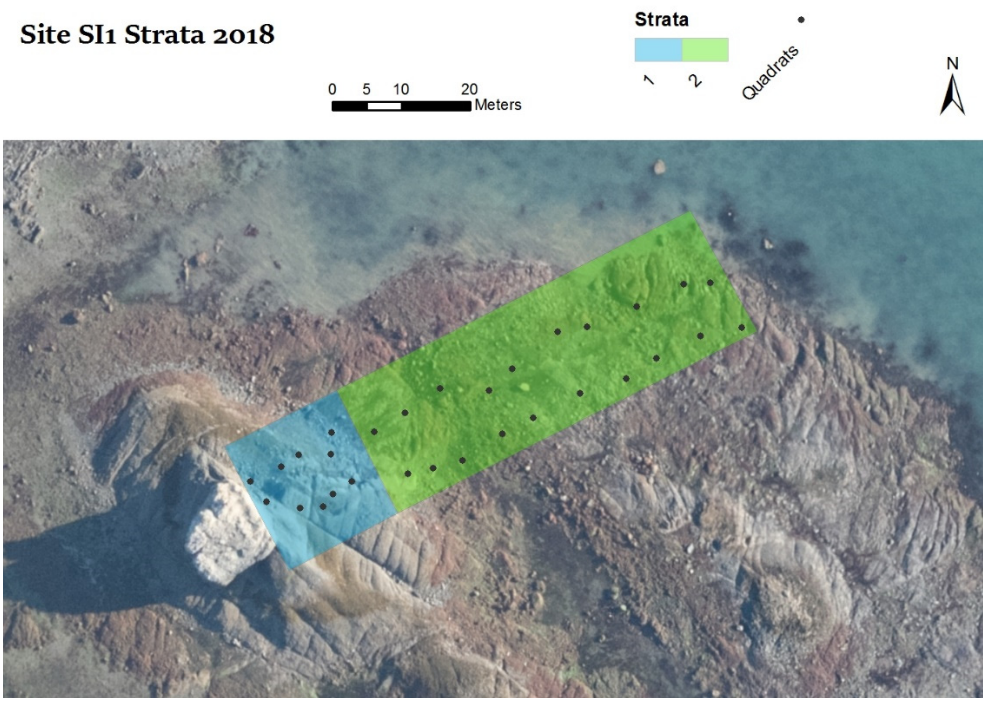


Figure C.22. Site SI1 survey layout in 2018 illustrating strata divisions and quadrat placement.

Figure C.23. Site TR1 survey layout in 2017 illustrating strata divisions and quadrat placement.

Figure C.24. Site TR1 survey layout in 2018 illustrating strata divisions and quadrat placement.

9 Appendix D: Additional Intertidal Assessment Graphs and Analyses

Methods Comparison: Species Richness

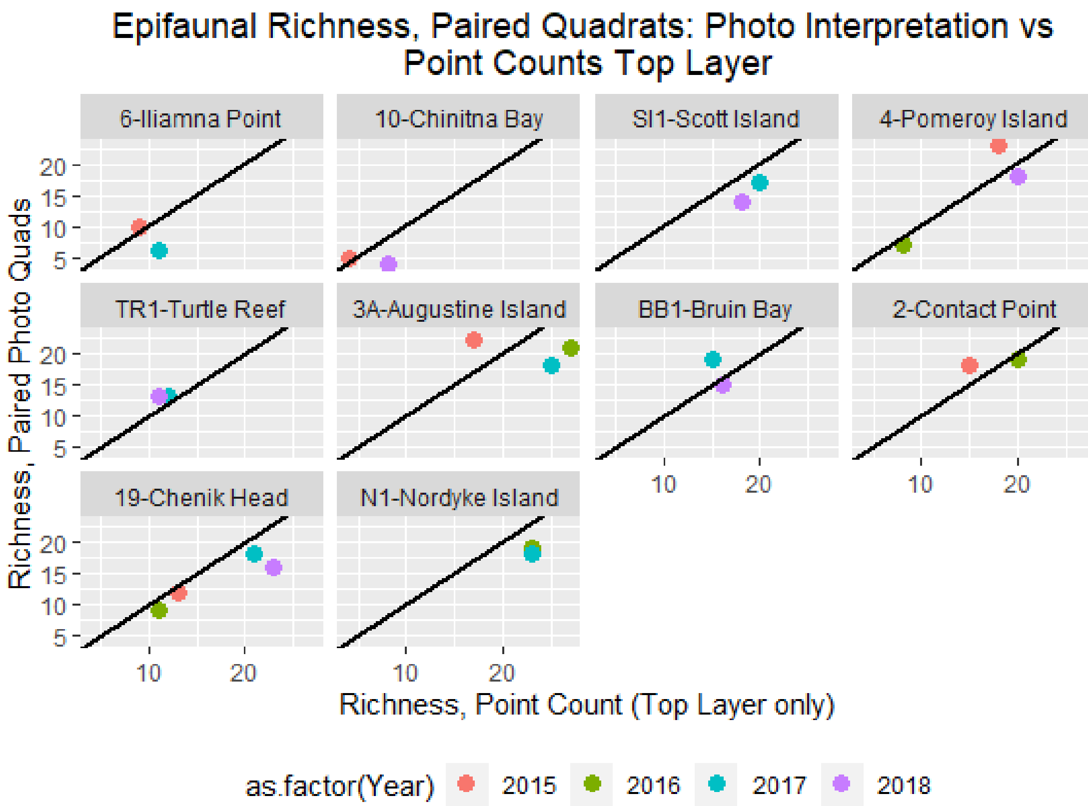


Figure D.1. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epifloral data (using only photo quadrats where point-count quadrat data were also collected) and the "top layer" data from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

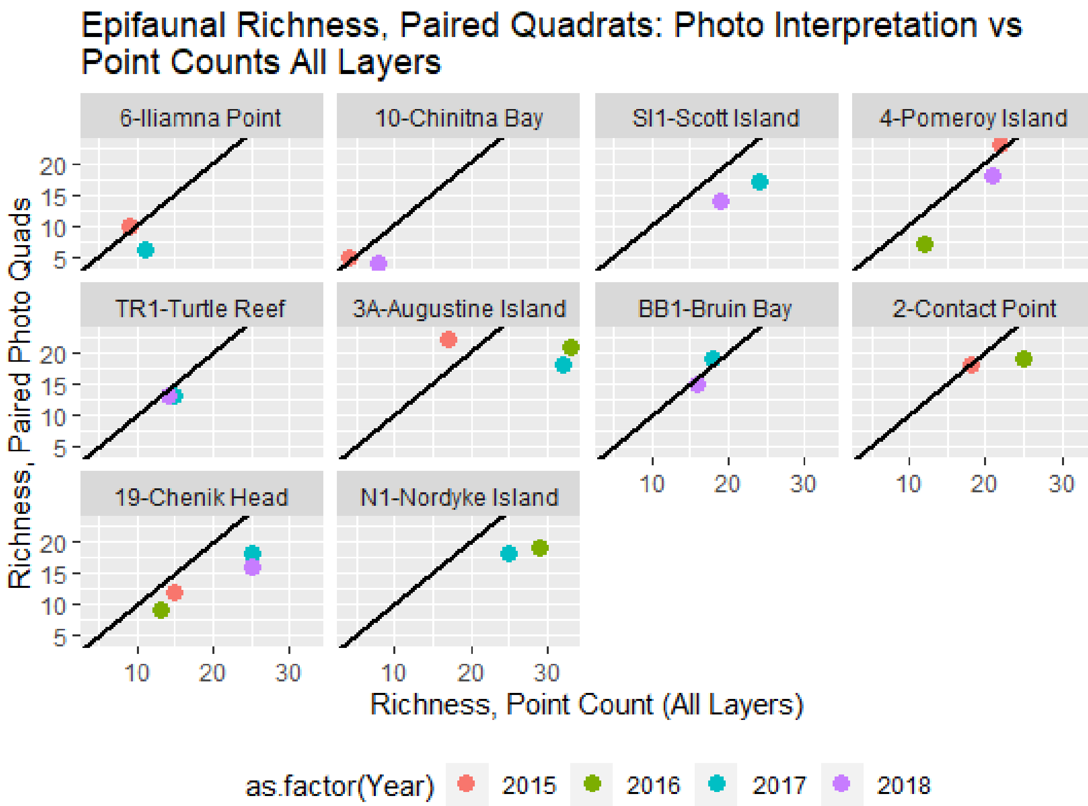


Figure D.2. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epifloral data (using only photo quadrats where point-count quadrat data were also collected) and data for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

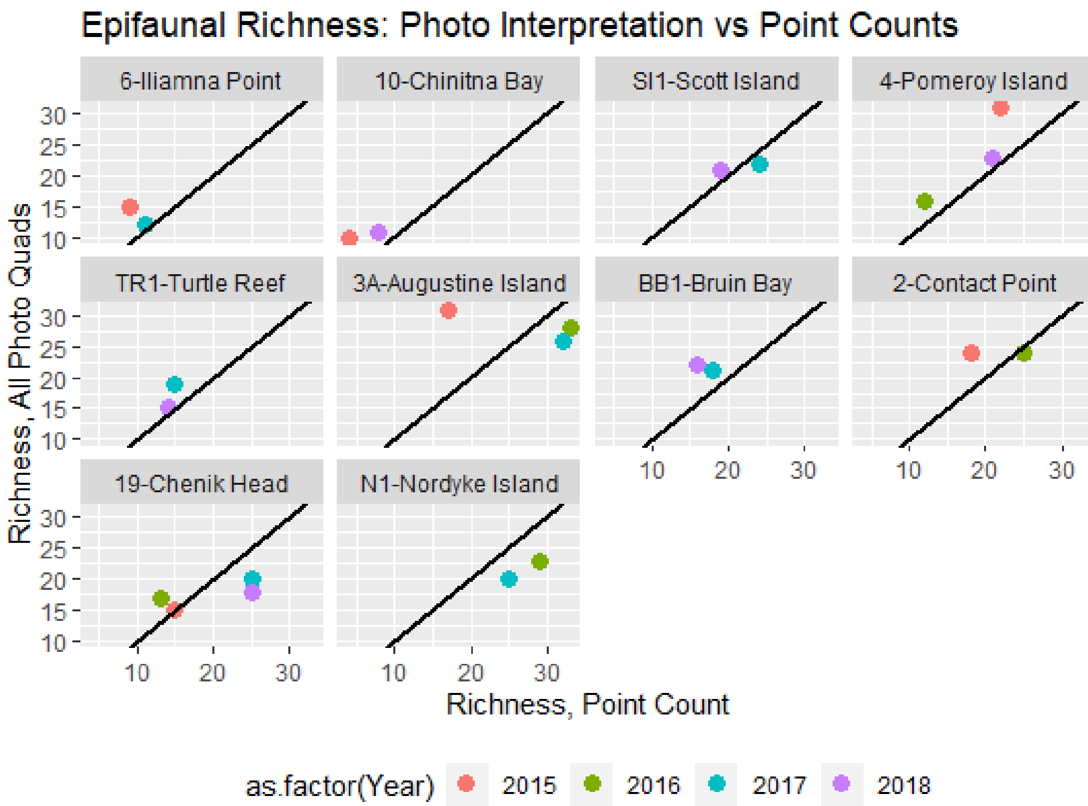


Figure D.3. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat epifloral data (using all photo-quadrat data) and data for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'). Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

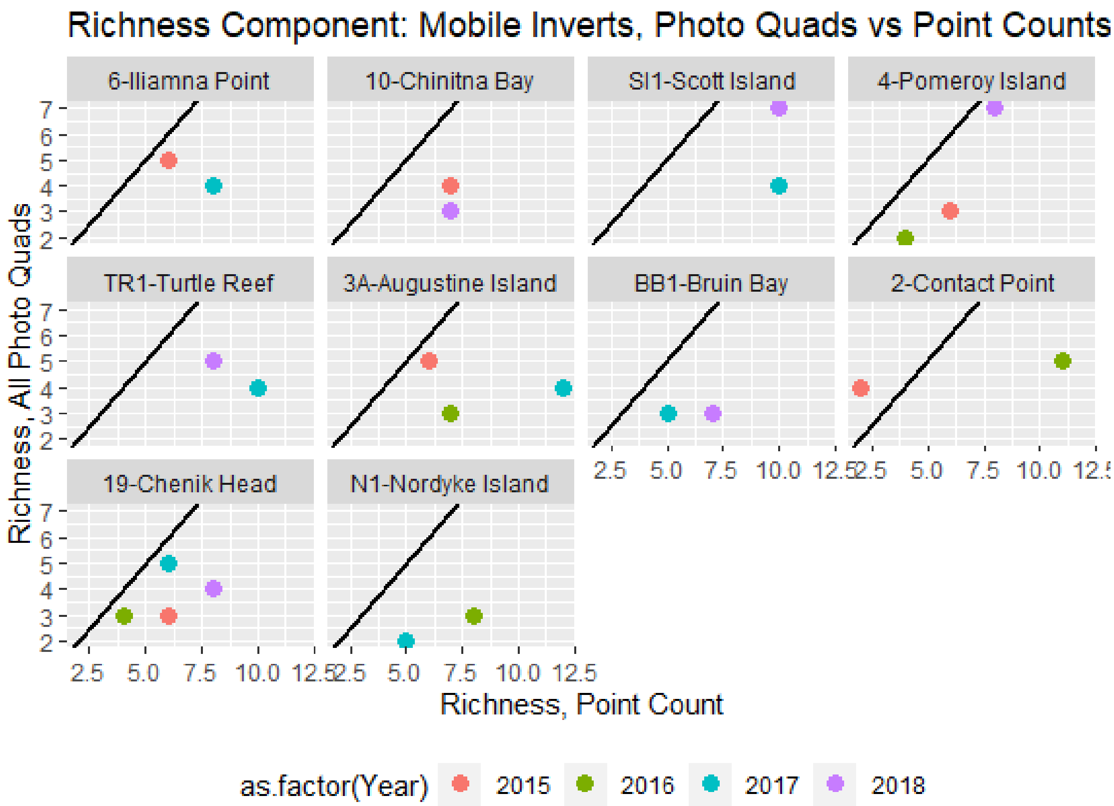


Figure D.4. Graphics showing intertidal site and year data for quadrat richness comparisons of photo-quadrat mobile invertebrates (using all photo-quadrat data) and mobile invertebrates for 'all layers' from point-count quadrats.
The black line is the 1-1 reference line of 'equal richness'. Symbols below the line show greater site richness for point-count quadrat data and symbols above the line show greater richness for photo-quadrat data.

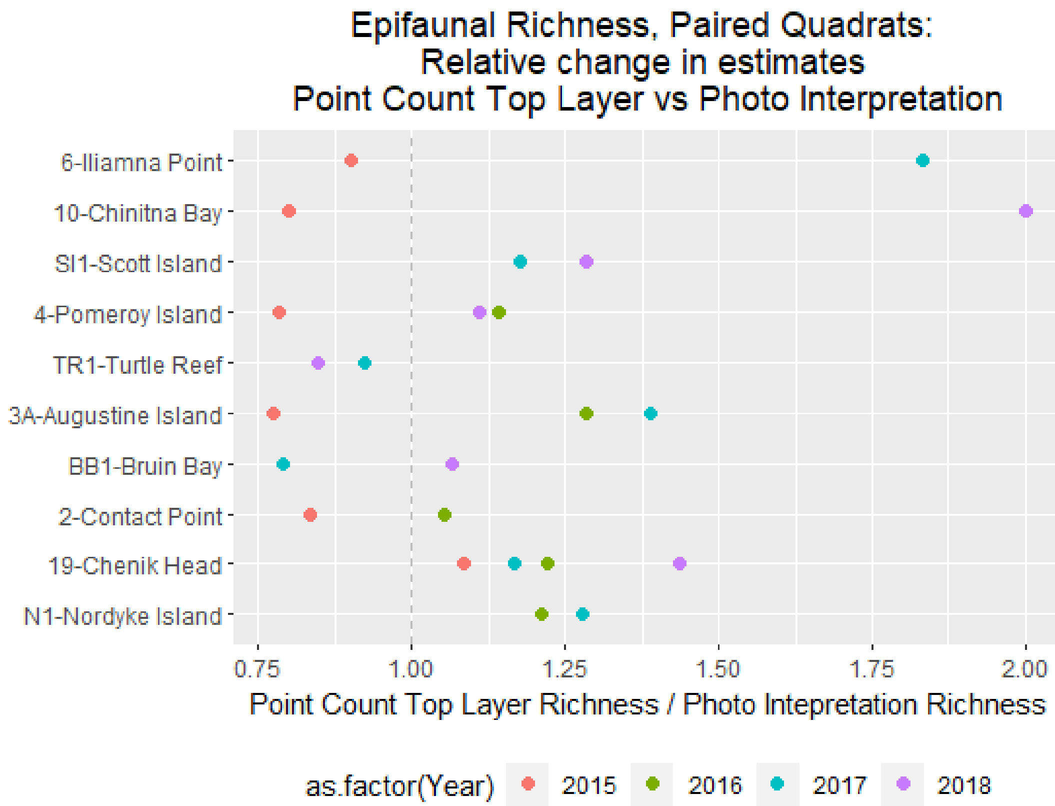


Figure D.5. Intertidal site and year data for all graphs shown in Figure 3.4.1.2.1 as a ratio of the top layer of point-count quadrat data to photo-quadrat data.
The dotted line is a 1-1 'equal richness' reference line and symbols to the left represent higher site species richness for photo quadrats and symbols to the right of the dotted line show higher site species richness for the top layer of point-count quadrat data.

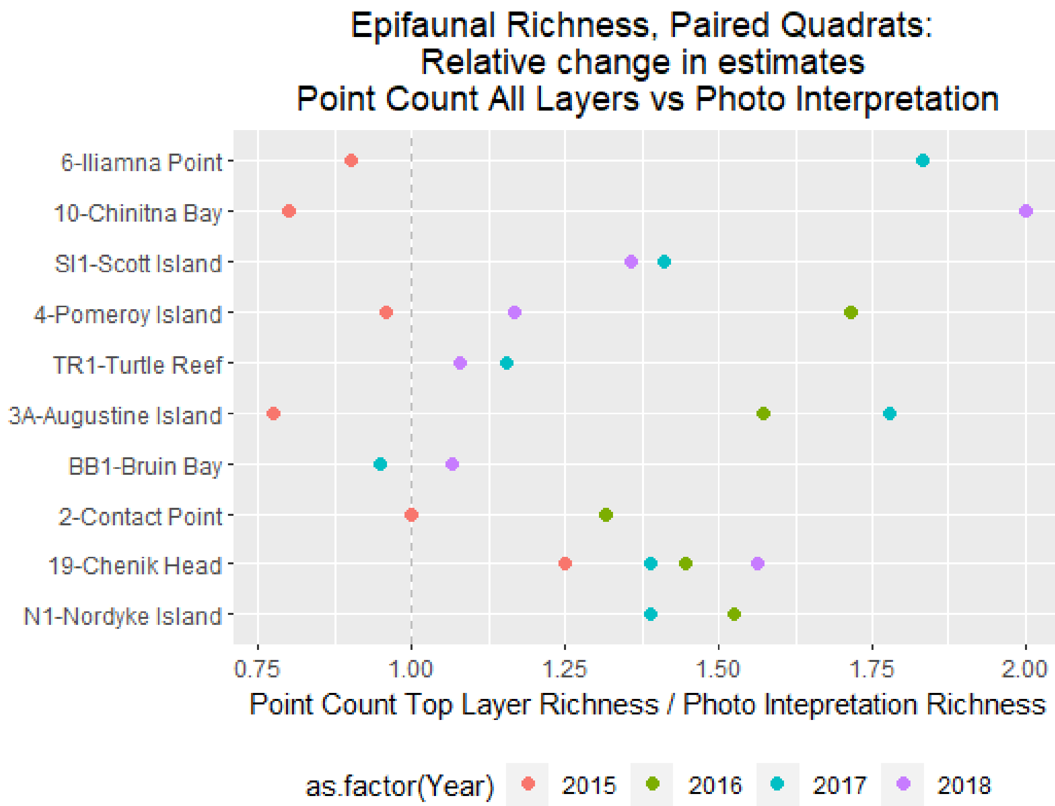


Figure D.6. Intertidal site and year data for all graphs shown in Figure 3.4.1.2.2 as a ratio of all layers from point-count quadrat data to photo-quadrat data.
The dotted line is a 1-1 'equal richness' reference line and symbols to the left represent higher site species richness for photo quadrats and symbols to the right of the dotted line show higher site species richness for all layers of point-count quadrat data.

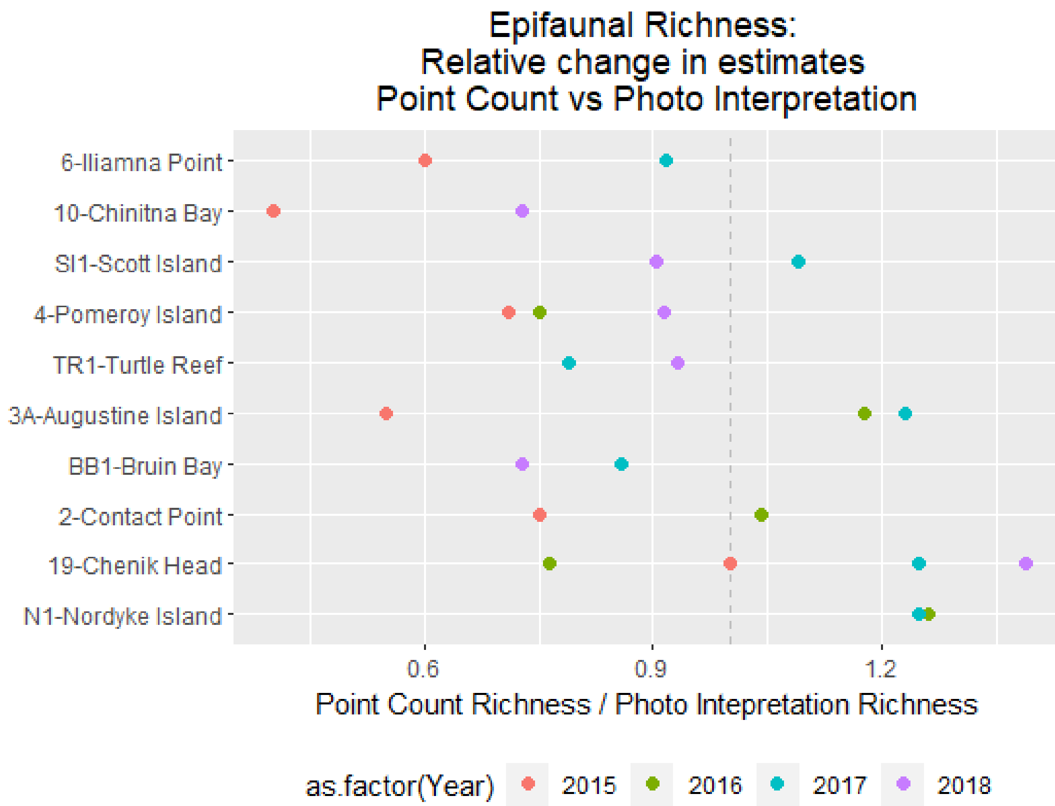


Figure D.7. Intertidal site and year data for all graphs shown in Figure 3.4.1.2.3 as a ratio of all layers from point-count quadrat data to photo-quadrat data.
The dotted line is a 1-1 'equal richness' reference line and symbols to the left represent higher site species richness for photo quadrats and symbols to the right of the dotted line show higher site species richness for all layers of point-count quadrat data.

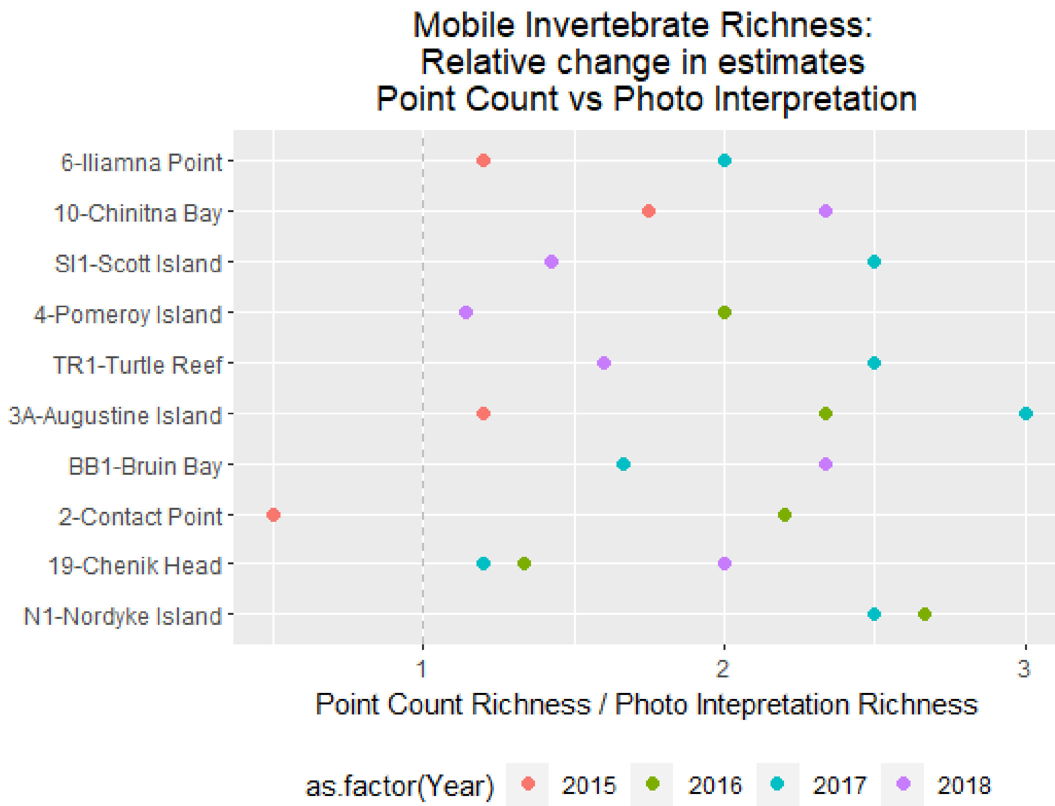


Figure D.8. Intertidal site and year data for all graphs shown in Figure 3.4.1.2.4 as a ratio of mobile invertebrate richness through all layers from point-count quadrat data to photo-quadrat data. The dotted line is a 1-1 'equal richness' reference line and symbols to the left represent higher site species richness for photo quadrats and symbols to the right of the dotted line show higher site species richness for all layers of point-count quadrat data.

Multi-variate Analyses

To gain insight into possible limits of the 2-d nMDS, the Bray-Curtis similarities were also used to construct a minimum spanning tree (Clarke et al. 2014). This was added to the nMDS to check for inconsistencies, e.g., collections directly linked by the tree but whose relative distance in the nMDS plot isn't consistent with such 'closeness' in terms of similarities. Lastly, the similarities were also used in an agglomerative cluster analysis using 'average linkages', another tool for summarizing relationships among collections in terms of their Bray-Curtis similarities. The dendrogram from the cluster analysis was added to the nMDS as another check for inconsistencies between the similarities and the 2-d nMDS map (ibid).

Based on a scree plot of stress values from nMDS under a variety of data transformations and desired number of mapping dimensions, the 4th root transformation was applied. Given that the 2-d and 3-d nMDS solutions still generated stresses in the $0.10 < \text{stress} < 0.20$, attention focused on the 2-d nMDS and using other assessments of consistency to check for higher-dimensional structure obscured in the 2d map.

The Shephard diagram of the final nMDS (Figure D.9) revealed relatively consistent scatter of ordination distances for any dissimilarity value, with not many extreme departures.

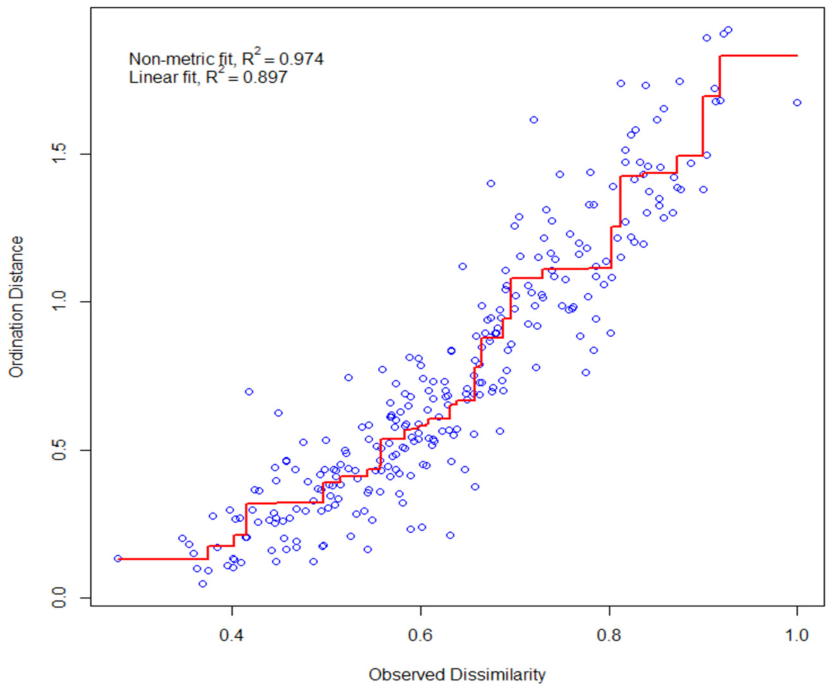


Figure D.9. Shepard plot for a 2-D nMDS of community assemblage data (site-level estimated mean percent cover for each of 82 taxon, see Appendix Table B.1) from ten intertidal non-reef sites and all years of collection under 4th square root transformation.

Before interpreting the nMDS, inconsistencies due to the compression to two dimensions were assessed by adding the minimum spanning tree (Figure D.10) and, then, the cluster analysis dendrogram (Figure D.11) to the nMDS (Figure D.12).

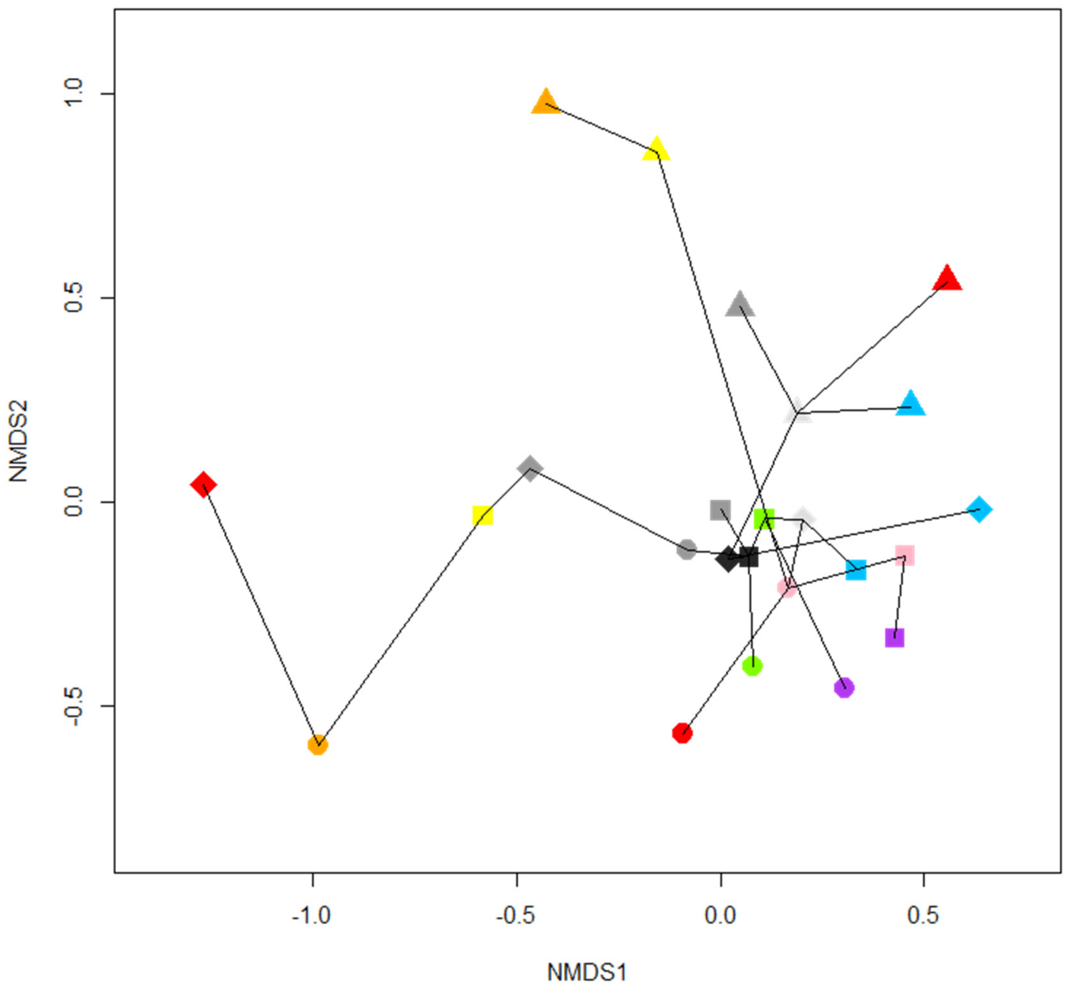


Figure D.10. nMDS with minimum spanning tree added to check for inconsistencies forced by the nMDS's reduction to 2 dimensions.
Inconsistencies appear as crossings of line segments (e.g., a point's closest neighbor in similarity is not the nearest neighbor in the nMDS).

Adding the minimum spanning tree reinforced the general broad scale adequacy of the nMDS but also revealed the presence of some inconsistencies, especially with regard to the tightly visually clustered collections in the lower right quadrant of the plot which clearly have a higher dimensional structure lost in the 2-D nMDS. For example, the minimum spanning tree shows that the 2018 BB1-Bruin Bay assemblage (dark grey circle at NMDS1=0.08, NMDS2=-0.4) is actually closest (hence connected by minimum spanning tree) in terms of Bray-Curtis distances to the 2017 N1-Nordyke Island assemblage (darkest square directly above it), though this 'nearness' is not reflected in the nMDS. Similarly with some of the other collections.

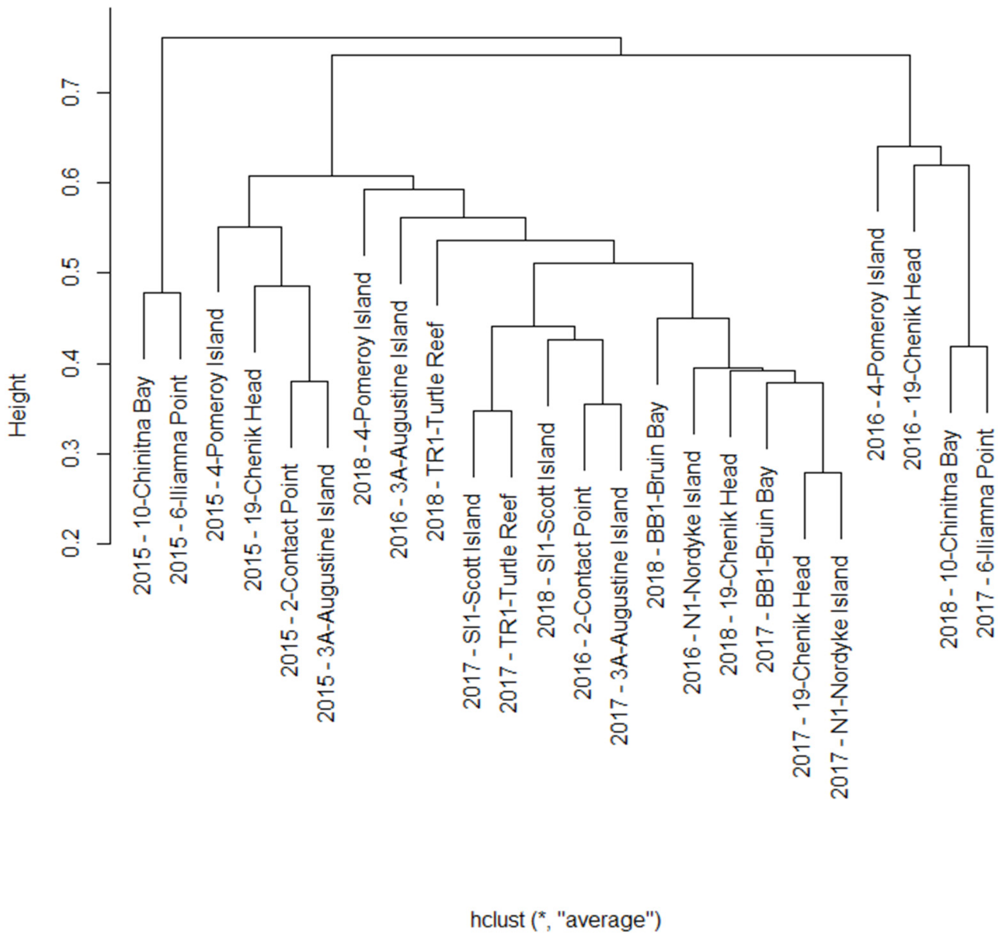


Figure D.11. Dendrogram from cluster analysis of the Bray-Curtis distances among the intertidal community assemblage collections by year visited.

The dendrogram shows the clustering hierarchy with the highest correlation between the similarities from the original Bray-Curtis distance and the dissimilarities estimated from the final dendrogram; the correlation was 0.81. The dendrogram clarified some of the higher-dimensional structure, especially among the more southerly sites (BB1-Bruin Bay, 2-Contact Point, 19-Chenik Head, and N1-Nordyke Island) whose collections are concentrated in the lower right quadrat. Overlain on the nMDS, the dendrogram highlighted the rather complicated relationships among these collections, giving a sense of the limits of interpreting the nMDS too closely.

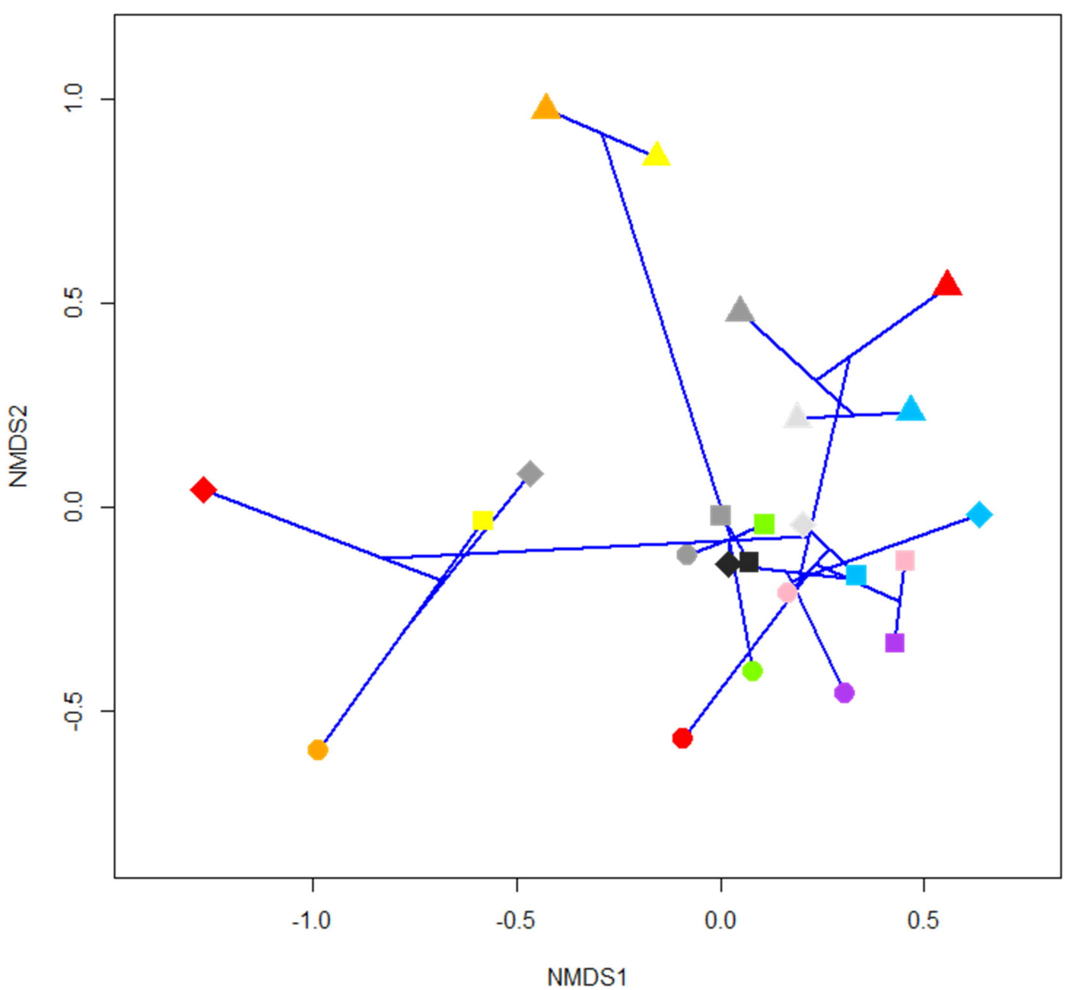


Figure D.12. The nMDS ordination with the hierarchical clustering overlain.