OCS Study
BOEM 2014-657

ShoreZone Mapping of the North Slope of Alaska

Final Report

US Department of the Interior
Bureau of Ocean and Energy Management
Alaska OCS Region
November 12, 2014

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Final Report

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DISCLAIMER

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Introduction

Nuka Research and Planning Group, LLC and partners Coastal & Oceans Resources and Archipelago Marine Research Ltd. submit this final report to the Bureau of Oceans and Energy Management (BOEM) for ShoreZone Mapping of the North Slope of Alaska (Contract No. M11PC00037).

This report provides background on the ShoreZone methodology and the need for its application on the North Slope of Alaska; the project activities conducted, challenges encountered, and deliverables completed; and recommendations for the future expansion and application of ShoreZone mapping to support the assessment of environmental risks.

Background and Need for the Project

Overview of ShoreZone

ShoreZone is a coastal habitat mapping system, originally developed in British Columbia (Howes 2001), Canada, and now applied to the entire coasts of Oregon, Washington and British Columbia, and more than two-thirds of the Alaska coast. The mapping system catalogs coastal geomorphology and biology into searchable databases[1] (NOAA Fisheries 2014). All of the Alaska data are web accessible. The dataset has been used for coastal planning, identification of vulnerable resources, strategic oil spill response, habitat capability modeling, and scientific research (Harper and Morris 2014).

The ShoreZone system classifies coastal segments by combining spatially referenced, oblique aerial video and digital still imagery with interpretation of that imagery by a team of physical and biological scientists. The mapping system, housed in an ArcGIS geodatabase, catalogs both geomorphic and biological coastal resources at effective mapping scales of better than 1:10,000 and provides a spatial framework for coastal habitat assessment on local and regional scales. (Harper and Morris 2014)

Need for ShoreZone on the North Slope of Alaska

The North Slope of Alaska lies on the north side of Brooks Range and includes extensive coastlines along the Chukchi Sea and Beaufort Sea. These shorelines are fundamentally different from most of the coastline in the US as they are consolidated by permafrost and subject to periglacial processes, including cryogenic processes onshore and nearshore seasonal pack ice formation.

These coasts are highly dynamic and undergoing some of the fastest retreat rates in North America (Gibbs and Richmond n.d.). Proposed offshore oil development activities in the

[1] http://alaskafisheries.noaa.gov/shorezone/default.htm

Chukchi Sea coast and existing offshore drilling islands along the Beaufort Sea coast pose environmental risks for these coasts. Environmental concerns include increased air and sea traffic, accidental oil spills, and potential port developments.

BOEM requires up-to-date, digital mapping that can be used to systematically assess these environmental risks. The ShoreZone coastal habitat mapping system provides an attribute-rich, geographic information system (GIS) that can be used to delineate habitats for habitat modeling of a wide variety of coastal species and communities. Associated web-posted imagery plus web-accessible spatial data describing coastal habitats allows easy access by both researchers and regulators.

Project Scope, Goal and Objectives

The spatial scope of the study area is the shoreline and associated intertidal zone along the Alaska North Slope from the Canadian border on the east to Point Hope on the west. Figure 1 depicts the study area and the location of potential ground station sites described in Task 4 below.

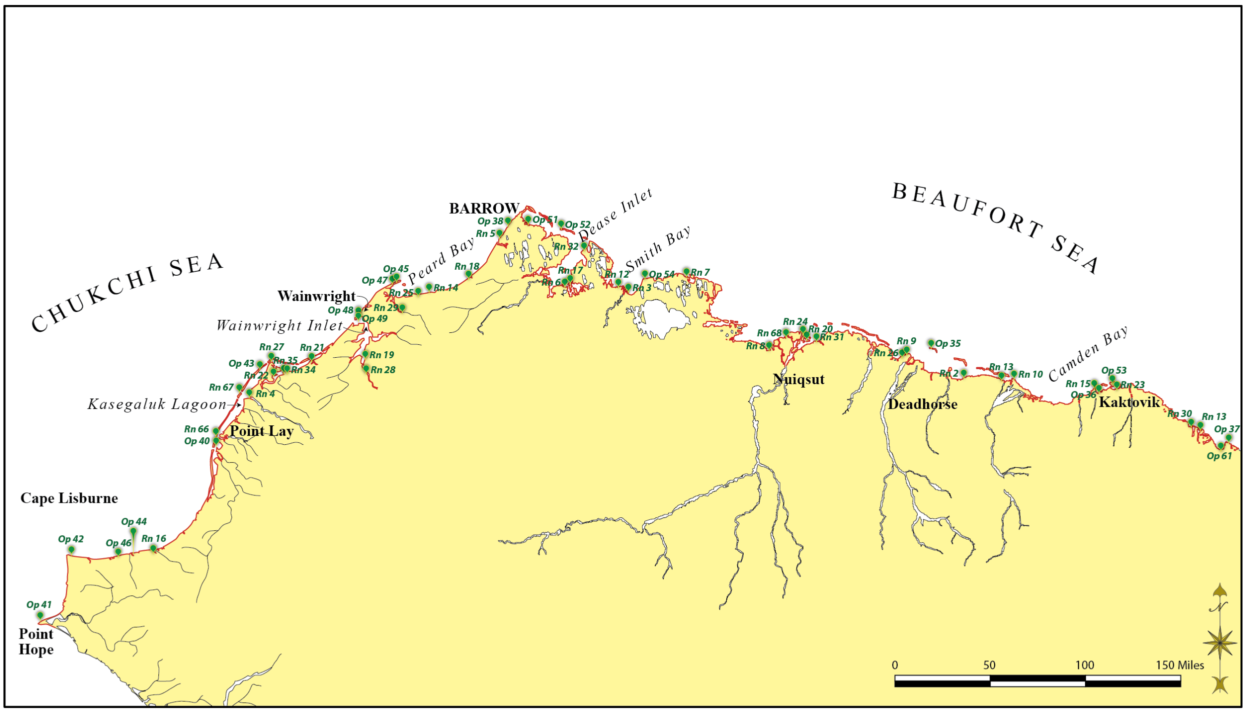

Figure 1. Map of study area and potential ground station sites

The overall goal of the project was to complete ShoreZone mapping for the North Slope for the purpose of facilitating the assessment of offshore oil development risks and to inform other coastal zone management initiatives. The primary project objectives were to (1) use existing videographic and photographic imagery to *complete ShoreZone classifications*; and (2) *collect field data* to verify mapping interpretation, to identify species and community assemblages associated with various mapped habitat types, and to collect new coastal imagery to fill gaps in existing videography where possible.

Specific project objectives were to:

1. Collate and classify existing coastal video imagery for the Chukchi and Beaufort Sea coastlines.
2. Identify gaps in the existing imagery coverage and collect new imagery to fill those gaps.
3. Update the existing Gulf of Alaska ShoreZone mapping protocols to accommodate morphologies and biotic assemblages that occur on the Arctic coasts.
4. Interpret existing coastal imagery following the North Slope ShoreZone protocol to build a searchable biophysical GIS dataset to characterize coastal morphologies, substrates and habitats of the North Slope shoreline.
5. Conduct a ground station survey to verify mapping interpretations and to add detail (e.g., across-shore profiles, species assemblages of biobands) to mapping units (see Harper and Morris 2014; p. 121, Table A-22)
6. Collect sediments samples that can be added to an existing statewide baseline dataset on intertidal hydrocarbons.
7. Make the mapping datasets widely available via the existing National Oceanic and Atmospheric Administration (NOAA) ShoreZone website.

The project's ShoreZone dataset is included with the web-posted data for the state-wide dataset of Alaska. This includes other new mapping of the Arctic coastline in the Kotzebue Sound region, as well as previous mapping completed across the Gulf of Alaska, and creates a contiguous spatial dataset across the state.

Project Implementation

The project was implemented from October 2011 – February 2014, with the fieldwork conducted during the summer of 2012.

Project Tasks

The following tasks were completed for this project:

Task 1. Project Startup Meeting

A Post-Award Conference meeting was held at the BOEM office in Anchorage Alaska on October 13, 2011.

Task 2. North Slope ShoreZone Protocol Development

Prior to the start of the mapping part of the project, the Alaska ShoreZone Coastal Habitat Mapping Protocol was expanded and updated to include attributes for biophysical features of Arctic coasts. The new protocol forms an important part of the deliverables for this project and has been provided as a separate deliverable.

ShoreZone Alaska mapping protocols were previously released in 2004 and 2008, to include procedures for the Gulf of Alaska shoreline from Southeast Alaska to the Aniakchak coast. The new update adds ShoreZone attribute definitions for Alaskan Arctic coasts, where permafrost is one of the dominant factors influencing the biology, landscape morphology and coastal processes.

The primary purpose of this protocol update was to specify standards of mapping and classification to ensure a consistent data standard across Alaska coasts, which has been completed from 2001 to present.

The protocol update was also intended for users who are applying the data to coastal resource management issues, as well as for defining the standards for interpreting imagery and classifying data attributes. Rules for classification of features are listed, along with expanded data dictionary for attributes and photo examples of most biophysical attributes.

In the geomorphic attributes, new 'Form' and 'Material' codes were included to describe Tundra (new *Form*) and Permafrost (new *Material*). Several new Shore Types were also added, to describe the unit-wide 'periglacial dominant structuring process'. New arctic *shore types* are: Lagoon, Inundated Tundra, Ground Ice Slumps, and Low Vegetated Peat.

In the biological mapping, new *habitat class* attributes were added to match the new arctic shore types. Two new *bioareas* were added for Chukchi Sea and Beaufort Sea coasts to help summarize regional differences in coastal habitats. New arctic *biobands* were also defined for Tundra and Biofilm. Characteristic indicator and associated species of biota were described for those new biobands as well as additional characteristic species for other biobands in arctic bioareas. Detailed observations from the shore stations surveys were also incorporated into the protocol definitions and photo examples.

External reviewers provided valuable and constructive feedback on content of the updated document.

Task 3. ShoreZone Mapping

A total of 5,894 km (3,662 mi.) of shoreline were mapped as part of the project; with almost twice the shoreline length occurring on the Beaufort Sea coast in comparison to the Chukchi Sea coast. The shoreline lengths for Shore Types along the North Slope shoreline are shown in Table 1 and summarized in Figure 2.

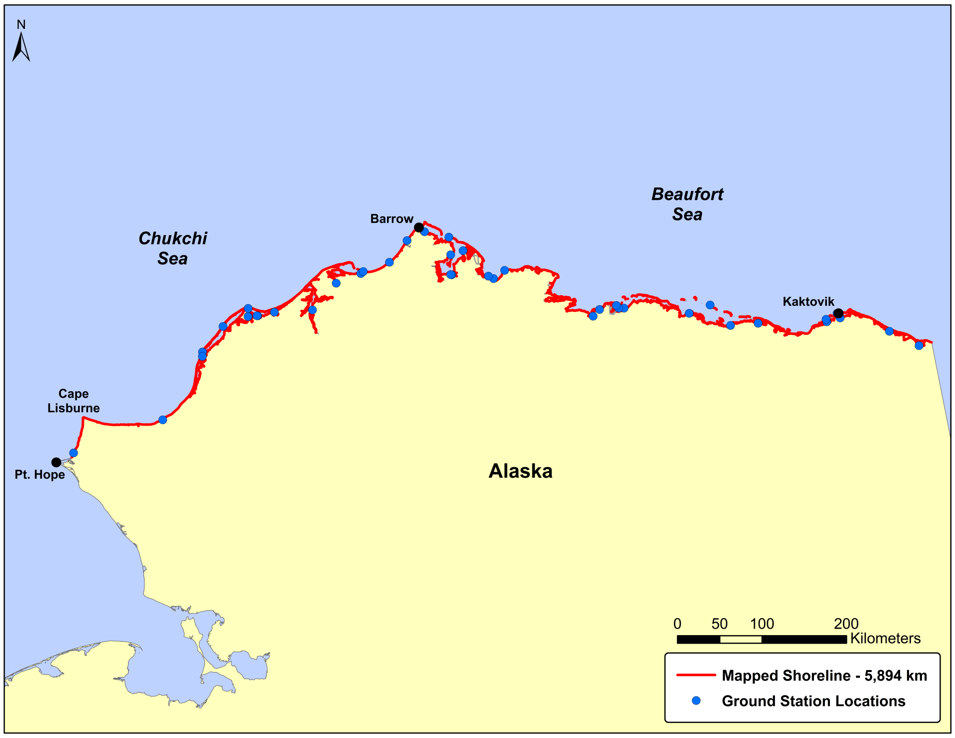

Figure 2. Extent of shoreline mapped and ground station locations. All of the North Slope shorelines are unconsolidated sands and gravel (but bonded by permafrost) except for two very short sections of bedrock at Cape Lisburne to the north of Pt. Hope and Skull cliffs, to the south of Barrow.

Less than two percent of the North Slope shoreline is bedrock (Cape Lisburne and Skull Cliffs to the south of Barrow). The vast majority of shoreline is comprised of unconsolidated sediments. These shorelines are "structured" by a variety of processes (Fig. 3), including *sediment shorelines* (54%) where morphologies are dominated by wave processes, *periglacial shorelines* (37%), where the shoreline morphology is largely controlled by thermal processes, *lagoon shorelines* (5%) where morphology is controlled by processes common lagoons and estuarine shorelines, where estuarine processes (3%) dominate (see Harper and Morris 2014; Table A-14 for additional discussion of structuring processes). There are further categorizations of Shore Types summarized in Table 1. The *Shore Type* is a simple generalization of the dominant substrate and morphology for each units or mapping segment. Sediments are being redistributed along barrier islands and on deltas so sand of sand & gravel flats are relatively common shore types. Permafrost strong influences morphology with inundated tundra. ground-ice slumps and slumping peat shorelines found along nearly 40% of the coast.

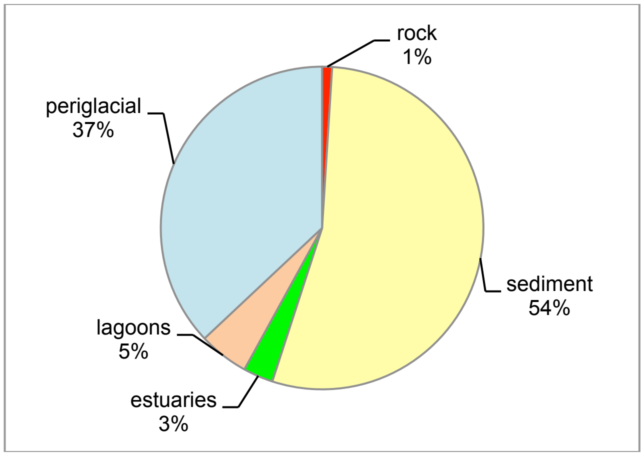

Figure 3. Summary of basic shore types mapped along North Slope shoreline

Table 1. Summary of shore types mapped in North Slope project

Shore Type	Substrate Category	Description	Chukchi Sea		Beaufort Sea		North Slope		Basic Shore Type (%)
			Length (km)	% Total	Length (km)	% Total	Length (km)	% Total	
3	rock	rock cliff	36	1%	--	0%	36	1%	1%
8	rock + sediment	cliff w gravel beach	6	< 1%	2	< 1%	8	< 1%	< 1%
9		ramp w gravel beach	--	0%	1	< 1%	1	< 1%	
13		cliff w S&G beach	10	< 1%	--	0%	10	< 1%	
18		cliff w sand beach	1	< 1%	--	0%	1	< 1%	
21	sediment	gravel flat, wide	3	< 1%	< 1	< 1%	4	< 1%	54%
22		gravel beach, narrow	16	< 1%	5	< 1%	21	< 1%	
23		gravel flat or fan, narrow	7	< 1%	--	0%	7	< 1%	
24		S&G flat or fan, wide	405	7%	278	5%	683	12%	
25		S&G beach, narrow	297	5%	323	5%	620	11%	
26		S&G flat or fan, narrow	207	4%	121	2%	328	6%	
27		sand beach, wide	18	< 1%	37	1%	54	1%	
28		sand flat, wide	217	4%	719	12%	936	16%	
29		mud flat, wide	1	< 1%	130	2%	131	2%	
30		sand beach, narrow	56	1%	342	6%	398	7%	
31	organics	estuarine	46	1%	124	2%	169	3%	3%
32	man-made	anthropogenic, permeable	2	< 1%	15	< 1%	17	< 1%	< 1%
33		anthropogenic, impermeable	--	0%	3	< 1%	3	< 1%	
36		lagoons	162	3%	147	2%	309	5%	5%
37	periglacial	inundated tundra	81	1%	714	12%	796	13%	37%
38		ground ice slumps	277	5%	371	6%	649	11%	
39		low vegetated peat	229	4%	487	8%	715	12%	
		Totals:	2,075	35%	3,819	65%	5,894	100%	100%

The occurrence of biobands on the Beaufort and Chukchi Sea coasts is summarized in Table 2 and Figure 4. It is important to note that these biobands are all within the "marine limit" and can be occasionally flooded during storm surges. A *Continuous* distribution indicates that the bioband is observed in more than 50% of the unit and a *Patchy* distribution indicates that the bioband is present, but in less than 50% of the unit (see Harper and Morrris 2014; Tundra is the most common bioband along these coasts and a considerable length of the North Slope shoreline (~70%) has the Tundra biobands mapped. Salt Marsh is also common (42%) and is more frequently inundated. Remaining biobands occur along less than 10% of the coastline.

Table 2. Summary of biobands mapped in North Slope project

Bioband Code	Bioband Name	Chukchi Sea		Beaufort Sea		North Slope			
		Patchy (km)	Continuous (km)	Patchy (km)	Continuous (km)	Patchy (km)	Continuous (km)	Patchy (%)	Continuous (%)
VER	Splash zone	--	2	--	--	--	2	< 1%	< 1%
TUN	Tundra	94	1,340	18	2,797	111	4,136	2%	70%
GRA	Dune Grass	313	236	109	38	422	274	7%	5%
SED	Sedge	128	56	605	164	733	220	12%	4%
PUC	Salt Marsh	386	625	640	1,870	1,026	2,495	17%	42%
ULV	Green Algae	21	8	59	23	80	31	1%	1%
RED	Red Algae	--	2	< 1	--	< 1	2	< 1%	< 1%

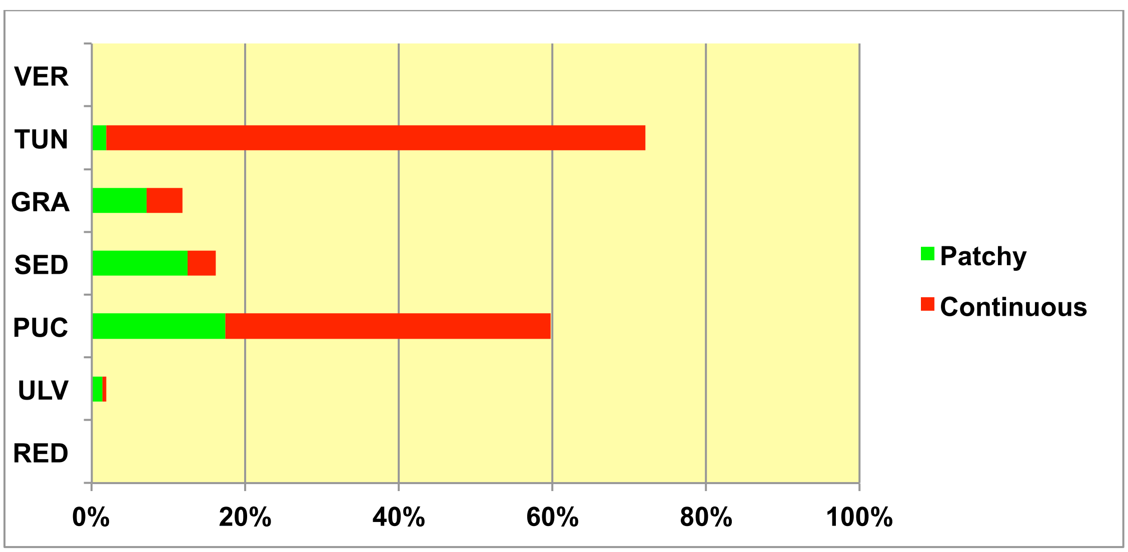

Figure 4. Summary of biobands mapped in North Slope project

Task 4. Conduct ShoreZone Ground Station Surveys

The shore station sites were visited August 1 through 18, 2012 and 42 shore stations were documented, with 25 on the Beaufort Sea coast and 17 on the Chukchi Sea coast. Across shore profiles and observations of biophysical features were recorded, including species present and geo-referenced photos. ShoreZone exposure categories, description of coastal substrates and morphologies, and shore type were also noted.

The Validation or verification portion of the project was designed to provide a field check of the aerial mapping interpretations. The concept was that approximately 50 ground stations would be sampled by a field crew and that the ground data would then be compared to the aerial mapping data. We modified the procedure somewhat by imaging each of the shore units that encompassed the ground station site. The "low and slow" imagery was considered to be equivalent to a crew walking the entire unit. In that way, the "ground" unit could be compared to the "aerial" mapping unit. A Validation Report is included as Appendix A and completely describes the methodology and results.

*Shore typ*e and *ESI type* have exact to close matches for 60-70% of the units compared and poor matches for <15% of the comparisons. An audit of poor matches identified sources of differences as: (a) a mapping location error (one case), (b) ShoreZone's poor characterization of delta morphologies and (c) differences in water level and morphology between originals surveys and the 2012 ground surveys. *Exposure* and *ORI* have exact or close matches above 90%. *Habitat Class*, a general indicator of the biophysical nature of the unit, showed close matches in more than 89% of the comparisons.

Exact to close matches ranged from 95% (*Biofilm bioband*) to 62% (*Sedge bioband*). Detectability appears to be greatest for *Tundra* and *Biofilm biobands* (missed in only 5% of the units) and poorest for *Dune Grass* and *Sedge biobands* (missed in ~30% of the units). False positives were least for the *Dune Grass* and *Biofilm biobands* (<5%) and greatest for *Salt marsh* and *Tundra biobands* (~15%).

Task 5. Database Management and Web Posting

In terms of the organization the ShoreZone dataset, there are two primary elements: (1) the digital shoreline (i.e., a shape file), which is segmented into alongshore units where each unit receives a unique identifier and (2) a relational database that includes physical and biological information of each unit. The digital shoreline and relational database are linked through the unit identifier and combined into a single Geodatabase. The Geodatabase is the primary GIS deliverable for the project. North Slope data were added to the state-wide coverage and posted to the NOAA Alaska ShoreZone website (http://alaskafisheries.noaa.gov/shorezone/).

The shore station data were compiled in the existing Alaska Shore Station database and formatted for inclusion in the newly-redesigned NOAA hosted on-line shore station dataset, which is integrated with the main NOAA ShoreZone website. All shore station data, including species lists, example photos, site descriptions and other attributes can be viewed through the ShoreZone website, and downloads of data summary for species observations and photos are available from the site (Figure 5).

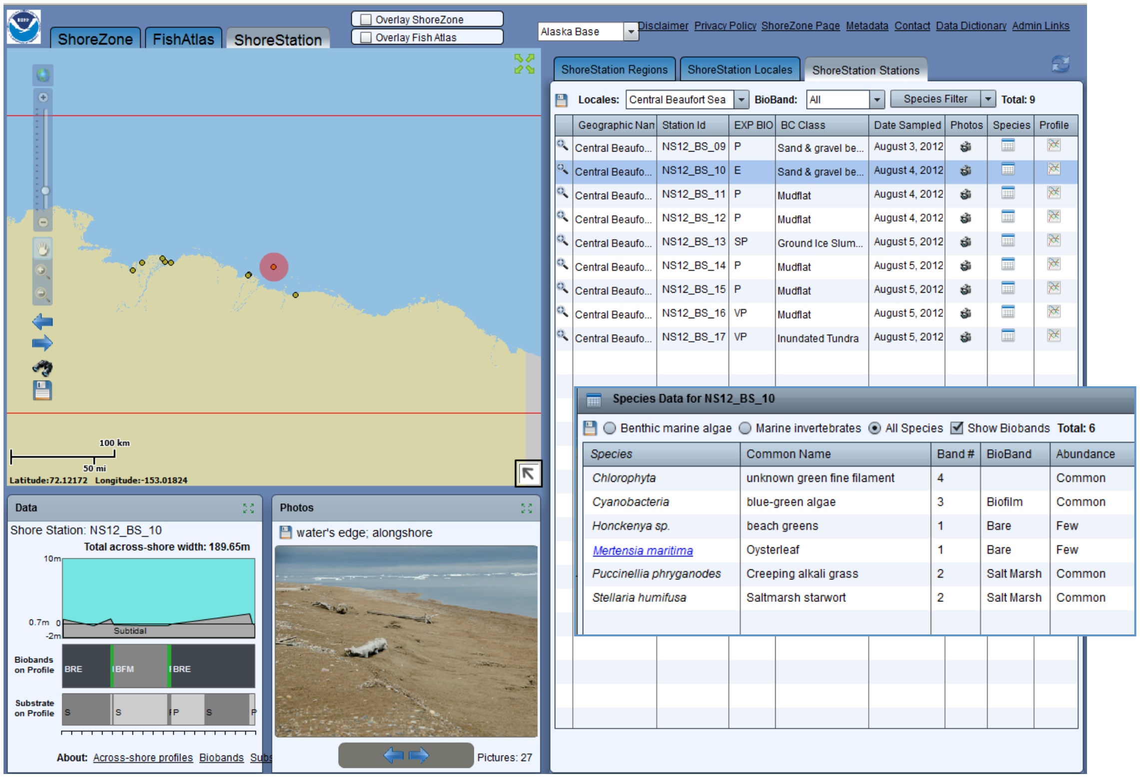

Figure 5. Example showing web-posted shore station data for Beaufort Sea station (NS12_BS_10), including station species list, across-shore profile diagram, and example photo http://alaskafisheries.noaa.gov/habitat/shorestation/default.htm; http://alaskafisheries.noaa.gov/mapping/szflex/index.html?T=SS@L=B

Task 6. Program Management

General program management tasks included both initial and occasional follow-up meetings with the project team as well as quarterly reporting. Permitting and consultations with various entities related to the field work was a significant program management task, but was not referenced in the Request for Proposals. We suggest that future such projects should consider this project burden.

Additional Deliverables

The project was presented with a poster display at the Alaska Marine Science Symposium on January 21-25, 2013 (Coon et al 2013). A poster was also presented at the Symposium on January 20-24, 2014 (Coon et al 2014). The posters are attached as Appendices B and C, respectively.

Nuka Research distributed DVDs created by Coastal and Ocean Resources Inc. with coastline imagery to the communities that provided permits or other cooperation with the fieldwork in the summer of 2012. This was done as part of the education and outreach work.

A peer review paper is in progress for completion within the project period by 2015.

Challenges and Modifications to the Work Plan

Our original estimate of the shoreline length of the project area was 4,431 km (2,753 mi.), based on the Coast63 digital shoreline, and the final mapped shoreline length of 5,900 km (3,666 mi.), representing a 33% increase over the original estimate. The substantial increase in shoreline length stretched our resources during the mapping effort.

In addition, some of the older imagery was challenging to use as it was flown with a fixed-wing aircraft and tended to "round" the coast in many locations. This 2001 imagery also had no associated photos, just videography collected to a "digital video or "DV" resolution. The mapping of the head-waters of some estuaries suffered because of the poorer resolution imagery. While the gap-infill program of the 2012 field survey addressed missing sections of shoreline, the 2012 field survey did not always collect imagery in sections where poorer imagery existed. Overall, we estimate that this challenge affected no more than 5% of the coastline and that the more poorly imaged areas were usually within low-energy estuaries with low-vegetated peat shorelines (Shore Type 39) or estuarine shorelines (Shore Type 31)

As noted, the permitting and consultations required for the field work presented a significant challenge and effort to ensure the necessary access for the collection of imagery and ground station data.

Recommendations for Future Expansion and Application of ShoreZone in the Arctic Region

In conclusion, we offer the following recommendations for the future expansion and application of the ShoreZone mapping methodology in the Arctic Region:

1) The Alaska North Slope is one of the most at-risk shorelines in the United States as a result of the near-coast proximity of oil exploration and production facilities. Proposed offshore drilling also contributes to the risk. Much of the coast is also highly sensitive, being comprised of organic-rich shorelines in low-energy areas. As such, the coastline is considered both high-risk and of high sensitivity. The

remoteness of the coast from logistical support will be a significant challenge should accidental spills occur.

Spill response planning could be improved by acquiring state-of-the-art aerial imagery the coast, in formats and resolution similar to the 2012 shoreline imagery collected as part of this BOEM project. Given the risk and sensitivity of this coast, the North Slope shoreline should be the model for high-resolution imagery that can be used in planning and in emergency response.

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Appendices A-C

APPENDIX A: VALIDATION REPORT
APPENDIX B: 2013 ALASKA MARINE SCIENCE SYMPOSIUM POSTER
APPENDIX C: 2014 ALASKA MARINE SCIENCE SYMPOSIUM POSTER

Appendix A. Validation Report

11-18 12 November 2014

North Slope ShoreZone Verification Project

prepared by: John Harper, Coastal & Ocean Resources
Mary Morris, Archipelago Marine Research Ltd.

prepared for: Nuka Planning and Research LCC
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SUMMARY

As part of a coastal habitat mapping project of the North Slope of Alaska that used the ShoreZone mapping protocol, ground station data were collected to compare to mapping data. The ground stations were surveyed at 39 randomly-chosen sites along the 6,000 km shoreline of the North Slope. As part of the ground station survey, “low and slow” aerial imagery was collected during 2012 for the entire shore unit in which each ground station was located. The “low and slow” imagery was collected at speeds of 20 knots from elevation of <20m so the imagery is considered equivalent to “walking the unit.” The unit was then mapped following the ShoreZone mapping protocol (Harper and Morris 2014) but using the “ground imagery” to classify morphology, substrate and biota within the unit. This mapping is termed the *Ground Mapping Data* and was then compared to the *ShoreZone Mapping Data*, which used previously collected aerial imagery (collected in 2001, 2006, 2009) to create a standard ShoreZone dataset. Comparison the *Ground Mapping Data* to the *ShoreZone Mapping Data* provides a means estimating the level of confidence in the aerial mapping data.

Unit attributes provide general information about the entire unit and include: the *Shore Type*, the *ESI Shore Type*, the *Wave Exposure Class*, the *Oil Residence Index (ORI)* and the *Habitat Class*. Shore type and ESI Type have exact to close matches for 60-70% of the units compared, and poor matches for <15% of the comparisons. An audit of poor matches identified sources of differences as: (a) a mapping location error (one case), (b) ShoreZone’s poor characterization of delta morphologies and (c) differences in water level and morphology between originals surveys and the 2012 ground surveys. *Exposure* and *ORI* have exact or close matches above 90%. *Habitat Class*, a general indicator of the biophysical nature of the unit, showed close matches in more than 89% of the comparisons.

The ShoreZone dataset also includes information on the occurrence of *biobands*, which are recognizable assemblages of biota that have a unique color/texture signature and can be mapped. The *biobands* are very elevation dependent, extending from the supratidal to the shallow, subtidal. On the North Slope, all the *biobands* are in the supra tidal and upper intertidal zones; the mobility of the sediments prevents intertidal and subtidal biota from attaching to the fixed substrate. Biobands mapped on the North Slope include: the *Tundra (TUN) bioband*, the *Dune Grass (GRA) bioband*, the *Sedge (SED) bioband*, the *Salt Marsh (PUC) bioband*, the *Biofilm (BFM) bioband* and the *Green Algae (ULV) bioband*. Exact to close matches ranged from 95% (*Biofilm bioband*) to 62% (*Sedge bioband*). Detectability appears to be greatest for *Tundra* and *Biofilm biobands* (missed in only 5% of the units) and poorest for *Dune Grass* and *Sedge biobands* (missed in ~30% of the units). False positives were least for the *Dune Grass* and *Biofilm biobands* (<5%) and greatest for *Salt marsh* and *Tundra biobands* (~15%).

It is clear that one of the sources of difference between the “ground survey” data and the “aerial mapping data” is the time difference between the aerial surveys (some occurred in 2001) and the ground survey (2012). Difference in water levels between the two surveys was a factor in several of the poor matches. In one case, the morphology changed (from an eroding cliff to a prograding beach) between the two surveys. Also, all of the aerial mapping interpretation was completed prior to the ground survey program, so detailed observations from the ground survey program could not inform the aerial mappers. *In future programs of this type it is recommended that ground and aerial survey programs are conducted at the same time to minimize temporal changes between the surveys and to allow ground data to inform the mapping team.*

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As part of the North Slope ShoreZone mapping project, BOEM desired a comparison component where detailed ground information could be used verify the ShoreZone mapping classification, which is based on interpretation of aerial videography and photography. This component of the project was developed to establish a verification protocol.

Approach

Our overall approach was to collect very detailed aerial imagery that could be used to classify the unit. This detailed aerial imagery is assumed to be equivalent to "walking the unit" and making detailed "ground observations." The "ground observation" would then be used to classify the unit using the standard ShoreZone mapping protocol.

Because there may be some alongshore variability associated with each ShoreZone mapping unit, the use of observations from a single ground station would not provide sufficient information to verify the mapping for an entire unit (which average around 750 m in length). To address this issue, the field crew collected "low and slow imagery" for the shore unit in which each randomly-selected, ground station fell; the "low and slow video imagery" was considered equivalent to "walking the unit" and making systematic "ground observations." We refer to the mapping data derived from standard ShoreZone imagery to as the *ShoreZone Mapping Data,* and the classification data from the "low and slow videography" as the *Ground Mapping Data*. The same classification protocol (Harper and Morris 2014) was used for both datasets so that comparison provides a systematic means of checking a dataset based on high resolution imagery to a dataset based on lower resolution imagery. The *Ground Mapping Data* are assumed to be "correct" and the standard against which the *ShoreZone Mapping Data* are compared.

Although the *Ground Mapping Data* are assumed to be "correct", there are a number of reasons that *ShoreZone Mapping Data* and *Ground Mapping Data* might differ:

(1) Small differences in water-level elevation can result in differences in the visible morphology and resulting classification. Because the tides in the Beaufort and Chukchi Seas are driven primarily by meteorological events, they cannot be predicted and there is no way to work around this issue. The tidal effect may result in an interpretation difference, *neither of which is incorrect*.
(2) Different mappers may characterize the morphology features slightly differently. Unit-level classifications that involve generalization of more detailed mapping observations (i.e., lumping) are often challenging. This caveat on generalization applies to both aerial and ground interpretations. Although there are mapping rules in place to minimize differences in generalizations, such differences may occur and neither is incorrect.
(3) There are sections of poor coastal imagery that were used in the aerial interpretation surveys (especially 2001 and 2006 imagery). Poor imagery could contribute to poor interpretation. In this case, the ground observations are very likely to be "better" and "correct" in comparison to the aerial classifications.

Identification of Ground Station Locations

The sites used in the verification component of the North Slope ShoreZone projects are summarized in Table 1 and the distribution shown in Figure 1. The original plan was to verify 50 sites but because of weather and other logistical constraints, only 40 stations were completed. On one station, ground station information was collected but no shoreline imagery was collected. The total number of comparable stations is 39.

ShoreZone and Ground Mapping Comparisons

Physical Unit Data

The ShoreZone data is compiled into four primary tables within the geodatabase: the Unit, the BioUnit, the Across-shore Component and the BioBand tables. The unit databases include attributes that apply to the entire unit. For example, *Wave Exposure* is the same for the entire unit. Also the *Shore Type* is a general description of morphology for the entire unit (e.g., wide rock platform or narrow rock cliff). And the BioUnit features include a general unit *Habitat Class*.

A senior geologist and a senior biologist classified the unit attributes using the 2012 "low and slow" imagery, and a classification for the unit was completed according to the ShoreZone protocol (Harper and Morris 2014) in which the ground station occurs.

The next step was to compare the *ShoreZone Mapping Data* to the *Ground Mapping Data* on a unit-by - unit basis. Because each of the unit attributes is quite different, match criteria were developed for each attribute (Table 2) using a one to five match scale; a *one* rating indicates the match was basically identical and a *five* rating indicates a very poor match. In some cases where there a many values for a unit attribute (e.g., there are 39 different *Shore Types*), five match categories are used but on attributes with only a few values (e.g., *Wave Exposure* has five exposure categories) only three match categories are used (e.g., 1, 3 or 5).

All of the unit attribute comparisons that were classified as *moderately poor* to *poor* (4 or 5) were checked by a side-by-side review of imagery used in the *Aerial Mapping Data* and in the *Ground Mapping Data* (Appendix A). To minimize any review bias, two mappers participated in this review and provided a conclusion as to each classification. Where it was felt that a classification error associated with the *Ground Mapping Data*, the match class was revised to reflect an updated assessment.

BioUnit Data

BioUnit features compared *Biological Wave Exposure* and *Habitat Class*. Wave exposure categories are normally defined by observations of biota in each unit, which is considered to be the 'best available exposure estimate'. However, on the North Slope coast, most of the shoreline is dominated by mobile sediment beaches where attached biota are largely absent. On those bare beaches, the "best available wave exposure" estimate is the attribute assigned by the physical mappers determined from wave fetch observations and expert knowledge. Comparisons of the wave exposure values in the *ShoreZone Mapping Data* and the *Ground Mapping Data* are based on the physical mappers', *Exposure Observed,* so no *Biological Wave Exposure* comparisons were made.

Table 1 Verification Units and Associated *Ground Mapping Data* Classifications

ID	ShoreZone Unit ID	Station	SHORE TYPE	SHORE TYPE DESCRIPTION	ESI	ESI TYPE DESCRIPTION	EXP_OBSER
1	18/05/0090/00	OP69	37	Inundated tundra	10E	inundated, low-lying tundra	Very Protected
2	18/05/0559/00	RN30	37	Inundated tundra	!0E	inundated, low-lying tundra	Protected
3	18/05/0271/00	RN23	30	narrow sand beach	3C	tundra cliffs	Protected
4	18/05/1435/00	OP53	38	ground ice slump	3C	tundra cliffs	Semi-Exposed
5	18/05/1346/00	OP36	37	Inundated tundra	9B	vegetated low banks	Very Protected
6	18/05/1500/00	RN15	27	wide sand beach	4	coarse sand beach	Semi-Exposed
7	18/04/1067/00	RN10	27	wide sand beach	5	S&G beach	Semi-Exposed
8	18/04/3232/00	RN02	25	narrow S&G beach	5	S&G beach	Semi-Protected
9	18/04/3604/00	OP55A	25	narrow S&G beach	5	S&G beach	Protected
10	18/04/3603/00	OP55N	25	narrow S&G beach	5	S&G beach	Semi-Exposed
11	18/04/4062/00	RN09	29	mudflat	9A	sheltered tidal flat	Very Protected
12	18/04/4061/00	RN26	29	mudflat	9A	sheltered tidal flat	Very Protected
13	18/04/0005/00	RN31	38	ground ice slump	3C	tundra cliffs	Protected
14	18/04/0001/00	RN20	29	mudflat	9A	sheltered tidal flat	Very Protected
15	18/04/5168/00	RN24	29	mudflat	9A	sheltered tidal flat	Very Protected
16	18/04/5194/00	RN68	29	mudflat	9A	sheltered tidal flat	Very Protected
17	18/04/5086/00	RN08	37	Inundated tundra	10E	inundated, low-lying tundra	Protected
18	18/03/1176/00	OP54	38	ground ice slump	3C	tundra cliffs	Semi-Exposed
19	18/03/1143/00	RN03	29	mudflat	9A	sheltered tidal flat	Very Protected
20	18/03/1142/00	RN12	37	Inundated tundra	10E	inundated, low-lying tundra	Very Protected
21	18/03/1013/00	RN32	38	ground ice slump	3C	tundra cliffs	Semi-Protected
22	18/03/0140/00	OP51	38	ground ice slump	3c	tundra cliffs	Protected
23	18/03/0377/00	OP71	31	estuarine or organic	9B	vegetated low banks	Protected
24	18/03/0532/00	RN06	31	estuarine or organic	9B	vegetated low banks	Very Protected
25	18/03/0048/00	OP52	24	wide S&G flat	5	S&G beach	Semi-Exposed
26	18/02/2059/00	RN29	38	ground ice slump	3C	tundra cliffs	Very Protected
27	18/02/1022/00	RN25	38	ground ice slump	3C	tundra cliffs	Protected
28	18/02/1021/00	RN14	25	narrow S&G beach	5	S&G beach	Protected
29	18/02/1023/00	RN18	38	ground ice slump	3C	tundra cliffs	Semi-Exposed
30	18/02/1024/00	RN04	24	wide S&G flat	5	S&G beach	Semi-Exposed
31	18/02/1016/00	RN19	25	narrow S&G beach	5	S&G beach	Very Protected
32	18/02/1010/00	RN27	29	mudflat	9A	sheltered tidal flat	Very Protected
33	18/02/1011/00	RN35	38	ground ice slump	3C	tundra cliffs	Very Protected
34	18/02/1012/00	RN22	38	ground ice slump	3C	tundra cliffs	Very Protected
35	18/02/1008/00	RN67	24	wide S&G flat	5	S&G beach	Semi-Exposed
36	18/02/1013/00	RN21	30	narrow sand beach	9A	sheltered tidal flat	Very Protected
37	18/02/1006/00	RN66	24	wide S&G flat	5	S&G beach	Semi-Exposed
38	18/01/1005/00	OP40	25	narrow S&G beach	5	S&G beach	Protected
39	18/01/3079/00	OP100	3	narrow rock cliff	1A	exposed rocky shore	Semi-Exposed

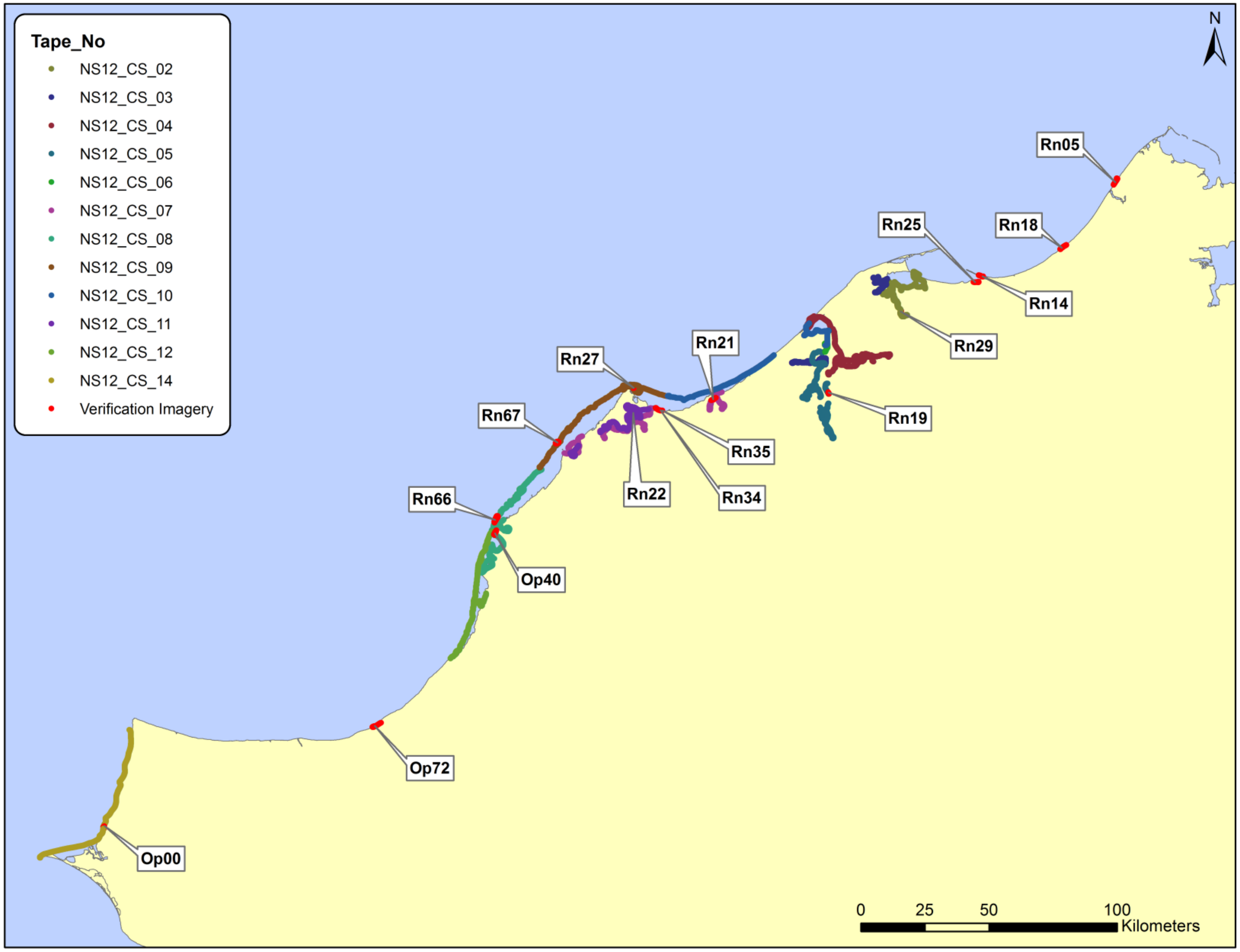

Figure 1a. Ground stations surveyed along the Chukchi Sea coast in 2012.

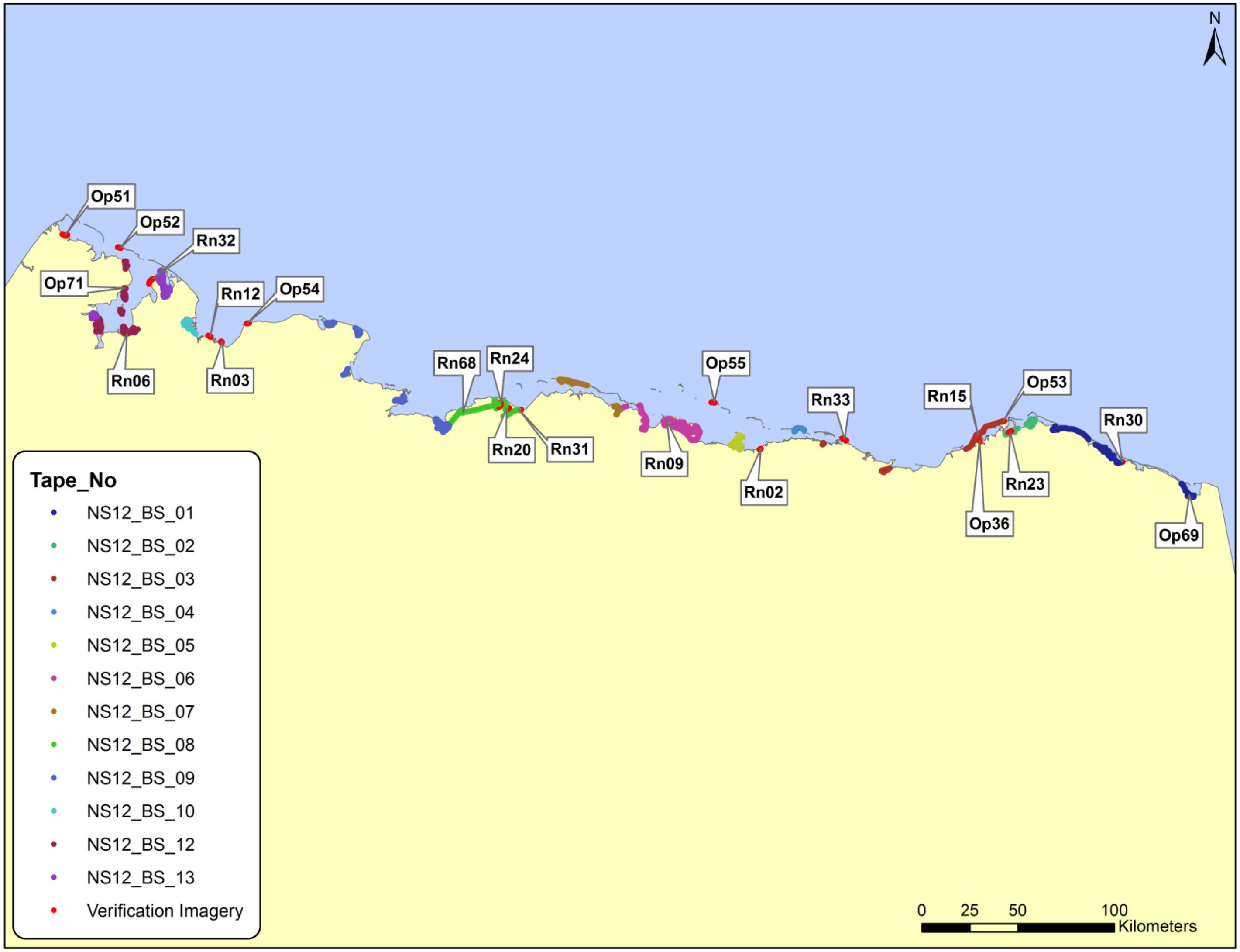

Figure 1b. Ground stations surveyed along the Beaufort Sea coast in 2012.

Table 2 Criteria Used for Assignment of Match Classes

Attribute	Exact Match 1 (exact match)	2 (close)	3 (moderate)	4 (moderate)	Mismatch 5 (poor)	Number of Attribute Classes
Shore Type	Identical shore type	Category off by minor substrate, usually gravel or width category	Category off by substrate that would change oil retention	Category off by several factors but basic morphology correct	Doesn't appear to be related at all	39
ESI type	Identical ESI Number	Category within 2 ESI Types	Category within 3 ESI types	Category off by several factors but basically morphology correct	Doesn't appear to be related at all	27
Exposure	Identical categories	Category one off between VP and P	Category one off		Category 2 or more off	6
ORI	Identical		Category one off		Category 2 or more off	5
Sediment Source	Identical		Not definitive (one interpre-tation missing)		Disagree	5
Sediment Abundance	Identical		Off one category		Off two categories	3
Sediment Transport Direction	Identical		Not definitive (one interpre-tation missing)		Disagree	8
Shore Change Type	Identical		Off one category		Off two categories	3
Intertidal Width Estimate	With 10m	Within 20 m	Within 30 m	Within 30m to 50m	Difference >50m	many
Habitat Class	Identical or match dominant structuring process and exposure within one class		Dominant structuring process differs but wave exposure match		Both structuring process and wave exposure differ	46

Habitat Class is determined from the 'best available wave exposure' together with the 'dominant structuring process' for each unit. Wave energy is the most common 'dominant structuring process'. Wave energy on sediment shorelines determines the substrate mobility and defines *Habitat Class* for *immobile, partially mobile,* or *mobile* habitats. Other common structuring processes on habitat on Arctic coasts include: estuarine, lagoonal, and periglacial processes. The habitat class category is assigned from a lookup table of the best available wave exposure (for the North Slope, the physical *Exposure Observed*) together with the *Shore Type* (which has dominant structuring process embedded within the *Shore Type* categorization). The match rationale for comparing the two estimates of *Habitat Class* are summarized in Table 2.

Bioband Data

Biobands in ShoreZone mapping are assemblages of biota that are recognizable features that have unique color and textures surfaces. Each *Bioband* typically has a wave exposure preference, and the collective observation of several *Biobands* can often be used to define exposure (i.e., biological wave exposure). *Biobands* are most common on stable or partially stable substrates that allow a stable epibiotic community of animals and plants to attach. Few *Biobands* are observed on the Arctic coast because the substrates are mobile and unstable. Almost all of the Arctic *Biobands* are in the supratidal and uppermost intertidal. The *Biobands* are assigned in one or more across-shore components (A1, A2, B1, B2, etc) and as a result have a one-to-many relationship with unit level attributes. For the purposes of this analysis, *Bioband* data were "flattened" and summarized to the unit level. In this manner, the maximum distribution of each observed *Bioband* was recorded once per unit, permitting the direct comparison of presence/absence and relative abundances between the *ShoreZone Mapping Data* and the *Ground Mapping Data*.

Bioband distribution was recorded in both the *ShoreZone Mapping Data* and the *Ground Mapping Data* as one of three values (Not observed = blank, Patchy distribution = P, or Continuous distribution = C). *Bioband* comparisons were scored as an *exact* match, *close* match, *aerial missed* or *ground missed* according to the criteria listed in Tables 3. Unlike the other attributes in the physical mapping, many of the bioband attribute values can be 'null', as the biobands are 'not observed' in the majority of cases. Where both the aerial and the ground mapping data observation for Biobands were 'null', the comparison was recorded as a 'match' but in a separate category (Table 3).

Where a bioband is recorded in the *Ground Mapping Data* but not the *ShoreZone Mapping Data*, this difference helps to define 'detection limits' of the bioband, where biobands had sparse vegetation cover or were present in small patches which are not visible in the aerial imagery.

Table 3. Criteria Used in Comparisons for *Biobands*

Match Category	Definition	Match Criteria
1	Match	Match of "absent" or blanks in both datasets
2	Match	Both Ground and ShoreZone Mapping Data record and at exactly the same value
3	Near Match	Bioband is recorded in both Ground and ShoreZone Mapping Data but with different distribution codes
4	Aerial Missed	Bioband recorded in the Ground Mapping Data not recorded in the ShoreZone Mapping Data (may define 'detection limit' of aerial observations)
5	Ground Missed	Bioband recorded in the *ShoreZone Mapping Data* but not recorded in the *Ground Mapping Data*, possibly due to changed conditions between timing of (older) aerial imagery and ground imagery or due to other error of interpretation.

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Unit Comparisons

ShoreZone *Shore Type*

There are 39 classes for the *Shore Type* attribute. For the 39 units that were compared, 67% are 1 (exact) or 2 (close) matches (Table 4). An additional 26% are 3 (moderate) matches. Only 8% are 4 (moderately poor) or 5 (poor) matches.

Table 4 *Shore Type* Comparison

Match Category	Count	% Match
1	9	23%
2	17	44%
3	10	26%
4	2	5%
5	1	3%
	39	*100%*

Given that this is a key attribute for many practical applications, we examined the 8% of the comparisons (4 or 5 match classes) to understand the nature of the poor matches (Appendix A). In one case there was a location error by the mapper, in two cases, ground stations within a delta sampled only a very small portion of the unit and did not provide adequate representation of the entire, long unit (>7 km). In several cases differences in water level variation between surveys resulted in different classification and in one case, the morphology had changed significantly between the two surveys. It was notable that interpretation differences due to poor imagery did not contribute to any of the class 4 or 5 mismatches that were audited.

Implications for Future Work: *The use of old imagery (collected 11 years prior to the ground survey program) contributed to some of the Level 4 & 5 errors. Water level variations, changes in shoreline morphology and the noted mapping error would not have occurred if the aerial and ground survey imagery be collected at the same time.*

ESI Shore Type

The *ESI Type* comparisons have a similar distribution to the *Shore Type* comparisons (above) with 69% exact or close and another 23% classed as a moderate match (Table 5). 8% are considered *moderately poor* to *poor* matches.

Table 5 *ESI Type* Comparison

Match Category	Count	% Match
1	11	28%
2	16	41%
3	9	23%
4	2	5%
5	1	3%
	39	*100%*

The moderate to poor (4 and 5) matches were reviewed (Appendix A) and a comment made on each of these reviews. Basically the same issues discussed above contributed to differences in the two classifications.

Implications for Future Work: *The use of old imagery (collected 11 years prior to the ground survey program) contributed to some of the Level 4 & 5 errors. Water level variations, changes in shoreline morphology and the noted mapping error would not have occurred if the aerial and ground survey imagery be collected at the same time.*

ShoreZone *Exposure*

Approximately 98% of the exposure comparisons were exact or close (Table 6).

Table 6 *Exposure* Comparison

Match Category	Count	% Match
1	24	62%
2	14	36%
3	1	3%
5	0	0%
	39	*100%*

The initial comparison of exposures was poor and revealed a systematic problem with the classification of exposure. Mappers used standard fetch rules of the protocol but these rules failed to account for nearly complete ice cover during much of the year and an ice-limited fetch window created by offshore ice pack during open-water seasons. Also mappers failed to initially consider the effect of shoals and very shallow nearshore gradients on wave energy. As a result, the exposure characterization used in the *Aerial Mapping Data* was reviewed and revised for the entire North Slope dataset using expert knowledge (Harper, Schoch). For this attribute the verification process identified a systematic error that could be corrected.

***Implications for Future Work:** In most ShoreZone projects, observations of intertidal biota are used to estimate exposure. However, in arctic regions where intertidal biota are rare, fetch measurements are used to estimate exposure categories. In future projects for arctic regions, it is important that expert knowledge be conveyed to mappers prior to initiation of mapping.*

Oil Residence Index (ORI)

Oil Residence Index is based on a combination of shore type information and exposure classification, where higher exposures lead to shorter duration of stranded oils on the shore. As such, it is not an "observed" attribute but rather a "derived" attribute based on both observed information (substrate and morphology) and measured information (exposure based on fetch data). With the ORI comparisons, 62% are *exact* matches and additional 31% are *moderate* matches. About 8% are classified as *poor* matches (Table 7).

Table 7 ORI Comparison

Match Category	Count	% Match
1	24	62%
3	12	31%
5	3	8%
	39	*100%*

***Implications for Future Work:** The ORI estimates are derived from a lookup table of Shore Type (substrate type) and Exposure. Given that Exposure values appear to be reliable (Table 6), improvement of ORI estimates would occur if substrate estimates are improved. We note that the aerial survey interpretations were more likely to underestimate gravel occurrence, possibly due to poorer image quality. As mentioned previously, if aerial and ground survey imagery is collected at the same time, the ground data would help calibrate the mapper's aerial interpretation.*

Other Unit attributes were compared and are summarized in Appendix B. As these attributes are rarely used in analyses and modeling they are considered less significant than the unit attributes of *Shore Type, ESI Type, Exposure and Oil Residence Index*.

Habitat Class

The Habitat Class provides an overall descriptor of the key habitat-controlling features within a unit, including the dominant structuring process, the energy and the nature of the substrate. The comparison between the Ground Mapping Data and the ShoreZone Mapping Data (Table 8) indicate a match or near match in 89% of the units. An estimated 10% are poorly matched.

Table 8 Habitat Class Comparison

Match Category	Count	% Match
1	32	82%
3	3	7%
5	4	10%
	39	*100%*

The Habitat Class is a derived attribute based on two observed features: *Shore Type* (that incorporates dominant, structuring process) and *Exposure*. The mobility of the substrate is also important and is related to the combination of substrate size and exposure. As such, the Habitat Class is a complex, derived attribute.

Implications for Future Work: *like the ORI estimates discussed above, the Habitat class is derived from a lookup table of Shore Type (substrate type) and Exposure. Given that Exposure values appear to be reliable (Table 6), improvement of Habitat Class estimates would occur if substrate estimates are improved. We note that the aerial survey interpretations were more likely to underestimate gravel occurrence, possibly due to poorer image quality. As mentioned previously, if aerial and ground survey imagery is collected at the same time, the ground data would help calibrate the mapper's aerial interpretation and improve overall quality of mapping.*

BioBand Comparisons

Aerial mapping data was compared with the ground mapping data for six biobands observed in the 39 units in the study (Table 9). The most commonly observed biobands were the *Tundra* (TUN) and the *Salt Marsh* (PUC) biobands which occurred in 64% and 56% of the *Ground Mapping Data* and *ShoreZone Mapping Data*, respectively. *Dune Grass* (GRA) and *Sedges* (SED) were also common, occurring in more than a third of the ground units. *Green Algae* (ULV) and *Biofilm* (BFM) were the least common, both occurring in only a few the ground mapping observations.

Table 9. Biobands Occurrence

Bioband	Aerial	Ground	% of Total Units where Bioband Ground Mapped
TUN (tundra)	28	25	64%
GRA (dune grass)	5	15	38%
SED (sedge)	5	14	36%
PUC (salt marsh)	23	22	56%
BFM (biofilm)	0	2	5%
ULV (green algae))	4	5	13%

In Table 9, where the "aerial" number exceeds the "ground" number it suggests there may have been false-positives (e.g., TUN bioband) but where the "ground" number exceeds the "aerial" number, it suggests that there is a resolution or detection limit where biobands are just not seen in the aerial imagery because of in sufficient resolution. The GRA and SED biobands appear to be most sensitive to detection limit.

Comparisons of match scores between *ShoreZone* and *Ground Mapping Data* for each *Bioband* are summarized in Table 10. Note that this table considers the "absence" category as an observation.

Table 10. Summary of Matches for Biobands, Comparing SZ Mapping to Ground Mapping

ShoreZone Mapped Value	Ground Mapped Value	Match Category	Match Definition	Count (n = 39)	% of Count	Summary %
Tundra (TUN)						
blank	blank	1	--	9	23%	82%
P/C	P/C	2	Match	18	46%	
P or C	C or P	3	Near Match	5	13%	
blank	P or C	4	SZ Map Missed	2	5%	18%
P or C	blank	5	Ground Miss (false-positive)	5	13%	
Dune Grass (GRA)						
blank	blank	1	--	23	59%	70%
P/C	P/C	2	Match	3	8%	
P or C	C or P	3	Near Match	1	3%	
blank	P or C	4	SZ Map Missed	11	28%	31%
P or C	blank	5	Ground Miss (false-positive)	1	3%	
Sedge (SED)						
blank	blank	1	--	22	56%	62%
P/C	P/C	2	Match	1	3%	
P or C	C or P	3	Near Match	1	3%	
blank	P or C	4	SZ Map Missed	12	31%	39%
P or C	blank	5	Ground Miss (false-positive)	3	8%	
Salt Marsh (PUC)						
blank	blank	1	--	11	28%	72%
P/C	P/C	2	Match	10	26%	
P or C	C or P	3	Near Match	7	18%	
blank	P or C	4	SZ Map Missed	5	13%	28%
P or C	blank	5	Ground Miss (false-positive)	6	15%	
Biofilm (BFM)						
blank	blank	1	--	37	95%	95%
blank	P or C	4	SZ Map Missed	2	5%	5%
Green Algae (ULV)						
blank	blank	1	--	31	79%	82%
P/C	P/C	2	Match	1	3%	
blank	P or C	4	SZ Map Missed	4	10%	18%
P or C	blank	5	Ground Miss (false-positive)	3	8%	

Tundra (TUN) Bioband

For the common *Tundra* (TUN) bioband, 82% of observations were considered as 'match' or 'near match' (Table 10). The ShoreZone "missed" category reflects a possible detection limit and occurred in only 5% of the compared units. The ground mapping data "missed," (the "false positive" category) occurred in 13% of the comparisons.

Dune Grass (GRA) Bioband

The dune grass (GRA) Bioband compared favorably in 70% of the compared units (Table 10). The ShoreZone mapping missed the *Dune Grass* (GRA) bioband in 28% of the units, indicating that higher densities of the bioband are required for detection. There are relatively few false positives of the *Dune Grass* (GRA) bioband (3%).

Sedge (SED Bioband

About 62% of the compared units matched or closely matched for the *Sedge* (SED) bioband (Table 10). With 31% of the units missing the *Sedge* (SED) bioband in the ShoreZone mapping, it is clear that larger or denser concentrations of sedges are required to be detected. An estimated 8% of the comparisons showed false positives.

Salt March (PUC) Bioband

An estimated 72% of the comparisons for the *Salt Marsh* (PUC) bioband are matches or close matches (Table 10). However, a relatively high percentage of poor matches also occurred – 28% - of which 13% are detection mismatches and 15% are false positives.

Biofilm (BFM) Bioband

The Biofilm (BFM) bioband had a good match comparison (Table 10) although all of the 37 matches are for *absence* matches (in both the ShoreZone and Ground Mapping data, "did not occur" was common). There were two ground stations (5% of the comparisons) that detected the *Biofilm* (BFM) bioband where none was mapped in ShoreZone (detection issue). Overall, biofilms are a very rare bioband.

Green Algae (ULV) Bioband

An estimated 82% of the green algae (ULV) bioband comparisons are matches although "absent" categories make up 79% of these (Table 10). For 10% of the comparison the ShoreZone mapping missed the *Green Algae* (ULV) bioband (detection problem) and in another 8% there are "false positive" comparison classes.

The implication is that some of the biobands are not as detectable on aerial imagery as compared to ground data. GRA SED and PUC are biobands that appear to be substantially underestimated in the aerial mapping data.

Implications for Future Work: *One uncertainty with this comparative dataset is if conditions have changed since the aerial imagery was collected (in some cases, separated by 11 years). Also imagery collected in a slightly different season will not match well. For future surveys where both aerial and ground data are collected, they should be collected at the same time to avoid differences due to temporal change. In addition, if the ground data is available to mappers prior to the initiation of mapping, it will inform the mappers.*

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CONCLUSIONS

1. The methodology developed to verify the mapping data appeared to work well. The "low and slow" aerial survey of the unit appeared to be a highly adequate proxy of "walking data".

2. Shore type (*ShoreZone* and *ESI*) characterization of the unit had exact or close matches for 60-70% of the units compared and poor matches for less than 15% of the comparisons.

3. An audit of the "poor" shore type matches was conducted to determine the nature of mismatches Three types of differences were noted: (1) an error in mapping position (single occurrence), (2) poor characterization is delta areas where units are typically very long and the ground sampling was very limited, and (3) differences in interpretation due to water level or morphology differences between the aerial surveys and the ground surveys.

4. *Wave Exposure* and *ORI* matches were above 90%. The initial *Exposure* characterizations did not match well and prompted a review and revision of all the original exposures.

5. *Habitat Class* is a derived variable that incorporates elements of the energy, substrate and structuring process in its definition. An estimated 89% of the matches are exact or close and ~10% are in the "poor match" category.

6. Bioband comparisons ranged from better than 80% close matches (*Biofilm, Tundra and Green Algae biobands*) to better than 70% close matches (*Salt Marsh, Dune Grass biobands*) to 62% close matches for the *Sedge biobands*. Detection limits appeared to be better for *Tundra, Biofilm and Green Algae biobands* than for *Dunes Grass, Sedge and Salt Marsh biobands*. False-positive classifications for biobands was greatest for the *Salt Marsh bioband* (15%) and least for the *dune grass bioband* (3%)

7. Review of the bioband mapping data showed that mismatches were higher for fixed-wing derived data (2001 and 2006/2009 surveys) than for 2012 helicopter-derived data.

8. In future programs, it is recommended that aerial and ground data be collected at the same time to minimize differences in interpretation due to temporal difference in features or biota and to allow the ground data to inform the mappers prior to the initiation of mapping.

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REFERENCES

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Appendix A - Audit of Discrepancies for Poor Unit Comparisons

The initial comparison of unit data derived from the *Aerial Mapping Data* and the *Ground Mapping Data* showed a number of poor matches between the two datasets. As a result, an audit (Table A-1) was conducted of all the units where the match was rated as either *Moderately Poor* (Class 4) or *Poor* (Class 5) so that the nature of the mismatch could be determined. The audit involved two mappers reviewing the imagery for the original mapping (*ShoreZone Mapping Data*) and the high resolution imagery collected during the ground survey program (*Ground Mapping Data*); the two mappers agreed on the cause(s) of the interpretation differences and recorded those (Table A-1).

Three types of mismatches were identified by the audit:

- **Location Error:** in one case, overlapping flight-tracks caused to the aerial mapper to classify the wrong section of shoreline. This particular unit was mapped prior to the ground survey and as such was an isolated mapping unit. Normally a mapper is working on a contiguous section of shoreline, and this type of error would be very unlikely to occur.

- **Deltaic Complexes:** deltaic complexes often involve tens of kilometers of shoreline with a variety of morphologies (channels, flats, inundated tundra, low-vegetated peat cliffs, ground ice slumps and estuaries). The complexity of deltas makes them difficult to map from the "fly-by" imagery. ShoreZone mapping units are often "kilometers" in length and are most commonly classified as *Estuaries* (Shore Type 31) to reflect a combination of riverine and marine processes. Ground stations were much more detailed and usually encompassed only a few hundred meters of shoreline. As such, the feature scales are very difficult to compare. For the purpose of discussion on mapping confidence, it is fair to say that deltaic complexes are not well characterized by ShoreZone.

- **Environmental Change:** at two of the stations, morphologies or water levels were different between the original aerial imagery and the ground imagery. High water levels can obscure features normally visible and therefore affect the classification (e.g, a mud flat or sand flat may be submerged during the imagery overflight). In one case, the 2001 aerial imagery was collected immediately after a storm, so that the cliff-face was freshly cut and ground ice features exposed; but in the 2012 imagery of the same section of coast, cliffs had obviously not been eroded for a long period of time and a wider sand beach was present in the intertidal, resulting in a different classification. This type of difference did not appear to be common (two of 39 unit comparisons).

Table A-1 Audit of Poor Matches between Aerial and Ground Mapping.

Unit	Ground Station	Mismatch	Conclusion about Mismatch
18/01/1005	OP40	Ground Shore Type = 25 Aerial Shore Type = 36 Mismatach Class = 5	Ground Shore Type was incorrectly assigned – revise to 36 (small lagoon in front of cliff at Pt Lay village)
18/02/1013	RN21	Ground Shore Type = 30 Aerial Shore Type = 30 Mismatach Class = 4	Unit was miss-located during aerial mapping. Two flight tracks crossed and the wrong fix points were selected (wrong side of estuary mapped).
		Ground ESI = 9A Aerial ESI = 3C	Ditto
18/03/1013	RN32	Ground Shore Type = 38 Aerial Shore Type = 39 Mismatch Class = 4	After looking at imagery and the two classifications, it was decided that a Class 4 mismatch was too severe and the Mismatch Code was revised to Class 2.
18/03/1142	RN12	Ground Shore Type =37 Aerial Shore Type = 29 Mismatch Class = 5	This is a complex delta (Ikpikpuk River/Smith Bay; Fig. A-1, A-2). The 2001 flight flew by the delta front, whereas the ground station was located within the delta complex. The *ShoreZone Mapping Data* unit is 7.5 km long whereas the ground team flew only a few hundred meters (Fig. A-1). The mismatch is an example of scale mismatch – the aerial mapper classifying an entire delta front and the ground mapper classifying a site.
		Ground ESI = 10E Aerial ESI = 7 Mismatch Code = 4	Ditto
18/04/005	RN31	Ground ESI = 3C Aerial ESI = 8E Mismatach Code = 4	After reviewing imagery and classification, review mappers agreed that the initial Mismatch Code was too severe and should be revised to a 2.
18/04/3232	RN02	Ground ESI = 5 Aerial ESI = 10E Mismatch Code = 5	Differences during the water level at the time of the aerial overflights resulted in different classifications. The two review mappers agreed that both classifications are valid.
18/04/4061	RN26	Ground Shore Type = 29 Aerial Shore Type = 31 Mismatch Class = 4	As per the units above, this is an issue of scale associated with deltaic units (Sagavanirtok River; Fig. A-3 and A-4) where the unit was 11 km in length.
18/04/5914	RN68	Ground ESI Type = 9A Aerial ESI = 3A Mismatch Code = 4	After reviewing imagery, review mappers agreed that the original mismatch code was too severe and revised the code to 2.
18/05/0271	RN23	Ground Shore Type = 30 Aerial Shore Type =38 Mismatch Code = 38	Review of 2001 imagery showed that a large storm must have occurred just prior to imagery collection causing extensive erosion and also that water level was high. The 2012 imagery showed that beach material had been deposited subsequently and shore widths to be greater. The review mappers concluded that both classifications were valid.

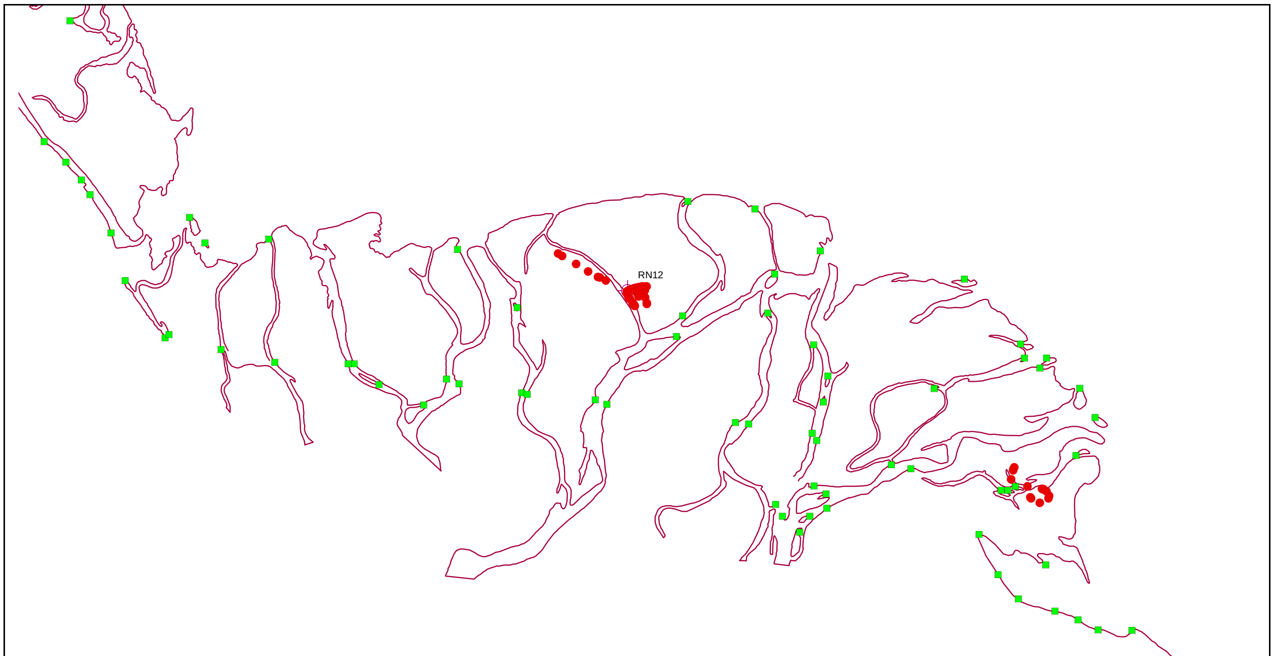

Figure A-1. Digital shoreline of Smith Bay showing ground station location. The ground station crew surveyed only a short portion of the 7.5 km unit (red dots are the limit of ground station photos).

Figure A-2. Google Earth image of Smith Bay showing the location of the ground station.

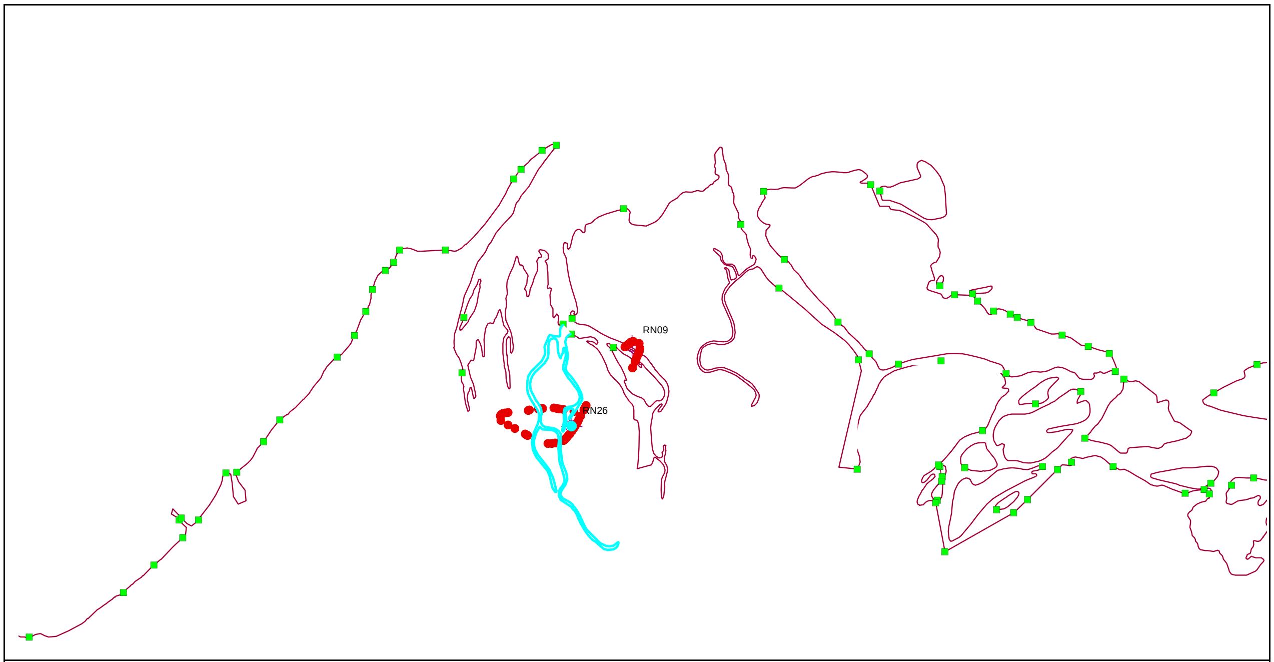

Figure A-3. Digital shoreline of Sagavanirtok Delta (Prudhoe Bay just to west) showing ground station location. The ground station crew surveyed only a short portion of the 11 km unit (red dots are the limit of ground station photos).

Figure A-4. Google Earth image of the Sagavanirktok Delta showing the location of the ground station.

Appendix B Comparison of Minor Unit Attributes

Sediment Source

There are five potential classes for *Sediment Source*. The comparisons showed an exact match in 46% of the comparisons and a moderate match in 54% of the comparisons (Table B-1). All the moderate matches were for units where the aerial mappers used a "cannot determine" class so this is really not a strong mismatch. The aerial mappers were more likely to use this category (42% of the units compared) than the ground-survey mapper (10% of the observations).

Table B-1 Sediment-Related Attributes

Sediment Source				**Sediment Transport**				**Sediment Abundance**		
Category	Count	% Match		Category	Count	% Match		Category	Count	% Match
1	18	46%		1	24	62%		1	17	44%
3	21	54%		3	13	33%		3	22	56%
	39			5	2	5%			39	100%
					39	100%				

Sediment Transport Direction

Mappers estimate the direction of alongshore sediment transport when they can observe a feature within the unit that provides a direct indication of alongshore sediment transport. There is a "cannot determine" category and all but two of the 39 comparison sites had a "cannot determine" category in either the ground or aerial data. The 62% exact match category (Table B-1) is all for "cannot determine" classes so is not really significant. An additional 38% are classified as *moderate* matches, but again, these are where one or the other of classes were "cannot determine".

Sediment Abundance

Sediment Abundance represents a general estimate of how much sediment is available for reworking within the unit and there are three possible classes: *abundant*, *moderate* and *scarce* . 44% was classified as an *exact* match and 56% classified as *moderate* (Table B-1).

Shore Change

Shore change is meant to provide an estimate of shoreline stability with three possible categories: accretional, stable or erosional. The comparison showed 54% exact match and an additional 41% moderate match (Table B-2).

Table B-2 Shore Stability

Category	Count	% Match
1	21	54%
3	16	41%
5	2	5%
	39	100%

Intertidal Width

Table B-3 Shore Width

Category	Count	% Match
1	16	44%
2	9	25%
4	2	6%
5	9	9%
	36	100%

Mappers estimate the across-shore width of each intertidal component and the sum of these widths provides an estimate of intertidal width. Widths are challenging to estimate as there are no spatial reference features in the imagery. In addition, the high-water line is not as distinctly defined in the Beaufort-Chukchi region as it is in other, higher tidal range regions of Alaska. 69% of the estimates are classified as *exact* or *close* whereas about 15% are classified as *moderately poor* or *poor* (Table B-3).

Appendix B. 2013 Alaska Marine Science Symposium Poster

ShoreZone in the Arctic

8,000 km of Coastal Habitat Mapping

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Acknowledgments & CREDITS

Project support is provided by the Bureau of Ocean Energy Management (BOEM), National Park Service (NPS), Arctic Landscape Conservation Cooperative (ALCC), Western Arctic Landscape Conservation Cooperative (WALCC), Alaska Department of Natural Resources and NOAA/NMFS Auke Bay Laboratories.

The *extensive dataset* will provide a continental-scale characterization of the Arctic shoreline and support planning efforts related to oil spills, coastal development, and climate change.

Web-posting of aerial imagery provides access to spatial imagery and the regional *mapping of coastal habitat features* provides a broad-scale planning tool.

Over *60 ground stations* provide high-resolution descriptions and photos.

Inundated polygons, Beaufort coast

Permafrost, Beaufort coast

Barrier island and lagoon, Beaufort coast

Lagoon north of Kivalina

Marshes East of Kotzebue, in Holtham Inlet

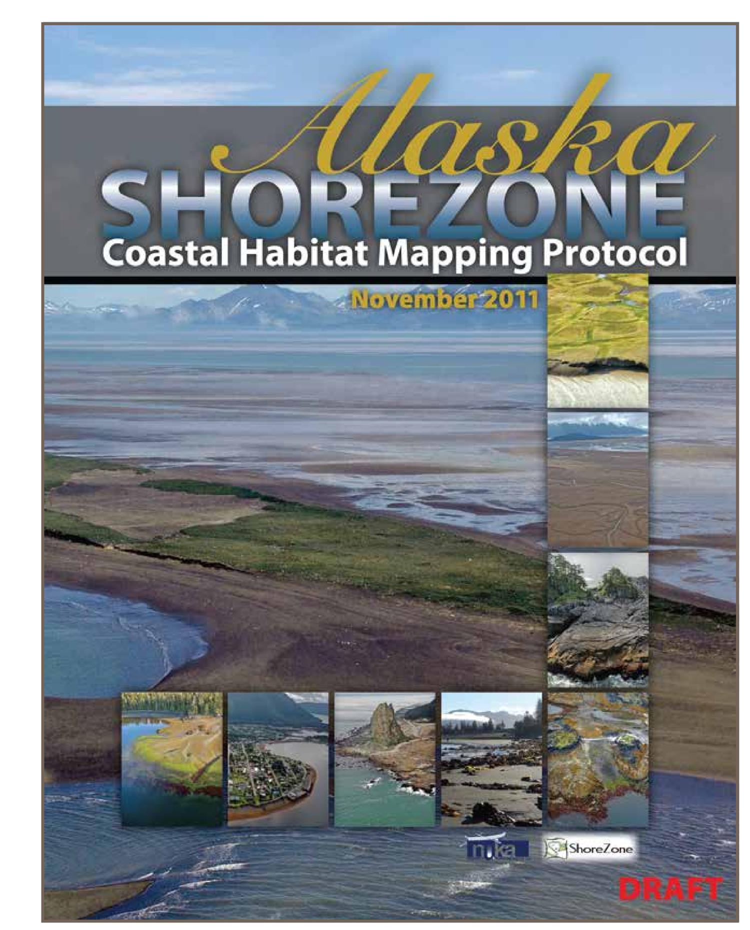
Chukchi coast near Wales

ShoreZone coastal habitat mapping is underway along 8,000 km of Arctic shoreline.

Kivalina, Chukchi coast

A *coastal hazards map* for selected areas will identify locations most sensitive to erosion, thaw subsidence, and storm-surge/sea-level-rise inundation.

Deering, south Kotzebue Sound



The *Alaska ShoreZone Coastal Habitat Mapping Protocol* has been updated to incorporate descriptions for periglacial landforms and biota observed on Arctic coastlines.

Appendix C. 2014 Alaska Marine Science Symposium Poster

ShoreZone for Alaska's Arctic

ShoreZone's new Arctic data form part of a continental-scale characterization of the coast which can be used for planning related to oil spills, coastal development and climate change.

The web-posted aerial imagery and mapping makes it possible to view and download many thousands of georeferenced Arctic coastal images or shoreline maps directly to your desktop.

Visit *www.shorezone.org* to fly the coastal imagery or view the ShoreZone maps and reports.

By the Numbers:

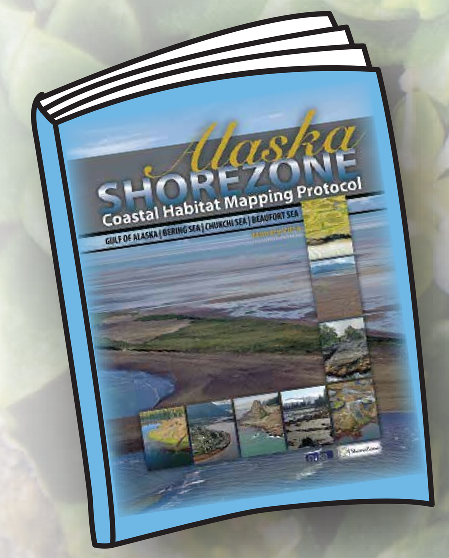
Alaska's Arctic:*

Total shoreline length: ~ 10,600 km

Total number of ShoreZone Units: 9409

Average length per Unit: 1,125 meters

*Wales to the Canadian border…

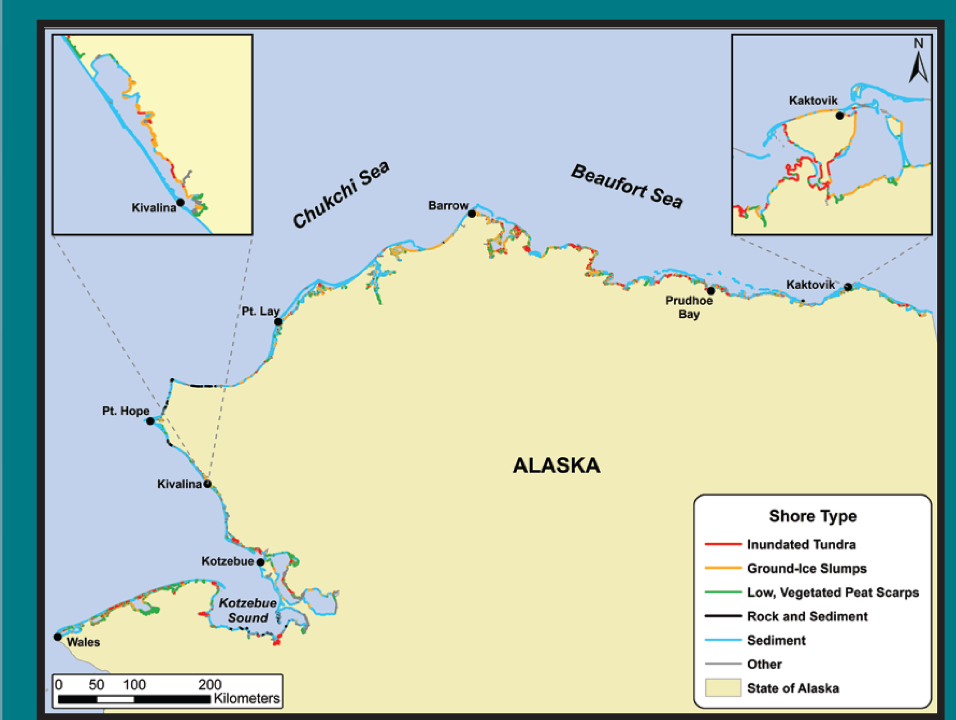


The new *Alaska ShoreZone Coastal Habitat Mapping Protocol* now includes Arctic coasts.

Over *60 ground stations* have been added to the ShoreZone shore station on-line dataset, with detailed observations and photos of shore sites.

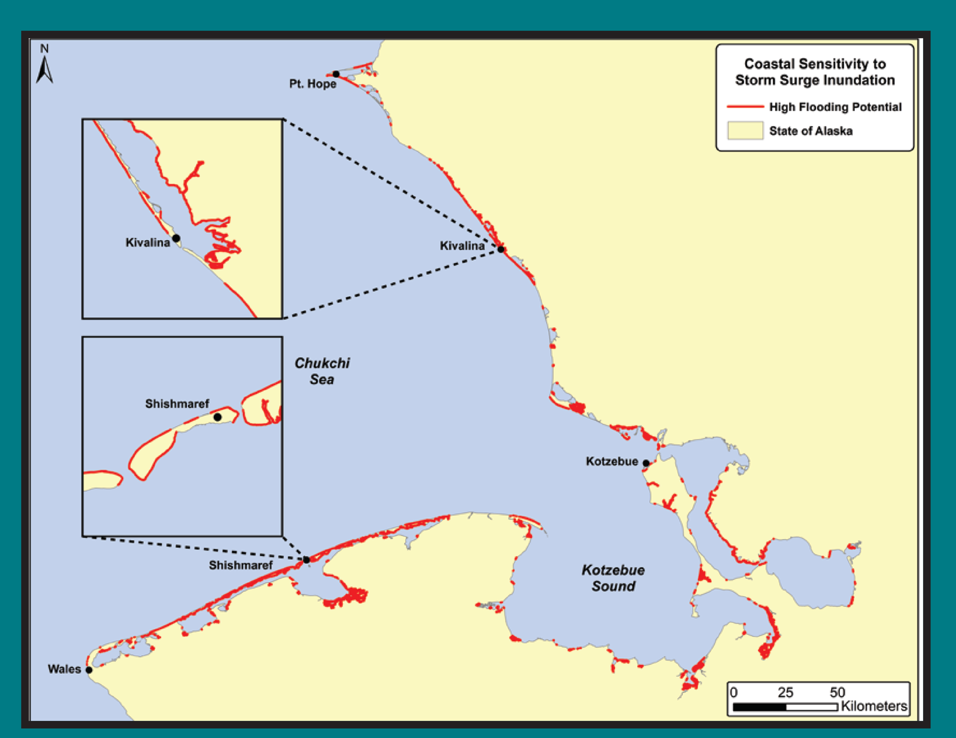
Arctic coastline now part of ShoreZone, showing BOEM North Slope project (red) and NPS Kotzebue project (blue).

New Shore Types were added to SZ protocols to describe periglacial coasts: Inundated Tundra, Ground Ice Slumps, and Low Vegetated Peat, which together make up ~40% of the coastline mapped.



Summary of Arctic Shore Types.

Salt marsh vegetation (dominated by mixture of salt tolerant grass, herbs and sedges) is very common (70 % of shoreline) and is considered highly sensitive to spills.



Example of Flooding Sensitivity Index of CVM where the observed storm surge inundation indicated by the highest logline was >100m inland from high water line.

A new Coastal Vulnerability Module (CVM) for ShoreZone was part of the classification of shore units in the Kotzebue project, and provides an index of coastal sensitivity to climate change. Details of CVM are included in the new ShoreZone protocol document.

Inundated polygons, Beaufort coast

Permafrost, Beaufort coast

Barrier island and lagoon, Beaufort coast

Lagoon north of Kivalina

Marshes East of Kotzebue, in Holtham Inlet

Chukchi coast near Wales

Kivalina, Chukchi coast

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