



Protocol for High-Resolution Geospatial Analysis of Coastal Change in the Arctic Network of Parks

Natural Resource Report NPS/ARCN/NRR—2012/537



ON THE COVER

An eroding bluff east of the Anigaaq ranger station, Cape Krusenstern National Monument, in 2006.
Photograph by: William Manley

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Natural Resource Report NPS/ARC/NRR—2012/537

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Contents

	Page
Figures.....	iv
Executive Summary	v
Introduction.....	1
Background.....	4
Coastal Erosion in the Arctic.....	4
Coastal Zones in BELA and CAKR	4
Monitoring Objectives	6
Historic Coastal Change in BELA and CAKR.....	9
Methodology and Design.....	12
A Geospatial Approach to Monitoring Coastal Change	12
Sampling Design.....	14
Other Relevant Protocols.....	15
Data Management, Analysis, and Reporting	17
Personnel and Operational Requirements.....	18
Future Research for BELA and CAKR	19
Literature Cited.....	21
Standard Operating Procedures.....	26
SOP #1: Spatial Data Management	26
SOP #2: Digitizing the Shoreline	34
SOP #3: Analysis of Error for Coastal Change Rates	42
SOP #4: Spatial Analysis of Coastal Change Using DSAS	48
SOP #5: Synthesis and Presentation of Results.....	61

Figures

Page

Figure 1. Map of BELA and CAKR, showing portions of the shoreline that from 1950 to 2003 have experienced accretion (in blue) or erosion (in red). Data from Lestak et al. (2010).	2
Figure 2. Map of the study area, including BELA, CAKR, and portions of surrounding areas. The base imagery is a GeoCover Landsat mosaic from 2000.	5
Figure 3. Photograph from 2006 of a bluff eroding along the southwest BELA shoreline, adjacent to an archeological site.....	7
Figure 4. Maps of imagery showing closure and widespread flooding of Kiligmak Inlet at some point between 1980 (left) and Sept. 19, 2003 (right). Imagery from Manley et al. (2007b,c).	7
Figure 5. Map showing long-term erosion rates (from the 1950's to 2003) for BELA, with low rates (blue) to high rates (red). Also shown is no change or accretion (black). Data from Lestak et al. (2010).....	10
Figure 6. Map showing long-term erosion rates (from the 1950's to 2003) for CAKR, with low rates (blue) to high rates (red). Also shown is no change or accretion (black). Data from Lestak et al. (2010).	10
Figure 7. Map showing digital shorelines from the 1950, 1985, and 2003 superimposed on imagery from 2003, documenting tens of meters of bluff erosion. Data from Manley et al. (2007c, 2010).	13
Figure 8. Photograph from 2006 showing field measurement of the distance of a low, eroding bluff from a benchmark, at the seaward side of a barrier island in BELA. This is one of many coastal monitoring stations established for BELA and CAKR (Jordan et al., 1999, 2008).	14

Executive Summary

Coastal zones for Bering Land Bridge National Preserve (BELA) and Cape Krusenstern National Monument (CAKR) extend for over 450 km (280 miles), and include critical habitats, sensitive ecosystems, and cultural resources (including threatened archeological sites). These areas are sensitive to tundra bluff and beach erosion, shifting of tidal inlets, sediment deposition, changes to lagoon hydrology, loss of wetlands, and coastal flooding. Most of the coast has experienced erosion from 1950 to 2003. Where erosion has occurred, rates have averaged -0.5 m/yr (-1.7 ft/yr), reaching more than -3 m/yr (-10 ft/yr) – with shoreline retreat of tens to hundreds of meters (or feet). Continued, periodic inventory and monitoring of coastal change in the Arctic Network of Parks (ARCN) are necessary to address primary objectives concerning temporal trends, spatial variability, and impacts. This protocol provides background, a summary of historic coastal change, methodological rationale, data and operational guidelines, and stepwise procedures for geospatial analysis of coastal change (specifically, erosion and accretion of the shoreline). Future research should obtain new imagery, make sure it is properly orthorectified for required accuracy, and then: build a spatial database; digitize new shorelines; assess errors; analyze the shorelines using the USGS Digital Shoreline Analysis System (DSAS); and then synthesize and present the results as tables, graphs, and maps in reports. End results are precise, empirical, comprehensive, and representative. Future research can build upon previous data releases and use this protocol to answer the most pressing question: Is coastal erosion in BELA and CAKR increasing with sea-level rise and arctic warming?

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Introduction

Coastal environments within Bering Land Bridge National Preserve (BELA) and Cape Krusenstern National Monument (CAKR) are experiencing rapid environmental changes that are observable in the form of coastal erosion, bluff retreat, beach accretion, sediment deposition, permafrost melting, and coastal flooding. Protected by sea ice for several months each year, the fragile coastal zone may change rapidly as Arctic and global warming lengthens the ice-free season, causes sea-level rise, increases seawater temperature, and alters storm frequency and severity. A variety of near-shore marine, terrestrial, and freshwater habitats – including subtidal zones, sandy shores, barrier spits and islands, lagoons, bays and inlets, tundra bluffs, deltas, and wetlands – are threatened by coastal erosion. Such areas provide critical habitat for unique plant communities, bird nesting, seal haul-outs, potential denning sites, freshwater and anadromous fish, and migratory stopover sites for marine mammals and birds. Coastal zone changes will also impact human activities and cultural resources such as travel routes, subsistence fishing, egg gathering, and hunting of waterfowl and marine mammals – as well as altering or destroying archaeological sites.

To comprehensively assess the spatial and temporal variability in shoreline change and related impacts, an inventory and monitoring program can take advantage of recently feasible methods based on Geographic Information Systems (GIS) and remote-sensing imagery. High-resolution aerial photography and satellite imagery form the basis for delineating coastlines in detail. Measurements of shoreline position can be made every 50 m (165 ft) across large areas, ensuring that results are both locally accurate and broadly representative. Digital surveys can be extended decades back in time to provide historical perspective. And quantitative geospatial analysis can yield numerical rates of coastal erosion or accretion to identify geographic patterns and temporal trends (e.g., Fig. 1). The results are empirical, and provide the basis for clarifying: environmental controls on erosion rate and related processes; ecosystem response to drivers and stressors; and impacts on coastal habitats and associated ecosystem components.

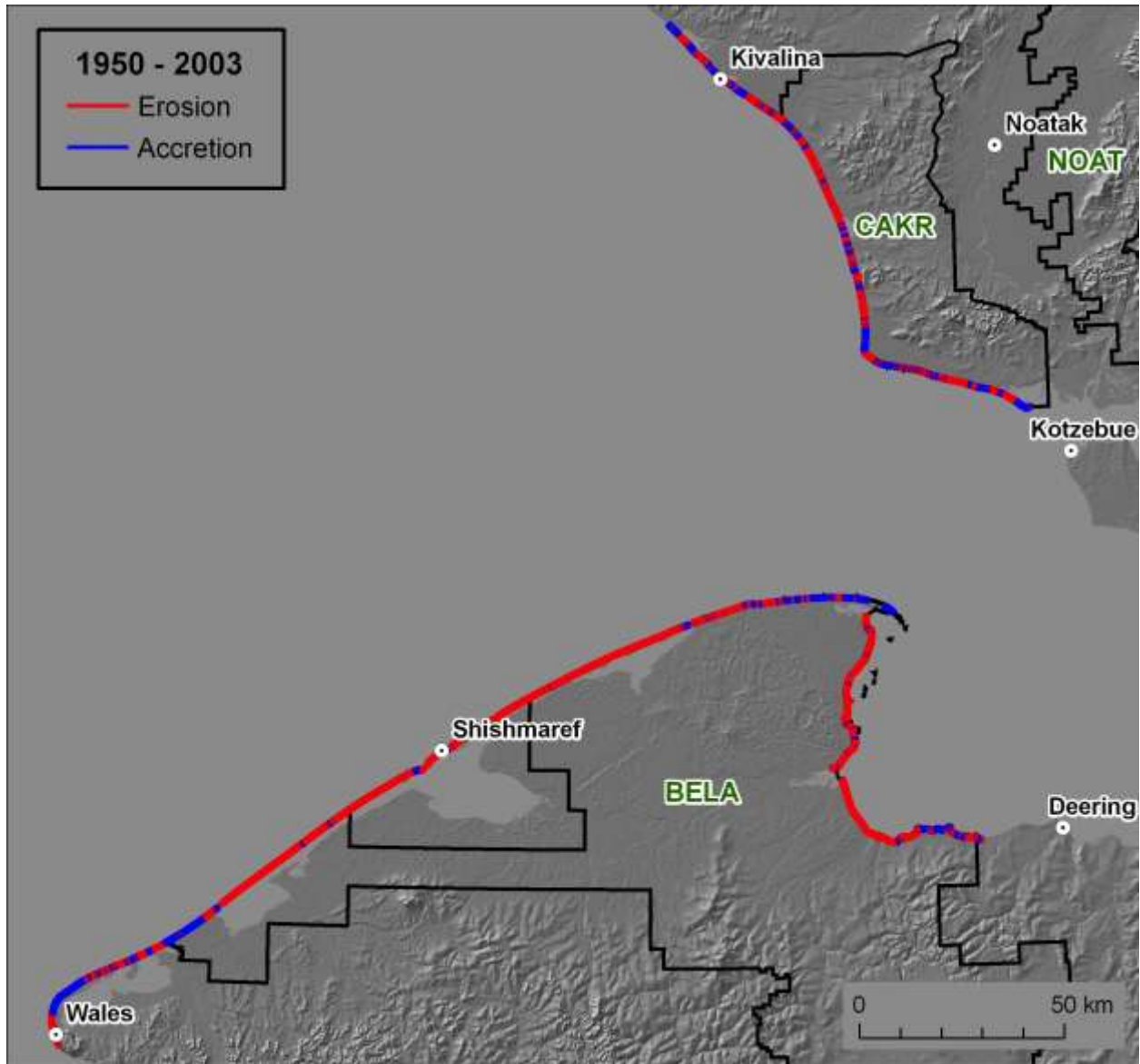


Figure 1. Map of BELA and CAKR, showing portions of the shoreline that from 1950 to 2003 have experienced accretion (in blue) or erosion (in red). Data from Lestak et al. (2010).

This document provides detailed guidance for geospatial data processing and analysis of changes in coastline position. Founded on recent best practices, it encompasses Standard Operating Procedures (SOP's) for spatial database management, digitizing coastlines (“Shoreline Reference Features”), estimating errors, and completing rigorous vector analysis using the USGS Digital Shoreline Analysis System (DSAS), with additional steps to synthesize and present results. The approach as documented here, with a structured workflow and geoprocessing tools, was used to create coastal-change datasets recently released for BELA and CAKR (digital shorelines, and DSAS transects with embedded results; Lestak et al., 2010; Manley et al., 2010). This document is targeted toward use in the Arctic Network of Parks (ARCNP), but is applicable to other arctic coasts or more broadly. A protocol such as this – for use of sophisticated software packages in

GIS and remote sensing – is particularly valuable to reduce learning curves and to ensure comparability of future results.

Future efforts for inventory and monitoring of coastal change for ARCN can get up to speed quickly and effectively by making use of this protocol coupled with previous data releases:

- high-resolution imagery for three time periods back to 1950
- digital shorelines for each of these time periods
- DSAS datasets with baseline, transects, and embedded analytical results of change rates
- each of these with well documented metadata

For more details on the data releases, see the section “Historic Coastal Change in BELA and CAKR”.

With these resources, a new study can avoid redundant effort and update the vital sign by:

- acquiring new imagery
- orthorectifying the new imagery, if not already processed for required accuracy
- digitizing the new shoreline
- re-running DSAS with the existing shorelines, baseline, and transects
- preparing progress and annual reports, including tables, graphs, and maps of the new results

Without the previous data releases, a new phase of coastal monitoring would be immensely more time consuming and costly. Further research could update previous analyses with shorelines and change rates newer than 2003 to assess potential increase in erosion with warming, achieve higher temporal resolution for selected key sites, run geostatistical analysis to assess environmental processes, or focus on past and future impacts.

Background

Coastal Erosion in the Arctic

Arctic coastal erosion rates are among the highest in the world (Jorgenson and Brown, 2005; Solomon, 2005; Lantuit et al., 2011; Forbes, 2011). Ice-bonded sediment and polygonal ground are susceptible to thermal erosion and block failure (e.g., Lantuit et al. 2008). These high rates: are typically the greatest environmental concern for coastal communities; have impacts through release of sediment and organic carbon on neighboring near-shore ecosystems; lead to loss of coastal and freshwater habitats; represent an important indicator of environmental response to climate change; and constitute some of the most rapid and most observable changes in Arctic ecosystems.

In Alaska, there is some evidence that coastal erosion is accelerating due to global warming. For example, mean annual erosion rates for a portion of the North Slope coast increased from 7 m/yr (1955-1979) to as much as 17 m/yr (2007-2009; Jones et al., 2009; Arp et al., 2010; see also Mars and Houseknecht, 2007; Ping et al., 2011; Wobus et al., 2011; Overeem et al., 2011). In general, there is solid inductive reasoning for this across much of the Arctic: Reduced sea-ice concentrations, longer ice-free seasons leaving the coastline exposed to wave action, increased seasonal permafrost thaw, rising sea level, and a potential increase in storm magnitude or frequency (eg., ACIA, 2005; IPCC, 2007).

However, studies to date in Alaska have been limited in extent or resolution, restricting a representative or comprehensive understanding of spatial variability and controlling properties. It remains unclear how the interaction of factors – ice edge, sea surface temperatures, sea-level rise, storm events, lithology, geomorphology, etc. – influence present and future erosion rates. Indeed, taking a lesson from temperate latitudes, one should expect erosion – especially on barrier spits and islands – without any change in climate. And coastal change goes beyond erosion to also encompass shoreline accretion, coastal flooding, inlet migration, etc. Inventory and monitoring at high resolution is required to quantify complex temporal and spatial variability in coastal change, and its impacts on ecosystems.

Coastal Zones in BELA and CAKR

The total shoreline in the Arctic Network of Parks (ARCN), including bay and barrier island ecosystems, is approximately 450 km (250 miles; Fig. 2). This is the third largest block of coastline that the NPS manages. Near-shore coastal waters and shoreline habitats include subtidal zones, sandy shores, barrier spits and islands, lagoons, bays and inlets, tundra bluffs, dune systems, rocky bluffs, deltas, and wetlands. These habitats are critical for bird nesting, seal haul-outs, potential denning sites, freshwater and anadromous fish, and migratory stopover sites for marine mammals and birds. As a result, the coastal zone has a long history of and is still very important for subsistence fishing, egg gathering, and hunting of waterfowl and marine mammals. Many hunting and fishing camps and travel routes associated with subsistence activities are in the coastal zone of BELA and CAKR. Nearby communities include Wales, Shishmaref, Deering, Kotzebue, and Kivalina.

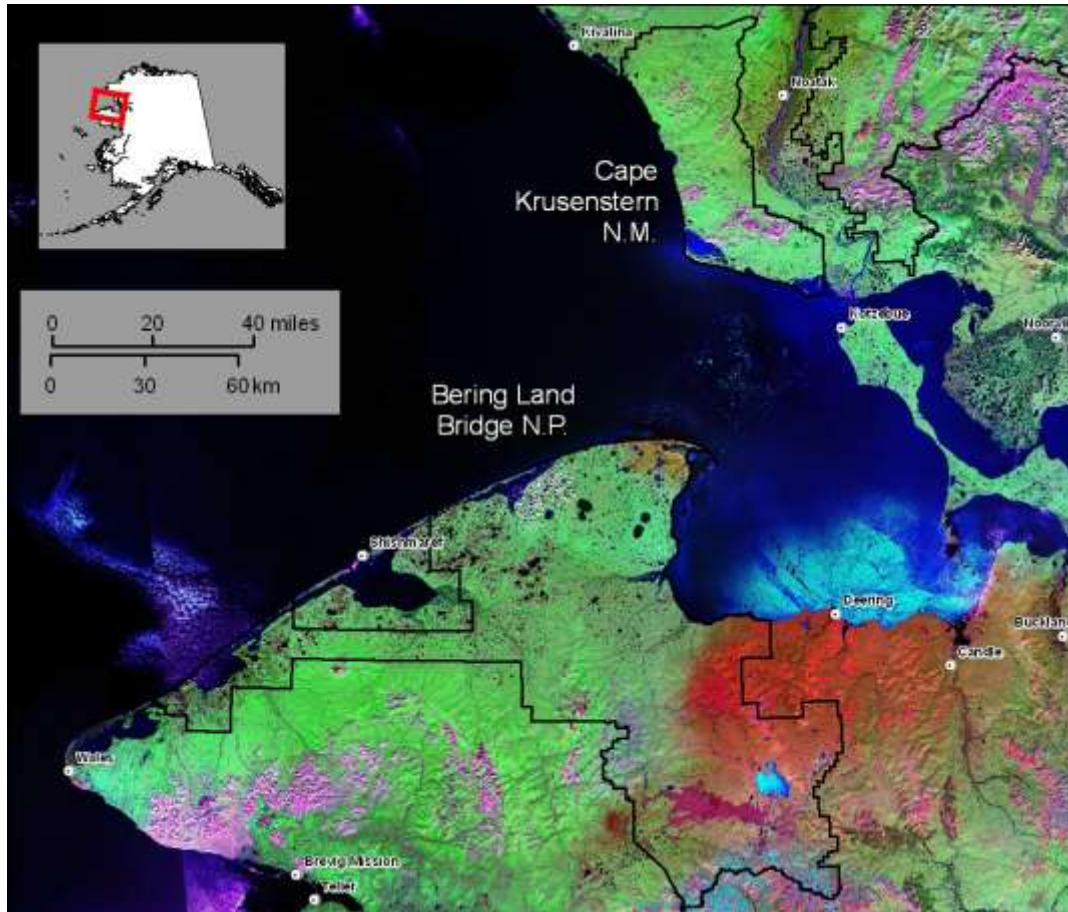


Figure 2. Map of the study area, including BELA, CAKR, and portions of surrounding areas. The base imagery is a GeoCover Landsat mosaic from 2000.

The shores of BELA and CAKR front low-lying coastal plains along the southeast Chukchi Sea (cf. Mason and Jordan, 1993; Mason et al., 1995, 1997; Jordan and Mason, 1999). Coastlines are wave-dominated and microtidal, with seasonal sea-ice cover and approximately five months of open water each year. Offshore bathymetry is relatively shallow, with circulation driven by the Alaska Coastal Current. The region is sensitive to interannual and interdecadal variability in cyclone magnitude and frequency. Low, unlithified bluffs are common, with relatively low backshore elevations. Permafrost ranges from continuous to discontinuous, with low to medium ground ice contents (e.g., Lantuit et al., 2011). The two park units offer contrasts in coastal geomorphology: coastal zones in BELA are typified by sand-dominated beaches, barrier islands and spits protecting a lagoon system, dune-ridge complexes, and exposure to wind and waves mainly from the northwest and north; conversely, foreshores in CAKR are dominated by sand and fine gravel backed by beach-ridge complexes and low tundra bluffs, open primarily to the southwest and west.

Monitoring Objectives

The overall goals for this vital sign is to document and analyze the temporal and spatial variability in coastal change along the BELA and CAKR coasts, and to provide a scientific basis for understanding and responding to resulting impacts on natural resources. Coastal change consists primarily of coastal erosion and bluff retreat, as well as less common beach accretion, deposition of sediments during extreme storms, and modification to inlets and lagoons. Coastal erosion directly impacts beach geomorphology and nearshore ecosystems. Bluff erosion causes loss of terrestrial habitat and archeological sites (Fig. 3). Changes in sediment erosion and deposition can lead to capture of thaw-lake basins, migration of barrier inlets, flooding or closure of inlets (Fig. 4), and other modifications to freshwater habitats. Release of sediment and organic carbon alters nutrient fluxes in nearshore marine and lagoon ecosystems. Protected by sea ice for several months each year, the fragile coastal zone may change rapidly with Arctic warming, permafrost melting, sea-level rise, lengthening of the summer sea-ice free season, and changes to storm frequency and severity. Finally, coastal change is one of the most observable and sensitive indicators of environmental change for the Arctic.

Coastal erosion and accretion will be assessed primarily through remote sensing of the coastline coupled with field mapping and measurements at long-term monitoring sites. Remote sensing methods will involve repeated acquisition (approximately every 5-10 years) and analysis of finely detailed imagery. High-resolution, orthorectified imagery is required to measure erosion or accretion at rates of typically 0.1 to 5 m/yr. Precise digital elevation models are required to calculate volumetric loss or gain, as well as sediment and carbon fluxes to near shore marine ecosystems. Specialized software packages are then used to digitize the base imagery and determine erosion and accretion rates along the coast at various “timeslices”. Spatial and temporal patterns can be related to coastal geomorphology and processes, and can quantify impacts on plant communities and habitats.

Specific objectives for inventory and monitoring of coastal change are:

- 1) *Determine long-term trends in coastline accretion, erosion, and bluff retreat, and how these rates have changed through time.* In other words: Are coastlines experiencing rapid rates of erosion? Is erosion accelerating with global warming?
- 2) *Evaluate high spatial variability in erosion rates in relation to local environmental factors.* Why do coastal-change rates vary so much from one location to another? Are rates of erosion related to bluff height, bluff lithology, beach orientation, nearshore bathymetry, etc.?
- 3) *Detect areas that are most vulnerable, and assess impacts on ecosystems and habitats.* Is erosion or sediment deposition disproportionately affecting certain land cover classes or vegetation types? What effect does inlet migration or inlet closures have on lagoons?



Figure 3. Photograph from 2006 of a bluff eroding along the southwest BELA shoreline, adjacent to an archeological site.

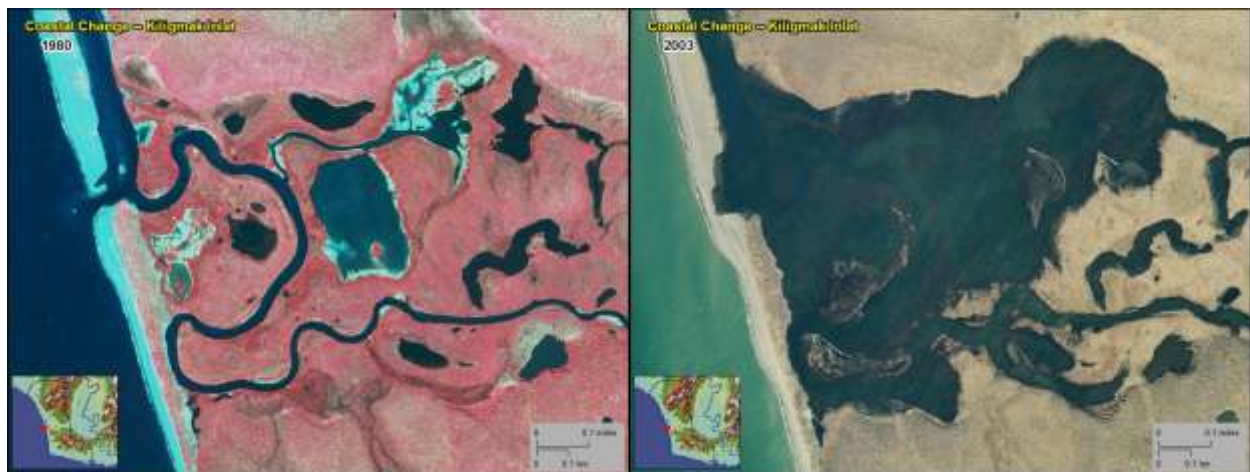


Figure 4. Maps of imagery showing closure and widespread flooding of Kiligmak Inlet at some point between 1980 (left) and Sept. 19, 2003 (right). Imagery from Manley et al. (2007b,c).

The second and third objectives above are discussed throughout the narrative. The first objective – relating directly to the inventory and monitoring of coastal change – is the focus of this protocol, and addressed explicitly in the SOP's.

In addition, there are practically endless secondary questions to address, such as: What effects do carbon fluxes have on the nearshore marine environment? Will tundra coasts experience accelerated erosion due to permafrost melting and thermokarst formation? What are the effects of ice-cover change and longer open-ocean seasons on shoreline ecosystems? For more along these lines, see documents relating to the NPS “Coastal Influenced Ecosystems Scoping Workshop” (e.g., NPS, 2004).

Monitoring results will help to inform management decisions. The coastal zone in Bering Land Bridge National Preserve and Cape Krusenstern National Monument harbors a substantial number of important subsistence species, including resident and anadromous fish, migratory birds, and migratory mammals; by tracking coastal change over time and space park managers will be better equipped to identify and manage vulnerable subsistence species. Also, Cape Krusenstern National Monument and Bering Land Bridge National Preserve were established to protect, among other things, archeological sites; many of the important archeological sites within these park units occur on the coast and are threatened by rapid changes in the coastal environment. Finally, modern day subsistence users rely on the coastline as a transportation corridor and, in some cases, as the foundation of their community. Changes in the coastline in Bering Land Bridge, for example, threaten the very infrastructure of the community of Shismaref.

The Arctic Network (ARCN) is a major component of the National Park Service’s strategy to better understand and manage park lands using scientific information. It is one of four inventory and monitoring networks in Alaska and 32 nationwide. The Arctic Network provides scientific support to five parks covering more than 19 million acres. Bering Land Bridge National Preserve and Cape Krusenstern National Monument share similar coastal resources and biogeographic ties to the former land bridge between North America and Asia. Kobuk Valley National Park, Noatak National Preserve, and Gates of the Arctic National Park and Preserve span extensive, mountainous terrain at the northern limit of treeline. ARCN is developing long-term monitoring protocols for 28 ‘vital signs’, or physical, chemical and biological indicators that were selected to represent the overall health of these parklands. Many of these vital signs are expected to show change due to regional and global stressors including climate change and deposition of industrial contaminants. Many vital signs also have important human values including for subsistence.

This protocol will be relevant, and can be linked, to other protocols such as: Climate, Fish Assemblages, Lagoon Communities & Ecosystems, Lake Communities & Ecosystems, Landbird Monitoring, Permafrost, Point Source Human Effects, Sea Ice, Small Mammal Assemblages, Snow & Ice, Stream Communities & Ecosystems, Surface Water Dynamics & Distribution, and Terrestrial Landscape Patterns & Dynamics.

Historic Coastal Change in BELA and CAKR

Coastal change for BELA and CAKR has consisted primarily of coastal erosion and bluff retreat, as well as less common beach accretion, deposition of sediments during extreme storms, and modification to inlets and lagoons. Coastal erosion directly impacts beach geomorphology and near-shore ecosystems. Bluff erosion causes loss of terrestrial habitat. Changes in sediment erosion and deposition can lead to capture of thaw-lake basins, migration of barrier inlets, flooding or closure of inlets, and other modifications to freshwater habitats. Release of sediment and organic carbon alters nutrient fluxes in near-shore marine and lagoon ecosystems.

High-resolution spatial analysis along the entire coastlines of BELA and CAKR shows that the area has experienced mainly erosion, with rates of change varying significantly along the shoreline (Manley et al., 2007, 2008, 2010; Lestak et al., 2010). This research, in collaboration with the Arctic Network of Parks (ARCN), began with creation of digital orthoimagery over a large area (>6000 km²) at high resolution (1.0 m or better) for three "timeslices": approx. 1950, approx. 1980, and 2003. Shorelines were digitized in a Geographic Information System (GIS) every 20 m along 480 km (290 mi) of coastline. Transects with 50-m spacing were generated using the USGS Digital Shoreline Analysis System (DSAS; Thieler et al., 2005), which reveal high spatial variability related to local morphologies and processes. A comparison of the 1950-1980 and the 1980-2003 intervals also suggests variability over time, with erosion rates decreasing slightly for BELA and shifting to net accretion for CAKR after 1980. In general, most of the coast has experienced erosion in the past five decades (75% of BELA and 60% of CAKR; Figs. 5 and 6). Overall, BELA and CAKR have experienced coastal change rates of -0.33 m/yr (-1.08 ft/yr) and -0.02 m/yr (-0.07 ft/yr), respectively, from the 1950's to 2003. Where erosion does occur, long-term rates are higher for BELA than for CAKR, average -0.5 m/yr (-1.7 ft/yr), and can reach more than -3 m/yr (-10 ft/yr). This approach provides detailed monitoring at local scales as well as comprehensive and representative documentation at regional scales.

As part of this study, ARCN has released high-resolution coastal imagery, digital shorelines, and coastal-change results. Fully orthorectified digital photography for the coastal and near-shore areas of BELA and CAKR encompasses black and white imagery from approximately 1950, color-infrared imagery from approximately 1980, and natural-color imagery from 2003 (Manley et al., 2007a-c). These "timeslices" have a resolution of 1 m or better with minimal horizontal errors. Beyond study of coastal erosion, the imagery documents environmental change through time, and may be of interest for change-detection studies of vegetation, permafrost, lake and stream hydrology, cultural resources, etc. Also available are shorelines digitized every 20 m or better (in shapefile format) representing the waterline (wet/dry line) for each time period across BELA, CAKR, and nearby areas (Manley et al., 2010). Finally, the detailed results of geospatial analysis are provided as attributed DSAS transects, complete with calculations of erosion or accretion rates (in m/yr) every 50 m or better, for display or further processing (Lestak et al., 2010). Each data release is fully documented with FGDC metadata. The data can be obtained directly from ARCN or from a new NPS Data Store through the "Integration of Resource Management Applications" (the IRMA Portal). The imagery can also be viewed and accessed through AlaskaMapped.org (see also NPS-ARCN, 2010).

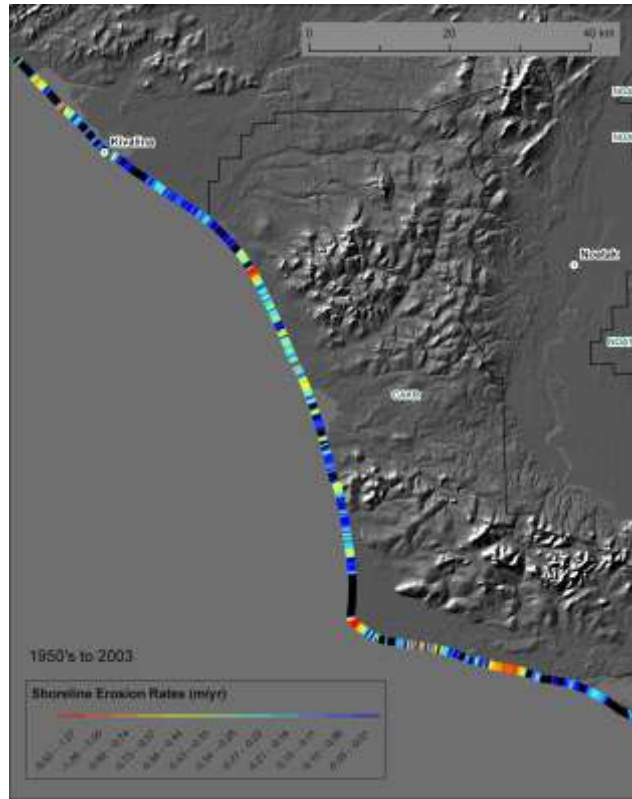


Figure 5. Map showing long-term erosion rates (from the 1950's to 2003) for BELA, with low rates (blue) to high rates (red). Also shown is no change or accretion (black). Data from Lestak et al. (2010).

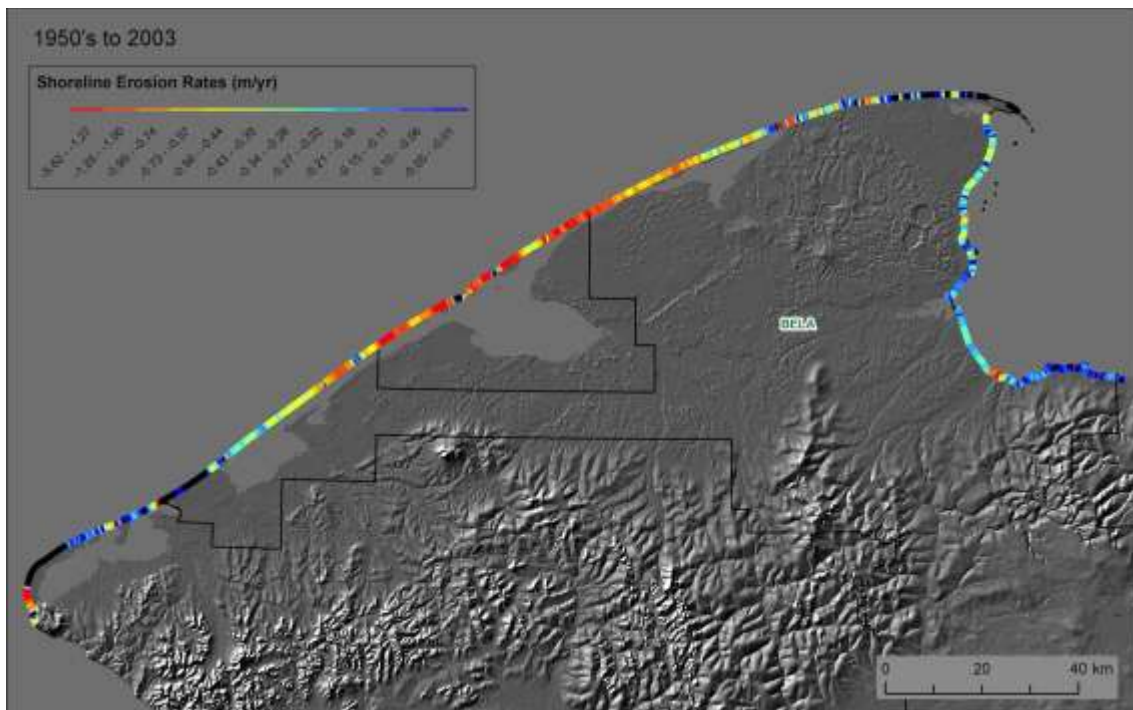


Figure 6. Map showing long-term erosion rates (from the 1950's to 2003) for CAKR, with low rates (blue) to high rates (red). Also shown is no change or accretion (black). Data from Lestak et al. (2010).

Field studies of coastal change have provided details for bluff erosion at 27 coastal monitoring stations. Established as early as 1987 and reoccupied in 2006, the long-term point measurements of bluff retreat vary from -0.1 to -2.0 m/yr for BELA and -0.1 to -1.3 m/yr for CAKR, with accretion being much less common (Jordan et al., 1999, 2008). Though limited in spatial coverage, the data suggest the importance of local geomorphic processes and exposure (fetch). The field-based measurements also provide validation that GIS-based measurements of bluff retreat near the monitoring stations are accurate (Manley et al., 2008).

A recent study independently analyzed historical coastal change and predicted future impacts for the BELA and CAKR coasts (Gorokhovich and Leiserowitz, 2012). They used the 1950's, 1980's, and 2003 imagery released by ARCN, digitized an "instantaneous waterline", and calculated past erosion rates. The study also assessed ties to climatology, and considered projections of sea-level rise to model future erosion rates. The results of historic change are comparable to those in the ARCN data release of coastal-change transects (Lestak et al., 2010). The article lacks detail, and they have not released their shorelines or results in digital form for further study. But it provides a useful overview of coastal change in the region.

Rates of coastal change for BELA and CAKR are lower than for portions of Alaska's North Slope, but are fairly typical for the Arctic. The southeast Chukchi Sea was included in a recent circumarctic compilation and analysis of coastal change (Lantuit et al., 2011). The Arctic Coastal Dynamics Database contains ten and six coastal segments for BELA and CAKR, respectively, with estimates of numerous parameters for each segment relating to geomorphic classification, lithology, ground ice content, and erosion rate. However, spatial resolution is relatively coarse; average segment length is 80 km (50 miles). And with limited observations during data compilation, the parameters were roughly estimated. Nonetheless, a few broad comparisons can be made: 1) erosion rates for BELA and CAKR are substantially lower than for a portion of Alaska's Beaufort Sea coast near Teshekpuk Lake (Jones et al., 2009), where low, ice-rich bluffs are exposed without barrier islands to thermo-mechanic erosion; and 2) long-term erosion rates for BELA and CAKR (Lestak et al., 2010) are slightly less than the average rate estimated for the circumarctic (Lantuit et al., 2011).

The US Army Corps of Engineers has conducted analysis of bluff retreat within the immediate vicinity of Shishmaref and Kivalina, where coastal erosion has damaged, and further threatens, community infrastructure (USACOE, 2006, 2009). For Shishmaref, this includes bluff-top mapping and analysis of retreat rates from aerial photography dated 1972 to 2003, and from field measurements dated 2001 to 2003. These data suggest that rates of erosion are increasing, though interpretation is complicated by the impact of geotechnical engineering for shore protection. The reports also include projections of future bluff-top positions impinging on both villages. A study by Mason et al. (in press) includes geospatial analysis of bluff-top erosion at Shishmaref, and evaluates the mix of coastal engineering, scientific research, anecdotal accounts, and media coverage of erosion at the village.

Methodology and Design

Coastal studies in Alaska and elsewhere are evolving rapidly with new technological opportunities. As captured in the Preface to "A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting" (Mayer et al., 2004, p. ix):

"... there can be little doubt that every so often there are concomitant technical developments that set the stage for a major leap in scientific understanding. This is indeed the case with respect to remote sensing, mapping, and data-handling technologies, where remarkable advances in the development of satellite-positioning systems, terrestrial and marine mapping sensors, and the digital manipulation of mapping data using geographic information systems have revolutionized our ability to collect, distribute, analyze, and visualize geospatial data. Along with these technological developments has come an evolution in our understanding of the fundamental importance of the coastal zone to the social, economic, and environmental well-being of the nation. With this increased understanding has also come a new appreciation for the complexity, sensitivity, and interconnectedness of the coastal zone system. This convergence of technology and scientific awareness heralds a new era of geospatial data handling and products that, for the first time, may allow us to address some of the key challenges faced by those charged with understanding and managing the coastal zone."

A Geospatial Approach to Monitoring Coastal Change

To assess the temporal and spatial variability in shoreline change and related impacts, a long-term monitoring program should take advantage of fairly new methods based on Geographic Information Systems (GIS) and remote-sensing data. Advances in technology – and the availability of sufficiently high-resolution aerial photography, satellite imagery, and other geospatial datasets – make it possible to comprehensively quantify erosion and accretion (horizontal change in the position of the shoreline through time) as apparent from co-registered "timeslices" of imagery (see Fig. 7). Observations of coastal change can extend decades back in time. Empirical analysis often reveals complex spatial and temporal patterns that can improve our understanding of geomorphic processes, environmental linkages, and resource impacts.

The foundation of this approach is imagery at a resolution of 2.5 m or better, preferably 1.0 m or better. The aerial photography or satellite imagery needs to be fully orthorectified to reduce horizontal errors as much as possible. This imagery and other "framework datasets" (e.g., Digital Elevation Model's, or DEM's) are then organized in a spatial database. The shoreline is carefully defined, digitized onscreen from the imagery, and saved as a linear vector file. An analysis of propagated error is completed. Digital shorelines from different time periods are quantitatively processed in the GIS to calculate rates of change, using the USGS Digital Shoreline Analysis System (DSAS; Thieler et al., 2005, 2009). Results can be tabulated or mapped, categorized and summarized, or even compared with other environmental datasets to reveal relationships among environmental processes. These steps are discussed further below, with details in the Standard Operating Procedures (SOP's).



Figure 7. Map showing digital shorelines from the 1950, 1985, and 2003 superimposed on imagery from 2003, documenting tens of meters of bluff erosion. Data from Manley et al. (2007c, 2010).

There are many advantages to this approach. It can provide accurate measurements of coastal change for any point of interest. More important, it can be spatially comprehensive, encompassing an entire area or region of interest, such that results are all inclusive and findings are truly representative. Finally, this approach has become a widely accepted “best practice” through studies undertaken by the USGS and others in the conterminous US (e.g., Moore, 2000; Fletcher et al., 2003; Moore and Griggs, 2002; Hapke et al., 2006, 2010) and more recently in Alaska (e.g., Mars and Housenecht, 2007; Jones et al., 2009; Gorokhovich and Leiserowitz, 2012).

There are some disadvantages. Mainly, this approach can be costly due to: acquisition of new imagery (unless adequate imagery is available from other sources at low cost or no cost through licensing); and extensive processing required with orthorectification to achieve acceptable accuracy (particularly for historic aerial photography; effort is substantially less with newer aerial photography and satellite imagery). This approach, based on visual interpretation, works best in microtidal areas. It requires that the “signal” of coastal change rises above the “noise” of horizontal errors – where erosion rates are high or with longer intervals between “timeslices”. Also, to avoid complications arising from high interannual variability in erosion rates, the intervals between timeslices should ideally be similar (ie., imagery every 10 years rather than time intervals of 30 yr, 30 yr, 5 yr, 2 yr, etc).

Other approaches can still be helpful. Point measurements (such as Jordan et al., 1999, 2008) are the most precise, can be conducted more frequently than is routinely possible with image

acquisitions, and is more feasible to capture the effects of individual storm events. Repeated surveys along established profiles can reveal detailed changes across the shorezone (Fig. 8). However, the inherent limitation of surveyed points and profiles is uncertainty about scaling and whether results are representative for a larger area. Still other possibilities, each with advantages and disadvantages, include: geospatial analysis as presented here but with a mixture of shorelines derived from LIDAR DEM's, imagery, and historic maps or charts; field-based Differential GPS surveys along the shoreline; and repeat acquisition and analysis of high-resolution DEM's.



Figure 8. Photograph from 2006 showing field measurement of the distance of a low, eroding bluff from a benchmark, at the seaward side of a barrier island in BELA. This is one of many coastal monitoring stations established for BELA and CAKR (Jordan et al., 1999, 2008).

For BELA and CAKR, the methodology outlined in this document – with geospatial analysis of repeat imagery – is the best to address monitoring goals. This approach: provides both local and regional results; is both comprehensive and representative; and is especially favorable given the extent of the BELA and CAKR shorelines (approximately 450 km, or 250 miles) and the logistics that would be involved for remote field operations. The geospatial approach can be supplemented with field-based efforts for cm-level accuracy for selected key sites, or with photography and videography before, during, and after extreme events. In these ways, inventory and monitoring of coastal change can meet the objectives outlined above.

Sampling Design

With the methodology highlighted here, site selection and spatial design boils down mainly to extent, frequency, and timing of imagery selected for processing. These are discussed further below.

The location of coastal-change observations is determined primarily by the selected geographic extent of imagery to be analyzed. Clearly identify an “Area of Interest” (AOI, a geographic bounding box or polygon that encompasses the study area for coastal change analysis). Consider factors such as: the extent of previously released orthoimagery, digital shorelines, and DSAS baselines and transects; the mission of the project (e.g., the entire ARCN coastline); whether to include only outer shorelines or the inner portions of barrier islands and mainland lagoon coasts as well; how far to go up rivers or inlets; whether to include non-NPS lands that form gaps along the coastline for comprehensiveness, etc. If at all possible, future monitoring for BELA and CAKR shorelines should encompass the entire area previously analyzed (see Figs. 5 and 6). Other considerations related to geographic “sampling” are: the shoreline should be digitized as a line with points separated every 20 m (66 ft), with points added where extra detail is needed; adequate spacing of “observations” – in this case, the horizontal separation between DSAS transects along a shoreline – should be about every 50 m (164 ft).

The frequency of coastal-change observations equates with the time interval between “timeslices” of imagery to be analyzed. In general: go as far back in time as possible; in many areas, this will depend on what imagery is available; for Alaska before year 2000, most areas outside villages are limited to statewide 1950’s and 1980’s aerial photography; some areas in Alaska have wide coverage with high-resolution aerial photography or satellite imagery after the year 2000 (e.g., see the Statewide Digital Mapping Initiative, or SDMI; <http://www.alaskamapped.org/sdmi/>). With ongoing vital sign monitoring, the repeat interval for acquisition and processing of additional imagery should be every 5 years (or at most every 10 years). Ideally the interval between timeslices should be consistent. Even more frequent image acquisition would be quite useful for researching the processes and impacts of storm climatology and extreme events.

The intra-annual timing of coastal change observations relates to when during the year new imagery should be acquired. In many cases, studies will be limited to the dates of available historic imagery. But when tasking new acquisitions of either aerial photography or satellite imagery, consider that mid-summer to earliest fall is best; avoid snow cover or sea ice that obscures the bluffs, beach, or nearshore areas. If possible for macro-tidal areas, the imagery should be tide-coordinated to capture a selected water level. New imagery should be cloud free, and acquired during periods of stable weather with calm winds (avoid wind and wave setup with locally higher, transient water levels associated with storm events; and avoid a week or longer after a storm or wind event; see also Psuty et al., 2010).

For additional considerations specific to ARCN, see the section below, “Potential Future Research for BELA and CAKR”.

Other Relevant Protocols

A few other NPS protocols address monitoring of coastal zones and ecosystems. The most relevant is Psuty et al. (2010), which focuses on changes in shoreline position for the Northeast Coastal and Barrier Network. They provide a thorough discussion of the ocean beach-dune ecosystem, a comparison of methods, and sampling design. SOP’s cover repeat DGPS surveying by ATV of the neap high-tide swash line, GIS analysis using DSAS, and spatial data management, among others. They highlight the importance of consistency in data collection and

processing for comparability of results. Although the geomorphic processes and coastal landforms in the eastern and northeastern US are quite dissimilar from those in ARCN (e.g., seasonal variation in beach profiles, greater tidal range, visitor use, lack of sea ice, easier logistics, etc.), much of what is covered by Psuty et al. (2010; see also Psuty and Silveira, 2011a) is pertinent for coastal change studies in Alaska. And note also that the protocol by Psuty et al. (2010) is becoming adopted also by the U.S. Fish and Wildlife Service (see Psuty and Silveira, 2011b).

Another NPS protocol for monitoring coastal change in Alaska, by Jorgenson and Miller (2010), focuses on changes to ecosystems in the coastal salt marshes of the Southwest Alaska network. They cover a range of procedural steps and vital signs, including: georectification of aerial photography, delineating waterbodies, measuring shoreline change from repeat imagery using DSAS, measuring topographic profiles, establishing tide gauges, and assessing changes to soil, vegetation assemblages, and ecotypes. Although the coastal geomorphology, ecology, and especially the tides differ considerably from those in BELA and CAKR, the protocol by Jorgenson and Miller (2010) provides a useful reference.

Other protocols relating to remote sensing of landscape change, or to other ARCN vital signs, may be of interest. Several address use of satellite imagery for landform classification and detecting landscape change (e.g., Reed et al., 2006; Kennedy et al., 2007; Townsend et al., 2006). Wells and Macander (2010) document ecotypes and the IKONOS imagery covering the ARCN parks. Other relevant protocols for the ARCN parks encompass coastal lagoons (Reynolds et al., 2010), shallow lake limnology (Larsen et al., 2011), terrestrial vegetation (Swanson, in review), and permafrost (Swanson, in review), among others.

Data Management, Analysis, and Reporting

This protocol fundamentally encompasses creation, analysis, and availability of geospatial datasets. These are addressed in detail in the Standard Operating Procedures (SOP's), with brief summaries below. A practical end goal is to generate new datasets that are standardized and thus compatible for analysis with previous data releases, and which are of high quality, properly documented, archived, and accessible.

Data management is the focus of SOP #1, "Spatial Data Management". Key points include: assemble a spatial database with the requisite or relevant datasets that have been previously released; to avoid confusion with an abundance of data layers, carefully organize the directory (folder) structure; similarly, pay careful attention to file-naming conventions for logical sorting and consistency; incrementally document in detail the steps taken during geoprocessing; complete FGDC-compliant metadata; and package the data and metadata for discovery and access.

Data analysis is at the heart of three SOP's. SOP #2, "Digitizing the Shoreline", provides guidelines and stepwise procedures for creating line features representing a carefully defined shoreline (for ARCN, the wet/dry line as visible on the beach in the imagery), with an eye toward compatibility with previously released digital shorelines. SOP #3, "Analysis of Error for Coastal Change Rates", involves a procedure to accurately quantify propagated errors. SOP #4, "Spatial Analysis of Coastal Change Using DSAS", provides details and steps for using the USGS Digital Shoreline Analysis System (Thieler et al., 2005, 2009) to calculate shoreline displacements and change rates for both erosion and accretion. The most important output for these analytical procedures is one or more data layers of shoreline "transects", each embedded with the analytical results.

Successful data reporting relies on the structure and completeness of data releases, including: a readme file with an abstract and list of files; the data itself – new imagery, digital shorelines, and attributed DSAS transects; FGDC-compliant metadata; and potentially a powerpoint overview of the data release. Datasets will be submitted to ARCN and peer-reviewed if possible. ARCN should manage data archiving, discovery, and access (through the NPS Data Store or other data repository).

Finally, successful reporting will include summary statistics, summary maps and figures, annual or progress reports, final reports, and potentially journal articles to document trends, patterns, and impacts. See SOP #5, "Synthesis and Presentation of Results", which presents guidelines for how to create effective tables, graphs, and maps. For data management and analysis in general, and for more on reporting, see Jorgenson et al. (2010) and especially Psuty et al. (2010).

Personnel and Operational Requirements

The analysis and research described here should be performed by a small team as part of – or in close collaboration with – the ARCN staff. A project leader, or Principal Investigator (PI) will be responsible for planning, implementation, and project management. This person should be a coastal geomorphologist, with working or expert knowledge of Arctic coastal processes, landforms, and coastal change. Vital to the team is one or more GIS and remote sensing specialists – a technician with experience working with imagery and proficient with ArcGIS, and preferably with prior experience in geospatial analysis of coastal change. The team might include one or more graduate students or postdoctoral students. Most important – given that errors in GIS with geoprocessing options or data management can be significant yet not apparent until much later – is attention to detail, quality control, and careful documentation of steps taken while processing is being conducted. Data management is a responsibility shared among the team and the park and Network data managers.

The project leader and preferably the GIS/RS specialist should be directly familiar with the environmental setting, natural resources, and coastal geomorphic types in BELA and CAKR. If new to the area, this objective could perhaps be met through field reconnaissance. Ideally the PI and GIS/RS specialist will have first-hand experience with the local expression of the shoreline in BELA and CAKR. This is particularly important because the identification and delineation of the shoreline from remote-sensing imagery is a visual and somewhat qualitative process. (At a minimum, the same person should digitize the entire coastline for any given “timeslice” of imagery; for more on this and roles, responsibilities, and qualifications, see Psuty et al., 2010).

Without requisite field research, equipment necessary for this protocol consists of computer hardware and software. Needed are a workstation with large display, reliable backup system, and peripherals. ArcGIS Desktop is recommended for spatial database management, metadata creation, and digitizing shorelines; it is required for DSAS analysis. Remote-sensing and specialized photogrammetry software may be needed to process and orthorectify imagery – e.g., ERDAS Imagine and Leica Photogrammetry Suite (LPS), ENVI, PCI Geomatica or similar.

Operational costs are primarily for salary (PI, GIS/RS specialist, and potentially one or more graduate students or postdoc’s). Some budget may need to be allocated for purchase of new data, in particular acquisition of new imagery (which can be quite expensive unless available through licensing for government agencies or academia). Also substantial may be orthorectification of the raw imagery; this processing is time-consuming for historic aerial photography, less so for newer airborne or satellite imagery, and is typically accomplished by contract specialists. Other budget items include computer hardware and software, office supplies, communication costs etc. Travel should cover meetings and presentations (coordination and collaboration) with the Network staff, presentations at national or international conferences, and potentially travel and logistical costs for field reconnaissance. It is expected that the work described here (with one or only a few imagery timeslices more recent than the year 2003) could be completed in about two years, every five to ten years. And it would be wise to anticipate special efforts immediately before, during, and after summer or fall storm events to better assess the impact of intermittent high-magnitude events.

Future Research for BELA and CAKR

To meet the ongoing monitoring objectives, future studies in ARCN should periodically update the analysis of coastal change. This is possible despite the considerable lengths of shoreline involved, paucity of geospatial data or imagery typical for Alaska, and the remoteness of the study area. Future research should be guided by the most pressing question: Is coastal erosion since 2003 accelerating with Arctic and global warming?

Future studies should first build upon previous data releases:

- high-resolution, orthorectified aerial photography from the 1950's, 1980's, and 2003 for the coastal areas of BELA and CAKR (Manley et al., 2007a-c)
- digital shorelines for each of these time periods (Manley et al., 2010)
- DSAS datasets with baseline, transects, and embedded analytical results of change rates (Lestak et al., 2010)

Each of these data releases was well documented with FGDC-compliant metadata, and can be obtained directly from ARCN or from a new NPS Data Store through the “Integration of Resource Management Applications” (the IRMA Portal). The imagery can also be viewed and accessed through AlaskaMapped.org (see also NPS-ARCEN, 2010).

To update this vital sign to quantify coastal change since the year 2003, the project should obtain newer imagery. Horizontal resolution should be 1.0 m or less. Options include: IKONOS imagery currently available for BELA and CAKR from 2006 and 2007; coastal SPOT5 imagery recently released, or soon to be released, through the Alaska Statewide Digital Mapping Initiative (SDMI; the resolution of 2.5 m might be acceptable; <http://www.alaskamapped.org/>); best would be to acquire new aerial photography (with airborne control through GPS and IMU) or especially new satellite imagery (such as WorldView-2, GeoEye, etc.; this imagery may be available through government licensing at low cost or no cost). Newer high-resolution imagery will form the foundation for future efforts with coastal change detection.

To reduce horizontal errors to acceptable levels, the new imagery will need to be appropriately orthorectified – processed from raw imagery, or initially georectified imagery, to create an accurate map layer (cf. ASPRS, 2006). In essence, this requires full orthorectification, using sophisticated remote sensing software (such as LPS, with bundle-block adjustment) to remove distortions relating to topographic relief as well as the position, orientation, and parameters of the camera or sensor. Such processing takes advantage of: sensor information (such as “RPC” files), a best-available DEM, tie points between overlapping scenes, and ground control points (use the 2003 orthophoto mosaic for image-to-image control points). For example, the absolute horizontal error for standard IKONOS scenes can be greatly reduced from about 25 m or more to about 3 m or less. The accuracy of the final orthoimagery should be quantified with manually measured, independent check points (also use the 2003 imagery as reference; don't rely on model-stated output errors). Avoid imagery that has not been checked for errors, is a standard georectified or “RapidOrtho” product level, or has been processed with polynomial transformations (e.g., “warped”, or “rubber-sheeted”). With a hypothetical time interval of 5 to 10 years and average rates of coastal change of roughly 1 m/yr, the imagery will need to have horizontal errors of generally 5 m or less.

The project can then process and analyze the imagery and other datasets:

- organize relevant data layers in a spatial database (SOP #1)
- define the shoreline and digitize onscreen for each new “timeslice” of imagery (SOP #2)
- estimate propagated errors (SOP #3)
- rerun DSAS (re-“calculate” transects) using the previously released baseline and transects with all available digital shorelines (SOP #4)
- integrate and synthesize the results with tables, maps, etc. (SOP #5)

In this way, future studies can build upon previous ones, applying a geospatial approach to capture high spatial variability and to obtain results that are locally accurate (for particular areas of interest) as well as regionally comprehensive and representative.

Other approaches to researching coastal change may be of interest also, as resources permit. For example, the project could pursue high temporal resolution for selected key sites or target areas, by analyzing shorelines apparent in large-scale aerial photography from 1976, 1987, and 1995-1997; this approach would be useful for assessing recent changes in erosion rate with a more appropriate historical perspective. A three-dimensional change-detection study could be completed with analysis of repeat DEM’s; such an approach would take advantage of the 2-m 2004 NOAA LIDAR that was captured in a narrow strip along the coast and is publicly available (<http://maps.csc.noaa.gov/digitalcoast/data/coastallidar>). This could be compared with other high-resolution DEM’s: perhaps the anticipated 5-m coastal SDMI DEM (<http://www.alaskamapped.org/>); or better would be to partner with the USGS to extend LIDAR acquisitions along the northern Chukchi coast of Alaska, south to the shores of ARCN (contact Ann Gibbs with the Pacific Coastal & Marine Science Center). Other possibilities are to: revisit and re-measure coastal transects first established in 1987 (Jordan et al., 1999; 2008); conduct aerial reconnaissance or field documentation with photography and videography shortly before, during, or after storm events; stratify the shoreline by geomorphic type to help broaden summary analysis; or complete rigorous geostatistical analysis to relate empirical coastal change to climate forcing or environmental variables to better understand the cause and effect of coastal processes.

Ongoing inventory and monitoring of coastal change can determine long-term trends and recent shifts in erosion and accretion, evaluate high spatial variability, and assess impacts on ecosystems and habitats, thus providing a strong scientific basis to help inform management decisions.

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Standard Operating Procedures

SOP #1: Spatial Data Management

Version 1.0 (June 2012)

Revision History Log

Version No.	Revision Date	Author	Changes Made	Reason for Change

Overview

This SOP provides guidelines to avoid confusion, and to make processing more efficient overall, for data related to spatial analysis of coastal change in the ARC� parks. To begin, assembly of a spatial database should include previously released imagery, digital shorelines, baselines, and transects. Addition to, and overall organization of the data, is facilitated by standardized approaches to directory structures, as well as file naming conventions. Progress with data management and processing should be documented internally with a journaling process. Files to be distributed should be fully documented with FGDC-compliant metadata, accompanied by additional support documents, archived, and made available for data discovery and access. Data managers and users should be familiar with discussion and similar procedures in SOP #8 of Psuty et al. (2010) and SOP #5 in Kennedy et al. (2007). See also sections in the narrative on “Methodology and Design”, “Data Management, Analysis, and Reporting”, “Personnel and Operational Requirements”, and “Future Research for BELA and CAKR”.

Relevant ARC� Coastal Datasets

Future efforts for inventory and monitoring of coastal change for ARC� can get up to speed quickly and effectively by making use of this protocol coupled with previous data releases:

- high-resolution orthorectified imagery for the 1950’s, 1980’s, and 2003 at 1-m or better resolution with minimal errors covering the entire BELA and CAKR shorelines and surrounding areas (in GeoTiff and .sid formats; Manley et al., 2007a-c).

- digital shorelines representing the wet/dry line, digitized every 20 m or better for 480 km, for each of the time periods of imagery (in shapefile format; Manley et al., 2010).
- coastal-change results generated using the three periods of digital shorelines and the USGS Digital Shoreline Analysis System (DSAS, an extension to ArcGIS; Thieler et al., 2005, 2009); the ARCN DSAS release (in ArcGIS geodatabase format; Lestak et al., 2010) includes DSAS baselines and transects; the transects are attributed with calculations of erosion and accretion rates, among other statistical parameters.

The ARCN coastal imagery is accompanied by extent and index layers, as well as a powerpoint overview. Each of the data releases includes well documented metadata and readme files. They share a common projection and datum (UTM zone 3, NAD83). The data can be obtained directly from ARCN or from a new NPS Data Store through the “Integration of Resource Management Applications” (the IRMA Portal). The imagery can also be viewed and accessed through AlaskaMapped.org (see also NPS-ARCEN, 2010).

Other relevant map layers (such as the park boundaries, lower resolution imagery and basemaps, etc.) can be accessed from ARCN, the IRMA Portal, AlaskaMapped.org, the Alaska Geospatial Data Clearinghouse, the Alaska State Geospatial Data Clearinghouse, and other common data catalogs. A few Digital Elevation Models may be of interest, such as the 60-m USGS NED DEM and the 30-m ASTER DEM (available from ARCN and the IRMA portal, cropped to BELA and CAKR) and particularly a 2-m 2004 NOAA LIDAR DEM (<http://maps.csc.noaa.gov/digitalcoast/data/coastallidar>).

File and Folder Management

Shoreline change analysis will generate a multitude of files, which need to be carefully organized in a directory structure. Proper file and folder management will minimize confusion and facilitate an efficient workflow. The following directory structure is recommended:

air_photos – subdirectories for camera calibration reports and tables, ordering information and photo indexes, if needed.

data – datasets actively being used for display, map making, study area orientation, etc.

data_dsas – subdirectories for results, statistics and output spreadsheets.

data_other – other geospatial datasets collected during project work that are not actively being used.

data_water_line – digitized water lines.

images – maps and other images in jpg or tif format, etc., as output from ArcGIS.

layers – ArcMap layer files.

maps – ArcMap map document files.

metadata – subdirectories for metadata templates, data release readme files, and master metadata files for orthoimagery, scans and accessory layers.

ortho_1950_approx – ca. 1950 orthorectified imagery.

ortho_1980_approx – ca. 1980 orthorectified imagery.

ortho_2003 – 2003 orthorectified imagery.

ortho_indexes – index shapefiles for orthoimagery. Each shapefile table contains detailed attribute information such as roll number, frame number, acquisition date, frame RMSE, and USGS Entity ID.

ortho_other – subdirectories for camera models, check points, control points, RMSE tables, and other files related to the creation or use of orthoimagery.

paperwork – subdirectories for reports, protocols, papers, budgets, proposals, workshops, and training.

presentations – subdirectories named with meeting date for project meeting and website presentations.

refs – journal articles, bibliography, and research related material.

scripts – detailed text files and spreadsheets containing step-by-step documentation of project work.

temp – temporary workspace.

Other directories can be added as the database grows (e.g., ortho_2012). A reliable backup system should be in place, whether through automated nightly transfers to a RAID device or server in another location, with cloud storage, or some combination.

File Naming Conventions

Similarly, a standardized approach to file names will ensure consistency, allow multiple users to work with the data, and enhance project documentation and tracking. The goal is to have as much information as reasonable tied to the filename, such that data processing can be conducted with or without a comprehensive “data dictionary”. Also, an approach like this enables a logical sorting order by filename. All of this will become more understandable as a GIS/RS specialist works through this protocol and the analysis.

The recommended file naming conventions for the most important types of files, below, include a few common codes:

- for the park – ParkCode: cakr = Cape Krusenstern National Monument; bela = Bering Land Bridge National Preserve; beca = bela + cakr, covers both parks
- for Shoreline Reference Feature (SRF) – this can be bluff top (bt), waterline (wl), lagoon, etc.
- for the year – YYYY (e.g., 1957) or YYYYa (for approximately, e.g., 1950a)

The naming conventions for different types of files are (in order of creation):

Scripts

Format: ParkCodeScriptNmbr_ProcessDescription.txt

ScriptNmbr = consecutive ID script number, 3 digits

ProcessDescription = Few word description of what processing steps the script describes.

Example: bela310_digitize_bela_wl_2012.txt

Shoreline Template Shapefile

Format: ParkCode_SRF_YYYY_template.shp

Example: bela_wl_YYYY_template.shp

Shoreline Shapefiles

Format: ParkCode_SRF_YYYY.shp

Example: bela_wl_2012.shp

Note: the year codes for waterlines for the 1950's and 1980's are appended by an "a" to reflect that they represent approximately 1950 or approximately 1980; e.g., bela_wl_1950a and cacr_wl_1980a.

Shoreline Shapefiles Combined for Each Time Period

Format: ParkCode_SRF_YY_YY.shp

Example: bela_wl_50a_80a.shp

Shoreline Shapefiles Combined for All Shorelines

Format: ParkCode_SRF_all.shp

Example: bela_wl_all.shp

Baseline Shapefiles

Format: ParkCode_SRF_baseline.shp

Example: cacr_wl_baseline.shp

Geodatabase Files

Format: ParkCode_SRF_dsas.mdb

Example: bela_wl_dsas.mdb

Map Documents for DSAS Analysis

Format: ParkCode_SRF_dsas.mxd

Example: bela_wl_dsas.mxd

Transect Template Layer in GeoDatabase

Format: ParkCode_SRF_trans_template

Example: bela_wl_trans_template

Transect Layers in GeoDatabase for Each Time Period

Format: ParkCode_SRF_trans_YY_YY

Example: bela_wl_trans_80a_03

Transect Layer in GeoDatabase for All Shorelines

Format: ParkCode_SRF_trans_all

Example: bela_wl_trans_all

Transect Shapefiles for Each Time Period

Format: ParkCode_SRF_trans_YY_YY.shp

Example: bela_wl_trans_03_12.shp

Transect Shapefiles for All Shorelines

Format: ParkCode_SRF_trans_all.shp

Example: bela_wl_trans_all.shp

Transect Results Excel Tables for Each Time Period

Format: ParkCode_SRF_trans_YY_YY_results.xls

Example: cakr_wl_trans_50a_80a_results.xls

Transect Results Excel Tables for All Shorelines

Format: ParkCode_SRF_trans_all_results.xls

Example: cakr_wl_trans_all_results.xls

Standardized Transect Color Ramps

Format: ParkCode_SRF_trans_ramps

Example: cakr_wl_trans_ramps

Template Map Documents for Display of Results

Format: ParkCode_SRF_trans_YY_YY.mxd or ParkCode_SRF_trans_all.mxd

Example: bela_wl_trans_03_12.mxd

For use with ArcGIS, avoid spaces in directory paths or file names; use underscore characters instead. A simple trick for assuring version control and to avoid corrupted files is to create copies and append filenames with the date (e.g., “_120516” for May 16, 2012) for files that will continue to be modified, prior to being made final. “Template” files can be useful as a common starting point for multiple related files for certain types of files. And files that are for temporary use only could use a filename prefix of “t_”. Ongoing research should use file naming structures that are consistent with the previous coastal-change data releases. See also the latest “GIS Naming Conventions” document from the North Coast and Cascades Network (NCCN, 2007).

Documentation of Processing Steps

Future research should carefully capture, or “journal”, details regarding geoprocessing steps as they are undertaken. Previous coastal research for ARCN has referred to each of these documents as a “script” – a text document, word processing document, or spreadsheet that captures the essence and fundamental choices of geoprocessing as it occurs. Scripts may or may not include actual code (command line code or python scripts, for example). Filenames are as indicated above, numbered sequentially as work progresses. The text should include operator and date, followed by anticipated steps for the processing objective at hand, data layers needed, the actual steps taken or problems encountered, and appended periodically on new days. Depending on desired granularity, new scripts can be started for high-order or for incremental steps. For example, scripts might be: “bela040_obtain_2006_IKONOS.txt”, “cakr070_DSAS_templates.txt”, “bela090_digitize_bela_2006_wl.txt”, or “cakr120_recast_DSAS_transects.txt”.

Such “scripts” can be important for documenting configuration settings, specific settings chosen for each use of geoprocessing tools, and overall project management. They can help at a later date to more efficiently conduct a similar processing step on another dataset. Appropriately, details can be later harvested while creating metadata. Perhaps most important, each script provides a working space for brainstorming and problem solving as the analysis proceeds.

Another NPS Protocol with an SOP on data management provides a well written, comparable perspective (Kennedy et al., 2007, SOP #5):

“It is recommended that an electronic text file journal be maintained to keep track of all filenames and decisions made during the steps of this protocol. This journal should be maintained in chronological order, with the date of each entry noted. Whenever a processing step is conducted, all of the relevant information about that step is entered into the journal. Enough detail should be given to fully replicate the step, including the names of all input and output files, the software module and tool used for the analysis, and all processing options (buttons selected, data types, etc.). The use of hyperlinks to other files also can be a useful feature because it provides full pathnames of files that can be used later for interpretation, even if the hyperlinks themselves become out of date because files are moved.

Additionally, the journal should be used to record rationale for making decisions and for noting observations about imagery or datasets that may be useful later for error tracking or evaluation of unexplained results.

Although the key steps leading up to any geospatial product also will be stored in the metadata, this journaling process allows much more flexibility in keeping track of details. Most of the time, these details are not needed later, but occasionally they are the difference between a quick fix and starting from scratch.”

Metadata

Metadata is “data about data”, in other words: information about how the dataset was created, it’s geospatial parameters, scope, etc. According to the NPS (2012), “Metadata is standardized descriptive information about datasets. Metadata describes the content, quality, and condition of a data set. It also provides standardized documentation using a common structure, format, and terminology.”

Datasets that are distributed without metadata are practically worthless. The dataset would not be discoverable in a data catalog. It may be technological impossible to use a dataset without certain parameters known. More importantly, without metadata it may not be possible to determine if a given dataset is appropriate or accurate enough for subsequent use. Thus, all project datasets that are disseminated should be accompanied by FGDC-compliant metadata.

Such metadata can be generated and edited in ArcCatalog, and distributed in .html, .txt, and .xml formats. Particular attention should be paid to the abstract, dataset citation, data sources, estimates of accuracy, and especially the description of processing steps. To some extent, new releases will be able to copy and paste relevant text from the previously released ARCN coastal datasets. When a data release contains numerous datasets that are identical in many respects (e.g., a multitude of .shp or .tif files), it can be helpful to create a master metadata template for the release, which then can be batch copied with appropriate new filenames (the same filename as for the dataset, but with .html, .txt, and .xml extensions). The NPS and potentially each network may have specific requirements for metadata. Note that the newest version of DSAS (Thieler et al., 2009) contains functionality for automatically drafting metadata for transect

layers. Other useful resources are from the FGDC (<http://www.fgdc.gov/metadata/>) and USGS (<http://geology.usgs.gov/tools/metadata/>). See also Kennedy et al. (2007) and Psuty et al. (2010).

Data Distribution

The most important geospatial datasets created in the future for the ARCN coastal monitoring project should be packaged and made available for discovery and access. This should include any new orthoimagery, digital shorelines, DSAS baselines and transects, and any other fundamentally valuable datasets.

Each data release should include the data itself, of course, as well as a set of related files. The data files could be nested within subdirectories for organization. Metadata should be seamlessly included with the same file name as each data file, but with .html, .txt, and .xml extensions. There should be a “readme” file that includes a title, abstract, dataset citation, and contact information for the release. There should also be a table listing the dataset files, a brief description or title, file type, associated files (e.g., .tfw, or .dbf, .prj, etc.), and comments for each. It can also be quite helpful to the end user to include an illustrated summary or overview of the data release as a powerpoint presentation or similar, describing the dataset and providing a visual overview of dataset qualities and applications.

Each data release should be submitted to ARCN and the I&M Program for archiving and dissemination through a data catalog such as the IRMA Portal. The project leader should work closely with the ARCN data manager. Where possible, the metadata and perhaps even the data itself should be made available through other spatial data infrastructures (metadata or data clearinghouses).

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SOP #2: Digitizing the Shoreline

Version 1.0 (June 2012)

Revision History Log

Version No.	Revision Date	Author	Changes Made	Reason for Change

Overview

With future research on coastal change in ARCN, shorelines should be digitized within the GIS (preferably ArcMap) based on visual interpretation and delineation from orthorectified, high-resolution aerial photography or satellite imagery. The first step in the process is to identify and define the shoreline explicitly as a Shoreline Reference Feature (SRF; e.g., Boak and Turner, 2005). Next is the actual onscreen digitizing of line vector files, one each for BELA and CAKR, formatted appropriately for use in the USGS Digital Shoreline Analysis System (DSAS, an extension for ArcGIS). Digitizing is one of the more time-consuming aspects of the research. The digital shorelines will be useful for visualization and display, but more importantly for analysis of erosion and accretion. See also SOP #2 in Jorgenson et al. (2010) and SOP #5 in Psuty (2010).

Define the Shoreline

The coastline should be carefully identified and defined as an SRF: a “visually discernable feature” apparent from contrasting color (hue, tone and saturation), texture, and pattern in orthoimagery, coupled with a sound understanding of coastal processes and geomorphology (e.g., Bird, 2000). In practice, this is based on beach face characteristics and the imagery. Previously released digital shorelines for ARCN defined the SRF as a “waterline” – the wet/dry line, similar to shoreline indicators as reported for example by Dolan et al., (1980); Fletcher et al. (2003); and Boak and Turner (2005). In general for ARCN, fortunately a microtidal area, the waterline is a fairly stable feature and easily visible in the absence of shorefast sea ice. See also: Moore (2000); FGDC Marine Boundary Working Group (2006); and Gorokhovich and Leiserowitz, (2012).

In detail, the “waterline” – as identified and delineated in the previously released ARCN digital shorelines (Manley et al., 2010) – varies slightly in definition and identification depending on the image data source (Fig. S2.1). For the 1950's B&W photography, the waterline varied from photo to photo, sometimes within the same photo, based on exposure and placement within the frame. No universal dictum can be claimed as a particular characteristic of that line, other than the water is black, the beach is white to grey to dark grey. For the 1980's color infrared (CIR) photography: water is dark blue with light blue to white breaking waves; the beach is light blue to white. For the 2003 natural color (NC) photography: Blue-green water becomes shallow and transparent to the substrate underneath, but usually maintaining a darker characteristic subaerially on approach of the beach, with occasional low white breaking waves. Textural differences can be important. Often the waterline jumps from one wave maximum to another, with an intervening segment of back swash and calm water or perhaps even subaerially exposed wet sand or gravel.

When delineating an SRF from new imagery for ARCN, future researchers should, and can, become fully familiar with how the SRF was previously defined by reviewing the previously released shorelines over the also available, corresponding imagery. Zoom in and pan across much or all of the shorelines. As a test, re-digitize the prior shorelines using only the imagery. Get a feel for the wet/dry line is identified, and the associated errors.

There are additional, related guidelines and recommendations. The shoreline should be digitized only from imagery that was fully orthorectified to reduce errors, and was captured during a period of calm, stable weather (see section in narrative, “Future Research for BELA and CAKR”). Hand-held field photos, or those from a helicopter or airplane, can be very helpful to understand the landscape and the beach/water interface in a particular area. Zoom in and review the new timeslice of imagery, and the expression of a comparable shoreline in various places. The project team (e.g., Project Leader, coastal geomorphologist, GIS/RS specialist, etc.) should work together closely to clearly define the shoreline before digitizing starts.

As an aside, an alternative SRF to choose for ARCN is the edge of a beach-facing bluff. Advantages for using the bluff top include: in terms of impacts to upland habitats, it is more relevant than the waterline; and in places, depending on sun angle, the bluff top can be more accurately located than the waterline. However, disadvantages are that the bluff top: varies significantly from one location to another in terms of geomorphic expression and formative process; can be confused with a vegetation limit, which is affected by other processes; and is rather discontinuous, absent along much of the area. The water line is recommended here for consistency with prior datasets, and mainly because it is a broadly applicable SRF that can be regionally comprehensive.

Digitize the Shoreline Onscreen

After the SRF has been defined, it can be captured in digital form by digitizing onscreen using ArcMap. Requirements and recommendations below are followed by details for procedural steps.

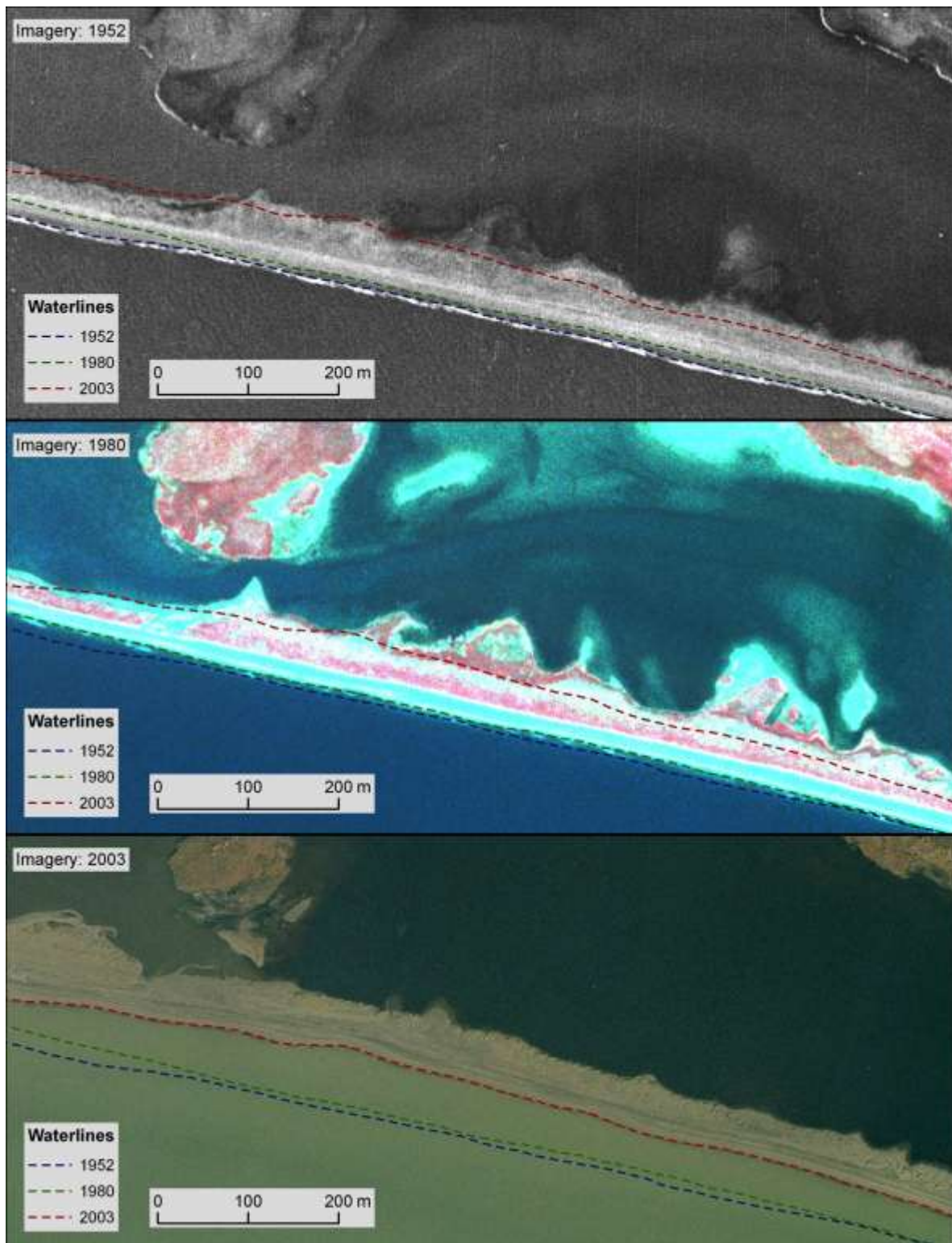


Figure S2.1. Maps of digital shorelines over corresponding imagery, zoomed into a small portion of CAKR east of the ranger station at Anigaaq. This small area shows minimal shoreline erosion from 1952 to 1980, but tens of meters of erosion thereafter. Also visible is a rise in the water level in the lagoon just to the north, which was closed at some point before the 2003 photography was acquired on Sept. 19.

Guidelines

In general, new digital shorelines should be compatible with those previously released. All geospatial data layers for the project should use a common projection and datum (depending largely on the original projection and datum of new imagery; UTM zone 3, NAD83 has been used previously for ARCN coastal monitoring). The shoreline on the mainland side of lagoons need not be digitized, as these are typically not well expressed; the previously released shorelines are for the mainland where there are no lagoons, and for the outer shores of barrier islands and spits. If at all possible, the new line feature should extend to cover the entire shorelines of BELA and CAKR, including some fairly large gaps, coinciding with the extent of the previously released digital shorelines.

The new shorelines should also be compatible with DSAS for subsequent analysis. The SRF should be digitized with the land always on the right-hand side: from southwest to northeast for BELA, and from south to north for CAKR. And the shoreline segments should be attributed with fields for date and accuracy, with additional fields recommended (see section below on shapefile template); it generally is easier to attribute the line segments while you proceed with digitizing them.

In our experience, shoreline delineation from imagery typical for Alaska cannot be automated, and they should be manually determined with visual interpretation. Typically the shoreline is to be digitized onscreen with a map scale of about 1:700. Shoreline segments should have points (vertices) every 20 m, supplemented with extra points where needed to capture local detail. The use of “streaming” while digitizing is recommended. It is acceptable to have breaks, or gaps, in the digitized shoreline; for example at stream intersections or lagoon or tidal outlets; and where the shoreline is not discernible with confidence. If working with individually orthorectified frames of aerial photography, digitize the shoreline continuously from frame to frame, usually choosing the center of each frame if possible. The final compilation may need to be edited slightly for consistency of extent among digital shorelines, and should be subject to a final check for quality in terms of line delineation as well as completion of attributes.

Starting with a shoreline template shapefile, there are a few other considerations. Do a practice run of digitizing first, to become comfortable with the process. If at all possible, the same person should digitize the entire coast, to minimize subjective errors. The GIS/Remote Sensing Specialist, if chosen to do so, should work closely with the coastal geomorphologist periodically, and especially before going too far with the process. Digitizing hundreds of km of coastline can be time consuming, and may take approximately one month per new timeslice.

Create a Shoreline Template

Start by creating a blank “template” line shapefile. The filename should be *ParkCode_SRF_YYYY_template.shp* (e.g., *bela_wl_YYYY_template.shp*). One may be available from the ARCN Data Manager. The template must include fields for “DATE_” and “ACCURACY” to use with DSAS (see Thieler et al., 2005, 2009). Additional fields – “Ortho_File”, “Comments” and “digit_erro” – are recommended for inclusion. Details for each of the fields:

DATE_	Text, Length of 10 or 22, User-created
ACCURACY	Short Integer, Long Integer or Float (any numeric), Precision of 0, User-created
Ortho_File	Text, Length = 30, Name of photo frame used to digitize shoreline
Comments	Text, Length of 75 characters
digit_erro	Float, Length of 13

Additional details are from Thieler (2005):

“The Date_ and Accuracy fields must be manually created by the user and populated with appropriate attribute data.



Date_ = length can vary from 10-22 depending on the timing between shorelines: Length = 10 for shoreline change spanning days, months or years and will have dates set up as mm/dd/yyyy; Length = 22 for shoreline change spanning different hours within the same day and will have dates set up as mm/dd/yyyyhh:mm:ss (using either 24-hour or AM/PM)

Accuracy= specifies accuracy of each shoreline. If a shoreline has an accuracy of zero it will use the value specified by the user in the default parameters window (see p.10).”

“Ortho_File” is recorded for each line segment. This field contains the name of the photo frame used to digitize the shoreline. “digit_erro” is recorded for each line segment. See SOP #3 for a discussion of digitizing error. The “Comments” field can be used for notes about that particular line segment, the digitizing process, or the digitizing error.

Digitize the Shoreline in ArcMap

In ArcMap (v. 9.x; steps might differ slightly for v. 10.x):

- 1.) Open a new map document .
- 2.) Save the map to the /maps subdirectory, using a standardized file name as defined in SOP #1.
- 3.) Click the Add Data button, , navigate to the index maps for this area and add the index map for the appropriate year. *For example: cakr_ortho_2012_index.shp*
- 4.) Make a copy of the SRF template file according to the filenaming conventions in SOP #1 (e.g., *bela_wl_2012.shp*). Add it and the NPS boundary file and any other appropriate layers.
- 5.) Add the first few photos or tiles, using the index shapefile to find the appropriate image files.

Notes:

Identify and make visible the frames or tiles for the target year; generally choose between overlapping imagery based on quality of expression of the waterline, due to image quality; also check that the imagery is well registered to the 2003 imagery; in almost all cases they are equally well registered. And generally it is a good idea to avoid the corners or edges of a frame. When displaying the image in ArcMap it helps to adjust image brightness and contrast with the effects toolbar.

Zoom into the photo to get a feel for how the waterline is expressed in this area. Move along the coast and back, look at the field photos, compare with other timeslice imagery, and compare with other overlapping frames or tiles from the same timeslice.

- 6.) Prepare to digitize the SRF.
- 7.) Zoom in to approximately 1:500 to 1:800 scale.
- 8.) Start Editing (Fig. S2.1). Choose the SRF shapefile in the editor toolbar pull-down list.




Figure S2.1. Start Editing selection on the Editor toolbar.

Digitize in “Stream Mode”

Stream mode digitizing lets you capture features continuously as you move the cursor. As you stream, ArcMap automatically adds vertices at an interval you specify; this interval is called the stream tolerance. Because the default stream tolerance is zero, a tolerance value must be entered before digitizing, or the vertices will join together or overlap each other. Vertex spacing (stream tolerance) of 20 m should be used. Change the stream tolerance at any time, even when in the process of digitizing a feature. And you can add additional points at any time by clicking.

Specify the number of streaming vertices to group together. This number tells ArcMap how many vertices to delete when the Undo button is clicked. For example, if streaming vertices is set to 50, when the Undo button is selected while digitizing a feature, ArcMap deletes the last 50 digitized vertices from the feature.

To begin digitizing in stream mode, choose “Streaming” from the Sketch tool  context menu. Toggle between point mode and streaming mode by pressing the F8 key. Before streaming, set the digitizer to work in “digitizing mode” rather than in “mouse mode”; this constrains the screen pointer to the digitizing area.

Continue Digitizing

- 9.) Digitize the water line, stopping streaming to move laterally.
- 10.) Stop and save edits (Fig. S2.2) periodically: Editor pull-down menu > Save edits.

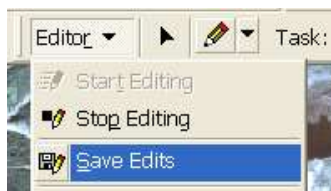


Figure S2.2. Save Edits.

- 11.) Zoom back out to the extent of the newly digitized line.
- 12.) Select the lines just created.
- 13.) Copy the orthophoto file name from the index map attribute table.
- 14.) Open the attribute table for the shorelines, click show selected only button.
- 15.) Open the index layer attribute table, copy the acquisition date for that photo frame, and paste into the shorelines “Ortho_File” field (put in leading zeros; must be mm/dd/yyyy, as in 09/06/2003). Sometimes ArcGIS puts a space in front of the text; delete the space.
- 16.) “Save edits” (Fig. S2.2). When finished choose, “Stop Editing” (also Fig. S2.2).

Notes:

Typically, do not show the lines for previously digitized timeslices while digitizing. In some cases it helps to turn them on briefly to verify the location of the SRF, to check gullies, inlets and other features, and to confirm that they start and stop on generally the same place along the coast. This shouldn't bias the digitizing.

To avoid corrupted files and to help with versioning, copy and save the shapefile each day with a code for the digitizing date at the end of the filename (e.g., *bela_wl_2012_130224.shp*). Repeat the digitizing for each park and each new imagery timeslice. And make sure the backup system is performing properly!

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SOP #3: Analysis of Error for Coastal Change Rates

Version 1.0 (June 2012)

Revision History Log

Version No.	Revision Date	Author	Changes Made	Reason for Change

Overview

Future research on coastal change in the ARCN parks should calculate horizontal error (in meters) for each new digital shoreline, as well the propagated error (in meters per year) for rates of coastal change. Shoreline error (E_{sj}) can be estimated for a given year by calculating the Square Root of the Sum of the Squares (SRSS) of orthorectification (o) and digitizing (d) errors. For example, the shoreline error for the BELA 1950 waterline is +/- 2.9 m. And the annualized change rate error (E_{cr}) can be estimated for a given time period by taking the SRSS of each bounding shoreline error, and dividing by the length of time period. For example, the error associated with a typical individual measurement for BELA, -0.29 m/yr (median for 1950 to 2003), is +/- 0.06 m/yr. (Arguably, the error for summary statistics – given randomized errors and $n > 2000$ – is much lower). This SOP presents the logic, steps, and results of error analysis for the previously released ARCN shorelines (Manley et al., 2010). This approach can be duplicated as future research creates additional digital shorelines and calculates new rates of erosion and accretion. Quantifying the magnitude of propagated errors is important for testing and establishing the validity of a geospatial analysis for coastal change.

Calculating Shoreline Error

Digital mapping of a shoreline is subject to two categories: measurement error and positional error (Moore, 2000; Fletcher et al., 2003). For BELA and CAKR, measurement errors stem from orthorectification of aerial photography, as well as onscreen digitization of the shoreline reference feature (SRF). Measurement error is discussed and presented further below.

Positional errors reflect the motion of the waterline across the beach profile, due to tides, waves, and wind setup. Positional errors for BELA and CAKR were assumed to be negligible because:

the area is microtidal, with the diurnal range estimated to be less than 0.5 m (Brower et al. 1977, Kowalik and Matthews 1982); stable weather is required for acquisition of aerial photography; climate records for the dates of imagery acquisition documented calm winds; and no or minimal waves are apparent in the imagery. Thus, the strategy presented below is based on measurement errors only, and is based on established practice for microtidal areas (cf. Moore, 2000; Morton et al., 2004; Hapke et al., 2006).

As an aside, future efforts should minimize – and could quantify – positional errors due to tides, wind and wave setup, etc. Previous efforts made use of available historical imagery, which was unfortunately limited. But future image acquisitions could be tidally coordinated. By all means, avoid aerial photography or satellite imagery acquired during a period of high wind speeds. A small study would be warranted to capture the waterline by GPS survey under varying tidal, wave, and wind setup conditions to actually quantify horizontal positional error.

Orthorectification Error

For the previously released orthoimagery (Manley et al., 2007a-c), root mean square (RMS) errors for each photo frame were calculated from independent checkpoints (see the metadata accompanying the data release). Then an orthorectification error (*o*) for each “timeslice” of imagery was calculated by averaging the frame RMSE values. Results are shown in Table S3.1. Because the 1950’s imagery and 1980’s imagery were orthorectified with control points from the 2003 imagery, their errors are appropriately relative, and the “relative” error for the 2003 imagery is zero.

Table S3.1. Orthorectification errors for each “timeslice” of imagery.

	ca. 1950	ca. 1980	2003
Orthorectification Error (avg. RMSE)	+/- 2.0 m	+/- 1.5 m	+/- 0.0 m

Digitizing Error

During coastline digitization, each line segment was attributed with image or frame acquisition date, the filename for the source imagery, various relevant comments, and an estimated digitizing error. The latter is a combination of both:

- uncertainty in the detection and visual identification of the interpreted line position (i.e., width of the envelope, band, or circle that defines the shoreline)
- error due to manual digitization: accuracy of shoreline placement by the hardware used and objectification of the shoreline.

This overall digitizing error was estimated as a +/- value during digitization. Digitizing error was entered for each line segment, then averaged by park (CAKR or BELA) and for each timeslice. The clarity of the aerial photos had a lot of bearing on this value judgment. Digitizing errors (*d*) are shown in Table S3.2, below.

Table 3-2. Digitizing errors for each shoreline.

	ca. 1950	ca. 1980	2003

BELA	+/- 2.1 m	+/- 2.3 m	+/- 1.0 m
CAKR	+/- 1.1 m	+/- 1.6 m	+/- 1.7 m

The error as attributed in the shapefiles does NOT incorporate error due to wind-related waves and tides at the time of image acquisition. The digitizing error also does not include orthorectification error. A valid check to quantify digitizing error would be to have three people digitize the same stretch of shoreline and then to measure offsets.

Total Shoreline Error

A single yearly shoreline position measurement error (E_{sj} ; see Morton et. al. 2004, Fletcher et. al. 2003, and Hapke et. al. 2006) can be calculated by taking the square root of the sum of the squares (SRSS) of orthorectification error (o), and shoreline digitization error (d). Thus, the error for the ARCN and BELA waterlines was quantified as shown in Equation S3.1:

Equation S3.1. Square root of the sum of the squares (SRSS) equation for total shoreline error.

$$E_{sj} = \sqrt{o^2 + d^2}$$

The SRSS equation above was then applied to the three yearly error values (Table S3.1 and Table S3.2) to calculate values as shown in Table S3.3:

Table S3.3. Total shoreline errors (E_{sj}) for each park and timeslice.

	ca. 1950	ca. 1980	2003
BELA	+/- 2.9 m	+/- 2.7 m	+/- 1.0 m
CAKR	+/- 2.3 m	+/- 2.2 m	+/- 1.7 m

Calculating Errors for Rates of Coastal Change

To calculate errors for mean rates of erosion and accretion, one must first quantify a few factors: the average year for a given “timeslice” of imagery and derived shorelines; and the number of years for time periods, or intervals, defined by the “timeslices”. Then a combined shoreline error can be calculated for these time periods, and divided by the length of the time periods to yield annualized errors (E_{sj}) for rates of coastal change. This approach follows standard practice (e.g., Hapke et al., 2009).

Average Date of Aerial Photography

The orthorectified ARCN imagery covers three “timeslices”: the 1950’s, the 1980’s, and 2003. Because the earlier photography spanning the BELA and CAKR coasts was not collected within only one year, there is a range of years for each: 1949-1956 for the 1950’s; and 1978-1985 for the 1980’s. The average year of photography was thus calculated, and is presented in Table S3.4:

Table S3.4. Average year for each “timeslice” of imagery and derived shorelines.

	ca. 1950	ca. 1980	2003
BELA	1950	1981	2003
CAKR	1952	1980	2003

Length of Time Periods

The length of time between average years was then simply calculated for early, late, and long-term time periods (Table S3.5):

Table S3.5. Number of years for each time period.

BELA	Early	Late	Long Term
<i>Time Period</i>	<i>1950-1981</i>	<i>1981-2003</i>	<i>1950-2003</i>
Total Years	31	22	53

CAKR	Early	Late	Long Term
<i>Time Period</i>	<i>1952-1980</i>	<i>1980-2003</i>	<i>1952-2003</i>
Total Years	28	23	51

Annualized Errors for Rates of Coastal Change

Then, errors for each time period should be calculated as the SRSS of the errors for the two shorelines that bound that time period. For example, the shoreline error for the Early time period for BELA is the SRSS of the 1950 and 1981 shoreline errors (Table S3.6):

Table S3.6. Shoreline errors for each time period.

BELA	Early	Late	Long Term
<i>Time Period</i>	<i>1950-1981</i>	<i>1981-2003</i>	<i>1950-2003</i>
Shoreline Error	+/- 4.0 m	+/- 2.9 m	+/- 3.1 m

CAKR	Early	Late	Long Term
<i>Time Period</i>	<i>1952-1980</i>	<i>1980-2003</i>	<i>1952-2003</i>
Shoreline Error	+/- 3.2 m	+/- 2.8 m	+/- 2.8 m

Finally, the shoreline errors for each time period (Table S3.6) are divided by the number of years for each time period (Table S3.5) to yield annualized errors for rates of change (Table S3.7):

Table S3.7. Final annualized errors (E_{a}), in meters per year, for each time period.

BELA	Early	Late	Long Term
<i>Time Period</i>	<i>1950-1981</i>	<i>1981-2003</i>	<i>1950-2003</i>
Final Error	+/- 0.13 m/yr	+/- 0.13 m/yr	+/- 0.06 m/yr

CAKR	Early	Late	Long Term
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<i>Time Period</i>	<i>1952-1980</i>	<i>1980-2003</i>	<i>1952-2003</i>
Final Error	+/- 0.11 m/yr	+/- 0.12 m/yr	+/- 0.06 m/yr

In essence, the last two steps are embodied in the equation:

Equation 3-2. Calculation of final annualized errors.

$$E_a = \frac{\sqrt{E_{a1}^2 + E_{a2}^2}}{\text{time}}$$

where E_{a1} and E_{a2} are the errors for shorelines representing the start and end of each time period. See, for example, Hapke et al. (2009).

These final annualized errors can be applied to calculations of mean coastal change per park. Quantifying uncertainties is important for determining if the results of coastal change research are accurate. Or, in other words, whether (or where) the detected changes are larger than the errors inherent in the method.

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SOP #4: Spatial Analysis of Coastal Change Using DSAS

Version 1.0 (June 2012)

Revision History Log

Version No.	Revision Date	Author	Changes Made	Reason for Change

Overview

The heart of the project comes with geospatial processing of digital shorelines for multiple years to empirically quantify coastal change rates (erosion or accretion, and overall mean or median change rate, in meters per year) every 50 m along 480 km of coastline for selected time periods. This is accomplished through use of the USGS Digital Shoreline Analysis System (DSAS, Thieler et al., 2005, 2009), an open source extension to ArcGIS, and follows well established best practices in Alaska (e.g., Jones et al., 2009) and elsewhere (e.g., Hapke et al., 2006). Note that the geospatial processing with DSAS is described by another NPS protocol (Psuty et al., 2010), which should be referenced also for future research. See also Psuty and Silveira (2011a, b).

The final output from DSAS analysis are “baselines” (lines approximately parallel to the shoreline but offset seaward) and, more importantly, “transects”: lines perpendicular to the baseline, extending inland, and equally spaced 50 meters apart for the entire length of the baseline (Fig. S4.1). Each of the thousands of transects is listed in an associated table showing distance of erosion or accretion between multiple shorelines, short-term and long-term rates of erosion or accretion, and a variety of other geostatistical parameters for coastal change. The transects and their associated data for ARCN (primarily change rate) can be displayed on maps, evaluated for trends and patterns, assessed with summary statistics, used for highlighting areas with greatest impacts, and further studied with geostatistical analysis to better understand environmental and climatic processes.

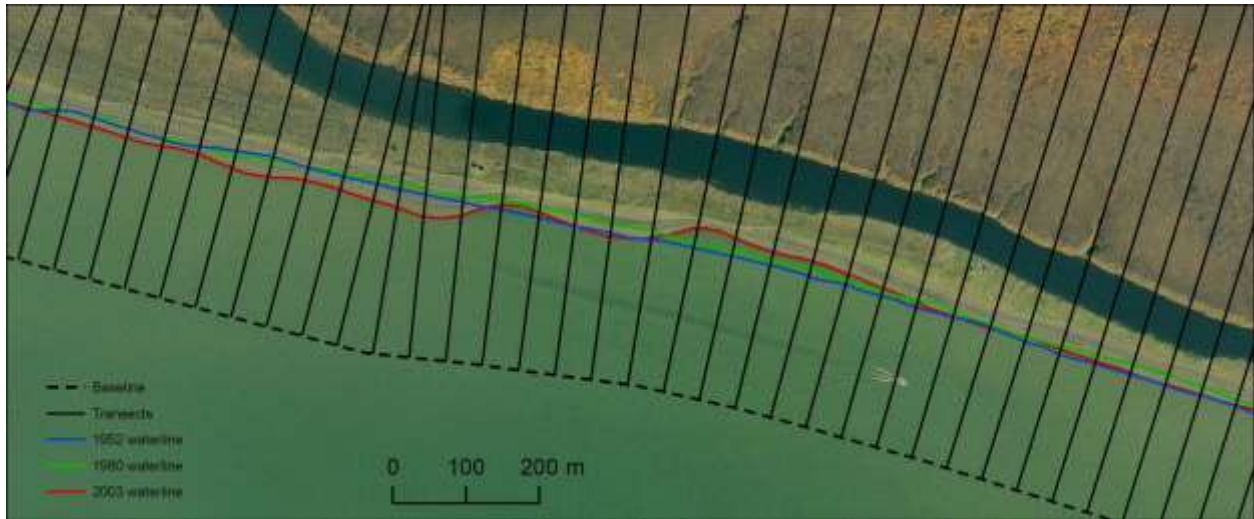


Figure S4.1 Baseline, transects, and digitized waterlines for a small area at the Anigaaq ranger station.

The steps described below walk the user through the structured workflow of DSAS as completed by Lestak et al. (2010) for BELA and CAKR with shorelines for the 1950's, 1980's, and 2003. The process can be repeated as future research creates new digital shorelines and calculates additional results.

The actual processing in DSAS can be tedious, but is facilitated by prior research for ARCN and goes fairly quickly. In preparation for DSAS analysis, start with the previously released digital shorelines for ARCN (Manley et al., 2010). Combine these shorelines, and any new ones, into one shapefile. Create new baselines, if really necessary; however, future research should simply use the baselines that were previously released (Lestak et al., 2010). Save the digital shorelines and baseline into an ArcGIS geodatabase. Initial steps in DSAS include creation of ArcMap documents, setting default DSAS parameters, and creating and adjusting new transect template files if necessary (similarly, future research should simply use the previously released transect templates of Lestak et al., 2010). Then run the final DSAS analysis, recalculating (“recasting”) the transect templates for each time period of interest and for all shorelines. Slight editing of the transects at this point will be necessary to remove those that cross less than two shorelines. The end result is a final set of transect layers for each park, with embedded analytical results (accretion rates are positive; erosion rates are negative) for each time period of interest (incremental intervals between shorelines) and for all shorelines (for calculation of long-term change rates).

The tremendous value of using DSAS is that it enables consistency and comparability with other studies, and that it avoids the time and problem solving of having to develop a new workflow of geoprocessing steps. Again, users should take advantage of a compatible series of steps provided by Psuty et al. (2010), as well as resources tied directly to DSAS: the Open-File Reports (Thieler et al., 2005, 2009); the DSAS website (<http://woodshole.er.usgs.gov/project-pages/dsas/>); DSAS sample data; an online support forum; and a DSAS User Guide (at the website).

Important notes regarding software versions: The steps below were compiled for ArcGIS 9.3 and DSAS 3.2. These steps could be followed with some modification for use with DSAS 4.x.

The GIS/RS Specialist should use the most recent release of DSAS. Avoid DSAS 4.0, which included a bug that was fixed with DSAS 4.1. As of 25 May, 2012, the most recent version is 4.3, which is compatible with ArcGIS 10.x.

Some overall guidelines for using DSAS analysis are: Be careful, go slow and systematically; the analysis actually runs quickly, but attention is required to avoid invalid results that might not be readily apparent. Document everything you do fully in one or more “scripts” (see SOP #1). Start by practicing with a test dataset. Be careful to keep track of file versions, if any, to avoid duplicated files and confusion. As part of the process, it is recommended that the user calculate the end point rate (EPR; simply the distance between two shorelines divided by the time elapsed) for each pair of temporally adjacent shorelines to better quantify how rates change through time. Another statistic, LRR or WLR, based on linear regression of all shorelines, could be completed with four or more shorelines to measure long-term rates. Near the end of the process, make sure to delete transects for a given time period that cross no shorelines, or only one shoreline. Double check the final results by spot checking in ArcMap: manually measure distance between shorelines on a number of transects, manually calculate change rates for those transects and shorelines, and compare with the DSAS output for those transects. While the process is still fresh, create metadata for the output results (you may be able to cut and paste relevant text from the metadata files for the previous release of DSAS results, Lestak et al., 2010). And make the data available for release through the NPS (see SOP #1).

In Preparation for DSAS Analysis

As summarized by Psuty et al. (2010, p. 86):

“The basic concept underlying the comparison of the shoreline positions and quantification of their differences within the DSAS program is that a series of preliminary steps are required to enable the calculation of shoreline change. These steps incorporate the development of an offshore baseline and the generation of equally-spaced transects extending inland from the offshore baseline. After these line products are created (they are generated once for each park), they are used in the processing of each shoreline.”

Actually, before generating baselines or transects, future analysis should first take advantage of previous ARCN coastal-change data releases: digital shorelines for the 1950’s, 1980’s, and 2003 (Manley et al., 2010); as well as DSAS baselines, transect templates, and final transect layers for BELA and CAKR (Lestak et al., 2010).

Throughout this SOP, refer to the filenaming conventions in SOP #1. And follow the steps below separately for each park.

Create Combined Shoreline Shapefiles

In preparation for baseline creation and DSAS analysis, all shoreline shapefiles must be put together into one shapefile. Instructions are included in the DSAS User Guide (see <http://woodshole.er.usgs.gov/project-pages/dsas/>). Essentially, you:

1) Copy the shoreline template file you created in SOP #2 or obtained from ARCN:
ParkCode_SRF_YYYY_template.shp (e.g., *bela_wl_YYYY_template.shp*)

2) rename it as:

a) *ParkCode_SRF_YY_YY.shp* for **each time period** bound by a pair of temporally adjacent shorelines (e.g., *bela_wl_50a_80a.shp*, *bela_wl_80a_03.shp*, *bela_wl_03_12.shp*, etc.) See filenaming conventions in SOP #1.

b) and as *ParkCode_SRF_all.shp* for all of the shorelines (e.g., *cakr_wl_all.shp*).

At this time, these template shapefiles will be “blank” (without line segments).

3) Use the ArcGIS “append” command to transfer all of the line segments from the relevant shoreline shapefiles to the new, combined shapefiles.

Create a Baseline

The baseline for each park is a smoothed version of one or more shorelines, acting as a reference from which all measures of coastal change are made. The baseline can be generated from a hand-digitized “trendline”, from one shoreline shapefile, or from the “all shorelines” shapefile created above, and then offset seaward about 200 m, using the “buffer” function in ArcGIS. From Psuty et al. (2010, p. 86):

“This creation of an offset reference for subsequent comparison is necessary so that future positions of the eroding or accreting shoreline will not intercept the Baseline and thereby complicate the mathematical calculations. The Trendline and Baseline are created once for each park, and will only need to be modified if they no longer represent the general trend of the shoreline; for example, if there is a major (catastrophic) change.”

Unless there has been a major change in position of the shoreline recently, **the GIS/RS Specialist should use the baselines for BELA and CAKR included in Lestak et al. (2010)**. If new baselines do need to be created, the user can follow the steps taken previously, documented below. Also, basic instructions are included in the DSAS User Guide.

For the baseline, we recommend you use the “buffer” command on the “all shorelines” shapefile you created above:

- 1) ArcToolbox > Analysis Tools > Proximity > Buffer
 - Input Features = *ParkCode_SRF_all.shp*
 - Output Feature Class = *ParkCode_SRF_all_Buffer.shp*
 - Distance = 200 meters
 - Side Type = FULL
 - End Type = ROUND
 - Dissolve Type = ALL

Simplify the buffered shapefile to smooth everything out. Use a 200-m “simplify” because it makes a smoother line:

2) ArcToolbox > Data Management Tools > Generalization > Simplify Polygon

- Input Features = *ParkCode_SRF_all_Buffer.shp*
- Output Feature Class = *ParkCode_SRF_all_Buff_Sm200.shp*
- Simplification Algorithm = BEND_SIMPLIFY
- Reference Baseline = 200 meters
- Handling Topological Errors = FLAG_ERRORS

Convert the polygon shapefile created above to a line file:

3) ArcToolbox > Data Management Tools > Features > Polygon to Line

ParkCode_SRF_all_Buff_Sm200_ln.shp

Use the editing toolbar in ArcMap to delete the onshore portion, straighten and extend the ends, and remove any irregularities:

4) First to create an offshore baseline, delete the onshore portion of the buffered line shapefile, *ParkCode_SRF_all_Buff_Sm200_ln.shp*.

5) Delete the curve at each end and use the ArcMap "Extend" command to lengthen the baseline straight out so that it extends beyond the end of the longest shoreline. Do this on both ends.

6) Curves, odd bumps and depressions create difficult angles when generating transects. Hand edit the baseline so that it is fairly smooth.

Then baseline segments are attributed by unique id's, and checked for consistent direction:

7) At this point baseline segments can be labeled with unique ids if necessary.

8) Check the direction of the baseline segments using arrows as symbology (Fig. S4.2). All lines in the baseline should be traveling in the same direction.

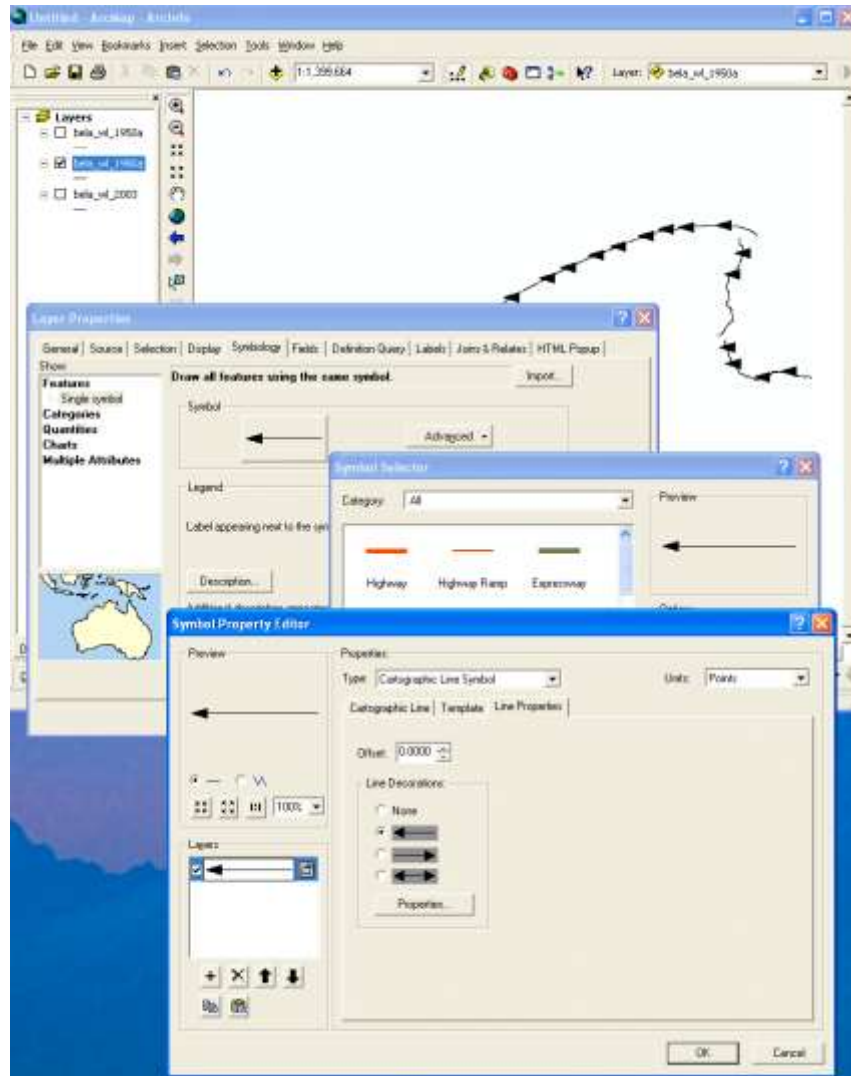


Figure S4.2. Symbolizing the baseline with arrows to show the direction of the line.

Then save the result:

9) Save and rename the edited *ParkCode_SRF_all_Buff_Sm200_In.shp* as the final baseline shapefile, *ParkCode_SRF_baseline.shp* (e.g., *bela_wl_baseline.shp*).

Create a Geodatabase

Similarly, the GIS/RS Specialist should use the ArcGIS geodatabase files in Lestak (2010), created for use with DSAS, with one geodatabase file each for BELA and CAKR. But if need be, basic instructions are in the DSAS User Guide, and simply consist of:

- 1) In ArcCatalog, make a new geodatabase for each park according to the convention: *ParkCode_SRF_dsas.mdb* (e.g., *bela_wl_dsas.mdb*).
- 2) Add the following shapefiles to the geodatabase:

- a) the shapefile combined for all shorelines, *ParkCode_SRF_all.shp*.
- b) the baseline, *ParkCode_baseline.shp*.

All transects and tables created by DSAS will be added to this geodatabase.

Initial Steps in DSAS

As summarized by Psuty et al. (2010, p. 88):

“Once the Baseline is created, transects are generated using the DSAS toolbar in ArcMap. [...] The DSAS software allows the user to generate transects at equally spaced locations ([50]m in this case) originating at the Baseline. These initial transects are created automatically in DSAS and may be subsequently adjusted using DSAS and ArcGIS so that they intersect the Trendline at approximately [50] m intervals and are all approximately perpendicular to the Trendline [...]. These transects are used in DSAS to measure distances between each GPS-measured shoreline and the Baseline. The even spacing of transects along the Trendline supports the unbiased and systematic calculations of descriptive summary statistics, such as the mean value and the standard deviation of shoreline change as well as trends in change over time.”

The initial steps in DSAS consist of: creating an ArcMap document, setting default DSAS parameters, and using the existing ARCN and BELA transect templates (or creating and adjusting new ones).


Create an ArcMap Document for Use with DSAS

A new ArcMap document for each park should be created for all subsequent DSAS processing, importing, exporting, and display:

- 1) Create a new ArcMap document named according to the convention *ParkCode_SRF_dsas.mxd* (e.g., *bela_wl_dsas.mxd*).
- 2) Add the geodatabase created above.

Set Default DSAS Parameters

Before proceeding, set the fundamental parameters for DSAS:

- 1) In ArcMap, on the DSAS toolbar, click on the first icon, "Set/Edit Default parameters" .

Choose the following:

- Baseline layer: *ParkCode_SRF_baseline.shp*
- Shoreline layer: *ParkCode_SRF_all.shp*
- Shoreline accuracy field: ACCURACY
- Shoreline date field: DATE_
- Set data accuracy (not applicable for this run or most likely this project):

- Default data accuracy 0 +/- meters (default is 6 meters)
- Confidence Interval (not applicable for this run or most likely this project): 90%


Click next >

- Transect spacing: 50 m
- Transect length: 700 m
- Baseline smoothing distance 100 m
- Direction of cast: Right
- Color: Blue
- Width: 1.0
- Baseline parameters: off-shore baselines
- Shoreline parameters: Closest intersection

Click OK

Create Temporary Transects Template

The GIS/RS Specialist should use the transect templates already created for BELA and ARCN, and available from Lestak et al. (2010) as layers within the BELA and CAKR geodatabases: *belawl_trans_template*, and *cakrwl_trans_template*. If so, then the user should skip to the section, “Run Final DSAS Analysis”. But if the shoreline has experienced major change recently, the steps below can instead be taken to create temporary transect templates, adjust them, and save the final transect templates. Note that the steps below for creating and editing transect layers will need to be modified for use with DSAS 4.3 or later, as the new version separates casting of transects from calculating statistics (see the User Guide).

1) To create, or “cast”, transects in ArcMap, on the DSAS toolbar click on the second icon, "Cast transects", ,

Transect storage parameters:

- Output Geodatabase: *ParkCode_SRF_dsas.mdb*
- New transect layer name: *t_ParkCode_SRF_trans_template* (e.g., *t_belawl_trans_template*)
- Log file output format: regular
- Set casting method: Smoothed baseline cast
- Don't check “Flip Baseline Orientation” box
- Click OK

These “temporary” transects are “cast” by DSAS, and can then be displayed in ArcMap.

Adjust Temporary Transect Template and Save Final Transect Template

Visually inspect the transects. Most likely they will need to be edited in ArcMap to assure that each transect intersects the shorelines perpendicularly at approximate 50 m intervals.

As stated in Psuty et al. (2010, p. 88):

“Transects crossing relatively straight sections of shoreline need little if any adjustment. However transects crossing the [shorelines] in more curvilinear sections will need to be adjusted, e.g. added, deleted, or moved, so that all transects intersect the [shorelines] perpendicularly at roughly [50] m intervals [...]. These adjustments can be accomplished [...] utilizing the feature editing capabilities of GIS software packages such as ArcMap.

In some cases you may need to go back and edit the baseline, recreate transects, and edit the new transects. After transects are deemed acceptable, they will need to be “recalculated” to update the geodatabase. Instructions are in the DSAS User Guide, and the steps are described below.


Edit Transects

- 1) Overlay the temporary transect template (*t_ParkCode_SRF_trans_template*) on top of all the shorelines before editing.
- 2) Delete or move transects that cross each other or that don't cross the shoreline at 90 degrees.

Recalculate Transects

When transect editing is complete, recalculate the transects to update the edits, saving the output as a final transect template layer.

- 1) To recalculate transects in ArcMap, on the DSAS toolbar, click on the third DSAS icon,

"recalculate transects", .

- Choose existing transect layer: *t_ParkCode_SRF_trans_template*
- Select Recalc Option: All
- Transect storage parameters: Output new
ParkCode_SRF_dsas.mdb
- New transect layer name:
ParkCode_SRF_trans_template
- Log file output format:
Regular
- Click OK

When recalculating transects new OID numbers are assigned, but the “transorder” numbers remain the same. The end result of this last step is one transect template for each park, for use in later steps.

Run Final DSAS Analysis

It can be helpful to plan ahead, and consider that it will be desirable to run the final DSAS calculations on:


each time period (e.g., 1950-1980, 1980-2003, 2003-2012), to evaluate increases or decreases in change rates through time, as well as:

all shorelines (e.g., 1950, 1980, 2003, and 2012 together) to quantify a long-term erosion rate based on least squares regression of coastal change.

In other words, you will need to follow the remaining steps several times. Each time you run final analysis, you will need to “recalculate” transects (change the DSAS default parameters and recalculate transects, saving temporary transect layers), select and delete transects that cross no shorelines or only one shoreline, and save the final results in the geodatabase. You may also wish to export the final results as shapefiles. It may seem daunting, but keep track in your scripts, be methodical, and really – you are almost there.

Recalculate Transects

To get the results you intend for each time period and all shorelines, you will need to recalculate transects for each time period, and then for all shorelines. For each iteration, set new DSAS parameters:

1) In ArcMap, on the DSAS toolbar, click on the first icon, "Set/Edit Default parameters" .


Choose the following:

- Baseline layer: *ParkCode_SRF_baseline.shp*
- Shoreline layer: *ParkCode_SRF_YY_YY.shp* (for each time period) or *ParkCode_SRF_all.shp* (for all shorelines)
- Shoreline accuracy field: ACCURACY
- Shoreline date field: DATE_
- Set data accuracy (not applicable for this run or most likely this project):
- Default data accuracy 0 +/- meters (default is 6 meters)
- Confidence Interval (not applicable for this run or most likely this project): 90%
- Click next >

- Transect spacing: 50 m
- Transect length: 700 m
- Baseline smoothing distance 100 m
- Direction of cast: Right
- Color: Blue
- Width: 1.0
- Baseline parameters: off-shore baselines
- Shoreline parameters: Closest intersection
- Click OK

And then recalculate transects, given the new settings:

2) To recalculate transects in ArcMap, on the DSAS toolbar, click on the third DSAS icon,

"recalculate transects", .

- Choose existing transect layer: *ParkCode_SRF_trans_template*
- Select Recalc Option: All
- Transect storage parameters: Output new
ParkCode_SRF_dsas.mdb
- New transect layer name:
t_ParkCode_SRF_trans_YY_YY (for each time period) or *t_ParkCode_SRF_trans_all*
(for all shorelines)
 - Log file output format:
Regular
- Click OK

Then recast transects for each time period, and then for all shorelines. Note that if you are currently viewing the transect layers in ArcMap, you will need to click on the “refresh” button to update intersect and distance tables.

Cull Out Unwanted Transects and Save Final DSAS Results in the Geodatabase

For any given set of shorelines there will be there may be transects that go through just one shoreline, or potentially through no shorelines. If this occurs, transects can be removed in ArcMap by “select by attribute”. You will need to follow this step for each temporary transect layer. (Note that you can avoid these final two steps with newer versions of DSAS, 4.3 or later, which include the ability when calculating statistics to apply a “shoreline intersection threshold”; see the DSAS User Guide).


1) In ArcMap click on Selection > Select by Attributes ...

- Layer: *t_ParkCode_SRF_trans_YY_YY* (for each time period) or *t_ParkCode_SRF_trans_all*
(for all shorelines)
- Create a new selection
- "PointCNT" > 1
- OK

You have selected only those transects crossing 2 or more shorelines. Save the selection as a new layer:

2) Right-click the layer, *t_ParkCode_SRF_trans_YY_YY* (for each time period) or *t_ParkCode_SRF_trans_all* (for all shorelines), and

Click on Data > Export Data ...

- Export: Selected features
- Use the same coordinate system as: this layer’s source data
- Output shapefile or feature class: Click on 
- Name: *ParkCode_SRF_trans_YY_YY* (for each time period) or *ParkCode_SRF_trans_all* (for all shorelines)

- Save as type: Feature Class
- Save
- OK
- Do you want to add the exported data to the map as a layer? Yes

Then select/export transects for each time period, and then for all shorelines.

Remember to double check the final results by spot checking in ArcMap: manually measure distance between shorelines on a number of transects, manually calculate change rates for those transects and shorelines, and compare with the DSAS output for those transects.

The entire set of final transect layers – for each time period and for all shorelines – are now stored within the geodatabase. Each transect layer is associated with a table listing a range of geostatistical values relating to coastal change. These are the final results you’ve been seeking: *ParkCode_SRF_trans_YY_YY* (for each time period) and *ParkCode_SRF_trans_all* (for all shorelines).

Export the Final DSAS Results as Shapefiles

For display in ArcMap, it can be helpful to create copies of the transect layers as individual shapefiles. You will need to follow this step for each transect layer (or write a python script). Use the Feature Class to Shapefile conversion tool to export each transect layer as: *ParkCode_SRF_trans_YY_YY.shp* (for each time period) or *ParkCode_SRF_trans_all.shp* (for all shorelines).

Now that DSAS analysis is complete, the end results form the fundamental output of the research. Further processing and synthesis of the results are the subject of the next SOP.

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SOP #5: Synthesis and Presentation of Results

Version 1.0 (June 2012)

Revision History Log

Version No.	Revision Date	Author	Changes Made	Reason for Change

Overview

Future efforts with coastal-change monitoring for ARCN should include integration and synthesis of the DSAS results to create tables, graphs, and maps for presentations and reports, capturing rates of coastal change for selected areas of interest as well as the entire BELA and CAKR shorelines. The results can also be used to examine increases or decreases in those rates through time, or to evaluate typically high spatial variability (especially for tidal inlets, the ends of barrier islands, and spits). Overall, the analysis and subsequent aggregation of results provide a better understanding of temporal trends, spatial patterns, and significant impacts of coastal change on ARCN habitats and ecosystems. Such an approach, after creation and analysis of new digital shorelines (more recent than 2003), will answer the most pressing question: Is coastal erosion accelerating with arctic and global warming?

There is no standardized approach within the research community for data synthesis and presentation. Below we document steps for creating tables, graphs, and maps. The current version of DSAS (4.3) includes new features that assist with these goals. Studies in other areas take a variety of approaches with figures and illustrations (e.g., Hapke et al., 2006; Jones et al., 2009; Gorokhovich and Leiserowitz, 2012). The most relevant and useful approach is presented by another NPS protocol on coastal change by Psuty et al. (2010) and by a related journal article (Psuty and Silveira, 2011); in particular, they have developed an extension to ArcGIS, the Shoreline Change Mapper, that generates the best map display of results we've seen.

A few general guidelines may prove useful. Become familiar with definitions for the geostatistical parameters calculated by DSAS (see the User Guide at <http://woodshole.er.usgs.gov/project-pages/dsas/>). In particular we recommend use of the End Point Rate (EPR) statistic for sequential time periods (e.g., 1950-1980, 1980-2003, 2003-2012),

as well as the Linear Regression (LRR) or Weighted Linear Regression (WLR) statistics for calculation of long-term rates for all of the shorelines (e.g., 1950, 1980, 2003, and 2012 together). As long as the transects were equally spaced for areas of interest or each entire park, derived summary statistics will be representative and valid. Avoid creating graphs that, for an x-axis, simply use the transect number; try to convert this to accurate distances along shoreline. Explore the range of presentation styles available. Recommended are the tables, graphs, maps, and report outlines as given by Psuty et al. (2010; see also Psuty et al., 2011a, b).


Also, presentation of results should reference and consider propagated errors (see SOP #3). Tables, graphs, and maps can all display associated errors, to provide context for measurements where the “signal” overcomes the “noise”. For example, the horizontal error could be displayed with lines on close-up maps of change rates. Or a map could be created to display those shoreline segments where rates of change rise above a threshold of uncertainty.

Tables

The information generated for each transect by DSAS (previous SOP) – distances from a baseline for each shoreline, shoreline change rates, and other geostatistical parameters – are stored in tables linked to the transect layers. This information can be exported to MS Excel, reformatted to create a “data matrix” for each transect layer, and used to generate summary statistics.

Create Excel Tables

Save the attribute tables from the transect feature datasets.

- 1) Right-click the layer, *ParkCode_SRF_trans_YY_YY* (for each time period) or *ParkCode_SRF_trans_all* (for all shorelines)
- 2) Click on Open Attribute Table
- 3) Click on Options
- 4) Click on Export ...
 - Export: All records
 - Output Table: Click on 
 - Name: *ParkCode_SRF_trans_YY_YY_results.dbf* (for each time period) or *ParkCode_SRF_trans_all_results.dbf* (for all shorelines)
 - Save as type: dBASE Table

Open the dBASE Table in Excel and save the table as an Excel formatted table. The data can then be used in statistical, spreadsheet and graphing software packages.

Create a Data Matrix

The project team may then be interested in reformatting the data so that distance measurements from baseline are combined in one table per park, for ease of additional processing and analysis. This formulation and use of this kind of table, or “Data Matrix”, is described by Psuty et al. (2010, p. 90), and included as Table S5.1 below:

“The distance output from DSAS (Table S7.1) can be formatted so that the shoreline position data are represented by a matrix of sequential shoreline distance measurements. The product of multiple surveys will be a matrix of comparable distance values (Table S7.2). The matrix approach supports the generation of comparisons among any of the shoreline positions and requires that each shoreline be processed only once.”

Table S5.1. An example of distance output from DSAS reformatted into Distance Matrix format (Psuty et al., 2010, Table S7.2).

Transect ID	Distance from Baseline (m) ($\pm 5m$)					
	Spring '06	Fall '06	Spring '07	Fall '07	Spring '08	Fall '08
---	---	---	---	---	---	---
7	217.21	251.84	233.90	269.99	241.41	273.02
8	218.51	252.37	233.00	269.55	242.06	273.46
9	219.76	252.24	231.22	268.28	241.99	272.96
10	220.87	247.37	218.88	262.76	238.11	267.63
11	217.99	244.15	215.58	260.17	233.76	265.82
12	81.48	48.51	72.61	34.26	59.54	28.87
13	79.51	51.11	77.02	35.58	60.37	31.03
14	215.45	240.57	214.00	257.39	231.45	265.05
15	212.12	237.49	212.39	255.27	229.74	263.67
16	211.36	235.07	210.39	253.90	228.72	263.07
17	211.46	233.49	208.55	253.14	227.48	262.71
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Create Summary Statistics

The excel tables and data matrices can then be used for generating summary statistics for selected areas of interest or each entire park (Table S5.2). Such statistics should include mean rates of change with standard deviation for selected time periods, or for the long-term values determined through linear regression. Also include the number of transects (n), minimum values, and maximum values. If the results are highly skewed, than a median value should also be reported.

Table S5.2. Summary statistics of coastal change rates for BELA and CAKR (in m/yr; erosion rates are negative; n = number of transects; data summarized from DSAS transects in Lestak et al., 2010)

BELA	Time Period	Mean	SD	n	Min	Max
Early	1950a - 1980a	-0.35	1.02	6545	-5.74	5.76
Late	1980a - 2003	-0.23	1.14	6672	-13.46	9.01
Long-Term	1950a - 2003	-0.33	0.75	6539	-5.62	4.10
CAKR	Time Period	Mean	SD	n	Min	Max
Early	1950a - 1980a	-0.18	0.90	2833	-3.27	26.93
Late	1980a - 2003	0.17	0.88	2838	-3.38	26.63
Long-Term	1950a - 2003	-0.02	0.66	2849	-2.17	14.80

Graphs

A variety of relevant point, line or bar graphs can be created. Instead of, or in addition to, a symbolized map, a graph can be constructed showing change rate (erosion or accretion, in meters per year) on the y axis, with transect number or distance along the x axis (e.g., Gorokhovich and Leiserowitz, 2012). A useful bar chart could be show mean change rates categorized by coastal geomorphic type and time interval (e.g., Jones et al., 2009). More important is a histogram to show the frequency distribution of horizontal shoreline displacement or change rates for a given time interval (cf. Psuty and Silveira, 2011a). Also important is a simple bar graph illustrating how rates have increased or decreased over time. Most important is a point and line graph showing mean change on the y axis with time on the x axis, with points for measurements and lines showing temporal trends in change rates (EPR, oldest to youngest shoreline, and linear regression; e.g., Fig. S5.1 below, from Psuty et al., 2010; and Fig. 7 in Psuty and Silveira, 2011a).

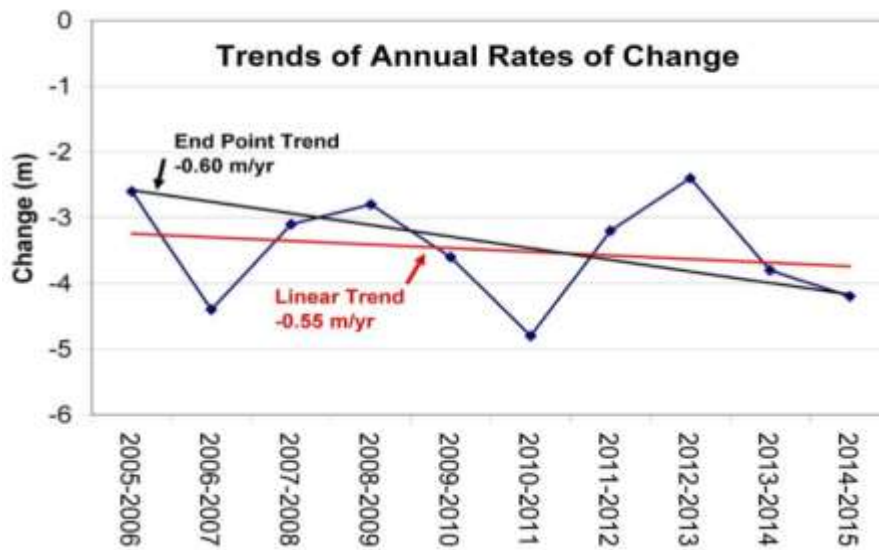


Figure S5.1. An example of measurements of shoreline change (points on blue line, in meters from a baseline) plotted against time, with straight lines illustrating trends (EPR in black; linear regression in red; Fig. S7.9 from Psuty et al., 2010).

Plots such as shown above will be more useful as temporal resolution for ARCN is improved in the future with creation of additional digital shorelines.

Maps

Arguably the most important means of presenting the coastal change rates is with a map to convey high spatial variation (change in sign or magnitude of erosion and accretion over short distances along the shoreline), overall spatial patterns, and to document those areas most vulnerable to coastal erosion. Below are steps that can be taken to symbolize the transects for display of change rates in ArcMap using a customized color ramp (e.g., Figs. 5 and 6 in narrative). (As an aside, note that the most recent version of DSAS, 4.3, includes a new feature to clip transects to the maximum extent between all shorelines, thus enhancing display of the

symbolized transects). Most promising, and recommended, is the anticipated release of an extension to ArcGIS by Psuty et al., called the “Shoreline Change Mapper”.

Symbolizing Transects by Change Rate in ArcMap

When using graduated colors to display transect coastal change rates, it is important to use a standardized color ramp that can be used for each time slice. This color ramp symbology can be saved and then imported into each layer’s symbology.

1) Create a standardized color ramp: Append all timeslice transect features into one feature.

Then color ramp the EPR statistic:

Properties > Symbology > Quantities > Graduated Colors >
32 classes
Classify (Quantile)
color ramp red-blue (red = erosion, blue = accretion, yellow = 0)

Save this definition out to a new feature in the geodatabase, and name it according to the convention: *ParkCode_SRF_trans_ramps* (e.g., *cakr_wl_trans_ramps*).

2) Create a new map document to be used as a template. Finalize the layout, use the standard color ramps, customize a color ramp legend, add scale bars, north arrow, and add any additional features such as graphs, photographs, etc.

Name it according to the convention: *ParkCode_SRF_trans_YY_YY.mxd* (for time periods; e.g., *bela_wl_trans_03_12.mxd*) or *ParkCode_SRF_trans_all.mxd* (for temporal trends using all shorelines; *bela_wl_trans_all.mxd*). Alternatively, you can plot map symbology for just erosion, blue to red, with black for no change or accretion (see Figs. 5 and 6 in narrative).

Shoreline Change Mapper

A useful tool for displaying the magnitude and sign of coastal change for a given time period, highlighting spatial variability, is the Shoreline Change Mapper – an application developed by a group at Rutgers University (Psuty et al., 2010; Psuty and Silveira, 2011a) – that runs within ArcGIS. Along with imagery as a basemap, the shorelines and baseline, are lines depicting the mean and standard deviation of change and, more importantly, a graph superimposed on the map view, parallel to the shoreline, with change varying by both length and color of the graph “bars” (Fig. S5.2):

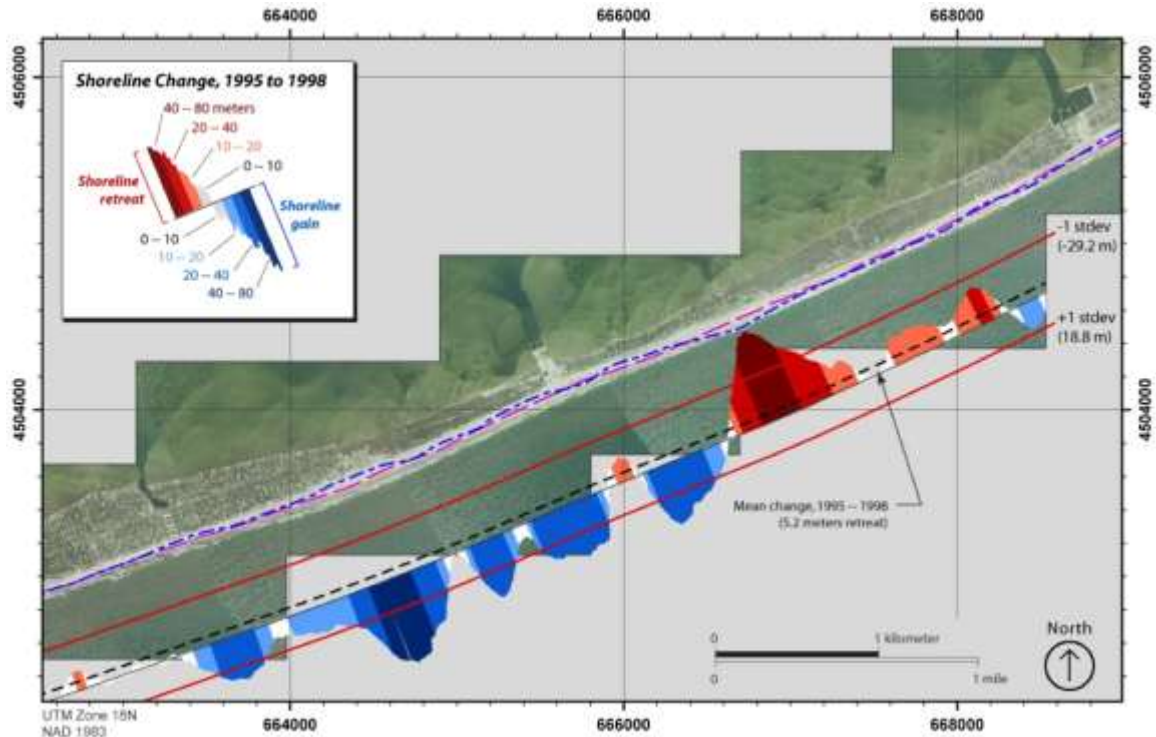


Figure S5.2. An example of map display of shoreline change (Fig. S7.10 from Psuty et al., 2010).

Release of the Shoreline Change Mapper for use by others is anticipated. It may be available now or in the future from the data manager for the NPS Northeast Coastal and Barrier Network (NCBN) or perhaps from Dr. Psuty directly (Sandy Hook Cooperative Research Programs, Institute of Marine and Coastal Sciences, Rutgers University).

Reports

Finally, the ARCN project leader for monitoring of coastal change should produce progress and final reports including the elements described above, as well as those outlined by Psuty et al. (2010) or similar. Coastal change studies for BELA and CAKR are challenged by the length of shorelines involved (480 km), a paucity of imagery and data, and the logistical difficulties associated with remoteness. Nonetheless, regularly repeated updates with new digital shorelines and reanalysis will address the monitoring objectives related to the temporal and spatial trends in coastal change, and resulting impacts on ecosystems and habitats.

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