



Protocol for Monitoring Coastal Salt Marshes in the Southwest Alaska Network

Natural Resource Report NPS/SWAN/NRR—2009/154



ON THE COVER

Silver Salmon Creek, Lake Clark National Park and Preserve
Photograph by: Amy Miller, Southwest Alaska Network

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Preface

Overview of Long-term Monitoring Program

The Southwest Alaska Network (SWAN) serves as a regional organization of the National Park Service for inventorying and monitoring Alaska's parks in the maritime ecoregion of southwestern Alaska. ABR, Inc. is assisting the National Park Service in the design and testing of monitoring protocols for implementation in SWAN. This effort has benefited from other efforts to develop regional monitoring protocols and it is expected that many of the protocols will be applicable to other parks with coastal ecosystems, as well as to U. S. Fish and Wildlife Service coastal refuges.

The long-term ecological monitoring program in SWAN is focusing on numerous ecological indicators, or "vital signs," including sensitive plant communities, of which salt marsh is one. Monitoring of salt marshes will include the measurement of a suite of physical, chemical, and biological components, each of which may have several parameters. Standard Operating Procedures (SOPs; Appendix 1) outline the methods used to measure each parameter. The program is designed, however, so that the SOPs can be integrated during fieldwork and the interrelationships among factors can be analyzed. For example, information acquired from the topography and sedimentation SOPs can be used to estimate the extent to which physical factors are contributing to vegetation change.

Protocol Organization

To maintain consistency among monitoring protocols developed by various monitoring networks, each protocol, including this one, is organized into a protocol narrative and SOPs. The protocol narrative is intended to provide the background and rationale for the monitoring program, identify the objectives of the monitoring protocol, provide justification for the recommended sampling program, and briefly describe the methods for fieldwork, data analysis, and reporting. Incorporation of relevant literature and presentation of data collected during the protocol development phase of the project are used to justify a particular sampling design, sampling method, or data analysis technique. The SOPs (Appendix 1) include step-by-step descriptions of the field, laboratory, data analysis, and data management aspects of the protocol. Initial results of salt-marsh monitoring during 2007–2008 using these protocols are summarized in Jorgenson et al. (2010).

1 Background and Objectives

1.1 Introduction and Rationale for Monitoring

Sheltered salt marshes and tidal flats in the SWAN are important ecological features of the Lake Clark National Park and Preserve (LACL) and Katmai National Park and Preserve (KATM) coastlines because they support productive, high-quality forage and serve as important feeding and resting areas for brown bears (*Ursus arctos horribilis*), waterfowl, and shorebirds (Bennett et al. 2006). In recognition of these important features, salt marshes have been identified for monitoring under the ‘sensitive plant community’ vital sign. A variety of physical, chemical and biological attributes associated with salt marshes will be monitored under this protocol, independently of other ‘sensitive communities,’ due to the complex interactions that shape the vegetation in these salt marsh ecosystems. Accordingly, this protocol identifies the components of a comprehensive monitoring program and the standard operating procedures (SOPs) for each monitoring component, consistent with other national monitoring efforts of the National Park Service (Oakley et al. 2003).

Development of a protocol for monitoring salt marshes in SWAN focuses on the major habitat characteristics that are important to other nearshore and terrestrial indicators (e.g., brown bears, seabirds, intertidal marine invertebrates, and algae), and on the major drivers of change. Salt marshes are highly dynamic systems with numerous important drivers that include erosional and depositional geomorphic processes associated with topography and hydrology; tidal fluctuations and storm surges; variable rates of sedimentation and erosion; and variation in salinity, physical disturbance and human impacts (Bird 2000). Tidal fluctuations and storm surges help control vegetation distribution by affecting water levels, sedimentation, and salinity. Sedimentation and erosion affect surface elevations, contribute nutrients, and can physically bury or disturb the surface. Winter ice-rafting can deposit sediments and disrupt levees. Salinity affects the osmotic potential of soil and is an important control over vegetation distribution (Vince and Snow 1984, Jorgenson 2000). Concerns about the potential effects of climate change on salt marsh ecosystems, particularly sea level rise, increased frequency and duration of storm events, and decreased sediment inputs as coastal glaciers recede, have elevated their status in the SWAN monitoring program. Salt marshes along Cook Inlet are also subject to oil spills and other contaminants from urban areas, oil platforms and pipelines, shipping, and military operations. Finally, the area is subject to tectonic uplift and severe earthquakes.

In the SWAN, the primary goal of salt marsh monitoring is to describe long-term ecological change in response to environmental drivers (e.g., climate variables), and to document ecosystem response, as measured by responses of vegetation and small waterbodies (e.g., ponds), to short-term perturbations (e.g., tsunamis, volcanic eruptions, and large storm events) and/or acute disturbance (e.g., oil or chemical spills). Forage species of value to wildlife and waterfowl include, but are not limited to, *Carex ramenskii* (*Carex subspathacea*), *Triglochin palustris*, and *Puccinellia phryganodes* (Jeffries and Rockwell 2002; Person et al. 2003).

1.2 Historical Development of Coastal Monitoring

Monitoring of changes along the nation's coastlines has a rich history of development (Melzian 2003, Thayer et al. 2005), and numerous existing federal and state coastal monitoring programs have already developed standard operating procedures (Hilary and Dionne 1999). For example, the National Park Service, as well as other federal and state agencies, have established monitoring programs for the Northeast Coastal and Barrier Network (Roman et al. 2001, McCobb and Weiskel 2003, Kopp and Neckles 2004), the Southeast Coast Network (DeVivo et al. 2007), the New Hampshire coast (Drociak and Bottitta 2005), the New York coast (Niedowski 2000) and the Louisiana coast (Steyer et al. 1995). They are all similar in their selection of which physical, chemical, and biological components to monitor.

Numerous studies of Alaska coastal marshes also have evaluated many of the principal components and drivers of coastal ecosystems. These investigations have included studies of coastal ecosystems along the North Gulf Coast (Ruby 1977), Cook Inlet (ADCE 1978; MacDonald et al. 1979; Ritchie et al. 1981; Reger and Updike 1983; Vince and Snow 1984; Snow and Vince 1984; Combellick 1994; Racine and Brouillette 1995; Talbot et al. 1995; Tande 1996; DeVelice et al. 1999; Jorgenson et al. 2003, 2006), the Copper River Delta (Hayes 1976; Thilenius 1995; Boggs 2000), Yukon Delta (Dupre 1980; Tande and Jennings 1986; Kincheloe and Stehn 1991; Sedinger and Newbury 1998; Jorgenson 2000; Jorgenson and Ely 2001), the Chukchi coast (Harper 1978; Mason et al. 1997; 1999; Jordan and Mason 1999; Jordan et al. 1999), and the Beaufort coast (Hartwell 1973; Hopkins and Hartz 1978; Reimnitz and Maurer 1979; Taylor 1981; Meyers 1985; Reimnitz et al. 1988; Brigham-Grette 1999; Solomon 1999; Jorgenson et al. 2002; Naidu et al. 2003; Brown et al. 2003; Jorgenson and Brown 2005). Nearly all of these studies were one-time inventories or process-based studies. However, the studies by Racine and Brouillette (1995) and Jorgenson (2000) were established for repeated monitoring of vegetation and those by Jorgenson et al. (2002) and Brown et al. (2003) for repeated monitoring of physical components.

Several studies are of particular relevance to the SWAN monitoring program. The mapping and classification of coastal marshes at LACL (Tande 1996) and upper Cook Inlet (Vince and Snow 1984; Jorgenson et al. 2003) provide the foundation for a classification system that can be used for mapping and analysis. The shore-zone mapping by Harper and Morris (2003) is useful for characterizing shorelines within the various coastal landscape units (subsections) that can be used for landscape-level stratification in the sampling program.

1.3 Rationale for Selection of Monitoring Parameters

Review of other existing coastal monitoring programs, Alaska-specific literature, and results of a scoping meeting attended by regional experts in Anchorage helped identify the principal components of the SWAN coastal monitoring effort. These general components are listed below and are followed by a brief discussion of the rationale for the selection of the main components. Rationale for the selection of specific measurement methods associated with each component is provided in the SOPs. The components include:

- 1) Time series analysis of remotely sensed imagery;
- 2) Waterbody extent;
- 3) Topography;

- 4) Tides and storm surges;
- 5) Sedimentation;
- 6) Soil water level, salinity, and pH;
- 7) Soil temperature;
- 8) Vegetation cover; and
- 9) Landscape-level changes in ecotypes (combined from plant communities and geomorphic units)

Time series Analysis of Remotely Sensed Imagery

A time series of georectified, or co-registered, aerial photographs and/or high-resolution satellite imagery is useful for evaluating future and historical changes in coastal geomorphology and vegetation. Compilation of historical aerial photographs can provide useful insight into the rates and magnitude of future changes that can be expected during the monitoring program. Future acquisition of aerial photographs or high-resolution satellite imagery provides a critical data source for documentation and analysis. In Alaska, repeat photography also has been used for a wide range of studies, including characterization of glacial dynamics (Hamilton 1965; Field 1983, 1988; Lawrence and Engstrom 1993), thermokarst (Jorgenson et al. 2001, Jorgenson et al. 2006), water-level changes (Hinzman et al. 2005), coastal erosion (Jorgenson et al. 2002, Brown et al. 2003), floodplain dynamics (Jorgenson and Shur 1999), shrub invasion (Sturm et al. 2001, Tape et al. 2006), animal censuses (Burgess et al. 1992, Griffith et al. 2002), plant succession after natural disturbance (Racine et al. 1987, Wang et al. 2004), and human disturbance (McKendrick 1976, Emers and Jorgenson 1997, McKendrick 2000). Aerial photographs and/or high-resolution satellite images provide an ideal time series because their vertical projection allows them to be accurately co-registered and are therefore more suitable for mapping of landscape components.

In Alaska, there are two main periods of historical photography. Initially, a statewide program in the 1950s acquired black and white aerial photographs (1:50,000 scale) that were used for statewide topographic mapping. Second, a nearly complete statewide mission under the Alaska High Altitude Program (AHAP) acquired color-infrared aerial photographs (1:63,360 scale) during the late 1970s and early 1980s. A limited mission was conducted to acquire black and white aerial photographs (1:24,000) along western Cook Inlet and Prince William Sound in 1993. Finally, the Alaska Region (NPS) has embarked on a program to acquire georectified, high-resolution (1-m panchromatic fused with 4-m multispectral) IKONOS satellite images. As of 2008, only a portion of Alaska's parks had been imaged.

Geomorphology

Geomorphology is the study of landforms and processes that shape the earth's surface. By understanding the distribution of landforms across the coastal landscape, insights can be gained regarding the erosional and depositional processes associated with the surface features (Valiela et al. 1978, Bird 2000). Coastal geomorphic features are determined based on the shape and geologic history of an area, texture and structure of the sediments, degree of protection from wave energy, and amount of hydrologic exchange with the receiving water body.

The various geomorphic units associated with coastal regions, such as tidal flats, dunes, barrier spits, and tidal channels, are formed by differing erosional and depositional processes associated with waves, wind, and currents (Clifton et al. 1973, Harper and Morris 2003). Consequently, the units have varying topography, sediment textures, hydroperiods, currents, salinities, and vegetative cover. Mapping the distribution of the varying coastal geomorphic units provides an essential technique for assessing landscape-level changes in surficial materials that respond to physical processes that cannot be adequately monitored in the field. Furthermore, the geomorphic maps integrate a number of topographic, hydrologic, and soil factors that influence vegetation change.

Coastal salt marshes are predominantly associated with active and inactive tidal flats. Within the tidal flats are tidal channels and varying surface microtopography that include levees adjacent to the channels and basins (pans) formed by impoundment of water behind the levees. The levees are formed by deposition of sand by tidal water that overflows the channel banks and drops the coarser sediment load as the water loses velocity. The levees are better drained and are usually dominated by dunegrass (*Leymus mollis*). In contrast, basins are slight depressions where seawater can become trapped during high spring tides. Over the growing season, the basins can become increasingly saline as water is lost from evapotranspiration. These high-salinity conditions limit seedling germination and plant growth. Without precipitation or additional tidal flooding, salt concentrations in basins can reach levels high enough to kill marsh plants and form a salt crust over the soil surface, limiting future recolonization of the area (Adam 1990).

Tidal channels through a marsh are important corridors for water, materials, and animals to move between vegetated tidal flats and the nearshore environment (Mitsch and Gosselink 2000). Water carrying suspended and dissolved material moves downstream during periods of low water levels and inland with tides and storms. Tidal channels also facilitate the drainage of the marsh during low tide, a process essential to the survival of many marsh plant species (Teal and Weinstein 2002). Animals such as fish and shellfish find refuge in creeks during low water levels and then enter tidal ponds to forage during times of high water levels (Rozas et al. 1988; Laffaille et al. 2001; Hampel et al. 2003). Crustaceans and fish that use salt marshes are usually found within 5 m of open water or tidal channels so they can quickly return to lower areas at low tide (Peterson and Turner 1994).

Sand dunes front many of the coastal marshes along the southwestern Alaska coast and protect the salt marshes from erosion during large storm events. The dunes formed by wind-blown sand usually rise high above the levels affected by tides and storms and are affected only by wind-blown salts. In addition, salts in the sandy materials are easily leached by rainfall so salinity levels typically are low. Consequently, non-saline vegetation can colonize the older portions of dunes and can lead to the development of forest vegetation. Along the LACL and KATM coasts, eolian sand is limited to thin deposits capping gravelly beach ridges.

Waterbodies

Ponds and other shallow water bodies provide a freshwater source to wildlife, as well foraging areas, habitat, and protection, particularly during moulting, to migrating waterfowl (Jeffries and Rockwell 2002). Waterbodies have been shown to be a sensitive indicator of climate change, and remote sensing has shown large changes in the surface extent of water bodies in the Northern

Hemisphere (Yoshikawa and Hinzman 2003, Smith et al. 2005, Klein et al. 2005, Riordan et al. 2006, Plug et al. 2008). The mechanisms of water-surface change have been attributed to thermokarst expansion, thermokarst draining, channel migration, drying from increased evaporation, changes in precipitation, and paludification. Within a region, some lakes have been found to increase in area while others have decreased, with the difference in response apparently due to differences in terrain. Further complicating the issue of image interpretation is the sensitivity of the image analysis to seasonality (spring vs. late summer) and year (wet vs. dry year), and the need for a robust time series of images to compensate for the seasonal/annual variation (Plug et al. 2008).

Waterbodies (water levels) in coastal areas have the added variability of tidal regimes and storm flooding. Ponds are also subject to drainage and tapping due to migration of tidal rivers and guts (Walker 1978). In coastal areas of SWAN, permafrost is lacking so permafrost degradation is not a factor in pond drainage. Mapping of waterbodies is therefore a relatively straightforward method for documenting long-term trends in the SWAN salt marshes, but is insufficient for assessing the numerous factors causing the changes.

Topography

Topography (surface elevations), and bathymetry in the case of submerged land, are the most important factors affecting the composition and productivity of coastal ecosystems because they affect water levels and hydroperiod, surface-water flow, groundwater table, sedimentation rates, carbon accumulation, salinity, and nutrients (Morris 2000, Jorgenson and Ely 2001, Langlois et al. 2001, Hussein et al. 2004, Merkey et al. 2005, van Proosdij et al. 2006). Changes in topography, even of a few centimeters (microtopography), through erosion, subsidence, or sediment deposition can alter plant communities and plant productivity because each plant species is adapted to germinate and grow under a specific tidal regime or hydroperiod as it relates to water depth (van der Valk and Davis 1978, Keddy and Reznicek 1982). Consequently, the topographic diversity of coastal sediments also increases the diversity of the plant community. In addition, the presence of channels in the marsh increases the ratio of edge to area and allows greater access to the marsh surface by fish and crustaceans, thus increasing the value of adjacent habitats (Rozas et al. 1988).

Coastal topography and flood frequency can be radically altered by large earthquakes (Reimnitz and Marshall 1965). The Alaska Peninsula marks the boundary of an active subduction zone for the Pacific plate, and earthquakes are frequent (Plafker and Berg 1994). The uplift or subsidence associated with tectonic activity has major effects on plant distribution (Thilenius 1995, Boggs and Sheppard 1999). Combellick (1994) has used peat stratigraphy in marshes to assess topographic changes associated with the great 1964 earthquake, in which coastal forests were flooded and experienced dieback in areas of subsidence, and mudflats converted to coastal meadow in areas of uplift.

Tides and storm surges

Tidal fluctuations and major storm events, particularly in winter, are both major factors that affect the distribution of surficial materials, topography, soil aeration and anaerobic processes, salinity, and nutrient availability. The tidal regime determines the hydroperiod, which is

characterized by water depth, duration, frequency, and timing of inundation, of varying portions of the coastal landscape. Mean sea level, one metric of the tidal regime, is one of the most important factors affecting long-term soil salinity and soil aeration, which in turn affects the composition and productivity of marsh vegetation (Phleger 1971, Morris 1995, Morris et al. 2002). Mean sea level can be affected by subsidence of unconsolidated sediments, uplift by tectonic events and rebounding of the earth's crust after deglaciation, and eustatic sea level rise from global warming (Bird 2000). In contrast to the daily tidal fluctuations that flood and drain the lower salt-marsh ecosystems, major storms are rare, high-energy events. They can cause major erosion and sedimentation, which alter the distribution of geomorphic units, drainage patterns, inland salinity levels, and short-term nutrient availability (Reed 1989, Goodbred and Hine 1995). Storms have only minor short-term effects, however, on sea water exchange and soil aeration in most of the marsh.

Tidal ranges in Cook Inlet are large. At Nikiski, across the inlet from LACL and KATM, the daily tidal range can be 7 m or more. The area also is subject to large storm events where winds are channeled and intensified by mountains along Shelikof Strait and Cook Inlet (Zingone and Hufford 2005). Tsunami records for Alaska extend back to 1737 and record 84 tsunamis over that period. Some of the largest include tsunamis generated from earthquakes at Yakutat Bay in 1989 (18 m maximum water height), Disenchantment Bay in 1905 (10 m), Lituya Bay in 1936 (45 m), and Prince William Sound in 1964 (20 m) (WCATWC 2007). The long-term effects of these tsunamis on coastal vegetation and nearshore communities are unknown.

Sedimentation

The accumulation of sediments from flood deposition and organic matter from decaying vegetation are important to ecosystem processes because they raise the ground surface, add nutrients bound to the sediments, and can disturb the surface and maintain early successional plant species (Nixon 1980, Odum 1980, Werner and Zedler 2002). The sediment supply may be altered by changes in upland runoff, reworking of marine-derived sediments, hydrologic patterns, and organic production occurring within the marsh (Cahoon and Turner 1989, DeLaune et al. 1989). Sedimentation and surface material accumulation lower flooding frequency by raising the surface relative to mean sea level, or may help counteract increasing flood frequency that can result from subsidence or increased sea level.

Changes in upland runoff and storm magnitude and frequency are the principal causes of increased sediment supply. Large storm events may cause high sediment deposition because of the higher sediment load associated with the higher energy levels of the surging water. In northern areas with seasonal ice cover, ice floes stranded during storms can be covered by sediments and leave thick mud mats that smother the vegetated surface. Over time, the continual compaction of unconsolidated Holocene sediments by the weight of the surficial materials, however, can cause submergence of the surface (DeLaune 1983). Often sedimentation offsets the compaction to maintain the elevation of the surface. Vegetation appears to have a substantial role in the re-suspension and movement of sediments within a salt marsh by affecting water velocities (Ruddy et al. 1998). Organic matter accumulation also can raise the surface, but varies in different areas of the marsh depending upon the degree of plant, animal, and microbial activity. Large amounts of organic matter, however, generally do not accumulate in most marshes because of tidal flushing, rapid litter turnover, and high rates of oxidation.

Four common approaches are used to measure sediment accumulation rates, including: (1) measurement of material mass using sediment traps with filter paper or water-filled containers; (2) measurement of surface elevation using a sedimentation erosion table (SET) that measures down to the sediment surface from a permanent, elevated table; (3) measurement of sediment thickness using a marker horizon that is either added or uses a distinctive buried horizon (van Erdt 1985); and (4) surveying ground-surface elevations relative to a permanent benchmark. For SWAN, the measurement of thickness from a distinctive buried horizon is most appropriate, because it is cost-effective, unobtrusive, reliable, and sufficiently precise for measurement over long periods. The principal disadvantage of this method is that, in some situations, distinctive buried horizons may be absent.

Soil Water Level, Salinity, and pH

Soil-water characteristics fundamental to the function of coastal ecosystems include water depth in the soil, temperature, salinity, and pH. Although these variables are important in themselves, they are also critical in determining what factors may cause changes in salt marsh vegetation. Water depth affects soil moisture and aeration, type and amount of soluble materials, osmotic potential, redox potential, and pH of the soil solution (Paul and Clark 1989). Marsh sediments are mostly anaerobic, however, which causes high levels of H₂S and low pH (Pomeroy and Wiegert 1981). Exchange between sediments and floodwater occurs through sedimentation, diffusion, bioturbation, and seepage (Wiegert and Freeman 1990). Salinity exerts strong control on the distribution and abundance of estuarine vegetation because species differ in their osmoregulatory abilities and salinity tolerances (Kuramoto et al. 1992, Jorgenson 2000). Soil-water pH provides a fundamental control on chemical mobility, nutrient availability, and microbial reactions (Paul and Clark 1989).

Soil Temperature

Soil temperature is a primary determinant of the rate of biological processes. Thus productivity and growth of phytoplankton (Goldman and Carpenter 1974) and submerged aquatic vegetation (Marsh et al. 1986, Bulthuis 1987), microbial metabolism (Christian et al. 1989), sediment oxygen demand (Portnoy 1991), nutrient remineralization (Nowicki and Nixon 1985), and faunal recruitment (Day et al. 1989) are all strongly influenced by temperature. In addition, annual patterns of primary production and consumption at temperate latitudes are largely a function of seasonal temperature differences (Day et al. 1989). For example, eelgrass (*Zostera marina*) becomes more susceptible to the negative impacts of algal epiphytes at high water temperatures (Neckles et al. 1993). Monitoring soil temperatures in salt marshes in SWAN will provide a useful comparison to soil-temperature data from the Yukon-Kuskowim Delta and coastal areas of the Arctic Network, and will provide an index of growing season length and local climatic variability. Permafrost is considered absent in SWAN coastal ecosystems.

Vegetation Cover

Vegetation is a fundamental component of salt marshes because it provides the primary food source for herbivorous mammals, birds, and invertebrates, and provides plant litter for microbial and invertebrate consumers. A salt marsh also is physically dependent on its plants because plant roots and stems anchor the substratum, reduce water velocities and affect sedimentation rates,

and enable the gradual build up of sediment and organic matter. Plant communities, along with variations in tidal regimes and chemical parameters, shape salt marsh habitats and help determine which species of invertebrates, fish, birds, and other animals will be found there.

Distribution and abundance of coastal plant species is affected by the extremely dynamic nature of coastal habitats resulting from wide daily and seasonal fluctuations in surface water and root-zone salinity, temperature, and dissolved oxygen. For this reason, the low numbers of plant species found in salt marshes fill extremely specialized ecological niches. The zonation of vegetation within salt marshes results from species-specific adaptations to physical and chemical conditions and is most broadly controlled by salinity gradients and duration of inundation. Vegetation cover and species composition provide good metrics for monitoring because they are sensitive to changes in environmental conditions, relatively easy to measure, relatively immobile and change slowly, and are highly correlated with biomass and productivity.

Nutrient pools and fluxes, which provide a fundamental control over the productivity and composition of salt marsh biota, were not included in the monitoring program because of high temporal and spatial variability, and the high cost of sampling and laboratory analysis. Water quality parameters and nutrient concentrations are common components of coastal monitoring in areas with substantial human populations (Kopp and Neckles 2004), and are being monitored in nearshore marine waters of the SWAN under a separate protocol.

Vegetation changes can be assessed in terms of individual species response and in shifts in composition of plant communities (Mueller-Dombois and Ellenberg 1974). A plant community is an abstract concept of how plant species organize themselves across the landscape, but there is a rich literature of how individual species co-occur across environmental gradients in a landscape and how they can be classified into communities for monitoring and mapping (Daubenmire 1968). Classification of plant communities not only partitions the variation in species abundance but also helps partition the variation in environmental factors that affect species distribution. Community classification is needed because salt marshes are comprised of numerous communities that span a wide range of environmental gradients. They can be divided simply into high and low (relative to the tidal range) marsh with distinctly differing species composition, although more rigorous quantitative analysis frequently differentiates numerous plant communities. For example, more than 30 plant communities have been identified for the Cook Inlet region near the SWAN parks (Vince and Snow 1984, Tande 1996, Jorgenson et al. 2003), although the number depends on the level of differentiation. Using a vegetation classification system developed from quantitative clustering and ordination analyses, and that identifies diagnostic characteristics that aid users of the system, the plant community concept can be applied through remote sensing or ground measurements to assess changes in their abundance across the study areas.

Landscape-level Changes through Photo-interpretation

Landscape-level changes in vegetation and geomorphic conditions are amenable to quantification through photo-interpretation of aerial photography and high-resolution satellite images. There are numerous techniques for assessing changes in vegetation or landcover through image processing of spectral characteristics of satellite images, but the approach is limited by the period of satellite image acquisition; the spectral variability in surface characteristics related to season,

phenology, and atmospheric conditions; and by classification of the type of change (USGS 2010). Alternatively, point sampling of vegetation types and geomorphic features from aerial photography is an efficient technique for assessing changes over time that can handle highly variable imagery and benefit from contextual or spatial patterning (Jorgenson et al. 2000, Jorgenson and Dissing 2010). Photo-interpretation also is limited by the classification system used to detect change and by the experience of the interpreter with the specific terrain.

2 Monitoring Objectives

Consistent with the goal of the monitoring program to detect changes in an interacting suite of physical, chemical, and biological parameters in salt marshes of SWAN, the specific objectives of the monitoring program are to:

- 1) Compile and georectify a time series of historical aerial photographs and modern imagery for documenting land-cover change;
- 2) Map changes in waterbodies and shorelines through remote sensing;
- 3) Quantify change in salt marsh topography across a gradient from lower to upper marsh to assess whether various marsh zones are accreting or eroding;
- 4) Monitor tidal fluctuations and storm surges in tidal channels;
- 5) Detect changes in sedimentation rates;
- 6) Quantify changes in soil-water characteristics, including water depth, salinity, and pH, across the topographic gradient;
- 7) Quantify changes in soil temperatures in wet and dry coastal conditions;
- 8) Detect change in the cover and/or frequency of vegetation across the topographic gradient; and
- 9) Determine extent of landscape-level changes through photo-interpretation of a time-series of imagery using an ecological classification system that differentiates both plant communities and geomorphic units.

The specific measurement or metrics associated with each one of the monitoring objectives is listed in Table 1. The SOP that describes the protocols for each measurement also is listed in the table and is presented in Appendix 1.

3 Sampling Design

3.1 Sampling Design and Rationale

Site selection

While recognizing that no sampling design can be optimized for all objectives satisfactorily, and that design selection necessarily involves compromises, a nested sampling design was developed in consultation with NPS. Our approach first subdivides the coastal ecoregion into landscape-level units (ecological subsections) that represent contiguous portions of the coast with similar

repeating geomorphic characteristics (e.g., tidal flats, river deltas, rocky shorelines, etc.). To accomplish this, the coastal subsections delineated for LACL by Spencer (2002) and KATM by Shephard (2000) were redrawn at a higher spatial resolution (~1:100,000 scale) over an IKONOS base image to more precisely delineate the boundaries of coastal ecosystems from inland freshwater ecosystems and to provide general characterization of coastline types (Figures 1 and 2). Image interpretation of geomorphic units associated with coastal and marine processes (e.g., deltas, tidal flats, beaches, beach ridges, coastal dunes) were used to differentiate between coastal and non-coastal ecosystems.

Table 1. List of potential variables and methods for monitoring coastal ecosystems in the Southwest Alaska Network.

Variable	Method(s)	Frequency	SOP
Physical			
Aerial Photographs	Manual interpretation of time series	10 yrs	1
Waterbody Distribution	Remote sensing	10 yrs	2
Topography/Bathymetry	Level survey, DGPS for benchmarks	10 yrs	3
Plot Establishment	Fieldwork and manual description	Initial	4
Tides/Hydroperiod	Water-level recorder, level survey	30 min.	5
Sedimentation Rates	Sediment patches, thickness measurement	10 yrs	6
Soil-water Depth	Well measurement	10 yrs	6
Soil Temperature	Dataloggers	2 hrs	7
Chemical			
Water pH	Field meter	10 yrs	6
Water Salinity	Field meter	10 yrs	6
Biological			
Plant Community	Point sampling or ocular estimates in plots,	10 yrs	8
Vegetation and Geomorphic Change	Photo-interpretation of airphotos and imagery	10 yrs	9
Other Options			
Exotic Species	Presence/absence surveys around airstrips and		
Herbivory by Bears and	Plot sampling, categorical data		
Woody Debris	Transect sampling of tidally deposited wood		
Trash	Beach inventory, transect sampling		
Camp-sites and Trails	Remote sensing		

Subsections comprised of complexes of tidal flats, beach ridges, and sandy deltas include Silver Salmon Coast (Red River) and Chinitna Tidal Flats in LACL (Figure 1), and Hallo Bay Coast in KATM (Figure 2). All sites are accessible by fixed-wing aircraft. The other subsections with bedrock cliffs (e.g., Cape Douglas Coast) and boulder and gravel coasts associated with glaciated uplands (e.g., Iniskin Outer Coast) are excluded because they do not contain extensive areas of salt marsh. Another potential site at Swikshak Lagoon within the Hallo Bay Coast was dropped because of difficult access. Within each selected subsection, we delineated a smaller area dominated by salt marshes: we term this smaller area for sampling a "study area".

Sampling is done systematically along four gradient-oriented transects perpendicular to the coast at uniform distances along the coast to reduce the bias in transect and plot allocation. Transects cross the entire topographic elevational and salinity gradient from mean high water (e.g.,

mudflats, beach) to the beginning of non-halophytic vegetation (e.g., alder, spruce) (Figure 3 and 4). To ensure spatial dispersion of transects, the coast with the study area is subdivided into 4 equal sections and the transects cross the coastline in the middle of each section. Many of the transects also cross tidal rivers and guts and thus encompass secondary gradients related to tidal cycles. The starting end of each transect is located 30–50 m into the non-coastal forest or shrubland. As this starting point is unrelated to the patterning associated with coastal processes within the salt marshes it can be considered to be a random starting location. Plots are systematically distributed every 100 m along each transect, so that the sampling provides a representative and unbiased sample across the subsections. While a 100-m spacing is inadequate to capture the small scale patterns and process with complex tidal habitats, the wider spacing is desirable to better distribute the limited number of plots across a broader area. Additional plots are established subjectively in uncommon ecosystem types to increase the sample size for unusual features. The additional plots also help capture some of the small scale patterns missed by the widely spaced systematic plots. Given a mean transect length of ≥ 600 m, this design generates a total of 30–40 plots per study area. The additional, subjectively allocated samples are used to analyze ecological characteristics by vegetation type, but these samples are excluded from analysis of overall mean conditions. The bias of using the subjectively placed samples, however, is reduced because the vegetation type for the plot is not known until the classification analysis is performed, thus it is hard to bias the characteristics of the vegetation type in the field when the vegetation type is still undefined. The benefits of using the subjectively allocated samples are that it greatly reduces variability within each class during analysis and better identifies plant species changes with differing types of habitats. Quantitative analysis using clustering and ordination techniques is used to classify the plots after field establishment, and characterizes the degree of overlap in species composition among communities. To the extent possible, sampling of biophysical characteristics is co-located with vegetation plots to allow analysis of relationships among physical, chemical, and biological variables.

3.2 Sample Units, Size, Number, and Location

Five types of sampling are used for all the salt marsh components that are being monitored. These types are listed briefly below and subsequently described afterwards:

- 1) Mapping of waterbodies and coastlines within each study area, such that the study area is the sample unit (SOP-2);
- 2) Measurement of elevations along topographic transects. Each measured point is the sample unit for detecting change at any location along the profile (SOP-3);
- 3) Measurement of water levels and soil temperatures using dataloggers installed at single, subjectively determined locations, so that the point where the instrument is located is the sample unit (SOP-4, SOP-7);
- 4) Field sampling of sedimentation, soil-water characteristics, and vegetation within 4 x 10 m plots, so that plot is the sample unit (see SOPs 5, 6, and 8 for more discussion); and
- 5) Photo-interpretation of landscape-level changes, based on an ecological classification system that differentiates plant communities and geomorphic unit, at grid-points spaced 200-m apart within the boundaries of each study area, so that the study area is the sample unit (SOP-9).

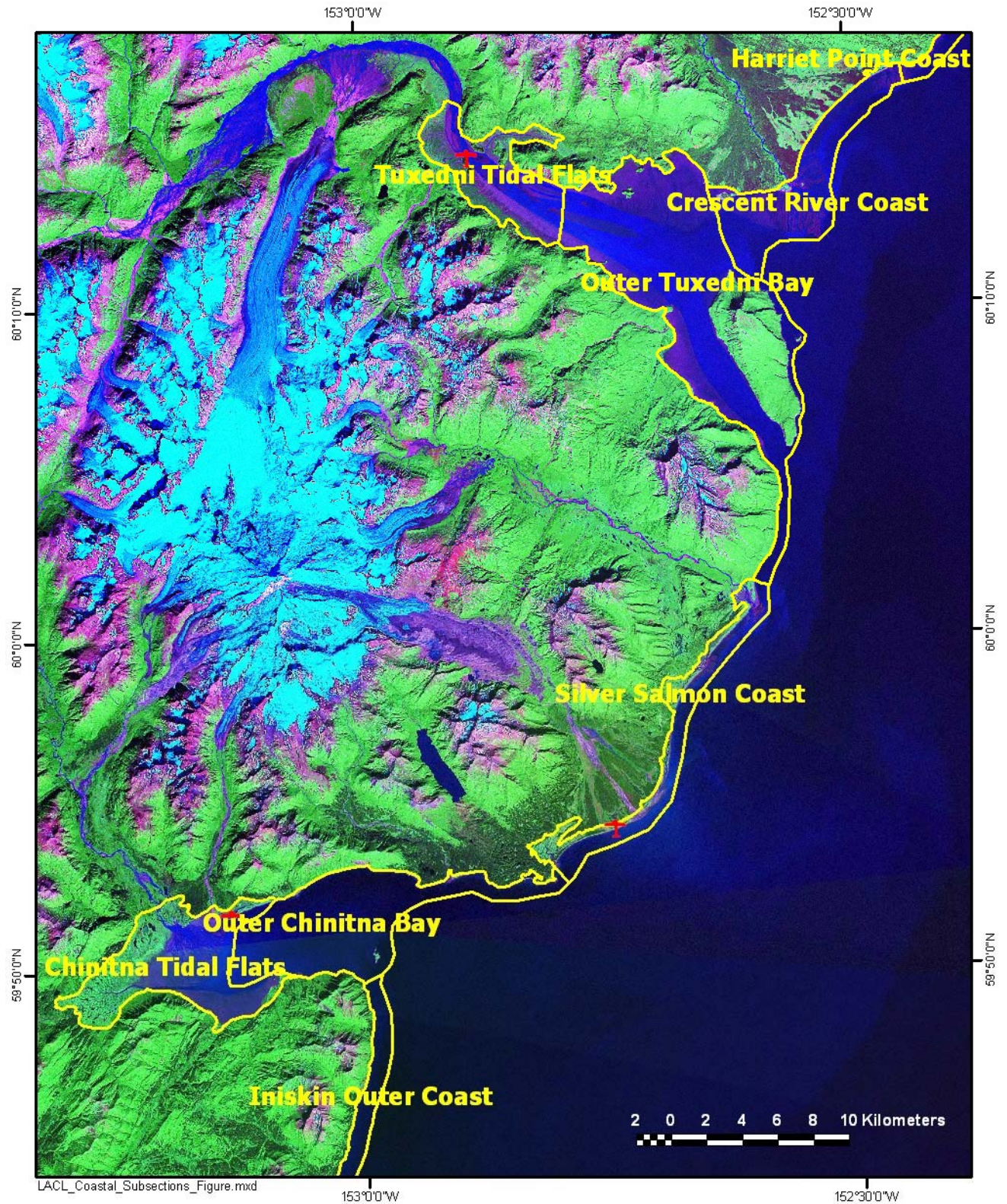


Figure 1. Map of coastal subsections in Lake Clark National Park and Preserve, Alaska. Subsections dominated by salt marshes include the Chinitna Tidal Flats and the Silver Salmon Tidal Flats. Access sites are noted by the red aircraft symbols. Outer Tuxedni Bay and Tuxedni Tidal Flats are most effectively accessed via skiff.

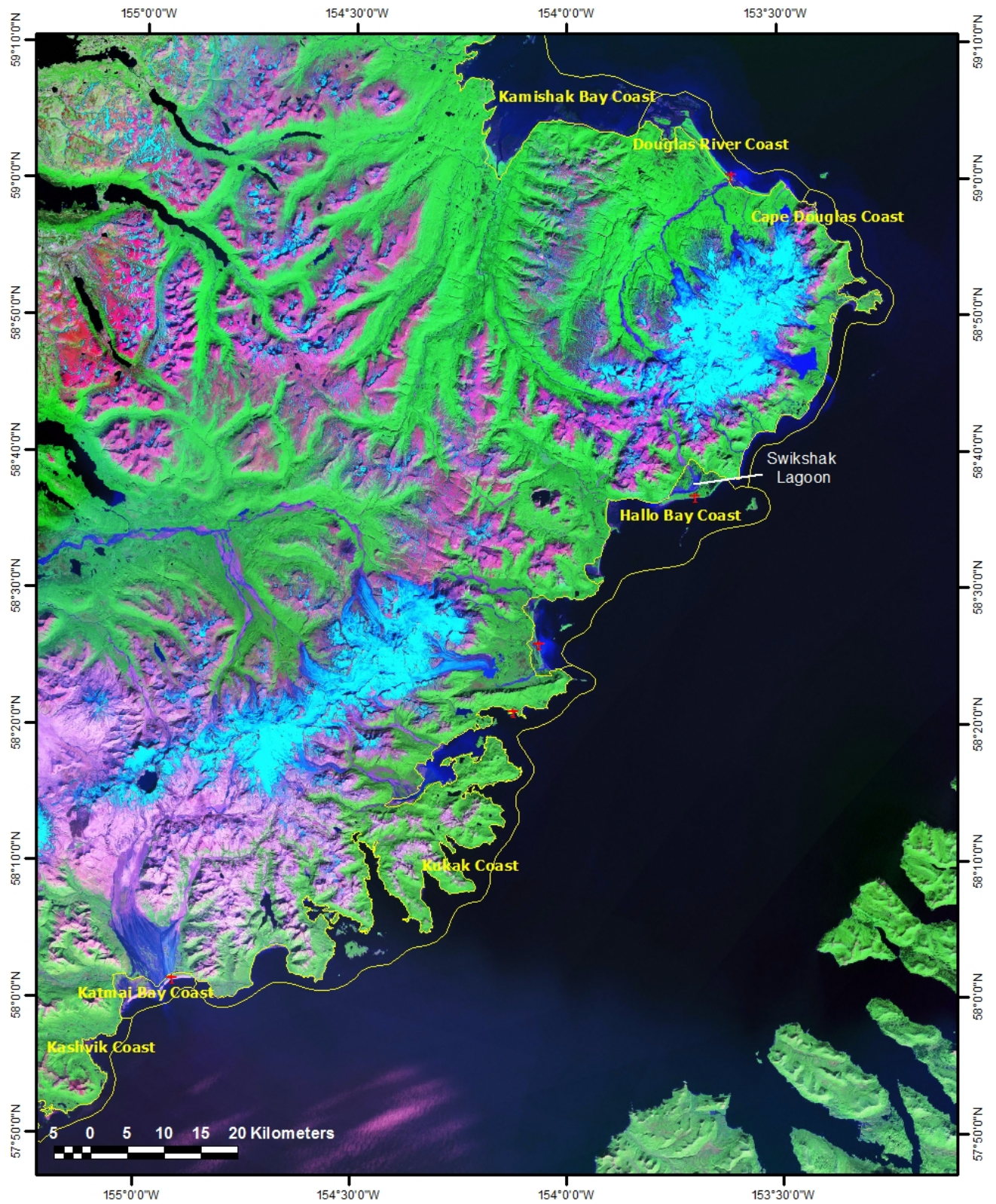


Figure 2. Map of coastal subsections in the Katmai National Park and Preserve, Alaska. Coastal access points by fixed-wing aircraft are shown in red plane symbol.

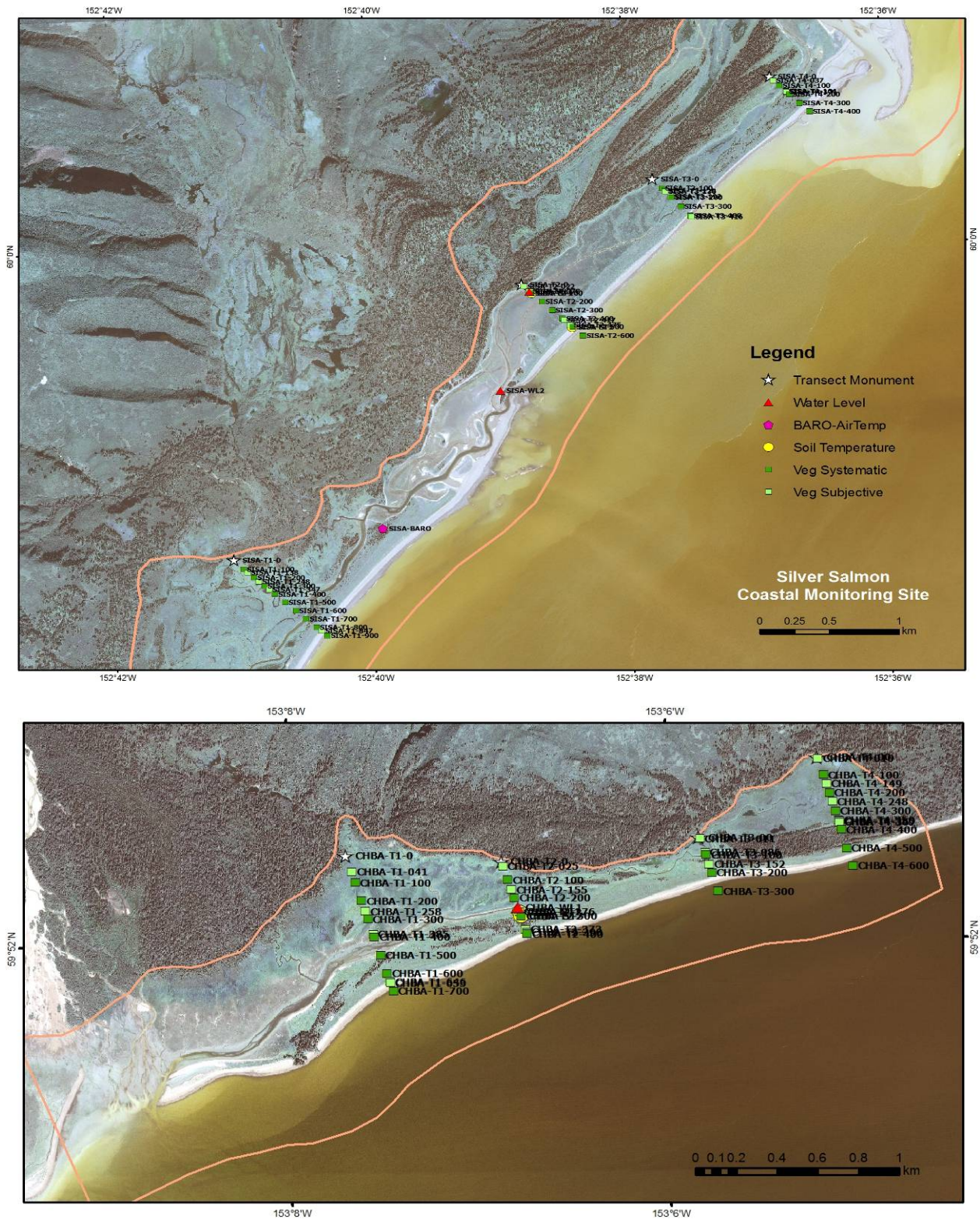


Figure 3. Layout of sampling locations along systematically distributed transects in the Silver Salmon (top) and Chinitna Bay (bottom) study areas (bounded by pink line). A central transect interval at Silver Salmon was skipped to avoid conflicts with park visitors at nearby lodges.



Figure 4. Layout of sampling locations along systematically distributed transects in the Hallo Bay study area.

Waterbody and coastline changes are assessed by mapping their distribution and abundance of within three of the six ecological subsections along the LACL and KATM coasts that have substantial tidal flats. Because the mapping of waterbodies within each study area provides a census of the total abundance of units within each area, the study area is the sample unit. Each study area is ~5–10 km² in size. From this sample inferences can be made of trends in salt marshes within the coastal subsections, but the areal extent of salt marshes relative to other coastal ecosystems has not been quantified. While it would be desirable to measure water levels in a series of ponds, the combination of waterbody mapping and topographic surveys that cross waterbodies will at least provide an estimate of major changes in pond water levels and extent.

Topography, or surface elevations, are systematically sampled along 600–1000 m transects spaced at equidistant intervals within each of the study areas. The transect starts at a location 30–50 m outside of the study area and is not subject to coastal processes, thus we consider the endpoint to be a random location in respect to salt marsh patterns. Measurements are taken at 5-m intervals, and additional measurements are taken at subjectively located major breaks in slope to better capture microtopography. Each transect has 100–200 elevation sample points and each study area has four transects, for a total of 600–800 measurement points for each of the three study areas. For detecting change at any single location along the topographic profile, the measurement points are considered the sample unit. We avoid using the transect as the sample unit because of the loss of useful information on topographic variation related to site-specific erosion and deposition. The transect locations, which also are used for co-location of vegetation, sediment, and soil-water sampling, are shown for the three study areas in Figures 3 and 4.

Water level and water temperature, and soil and air temperature, are measured with dataloggers. Only one water-level recorder is installed at each of three study areas because the instruments are expensive and the data from one site within a study area closely represents the water level for peak stages across the entire study area. The water-level data are replicated across three study areas to provide redundancy in the water-level record and for comparison of differences among sites. While high frequency of lower level tidal inundation can be approximated by NOAA tide tables, the water level recorders to provide more precise, site-specific water-level information and capture water levels during extreme flooding events. Temperature dataloggers are installed in two locations along a single transect at each study area—a lower, wet, halophytic meadow and a higher, dry, grass meadow on a dune, both of which are common vegetation types along every transect. These two landscape positions are replicated at each study area, for a total of three samples for each landscape position.

Vegetation, sediment accumulation, and soil-water characteristics (depth, salinity, pH) are measured within 4 x 10 m plots located at 100-m intervals along each of the four transects established for topographic measurements. Because each transect is 600–800 m long, ~25–30 systematically distributed plots are established within each study area. These systematic samples are used to calculate mean characteristics of the various parameters across all three study areas. In addition, 1–3 plots are subjectively placed along each transect in vegetation types not encountered by the systematic sampling, to adequately sample uncommon vegetation types. These additional plots, which increase the sample size for uncommon vegetation types, are used to test for changes in mean characteristics of each vegetation type. With these additional plots, 30–40 plots are sampled per study area and a total of ~120 for all study areas combined. For vegetation monitoring, a 4 x 10 m plot is used because the plot size encompasses the variability

in clonal vegetation patches (typically a few meters in diameter), reduces variance among samples, and is consistent with the plot (relevé) size that is used for plant community classification. This rationale is further discussed in SOP-8 for vegetation cover.

All these various sample units are permanently established to allow repeated sampling during each sampling period. Permanent plots or stations (point measurements) allow the application of more powerful statistical tests for detecting change (Elzinga et al. 1998). Permanent plot studies are the most direct way to indicate the pathways of ecological changes (what happens), and also can provide insights into mechanisms and causes (how and why) of vegetation change (Pickett et al. 1987). Permanent plots are more efficient to resample than temporary plots, because they only need to be established once and fewer plots or sampling stations are required to detect change or track trends. In using permanent plots we assume that repeated measurement does not affect the characteristic(s) being estimated (i.e., no destruction of vegetation, of change in vegetation caused by sampling) and that plots remain representative over time.

Landscape-level changes in vegetation and geomorphic conditions are amenable to quantification through photo-interpretation of aerial photography and high-resolution satellite images. Manual photo-interpretation is preferred because it can better handle a time-series of imagery with differing spectral characteristics (black and white, color-infra red, true color) and detect patterns on high-resolution imagery. It is constrained, however, by the knowledge and experience of the photo-interpreter. Once baseline conditions have been interpreted by personnel familiar with the vegetation and geomorphology of the area, classification and detection of further changes is tightly constrained. Due to spectral variability among imagery and limits in the accuracy of photo-interpretation, the technique is useful for detecting large changes in vegetation structure or geomorphic units but is not reliable for detecting subtle shifts in plant species with similar growth form. Once change is detected, the cause of the change must still be evaluated and attributed to specific factors to the extent possible. These challenges are further discussed in SOP-9, which addresses landscape-level changes.

3.3 Frequency and Timing of Sampling

Determining the frequency of sampling requires a balance between assessing the responses to small, high-frequency events such as tidal flooding, and to large, stochastic events, such as large storms, that may occur only after long intervals or rarely in short succession. In addition, the cost of sampling must be balanced against the expected rates of change. For this monitoring program, the basic period for repeat measurements is 10 yrs for most parameters (Table 1). Although a 10-year sampling frequency is not sufficient to quantify short-term fluctuations in very dynamic parts of the system, particularly early successional vegetation on tidal flats, we expect to detect the large magnitude, directional change that will be of interest to resource managers. Likewise, we expect that it could take at least 3-4 iterations of sampling to distinguish short-term perturbations ('noise') from longer-term change in some areas. This 10-year interval is suitable for most selected parameters because they typically show only small changes over many years and the small changes are difficult to detect with the precision of the measurement techniques being used. These parameters include distribution of geomorphic units, topography, sediment accumulation, and vegetation. In contrast, parameters that are highly variable temporally and amenable to measurement with dataloggers can be measured at short time-intervals of minutes to

hours continuously during the year. Some of the money saved by using longer sampling intervals, however, should be reserved for immediate response and sampling after large destructive events, such as an earthquake, tsunami, or oil spill, to capture initial ecological responses and establish the baseline for recovery. Sampling frequency and timing for the various components are discussed below.

- 1) The time series of aerial photographs should incorporate a repeat set of aerial photographs or high-resolution satellite images every 10 years. The existing time series of aerial photographs taken ~25 yrs apart show substantial changes. A higher frequency time series of every 10 yrs would better differentiate large, storm-related events and could be accomplished through targeted air photo acquisition, as has been utilized in the Central Alaska and Arctic Networks.
- 2) Waterbody mapping should be done after each acquisition of new imagery every 10 yrs.
- 3) Topographic surveying should be done every 10 yrs to coincide with the new imagery.
- 4) Tide levels and storm-surge heights should be measured every 30 min to capture the range of the tidal cycle, and peak water-levels at high tides and during storm surges. The water-level recorders also measure temperature, so water temperatures can be measured at the same frequency. These data should be downloaded at least every 2 yrs at remote sites and preferably twice a year (spring and fall) at sites staffed with NPS personnel.
- 5) Sediment thicknesses should be measured every 10 yrs. Although sedimentation is affected by high-frequency tides and lower-frequency storm events, decadal measurements of sediment accumulation are sufficient for analyzing factors affecting long-term vegetation response. The decadal measurements, however, will not be sufficient for analyzing sedimentation in relation to tidal fluctuation and specific storm events.
- 6) Soil-water depth, salinity, and pH should be measured every 10 yrs at the time that vegetation cover is measured in the permanent plots. Although decadal measurements are not sufficient to document seasonal fluctuations in soil-water characteristics, the data are useful for analyzing the relationship of vegetation cover to current environmental conditions, and for describing many other soil parameters (e.g., organic matter content, texture) that change slowly.
- 7) Soil temperatures should be measured every 2 hrs using inexpensive dataloggers. This interval is sufficient to calculate mean daily, monthly, and annual temperatures. Although temperatures can be measured more frequently, the dataloggers have limited storage capacity for accumulation of measurements over a 3-yr period.
- 8) Vegetation cover should be sampled in permanent plots every 10 yrs. Except for high-level disturbance from storm events, historical aerial photographs indicate that plant community changes are relatively slow.
- 9) Landscape-level changes in ecosystem types should be quantified through point-sampling and photo-interpretation of a time-series of photographs and newly acquire imagery every 10 years.

4 Level of change that can be detected

The sample size needed to detect a given amount of change varies for each physical, chemical, and biological parameter. Here we emphasize the sample size needed to detect changes in vegetation when evaluating the number of plots needed because this is the most important

variable for assessing ecological changes, and because the physical and chemical variables (elevation, water and sediment) are co-located with the vegetation plots.

The determination of sample size requirements is complicated because it is a function of what level of change is to be detected, the variance of the samples (variance among species), the confidence level for detecting change, the precision of the point-sampling method, and the wide diversity of plant species that are being monitored. We used two approaches to evaluate the sample sizes needed to measure change. First, we used the methodology of Elizinga et al. (1998) for determining the necessary sample size for detecting differences between two means when using permanent sampling units using data from LACL and KATM from 2007–2008. This analysis was conducted for analyzing change within a vegetation type. Second, we conducted a more complicated power analysis that incorporated the effects of measurement errors which was run on a time-series of salt marsh vegetation from the Yukon-Kuskokwim Delta collected over a ten-year period. This analysis was used for detecting change across a study area and within vegetation types, and included the effects of sampling precision. These are discussed in more detail below.

4.1 Simple Power Analysis for Detecting Change within Vegetation Type

We used the methodology of Elizinga et al. (1998, p. 354) to determine necessary sample sizes for detecting change using paired plots. For the analysis we used the standard deviation from the field data obtained from sampling salt marshes in LACL and KATM during 2007-2008, a false-change error rate of 0.10 ($Z\alpha=1.64$), and a missed change error rate of 0.20 for power of 0.80 ($Z\beta=0.84$). The minimum detectable change varied by the abundance of the species; 100% change in plant cover for species that have mean cover values $<5\%$ ($<5\%$ change in absolute terms), a 50% change for species with cover values of 5-20% (2.5 to 10% change in absolute terms), and a 25% change for species with cover values $>20\%$ (4 to $\sim 20\%$ change in absolute values). We chose these values because the precision of the sampling method is $\sim 5\%$ in absolute terms, so the detectable change is about as large or larger than the precision of the method. Because only one year of data were available, we estimated the standard deviation of the differences (Sdiff) between paired samples by assuming that SD was 90% correlated between years, based on the correlation of SD obtained from sampling of salt marsh vegetation in the Yukon-Kuskokwim Delta (M.T. Jorgenson, *unpublished data*). The calculations were done for three species within four different plant communities, with each species selected to represent a range in mean cover values.

The results from the power analysis show that the sample sizes needed to obtain 80% power ranged from 1 to 43 per species, depending on the cover value and standard deviation of the species within the various plant communities (Table 2). For 12 of 15 species conditions, a sample size of 20 would provide $\geq 80\%$ power, and for 10 of 15 conditions a sample size of 10 would provide $\geq 80\%$ power. For one plant community of particular interest, *Carex ramenskii*-*Stellaria humifusa*, a sample size of 13 plots was needed to detect a 25% change in *Carex ramenskii*. As a broad generalization, the analysis indicates that a sample size of 15 plots for each plant community type will be adequate to detect a minimum change of 100% for uncommon species with $<5\%$ cover (e.g., a change from 2 to 4% absolute cover), a 50% change for common species with 5 to 20% cover (e.g., a change from 10 to 15% absolute cover), and a

20% change for abundant species with >20% cover (e.g., a change from 50 to 60% absolute cover) with 90% confidence and >80% power for more than two-thirds of species.

4.2 Power Analysis Simulations for Detecting Change within Study Area

We conducted a separate analysis to assess sample size requirements using a time-series of salt marsh vegetation from the Yukon-Kuskokwim Delta (M.T. Jorgenson, *unpublished data*) and incorporating the effects of measurement errors. We performed the analyses to detect a mean 25%, 50%, or 100% change over a ten-year period in point-count values for individual species present on SWAN plots assuming the same plots would be recounted after ten years. In the analysis, plots with the species present during the first sampling period experienced a mean increase in species abundance as measured by point-counts of 25% with a 5% SD in change (or 50% and 10% SD, or 100% and 20% SD). It was further assumed that there was some random measurement error during the first sampling period and there would also be measurement error associated with the second sampling period. Testing for a significant difference in abundance was done with a paired-sample t-test of the two sampling periods for each plot using an alpha of 0.05 and a two-tailed test.

The measurement error was estimated from repeated measurements taken of plots with tundra vegetation in the Prudhoe Bay oilfield between 2005 and 2008 (ABR, Inc., *unpublished data*). One plot was sampled twice each year by two different observers in up to 4 consecutive years. The absolute difference between the two observers for each species (water, soil, and unknown species were eliminated) were calculated and the values in different bins were grouped based on the average point-count for the two observers. The relationship between average point count and the SD of the differences were modeled using a logarithmic equation of the form $y = B_0 + B_1 \cdot \ln(x)$ where y equals the SD and x = the binned average point count values. The equation was $0.3355 + 1.8558 \cdot \ln(x)$ ($R^2 = 0.77$). This was used as the measurement error component in simulations.

Table 2. Samples needed for detecting change in salt marsh species. Freq = frequency (%).

Floristic Class	Species Name	n	Mean	SD	Freq	CV	CI (90%)	Sdiff	MDC	Samples Needed
<i>Calamagrostis canadensis-Lupinus nootkatensis</i>										
	<i>Achillea millefolium</i>	8	31	14	100	44	7.9	6.1	6.2	6
	<i>Elymus arenarius</i>	8	8	8	75	108	4.7	3.6	3.8	6
	<i>Angelica lucida</i>	8	5	5	100	89	2.7	2.0	2.6	4
<i>Lathyrus maritimus-Senecio pseudoarnica</i>										
	<i>Lathyrus maritimus</i>	10	91	44	100	48	22.7	19.5	18.2	7
	<i>Leymus mollis</i>	10	70	31	100	44	16.0	13.7	14.1	6
	<i>Senecio pseudoarnica</i>	10	6	7	80	129	3.9	3.3	2.9	8
<i>Carex glareosa-Carex ramenskii</i>										
	<i>Carex glareosa</i>	13	53	42	100	80	19.3	18.9	10.6	20
	<i>Carex ramenskii</i>	13	27	31	77	116	14.3	14.0	5.4	41
	<i>Potentilla egedii</i>	13	18	16	92	86	7.3	7.1	3.7	23
<i>Carex lyngbyaei-Calamagrostis deschampsiioides</i>										
	<i>Calamagrostis deschampsiioides</i>	7	16	15	86	90	9.1	6.6	8.1	4
	<i>Carex ramenskii</i>	7	5	12	43	232	7.6	5.5	2.6	27
	<i>Potentilla egedii</i>	7	9	5	100	51	2.9	2.1	4.6	1
<i>Carex ramenskii-Stellaria humifusa</i>										
	<i>Carex ramenskii</i>	9	74.1	61.1	100	82	38.0	27.3	27.3	13
	<i>Stellaria humifusa</i>	9	7.2	8.7	77	121	5.4	3.9	3.9	7
	<i>Triglochin maritimum</i>	9	18.4	13.9	100	75	8.6	6.2	6.2	3

False-change error rate of 0.10 ($Z\alpha=1.64$)Missed change error rate of 0.20 for power of 0.80 ($Z\beta=0.84$)

MDC is minimum detectable change

Each simulation used the original data set for a species. For species with trace amounts present (usually denoted as 0.1), the percent cover was assumed to be equal to the recorded value (e.g. 0.1) and measured with no measurement error the first visit. This amount was then increased by 25% with a 5% SD (or other value when appropriate). The value on the second visit was then either equal to trace amount (no change) or 1. Values were set to one with a probability equal to $1-(1-pc)^{100}$, which is the binomial probability of detecting a species with percent cover ($pc \geq 0$) at least once with 100 attempts. For plots with greater than trace amounts, a random measurement error was calculated for each plot component from a normal distribution with mean 0 and SD from the equation for measurement error. This measurement error was added to the observed value to get a “true” initial value (this value was constrained to be no less than 0.1). A random percentage from a normal distribution centered on 25% with 5% SD was then added to the “true” initial value to get the “true” value after 10 years. Another random value from the measurement error distribution was added to this value to get an observed second value for that plot (rounded to an integer). This treated all species as having an equal measurement error rate relative to abundance. In reality, there is some variation due to size and ease of identification. The difference between the first and second observed values was used to conduct a paired t-test for a significant difference. The *P*-value from this test was recorded and the simulation was repeated 2000 times. The power to detect a difference was calculated as the proportion of

simulations that were significant at $\alpha=0.05$. Plots with a value of zero for the initial observations were assumed to have zero percent of the given species during both time periods and were not included in the analysis. An additional analysis with zero plots included as difference equal to zero and it did not change the power.

Results of the analyses show that power increases with plot count and also with the abundance of the species within those plots (Tables 3 and 4). This makes sense because with low abundance a 25% increase is not easily detectable. A multiple linear regression was analyzed to model the predicted power with average change and the number of nonzero plots as independent variables. In the resulting equation, $\text{power} = -0.341 + (\text{avg. Change} * 0.060) + (\text{num. plots} * 0.029)$, had an R^2 of 0.962, and was highly significant ($P < 0.001$, $n = 17$). This equation appears to work for different percent changes.

Table 3. Estimated power to detect a change in different species across all communities in a study area.

Species	Avg. Change	Number Plots	Percent Change	Power
<i>Achillea millefolium</i>	7.54	26	25	0.924
<i>Carex lyngbyaei</i>	11.46	23	25	0.950
<i>Carex ramenskii</i>	11.08	17	25	0.931
<i>Leymus mollis</i>	8.09	32	25	0.982
<i>Lathyrus maritimus maritimus</i>	6.39	27	25	0.847
<i>Hordeum brachyantherum</i>	7.25	3	25	0.051
<i>Puccinellia phryganodes</i>	4.26	9	25	0.077
<i>Stellaria humifusa</i>	2.19	10	25	0.085
<i>Stellaria humifusa</i>	4.28	10	50	0.202
<i>Stellaria humifusa</i>	8.47	10	100	0.411
<i>Achillea millefolium</i>	7.76	8	25	0.372

Table 4. Estimated power to detect a change in different species within communities.

Species	Avg. Change	Number Plots	Percent Change	Power
<i>Leymus mollis</i>	2.59	6	25%	0.067
<i>Leymus mollis</i>	5.07	6	50%	0.122
<i>Angelica lucida</i>	2.70	8	50%	0.094
<i>Carex glareosa</i>	13.21	13	25%	0.880
<i>Carex glareosa</i>	26.59	13	50%	1.000
<i>Carex ramenskii</i>	8.82	10	25%	0.512
<i>Potentilla egedii</i>	5.30	12	25%	0.390

The analysis indicates that, overall, a sample size of about 30 plots is needed per study area to detect a 25% change in abundant species at 95% confidence and >80% power (Table 3). A sample size of about 15 plots per community type is needed to detect a 25% change in abundant species with >80% power. Although there are widely varying results given all the factors that affect calculation of adequate sample size, we generalize from both analyses that 40 plots per study area and 15 plots per community type (across all study areas) will provide sufficient power to detect modest changes between sampling periods.

5 Field Methods

Methods used for each monitoring parameter are described in detail in the SOPs. A brief summary of how the field program is organized and how the measurements are integrated is provided here.

Ideally, a new set of aerial photographs or high-resolution images are taken every 10 yrs, at the same time that the main fieldwork is conducted. The aerial photographs are used to map the distribution of geomorphic units and shoreline position, and to sample the abundance of vegetation types through point sampling of aerial photographs. The fieldwork is integrated by measuring topography, sediment accumulation, soil-water characteristics, and vegetation cover during the same field visit. During each field visit, one crew of two people measure the topography, sediment, and soil-water characteristics. This crew can be trained to collect these routine measurements with modest training. The second crew of two people measures the vegetation cover in the plots. This requires one specialist with substantial botanical training and local expertise, and one vegetation technician who can be trained to identify the ~100 species that are likely to be encountered during the sampling.

The measurement of water levels and temperatures with submersible pressure transducers, and soil and air temperatures with small dataloggers requires a separate sampling routine. These instruments should be downloaded and maintained every 1–3 yrs, depending on the location. The more easily accessed dataloggers at Silver Salmon and Chinitna Bay should be visited every year to ensure that at least one high-quality, consistent data record is maintained. The more remote dataloggers can be visited every 2–3 yrs, which is the limit of the battery life and memory storage capacity for the datalogger. These sites are more expensive and more difficult to get to because of the weather, and are riskier for personnel safety. Thus, cost and risk of data collection must be balanced against risk of data lost by equipment failure. Because the data are continuous and high frequency, the intermittent loss of data is not catastrophic for long-term analysis.

6 Data Management

An important aspect of the monitoring program is the proper and efficient management of the collected data to ensure quality, standardization, sufficient metadata to allow data distribution, and secure storage and archiving. Specific standard procedures for field-data collection and backup, data compilation and quality control, storage and archiving, and access are provided with each SOP. This section provides only a brief overview of the general management of data.

Field data are collected almost exclusively in electronic format using handheld computers, dataloggers, GPS, and digital cameras. Each plot and station gets a unique ID that includes study area, transect number, and distance (e.g., CHBA_T1-100). Field notes also can be entered into the electronic databases, although general notes of activities can be entered in personal field notebooks. Electronic files from the fieldwork need to be backed up on two separate media at the end of each day. These files are tagged with the date to differentiate them from the main data files in which data are appended daily. These daily backups are kept until all data have undergone QA/QC and are secure in final format in the master database.

In the office, the field data are transferred to the master Access database (e.g., SWAN SaltMarsh Database 2007) that has tables for each component. For each table the fields are given a

description that identifies the unit of measurement that serve as metadata for the measurements. Plot and station photographs need to be labeled with study area, plot, theme, year, and photographers initials (e.g. CHBA_T1-100veg2007mtj). Once transferred, the data undergo a quality control review for completeness and accuracy, which corrects obvious field mistakes and identifies outliers that are possible mistakes. Some data, such as those from the topographic surveys and water level recorders, undergo manipulations for calculating new fields in specialized software and spreadsheets. These intermediate data files are archived once the manipulations are complete and are not used in subsequent analyses. Finally, nearly all field data are stored in the master Access database, including tables for: (1) topographic profiles, (2) plot descriptions; (4) soil-water characteristics (sediment accumulation, soil-water depth, salinity, and pH); (5) soil temperatures; and (6) vegetation cover. Water level data, however, are maintained in proprietary In-situ® data management software because the data storage requirements are too large for Access and because it has specialized data management routines. Original data also are maintained in text files independent of proprietary format. The data for each component has a table or fields for the original field data and a table for the final proofed data. This allows the field and final data to be structured somewhat differently and to preserve the field data exactly as it originated from the field. The Access database allows construction of forms and queries for the intermediate proofing state and presentation of the final data. The plot photos are hyperlinked to the PlotID in the plot description table. Photos are relabeled and managed using ThumbsPlus photo-management software (uses Access data tables) that can be linked to the plot description table in the master Access Database. The structure of each data set collected in the field is described in the SOPs.

The GIS data developed from this work include the time series of georectified aerial photographs and satellite images for each study area, as well as the raw imagery before georectification. It also includes the themes for study area boundaries, sampling transects, sample plots or stations, the 200-m sampling grid used for measuring abundance of vegetation types, geomorphic units, and shoreline position. All vector layers are maintained within a geodatabase.

In summary, data products include ground photos, airphotos and satellite images, Access and In-Situ databases for field data, and a geodatabase for GIS data layers.

7 Analysis and Reporting

7.1 Data Analysis

Numerous hypothesis testing and multivariate analysis techniques are available that can be used to analyze changes in field measurements over time (Roman et al. 2001). The most appropriate techniques are identified in each SOP and the rationale for using the techniques is described. For most data sets, a generalized linear model with repeated measures could be used for testing differences among multiple years for single variables. For multivariate analysis of change of community composition over time, non-parametric permutation procedures, such as the one-way analysis of similarities (ANOSM), could be used to quantify similarity among communities or composition of a community over time. Depending on the extent of the plant frequency or cover data, several ordination techniques are available that can be used to identify trends in community composition over time, including detrended correspondence analysis (DCA) and nonmetric multidimensional scaling (NDMS)(McCune and Grace 2002, McCune and Mefford 2006). Multiple-regression techniques and canonical correspondence analysis (CCA) could be used to

evaluate the response of vegetation to environmental variables. Although the data collection is designed to be analyzed by standard techniques described above, it is likely that the analyses will evolve over time.

7.2 Reporting

The reporting will include two levels. After the fieldwork and data management are completed, an annual report is produced that documents field activities and the types and amount of data that were collected. This is intended to be a brief interim report awaiting collection of the complete data set gathered over a two-year period.

The second level is a summary report that provides methods, presents the results of descriptive statistics on annual status of the salt marsh components, graphic presentations, and statistical analyses of change. At the time that the summary report is compiled, ancillary data may be harvested from various sources (e.g., Alaska Volcano Observatory; NOAA buoy and climate data sets) to aid in interpreting the results.

8 Personnel and Operational Requirements

The time required for gathering a complete set of data for each monitoring interval consists of two field seasons and one year of analysis and reporting, or three years of work every ten years. In addition, water level and soil temperature dataloggers must be downloaded in the field every 1-3 years.

The fieldwork is done during two weeks in mid- to late July for two consecutive summers. The fieldwork requires a minimum crew of four: 2 technician-level staff to conduct the topographic surveys and soil-water measurements, and a plant ecologist and botany technician to conduct the vegetation surveys. Due to high bear densities in the salt marsh environments of LACL and KATM, however, we recommend a crew size of 5-6 persons. Over the two year period, field mobilization requires 200 person-hours and fieldwork requires a minimum of 1200 person-hours.

Most of the work can be performed by trained technician-level staff. Project leadership and the vegetation sampling, however, need to be performed by a senior-level ecologist with substantial taxonomic expertise.

Equipment needs and startup costs are detailed for each SOP. Overall, the equipment and materials for starting up the program cost about \$5,000. Transportation costs will vary by site.

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Appendix 1: Standard Operating Procedures

SOP 1: Georectified Aerial Photograph Time Series

SOP 2: Water Bodies

SOP 3: Topographic Profiles

SOP 4: Plot Establishment and Environmental Description

SOP 5: Tides and Storm Surges

SOP 6: Sediment and Water Characteristics

SOP 7: Soil Temperature

SOP 8: Vegetation Cover

SOP 9: Photo Interpretation of Landscape-level Change

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 1

**Georectified Aerial Photograph Time Series
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

1 Georectified Aerial Photograph Time Series

This SOP for georectifying aerial photography describes the objectives, sampling design, methods, data management, and analysis and reporting procedures. These are presented below.

1.1 Measurable Objectives

Specific objectives of the georectification of historical imagery are to:

- 1) Compile a time series of scanned aerial photographs and satellite imagery for the three study areas.
- 2) Co-register the historical aerial photographs to the new IKONOS images with a reported accuracy.
- 3) Archive the georectified images to provide access to imagery for the public.
- 4) Provide a visual record of changes in the study area.

1.2 Sampling Design

The work is designed to provide georectified images for the top-level of sample stratification that involved the selection of three coastal subsections representative of the six coastal subsections in LACL and KATM with large salt marsh acreages. These salt marsh dominated subsections include Silver Salmon Coast, Chinitna Inner Bay, Hallo Bay Coast, and Douglas River Coast. Additional areas that could be georectified in the future include, but are not limited to, the Tuxedni Tidal Flats and Outer Tuxedni Bay subsections (LACL; Fig. 1), and the Swikshak Lagoon area in the Hallo Bay Coast subsection (KATM; Fig. 2). This design allows analysis of

changes across three sites over three historical time periods. Future co-registration of newly acquired imagery would be done every 10 yrs.

1.3 Methods

The typical sequence of steps for georectification of historical imagery by an in-house GIS department or GIS contractor are to: (1) determine availability of historical imagery, (2) acquire high-resolution scans of aerial photographs; (3) georectify images using orthorectification software, (4) determine and report co-registration accuracy, and (5) archive georectified images.

The availability of historical imagery is determined by searching four principal archives for Alaska:

- (1) U.S.G.S EROS Data Center

Sioux Falls, ND
<http://edcsns17.cr.usgs.gov/EarthExplorer/>
Online digital data and ordering
- (2) U.S. Bureau of Land Management

Anchorage, AK
Archived rolls of aerial photographs
- (3) Aero-Metric

2014 Merrill Field Drive
Anchorage, Alaska 99501
Phone: 907-272-4495
E-mail: aerometric@aerometric-ak.com
Archived aerial photograph rolls and printing services
- (4) National Park Service

Alaska Support Office
240 W 5th Ave
Anchorage, AK 99503
Phone: (907) 644-3554
Specialized archives

Images should be acquired with the following specifications:

- 1) Photographs should be scanned from negative or positive film when possible, not prints;
- 2) The entire photograph should be scanned to include labels (date, roll/frame #) and fiducial marks;

- 3) Photographs should be scanned at ~15 microns;
- 4) Overlapping photographs may need to be acquired to eliminate gaps or to allow georectification of the central portions of the aerial photographs; and
- 5) Photographs should be delivered on DVD.

Georectification of aerial photographs or satellite images is done in a multistage process. First, recent IKONOS imagery is used as the base map for controlling the historical airphotos. The orthorectified IKONOS imagery acquired by NPS is clipped to each site to allow better local rectification of the imagery. Second, the clipped images are georectified through a simple XY shift to ground control points obtained from differentially corrected GPS coordinates for monitoring plots in distinctive locations. Third, the historical photography from 1951-1957 and 1978-1982 periods are orthorectified to the original orthorectified IKONOS base image and DEM with a second-order polynomial transformation using Imagine software (ERDAS, Inc., Atlanta, GA). Distinctive features on the various sets of imagery, such as small deep waterbodies, are used to provide broad spatial control for the airphotos. Fourth, the airphotos are then clipped to the study area and re-rectified to the clipped IKONOS imagery with a second order polynomial transformation using ArcMap software (ESRI, Redmond, CA). The images are georeferenced to North American Datum of 1983 (NAD83) and Albers Alaska Equal Area Conic projection.

Accuracy of the co-registration is quantified as a root-mean square (RMS) error (in map units) by the software that calculates the difference between the source and target control points. This comparison provides a measure of accuracy across the entire image. If an area on the images is of specific interest, the average RMS can be calculated for the control points within that area of interest only.

Once georectified, digital files of photographs should be stored in standard file formats and labeled with standard attributes. Many GIS formats are available for exporting and saving the georectified images. Several formats are recommended for long-term archiving and short-term use. First, the original unrectified photographs should be archived on DVDs and/or a file server. Second, the rectified images should be saved as ERDAS Imagine format (.img) for ease of use in GIS systems, or as compressed ECW or MrSID formats if server storage space is an issue. Third, the time series of georectified images of the identical view of the study area should be exported to a highly compressed (~1 MB) image file for use in other reporting or presentation documents. Each file should be labeled with park code, study area name, year, roll/frame#, and projection. Example file labels are

“LACL_Silver-Salmon_1955_R123F10899.tif” for original photographs,

“LACL_Silver-Salmon_1955_R123F10899_AlbAK83.img” for georectified images, and

“LACL_Silver-Salmon_1955_R123F10899_AlbAK83.jpg” for more popular use.

1.4 Data Management

Management of the original and georectified images simply involves proper documentation of the file information as metadata and rigorous archival procedures to ensure preservation of the data.

1.4.1 Metadata Procedures

Each georectified image should be accompanied by standard Federal Geographic Data Committee (FGDC) -compliant metadata. Standard metadata forms that accompany the image can be completed within ArcMap GIS software. The minimum set of metadata should include:

1. Agency source of original photograph;
2. Roll and frame number;
3. File name for original photograph;
4. Date of photograph;
5. Original resolution;
6. Institution that performed the georectification; and
7. RMS error of rectification.

1.4.2 Data Archival Procedures

Archiving of the data involves three issues. First, the images need to be stored on at least two independent media, the computer server and DVDs. Preferably, the DVDs are kept in a separate office or building from the computer server. Second, the images need to be stored within a well-organized and explicit directory structure. These structures are already established by the GIS management team. Third, the imagery needs to be accompanied by the metadata. Image data are unusual in that they are not subject to updates and versioning problems, thus maintaining a versioning control sheet or labeling system is not needed.

1.5 Analysis and Reporting

No data analysis and reporting are required. The georectified images are delivered on DVD, along with their metadata.

1.6 Personnel Requirements and Training

The work should be done by a qualified in-house GIS team or GIS contractors. Thus, no special requirements or training are needed for the I&M team.

1.7 Operational Requirements

Annual workload for the I&M team is limited because the georectification work should normally be done by a separate GIS Team or contractor. Most of the work involves searching archives for

the availability of suitable aerial photographs and images. Once the images are created, the I&M team may be involved in metadata documentation and archiving.

Facility and equipment needs are limited to a computer server, which is the only equipment needed for storing the images once they have been created.

Startup costs involve three efforts: (1) personnel time for finding and ordering historical photographs or new satellite images; (2) georectification through in-house services or contracting; and (3) personnel time for metadata documentation and archiving. Each coastal study area usually requires 1–2 aerial photographs for each time period, as well as the recent or newly acquired satellite images. Georectification of images for each study area requires about 4 hours to organize the initial datasets (aerial photograph, DEM, camera model, file structures), about 4 hours to georectify each aerial photograph, and 1 hour per photograph to complete the metadata document and manage the files. No additional costs are needed after the initial work is completed.

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 2

**Waterbodies
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

2 Waterbodies

This Standard Operating Procedures manual for waterbodies (including coastline) is designed to quantify changes in waterbody extent within the various study areas. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

2.1 Measureable Objectives

The objectives of the waterbodies protocol are to:

1. Map the distribution of coastal waterbodies;
2. Determine changes in shoreline position over time; and
3. Quantify changes in waterbodies.

2.2 Sampling Design

The work is designed to provide maps of waterbodies for each study area, which represent the top-level of sample stratification. These study areas from three coastal subsections are representative of six coastal subsections of LACL and KATM that have large salt marsh acreages. These salt marsh-dominated subsections include Silver Salmon Coast, Chinitna Inner Bay, and Hallo Bay Coast. This design allows analysis of changes across three sites over time. Future mapping of waterbodies from newly acquired imagery would be done every 10 years and could be expanded to additional areas not visited by ground sampling (e.g., Tuxedni Tidal Flats (LACL); Swikshak Lagoon (KATM)).

2.3 Methods

2.3.1 Map the Distribution of Coastal Waterbodies

The coastal waterbodies are mapped from georectified aerial photographs or satellite images when new imagery is acquired. The mapping is done by manual photo-interpretation of pattern, texture, and color of image characteristics by a specialist knowledgeable in coastal geomorphology and processes. Classification follows the units described in Table 2-1 (adapted from Jorgenson et al. 2003, Bird 2000).

The waterbodies are mapped as a polygon on-screen at 1:3000-scale using ArcMap software. During mapping of waterbodies, only distinct waterbodies are delineated, and wet meadows or shallow marshes with indistinct water margins are not included. Each polygon should be attributed with the park code (e.g., LACL), study area (e.g., CHBA), year, and waterbody code (Table 2-1). All files developed as part of this SOP should have the same datum and projection as the images (NAD83; Alaska Albers Equal Conical Area). The mapping should extend across the entirety of each study area.

2.3.2 Determine Changes in Shoreline Position Over Time

An exact definition for mapping shorelines can be difficult to implement because water levels vary with tides and wind-driven events. On USGS maps, the shoreline is defined as mean water level, whereas NOAA defines shoreline as mean lower low water. In some coastal mapping schemes, shoreline is defined as the boundary of vegetation. Often the timing of acquisition of aerial photographs for mapping coastlines is specified to coincide with lower low tide to facilitate mapping. For monitoring of coastal changes in SWAN, which is based on remote sensing, shoreline is defined as the wetting line on the slope of the beach or on tidal flat. The wetting line is evident as a distinct change in color and tone on photography between dry, light colored sand not affected by normal tides and wet, dark colored sand that is saturated by the most recent tidal cycle. While this definition is imprecise and map accuracy is limited to several meters, it is sufficient for measuring change over decades. The boundary is more satisfactory than water's edge, because of the high tidal fluctuation and thus sensitivity to time of imagery, and the vegetated boundary, which can be considerably higher and inland than the higher high tide line and can be subject to disturbances, such as wind storms and tide surges, that affect vegetation, but have only minor affect on shoreline.

Table 2-1. Classification and description of coastal waterbodies associated with salt marshes along Cook Inlet, AK.

Waterbody	Description
Tidal Lagoons (Wetl)	Shallow estuarine water protected from open water by barrier islands and spits. Water is slightly brackish to brackish depending on the input of freshwater.
Tidal Ponds (Wetp)	Coastal ponds that are flooded periodically with saltwater during high tides or storm surges. Salinity levels often are increased by subsequent evaporation of impounded saline water. The substrate frequently is silt with some clay and fine sand, and occasionally contains peat.

Tidal River (Wetr)	Permanently flooded river channels that are affected by daily tidal fluctuations and have correspondingly variable salinity. The channels generally experience peak flooding during spring breakup and lowest water levels during mid-summer. During winter, deeper channels can have elevated salinity levels.
Tidal Active Chan. (Wetca)	Regularly flooded, dendritic, small channels (guts) on tidal flats. Typically they have muddy sediments and lack vegetation.
Tidal Inactive Channel (Wetci)	Irregularly flooded, dendritic, small channels (guts) on tidal flats affected only by storm events. Typically they have muddy sediments, are fresh to slightly brackish, and are vegetated by nonhalophytic vegetation that are slightly salt tolerant. Permanently flooded waterbodies within inactive channels are mapped as Tidal Ponds.
Nearshore Water (Wmn)	Marine water near the shoreline. Winds, tides, river discharge, and sea ice create dynamic changes in physical and chemical characteristics. Bottom sediments vary from wave cut bedrock, to gravel, to mud. During winter the water is covered with ice floes.
Shallow, isolated lakes (Wlsi)	Shallow isolated lakes and ponds are freshwater bodies that are not affected by tides or storm surges. These may occur on abandoned tidal flats and beaver impounded drainages at the margins to the tidal flats.

The shoreline is derived from the mapped polygons of nearshore waterbodies, which are mapped from georectified aerial photographs or satellite images when new imagery is acquired. The shoreline is created by copying the polygon feature classified as nearshore water from the waterbody layer to the shoreline layer, which is a polyline layer. The non-shoreline segment of the nearshore water feature is trimmed off from the polyline to leave only the shoreline segment. The shoreline should extend across the entire study area and should extend directly across river and tidal channels.

Changes in distance between shorelines mapped at decadal intervals should be determined at 100-m intervals along the coast at each study area. This determination can be done manually or by using the digital shoreline analysis system (DSAS version 3.0), which is an ArcGIS extension for calculating shoreline change. The distance is then divided by years between shorelines to obtain rates in m/yr. The minimum, maximum, and mean rates of erosion or accretion are then calculated.

2.3.3 Quantify Changes in Waterbodies

The areal extent of waterbodies closely associated with salt marshes provides an important measure of how the hydrology of salt marshes is responding to tectonic activity, sea-level rise, and climate change. The areal extent of each waterbody type is summarized by type and year. A mean area of each waterbody type across all sites can be calculated from the totals for each site. Differences in mean area across all sites can be statistically analyzed when a sufficient number of years have been mapped.

2.4 Data Management

Management of the GIS data has three aspects: (1) version control of changing GIS files, (2) metadata documentation, and (3) storage and access control to the files. The first two are managed by the geomorphologist or remote-sensing specialist that creates the GIS data layers, and the last is managed by the network data manager.

Over time, more information may be acquired from field studies that necessitate a modification of the waterbody classification. If the classification system changes, older files may need to be revised to maintain consistent mapping and classification among time periods. Consequently, the file names for the various GIS data layers should be tagged with a date or version number. For example, the waterbody layer produced from the 2004 IKONOS image should be labeled with network, theme, year, projection, and date version is complete (e.g., SWAN_Coastal_Waterbody_2004_AlbAK83_9Dec2007).

Metadata for each GIS data layer should be compliant with FGDC metadata standards and entered into the metadata form in ArcCatalog. The form indicates which fields are mandatory for FGDC compliance.

2.5 Analysis and Reporting

2.5.1 Data Analysis

Analysis of the waterbody data includes generating descriptive statistics for the extent of each waterbody and generation of derived metrics for shoreline change and overall extent of tidal ponds. These methods are described below.

Change in abundance and distribution of waterbodies can be determined by overlaying and splitting the maps from two time periods. However, because the imagery cannot be co-registered exactly, a large number of “slivers” are created between adjacent lines that may or may not represent change. This approach is only useful for illustrating large changes. A simpler approach to quantifying change is to summarize the areal extent of each waterbody type and then compare changes in acreages. For this analysis, the total acreage of each waterbody type is summarized for each study area, which becomes the sample unit.

2.5.2 Reporting

Reporting of methods and results should be done every 10 yrs after new imagery is acquired. The methods can reference the Waterbody SOP or include the methods with updated material. The report should include a picture of the new imagery, and time series of waterbody maps, charts of the mean aerial extent of each waterbody unit across the three study areas, and charts of the mean ($\pm$ confidence interval) change in shoreline position by time period.

2.6 Personnel Requirements and Training

The mapping of waterbody units should be done by a qualified coastal geomorphologist or landscape ecologist familiar with the study areas. This work can be done in-house by qualified NPS staff or by contracting with a specialist. Once the maps are created, the analysis of change can be done by a GIS specialist or ecologist with GIS skills. Statistical analyses should be done by a qualified statistician or by a geomorphologist or ecologist with advice from a statistician.

2.7 Operational Requirements

The work is done for the initial baseline images at the start of the monitoring effort and may be expanded to include historical photography. The initial effort for mapping waterbody units, derivation of shorelines, metadata documentation, and file management requires ~60 hours for the three study areas combined for each time period. Statistical analysis requires ~8 hours and reporting ~24 hours per time period. No fieldwork is required.

Equipment needed for the work is limited to a computer, ArcMap GIS software for mapping, statistical software for analysis, and word-processing software for reporting.

The cost for waterbody mapping, analysis, and reporting is approximately \$5,000 per time period.

2.8 References

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**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 3

**Topographic Profiles
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

3 Topographic Profiles

This Standard Operating Procedures manual for measuring topographic profiles across the salt marsh is designed to quantify changes in elevations along sampling transects. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

3.1 Measurable Objectives

Specific objectives of the measurements of topographic profiles are to:

- 1) Determine changes in ground and water surface elevations over time for each profile;
- 2) Analyze rates of erosion and deposition among geomorphic units and plant communities over all profiles; and
- 3) Provide data for evaluating relationships among topography, hydroperiod and storm events, sedimentation, salinity, and plant species composition.

3.2 Sampling Design

Within each of the study areas, four gradient-oriented transects are systematically distributed within the study areas. They are oriented perpendicular to the shoreline and extending from the coast to the margin of shrub and forest communities of non-salt-affected areas. For placement, each study area is divided into four sections perpendicular to the coast and a transect is situated in the middle of each section. Along each transect, ground- and water-surface elevations are to

be measured every 5 m, with additional measurements made at topographic breaks to capture microsite heterogeneity. This sampling design allows estimation of mean characteristics within and across all study areas and captures the entire topographic and environmental gradient.

3.3 Methods

3.3.1 Field Season Preparations and Equipment Setup

Field season preparation includes three components: transect allocation, equipment organization, and permitting and compliance. Transects are allocated in the office prior to fieldwork to determine specific transect-line locations, sampling intervals, and locations of permanent benchmarks. Transect locations are established using a GIS and georectified imagery. Four transects are located in each study area according to the sampling design described above and plotted over aerial photography. Up-to-date benchmark information and historical reference points are obtained prior to sampling when possible for use in “tying in” the survey transects to ensure data-set comparability.

Equipment needed for the topographic surveying is listed in Table 3-1. The data to be collected during the survey are provided in Table 3-2.

Table 3-1. Equipment needed for topographic surveys.

Item	Number
Transect Coordinates (decimal degrees WGS 84)	2 endpoints per transect
Large scale printout of aerial photograph with transects, laminated	2
Flagging Tape	1 roll per study area
Pin Flags	30
Binoculars	1
Wooden stakes (1x2x18 in) or rebar (3/8 in x 2 ft)	10 per transect, 1/100m
Rebar or drive rod for benchmark (1 m x 0.5 in)	1 per transect
Benchmark cap with Transect ID	1 per transect
Metal plate (4-in diam. with 3/4-in center hole) for benchmark	1 per transect,
100–m tape	2
Auto-level	1
Tripod	1
Rod (metric)	1
Rain hood for auto-level	1
Camera, memory card, batteries, waterproof bag	1
Handheld datalogger (PocketPC)	1
Charger for PocketPC	1
Memory card for PocketPC for data backup	1
Field notebook (write-in-the-rain)	
Handheld radios (FRS) and batteries	3
Chest Waders	2
Bear spray	1 per person
Insect repellent	1 per person

Table 3-2. List of parameters collected during topographic surveys in the field and later calculated in the office.

Parameter	Units	Description
Field Measurements		
TransectID	Text	Four-letter code for study area plus transect number, e.g., SISA-T1
SetupID	Text	Sequential letters for each setup of the tripod, e.g., A, B, C.
Dist-m	m	Integer measurements made at whole meter increments
Grnd_Ht_cm	cm	Integer measurements made to whole cm increments. Measurements round to nearest whole cm. Rod is allowed to rest on own weight at ground surface.
WatSurf_Ht_cm	cm	Integer measurements round to nearest whole cm.
PlotID	Text	ID of permanent plot at survey point when present
Notes	Text	Any observation that may relate to observation. Rarely used
Date	Date	Year, month, day of measurement, e.g., 2007/07/21. This only needs to be on first record for each transect in the field. It can be filled down later in the office.
Last Names	Text	Last names of instrument and rod personnel. This only needs to be on first record for each transect in the field. It can be filled down later in the office.
Office Calculations		
TBM_Elev_cm	cm	Elevation of temporary bench mark determined from differential GPS
Grnd_Elev_cm	cm	Ground surface elevation calculated from rod ht and TBM elevation
WatSurf_Elev_cm	cm	Water surface elevation calculated from rod ht and TBM elevation
GeoUnit	Text	Determine from the geomorphology map

3.3.2 Fieldwork

Establishing and measuring an elevation transect, or topographic profile, involves three main stages. First, the transect is initially laid out and flagged using pre-determined coordinates from an aerial photograph with transects marked on it. Second, staking and leveling is done along the transect to measure ground- and water-surface elevations. Finally, the elevations of temporary benchmarks along the transect are surveyed relative to established or newly created permanent benchmarks.

3.3.2.1 Transect Layout

The first step in measuring the topographic profile is to lay out a straight transect between the transect endpoints. This procedure requires two people. Initially, the endpoints are flagged with flagging tape and staked, with one endpoint starting at the water's edge and the second ending 30 to 50 m into the adjacent non-coastal vegetation just above the upper margin of the salt marsh. If the entire transect is visible, then one person can stand at one end, sight to the other end, and guide the second person along the transect. The transect can be moved slightly to avoid vegetation and to reduce impacts from clearing a view. The second person inserts pin flags or flags vegetation along the way. If the entire transect is not visible, an intermediate station that is visible from both ends may need to be flagged and used for sighting forward and back. A permanent benchmark (Section 2.3.4.3) should be established at the upland (0 m) endpoint of the transect.

3.3.2.2 Surveying

Topographic surveys can be performed using a variety of surveying devices (e.g., total station, laser level, auto-level, differential GPS; Morton et al. 1993). For simplicity, reliability, and acceptable repeatability, the surveys at the remote site should be done with an optical auto-level (self leveling) using standard methods (USACE 1999). This method provides cm-level accuracy in vertical and horizontal directions. A total station also can be used and is a little more rapid, but it requires careful power management and additional training.

The job requires two people, an “instrument person” and a “rod person”. The instrument person sets up the leveling device by first spreading the tripod legs so that the tripod head is approximately vertical. The legs should be far enough apart and secured well enough to stabilize the level. The instrument is then leveled by centering the bubble on the top of the instrument. The location of this bubble should be checked occasionally to ensure that the instrument remains level. The auto-level is capable of making reliable measurements out to 100–150 m. Because a transect is often 300–600 m, the tripod will need to be moved several times during the survey. Typically the instrument is set up at 100, 300, and 500 m distances from the upland endpoint of the transect, and elevations are recorded in both directions at each setup (e.g., from 0 to 100 m and from 100 to 200 m from a tripod position at 100 m (‘Setup A’) from the 0 m transect endpoint). Each tripod setup is recorded on the data form. The instrument person reads the height of the rod in the cross-hairs of the auto-level; the number on the rod represents the vertical distance between the level plane and the surface being surveyed. This number can be used to calculate the relative difference in elevation between any given surface and an established benchmark.

The rod person stretches out the 100-m tape, places permanent stakes (16” wooden stakes pounded to within 20 cm of the soil surface, plus 3/8” or 1/2” rebar pounded to 2-3 cm below the soil surface) every 100 m, and holds the survey rod. In subsequent years when measurements are repeated, some stakes may need to be replaced. Elevations are measured every 5 m, and at additional breaks in slope to capture major topographic changes that may occur within the 5-m increments. Approximately 100–200 measurements are needed to adequately characterize the 300–600 m topographic profiles. The first measurements are at the top and ground base of the benchmark from Setup A; the dual measurements help assess whether the bench mark has jacked out of the ground. During measurement, the survey rod is held in a vertical position, with the end placed on the ground surface adjacent to the outstretched tape. The rod is allowed to rest under its own weight, which may depress the surface slightly. The rod is measured only to the nearest 1 cm because the surface is often covered by vegetation, litter, and soft sediments that preclude greater accuracy. Measurements should also be made of the water-surface height when water is present. This measurement is typically done by holding the bottom of the rod steady at the water surface. For each individual waterbody encountered along the transect, this water-surface measurement only needs to be done once or twice, assuming the water is level across the water body.

At the end of each setup it is very important to record the rod height at the location of the last measurement and then make a duplicate reading at the same location at the beginning of the next setup. These readings at the same location from the two differing setups are critical to “tying in”

the measurements from the two setups and allows calculation of relative elevations along the entire transect.

The data are entered into a handheld computer (Pocket PC) by the instrument person. The data fields are listed in Table 3-2. The distance along the tape (transect) is transmitted by radio by the rod person. At long distances, the rod person may need to assist the instrument person in reading the rod height by moving an object to the edge of the cross-hairs, with the instrument person communicating by radio whether the object should be moved up or down to align with the instrument cross-hair. The rod person then reads the height and radios the measurement to the instrument person.

3.3.2.3 Benchmarks

Temporary benchmarks (TBM) should be established at the beginning of each transect and a more stable permanent benchmark should be established within each study area. The temporary benchmark is established at the upland (0 m) end of the transect to serve as an elevational control during surveying. The benchmark consists of a 0.5-in diameter rod, 0.5 m long, that is driven to within 10 cm of the ground surface at the starting end of the transect. A cap, stamped with study area and transect number are driven onto the rod. In subsequent years, the benchmark should be readily recoverable with GPS coordinates, but a metal detector may be needed if it becomes damaged or buried.

A permanent benchmark should be established at each study area, or if a permanent benchmark already exists nearby it should be used for geodetic control. Locations and descriptions are obtained from recognized federal (e.g., NOAA, USGS, etc.) or state (e.g., Department of Transportation and Development [DOTD], etc.) agencies. These benchmarks are also identified as first or second order. Permanent benchmarks are always referenced and easily reoccupied. Establishing a permanent benchmark in remote coastal areas may be problematic. Preferably a survey cap can be cemented on to a bedrock outcrop. The survey cap should be labeled with study area name (e.g., Chinitna Bay), “BM 1”, “NPS”, and year. If only unconsolidated sandy or silty sediments are present a more stable benchmark can be created by driving a $\frac{3}{4}$ -in diameter rod, 1.5 m long, with a slide hammer. A labeled survey cap should be tamped onto the rod. The true elevation of the benchmark should be obtained by differential GPS using a survey-grade GPS, by a qualified surveyor. The elevations should be referenced to GEOID99. The benchmark elevation can be further refined to a NAD83 elevation by calculation or to mean sea level, depending on long-term instrumentation.

Differential leveling should then be done to tie in the elevations of the Temporary Bench Mark (TBM) at each transect with the permanent benchmark for the study area. This should be done at every survey period.

2.3.4. Data Management

Data management involves field data entry, daily backup, office data transfer, manipulation and calculation, storage and archiving, and metadata documentation. These tasks are described briefly below.

Field data entry should be done on a handheld field computer (Pocket PC) equipped with spreadsheet software (e.g., Pocket Excel). The file should be labeled with the study area, theme,

and observer's initials (e.g., SISA_elev_mjtj). The data file should be located in a folder on a flash memory card and not in volatile RAM memory. The data can alternatively be collected in a field notebook. The data fields and relevant metadata are provided in 3-2.

Backup of data should be done at the end of each field day and backed up in two places. First, the file should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix "Z_", which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul07) should be added to the file name, which differentiates each daily backup.

Back in the office, the data are transferred first into Microsoft Excel software, where the true elevations are calculated. The data with complete calculations are then transferred into the master database in Microsoft Access for permanent storage and archiving. New fields (TBM_Elev_cm, Grnd_Elev_cm, WatSurf_Elev_cm, GeoUnit) are added to the database for calculation of true elevations. The original field data set should be archived in a separate field data folder.

Data manipulations and calculations are performed to convert the rod height to true elevations. First, the elevation of the 0-m distance is calculated by adding the TBM elevation (in cm) and the rod height of the TBM and then subtracting the rod height of the ground surface. An example of the cell formula is $(\$F\$1+\$D\$1)-D2$. Next, all the remaining measurements within the first setup, Setup A, are calculated to the elevation at the 0-m distance. This calculation is done by subtracting the rod height at the specified distance from the rod height at the 0 distance along the setup and then adding that to the known elevation from the end of each setup. An example of the cell formula is $(\$D\$48-D48)+\$G\$47$, where $\$D\$48$ is the rod height at the 0-m distance, D48 is the rod height at a subsequent reading within a setup, and $\$G\$47$ is the calculated true elevation at the end of the previous setup. Similar calculations are done for the WatSurf_Elev_cm field. Finally, the geomorphic unit (GeoUnit) associated with each measurement is determined from overlaying the transect on the geomorphology map. The GeoUnit is then used to summarize elevations, or changes in elevations over time, for each GeoUnit.

Data should be stored in the master Access database once the data are correctly calculated and proofed. After all the data sets from the other field components are stored in the master Access database, the database should be archived on two separate media, a CD and on a separate server.

Metadata documentation is simple because the elevation-data set has a small number of variables. The name, units, and descriptions of the variables are provided in Table 3-2. The metadata should be included in the documentation of the topography data table in Access.

2.3.5 Analysis and Reporting

3.5.1 Data Analysis

The analysis has three components: (1) graphing of the elevation data for each transect, (2) calculating three frequencies of erosion and deposition along each transect, and (3) determining changes in elevation within each geomorphic unit. These analyses are described briefly below.

Topographic profiles are created from the elevation data for visual presentation. Water-surface elevations and plot locations also can be added to the profile.

The frequency of how many locations have undergone erosion (loss of elevation) and deposition (gain of elevation) provides an indication of the stability of the surface and the magnitude of the changes. This comparison is achieved by calculating the difference in elevations from one period to another and then classifying whether there has been deposition (>2 cm increase), erosion (>2 cm loss), or no change (<2 cm difference). The 2-cm threshold is used because of the modest precision of the data related to the often spongy ground surface.

Areas of change along the transect can be visualized by plotting the elevational transects and by calculating differences in elevations for each survey point between years. The data quality is sufficient to detect larger changes associated with beach erosion and accretion, dune buildup and deflation, and channel erosion, but is unlikely to detect small changes associated with infrequent sedimentation or organic matter accumulation.

3.5.2 Reporting

The results of the topographic surveys for each period can be presented several ways. First, charts should be presented for each transect surveyed with the decadal surveys for each transect plotted on top of each other. Second, the frequency of erosion, deposition, and no change at the measurement stations are cross-tabulated by transect and data are presented in tabular format. In addition, the data can be cross-tabulated by study area and by all areas combined, and the data presented as bar charts.

Third, results of the statistical analysis of changes in elevation using the linear mixed models can be presented in tabular form. The summary results of mean elevation changes can be presented in bar charts.

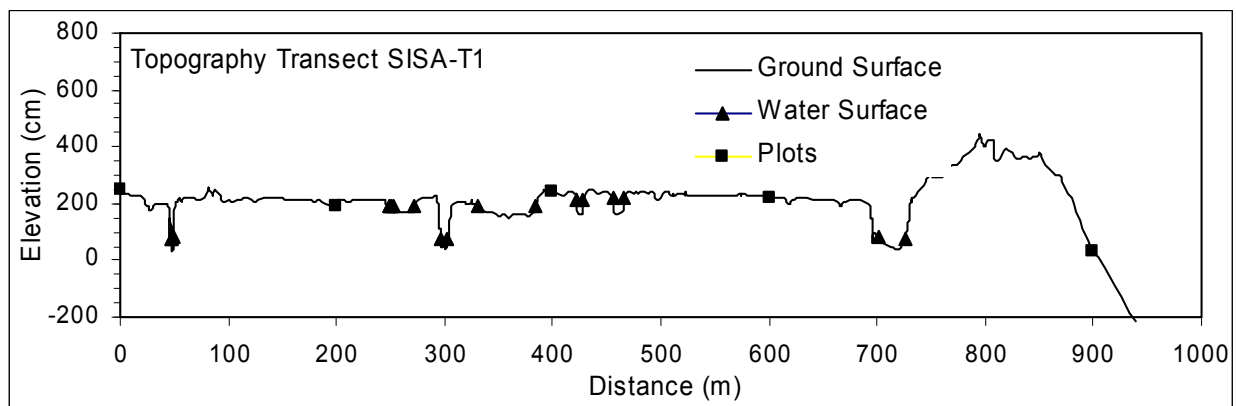


Figure 2-1. Example of the topographic profile for Transect T1 at Silver Salmon measured in 2007.

3.6 Personnel Requirements and Training

The topographic surveying is done by a two-person team. The personnel should be trained at the technician level and the specialized training for completing a topographic survey according to the specification of this protocol can be done in a few hours. Training is best done in the field with a person experienced with similar surveys.

3.7 Operational Requirements

The operational requirements are divided into the initial transect and benchmark establishment and the subsequent routine monitoring. The initial transect and benchmark establishment takes 1 day per transect for two people. The full complement of 16 transects over three study areas should be established over a 2-year period. Fieldwork requires ~120 hours combined for two people each summer, or 240 hours over 2 years. Data management requires ~80 hours for the three study areas combined for each time period. Statistical analysis requires ~40 hours and reporting ~40 hours per time period.

Field equipment needed for the work is listed in Table 3-1. Office work requires a computer, Excel and Access for data management, statistical software for analysis, and word-processing software for reporting. Cost for all equipment is ~\$2000 and material for setting up all 16 transects is ~\$500.

Startup cost for the topographic mapping is approximately \$32,000 for the initial time period. After the transects are established, the fieldwork is reduced to 160 hrs per period. Subsequent monitoring costs for each decadal repeated measurement is approximately \$28,000.

3.8 References

- Morton, R.A., Leach, M.P., Paine, J.G., and Cardoza, M.A. 1993. Monitoring beach changes using GPS surveying techniques, *Journal of Coastal Research* 9:702 -720
- U.S. Army Corps of Engineers (USACE). Engineering and Design - Control and Topographic Surveying. EM 1110-1-1005 ed. Vicksburg, MI. 104 pp.: U.S. Army Corps of Engineers; 1999.

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 4

**Plot Establishment and Environmental Description
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

4 Plot Establishment and Environmental Description

This SOP is designed to provide information on the location, observers, and general environmental characteristics of each sampling location. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

4.1. Measurable Objectives

Specific objectives of plot establishment and environmental description are to:

1. Establish permanent plots
2. Document location of plot with GPS, marking airphotos, and taking pictures
3. Record general environmental characteristics of plots

4.2 Sampling Design

Plots are systematically distributed every 100 m along transects that have been equally distributed across the study area. In addition, plots are established subjectively in uncommon vegetation types to increase the sample size for uncommon types. This design generates a total of 30–40 plots per study area. The plot size is 4 x 10 m.

For our purposes, we consider the plot to be an independent sample and the plot to be the sample unit. While we recognize that there may be some correlation in environmental characteristics among a few plots along a transect, plots nearly always occur within separate vegetation patches and most plots along a transect are in different vegetation types. This assumption can be tested

by evaluating the autocorrelation among samples along a transect. Alternatively, data from the plots can be pooled and the transect be considered the sample unit, but this approach loses substantial information.

4.3. Field Methods

4.3.1 Plot Establishment

Permanent monitoring plots are systematically established at 100-m intervals along each transect. An additional 1–3 plots are subjectively established along each transect in distinctively different vegetation types not sampled by the systematic plots, or in vegetation types requiring greater replication. A power analysis (protocol narrative, Section 4) indicated that a minimum of 15 plots per vegetation (community) type would need to be sampled in order to detect change in the cover of a dominant species. The long axis (10 m) of the plot is established perpendicular to the transect, usually on the north side of the transect. A wooden stake is driven into the ground at the mid-point of each end of the plot. Adjacent to the wooden stake at the transect end, an 8" spike is driven into the ground to allow relocation of the plot with a metal detector in case the wooden stake is damaged. The stakes should be labeled with the plot ID that includes transect and distance (e.g. T1-100). The study area (e.g. SISA) identifier entered on data sheets is not included on stake for brevity. Equipment needed for establishing a plot is listed in Table 1. Once established the plots are easy to relocate because they are located at specific recorded distances from the benchmarks along each transect.

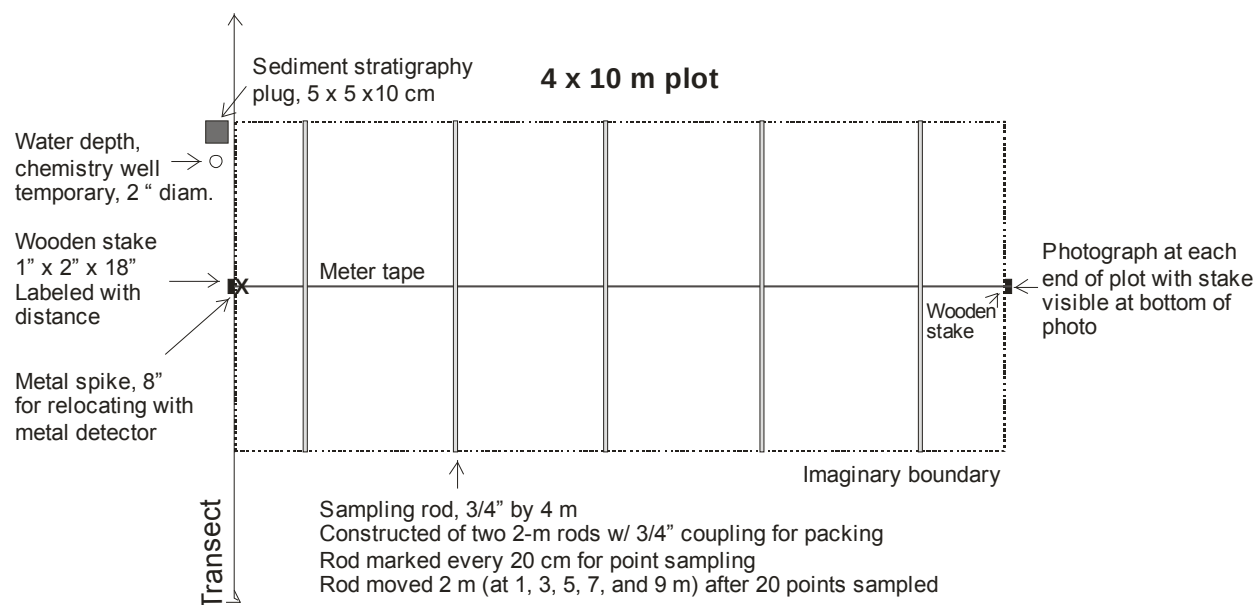


Figure 4-1. Layout of permanent plot for vegetation, sediment, and soil-water sampling.

Table 4-1. List of equipment needed for establishing and documenting permanent plots.

Equipment	Number
Meter tape, 10 or 25 m	1
Wooden stake, 1 x 2 x 18 in.	2 per plot

Rebar, 3/8 x 2 ft	1 per plot
Digital Camera	1
Flash memory card for camera	1
Camera batteries	2
Compass	
Clinometer	
Marking pen	2
Handheld GPS, preferably DGPS capable	1
Plot data form on paper or Pocket PC with data form	1

4.3.2 Plot Locations and Documentation

The geodetic coordinates of all sample locations coordinates are obtained with a Global Positioning System (GPS). Preferably GPS coordinates are obtained with a unit capable of differential correction through post processing to obtain horizontal accuracy of <3 m. The transect distance, GPS coordinates, and airphoto provide three types of locational information.

A digital photograph is taken from both ends of the plot. The photograph is oriented to have both stakes, and a thin portion of the sky, in the scene. The photograph should be level with the horizon. A third photo is taken vertically of ground when standing over the stake by the main transect, with the camera extended at arms length above the head. The time on the photograph's EXIF file provides a time stamp for helping to label the photographs. Be sure the time and date is set correctly on each camera before heading into the field. Each photograph should be labeled with study area, transect, distance, year, component, and initials (e.g., CHBA-T1-100-2007_gnd03aem).

Documentation of plot establishment is entered onto the plot data form or into a Pocket PC database that has the form. Fields for plot documentation include SiteID, Date, Time, Initials of Observer, GrndPhotoNo., SoilPhotoNo. (if optional soil plug is described), GeogLandMark, Lat(WGS84), Long(WGS84), ElevGPS(m), PinPrick, and PlotSize(m) (see field code sheet below).

4.3.3 Environmental Characterization

General environmental characteristics of the site are obtained at the time of plot establishment and are not intended to be routine monitoring variables. Environmental characteristics include both categorical and measured variables and include information on geology, topography, hydrology, soils, and vegetation (Tables 2). The sampling follows the plot description methodology used by Jorgenson et al. (2003). The characterization is intended to provide quick summary information and can be done in ~20 minutes. The variables and coding information are provided in field-compatible format below

Geologic and surface-form variables recorded include physiography, surface geomorphic unit, slope, aspect, surface form, and height of microrelief. Geomorphic units were classified according to a system based on landform-soil characteristics for Alaska, originally developed by Kreig and Reger (1982) and modified for this study. The classification emphasized materials near the surface (<2 m depth) because they have the greatest influence on ecological processes.

Within the geomorphic classification, waterbodies are classified based on their depth, salinity, and genesis. Surface forms (macrotopography) are classified according to a system modified from that of Schoeneberger et al. (2003). Microtopography is classified according to the periglacial system of Washburn (1985).

SOP-4 Table 2. List of environmental variables collected at initial plot establishment.

Variable	Description
PlotID	Generic site ID
Transect	Transect number
Date	Date of field work
Time	Time field work initiated
ObserverEnv	Environmental Variable observer initials
ObserverVeg	Vegetation species and structure observer initials
GeogLandmark	Geographic landmark description
Lat(dd83)	Field backup for Latitude recorded into data form from GPS unit in the field
Long(dd83)	Field backup for Longitude recorded into data form from GPS unit in the field
ElevGPS	Elevation recorded from field GPS unit
Pinprick	plot position marked on air photo
PlotSize(m)	Plot radius or dimensions in meters
PlotType	Plot type (I=intensive; R-rapid, V=Verification; A= Air survey)
photosTaken	y/n, confirmation that photos taken
Physiog	Physiography code, see REF_PhysiographyCodes for definitions
Slope(deg)	Slope in degrees
Aspect(deg)	in degrees, if slope = 0, aspect also = 0 (not north)
SurfGeomUnit	surface geomorphology code, see REF_TerrainUnitCodes
SubGeomUnit	sub-surface geomorphology code, used for specific underlying layer
Macrotopo	Macro Topography ; see REF_MacrotopographyCodes
Microtopo	Micro Topography see REF_MicrotopographyCodes
Microrelief (cm)	measurement of average surface roughness in cm
NWI WaterReg	National Wetlands Inventory hydrology, see REF_NWIWaterRegimeCodes
WatDepth:	depth to ground water (+ above soils surface) (cm)
Saturated<30 cm (y/n)	soil saturated in upper 30 cm. yes/no
Drainage	drainage codes, see REF_DrainageCodes
SoilMoist	Ref_SoilMoisture
LowMottDepth	Depth to low chroma mottles in top 40 cm, 999=unknown
LowMatrDepth	Depth to low chroma matrix in top 40 cm, 999 = unknown
Hydric Soil	yes/no/unknown
Water pH	pH measured in ground water, where present
Water EC (µS/cm)	EC measured in ground water, where present
SoilpH	pH measure in saturated soil slurry from 10 cm depth, when ground water absent
SoilpH30	soil pH measured from 30cm below soil surface
Soil EC (µS/cm)	EC measure in saturated soil slurry, usually when ground water not present
Thaw Depth (cm)	Depth to permafrost in cm, 999=unknown. Permafrost generally absent in area.
SurfOrg (cm)	depth of surface organic horizon in cm (continuous organic material from surface)
CumOrg40 (cm)	sum of all organic horizons in cm within top 40 cm of soil profile

DomMineral40	Dominant mineral soil type within top 40 cm, organic if no mineral soil present
DomText40	Dominant soil texture (can be organic) within top 40 cm of soil profile, ref_DomMinTxt
LoessThick (cm)	Depth of surface wind blown silt. Loess generally absent in salt marshes.
RockDepth (cm, >15%)	depth to horizon where coarse fragments >15% of matrix (cm)
SurfFragClass	codes for % rock and gravels on soil surface, see REF_SurfaceFrag
FrostBoil(%cov)	% cover of active partially vegetated frost boils. Generally absent in salt marshes.
Cryoturb (p/a)	Cryoturbation observed in soil profile,yes/no/unknown
SoilSample	y/n whether a soil sample is collected
SoilSampleDepth	Depth at which sample was taken
SampleMeth	Soil sampling method. l = soil plug, m = tile probe, see REF_SampleMeth
Soil Class 2006	NRCS Soil taxonomy code 2006, 10th Edition
VegCompleteness	c=complete or nearly so, p,partial; d,dominants
VegClass Code(L IV)	Viereck Veg class 4 Field call
Cutpoint	Viereck Veg class 4 Secondary field call
Ecotypevegstr	Field Ecotype Vegetation Structure
DisturbClass	Disturbance class, natural or human induced, see reference table
Ecotype Field Code	ecosystem code based on physiography, soil texture, moisture and veg class
Dominant Plants	List of 3 to 7 dominant plants at site
Notes	Other comments or observations

Hydrologic variables measured at each sampling site include a classification of water regime according to the National Wetland Inventory system, depth of water above or below ground surface, depth to saturated soil, pH, and electrical conductivity (EC). For NWI water regime: enter National Wetlands Inventory (NWI) Water Regime code from Cowardin et al. (1979). For water depth, the depth to free standing water is measured from a small soil pit or hole created with a small diameter soil probe. Allow sufficient time for infiltration and then measures are in cm with above surface level (+) and below ground level a (-) value. If water is not present enter 999 and also enter maximum measurement depth in maxobs field. For “AboveBelow” record if water is above or below the surface, or unknown (A, B or U). For “Saturated30cm”, record Yes or No based on if free water is evident within 30 cm of the soil surface or if water is infiltrating from the pit sidewall. Water or soil pH and EC are measured during initial environmental characterization, but the variables are also routinely monitored under SOP 6. WaterpH, pH of water in soil pit or if site is aquatic, is measured using an Oakton pH tester. Leave blank if no water or no data. WaterEC, electrical conductivity in soil pit or if site is aquatic, is measured with an EC tester and units will be $\mu\text{S}/\text{cm}$. Leave blank if no data or no water present.

Soil stratigraphy will be described from a shallow soil core or soil pit at each plot. Most soil profiles will be described from soil plugs dug with a shovel because groundwater is often present. For all intensive plots, the dominant mineral texture, the depth of surface organic matter, cumulative thickness of all organic horizons, depth to rock (>15% by volume), and depth of thaw should be recorded. When water is not present, EC and pH should be measured from a saturated soil paste. A single simplified texture (i.e. loamy, sandy, organic) should be assigned to characterize the dominant texture in the top 40 cm at each plot. Optionally, a more complete soil stratigraphy can be described at a handful of sites representing common geomorphic units or vegetation types. Methods should follow the standards outlined in Schoeneberger (2003).

Vegetation is classified in the field to Level IV of the Alaska Vegetation Classification (AVC) developed by Viereck et al. (1992). The classification is based on the dominant species in the top strata. This AVC classification can be refined with a more rigorous plant community analysis.

4.4 Data Management

Data management involves field data entry, daily backup, office data transfer, storage and archiving, and metadata documentation. These tasks are briefly described below.

Field data entry should be done on a handheld field computer (PocketPC) equipped with Access-compatible software (e.g., Pocket Excel, abcDB). The file should be labeled with the study area, theme, and person's initials (e.g., SISA_Plot_mtj). The data file should be located in a folder on a flash memory card and not in volatile RAM memory. If problems develop, the data can be collected in a notebook. The data fields and relevant metadata are provided in Table 2.

Data backup should be done at the end of each field day and backed up in two places. First, the file from the handheld should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix "Z," which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul) should be added to the file name, which differentiates each daily backup. Back in the office, the data from the main data entry file is transferred into the master database in Microsoft Access and proofed for permanent storage and archiving.

Data should be transferred to the master Access database back in the office and appended to the Field Plot Database. The Field plot data are then appended to the Final Plot Table and the data should be reviewed for accuracy and completeness soon after fieldwork is completed. The Field Plot table provides an archive of the original field collected data. After all the data sets from the other field components are stored in the master Access database, the database should be archived on two separate media, a CD and on a separate server. The data reside in a separate Access database table and are linked to the Plot database table with the PlotID.

4.5 Data Analysis and Reporting

The plot data provide general information on site characteristics and are not typically used in data analysis. The plot data provide documentation of activities and plot characteristics. It is useful to tabulate the plot data by study area, site and year to provide a summary table of sampling locations. In addition, the plots can be cross-tabulated with environmental characteristics, such as geomorphology and general soil properties, to summarize the number of plots representing various environmental conditions.

ENVIRONMENTAL PLOT DATA**PlotID:** Unique Identifier**Transect:**transect number**Date:** mm/dd/yy**Time:****ObserverEnv:** Initials of Observer**ObserverVeg:** Initials of Observers**GeogLandMark:****Lat(dd83):****Long(dd83):****ElevGPS(m):****PinPrick:** enter “y” after marked**PlotSize(m):** Usually 10 x 4 m**PlotType:** Intens,**Photos:** y/n**Physiography:**

A Alpine U Upland

L Lowland, P Lacustrine (ponded)

R Riverine, C Coastal

H Human

Slope(deg):**Aspect(deg):****SurfTerrUnit:** see Terrain Unit codes**SubTerrUnit:** see Terrain Unit codes**Macrotopo:** see codes**Microtopo:** see codes**Microrelief (cm):****NWI Water Regime:**

U Upland

Ts Subtidal

Te Irregularly exposed

Tr Regularly flooded

Ti Irregularly flooded

Np Permanently flooded

Nei Intermittently exposed

Nsp Semipermanently flooded

Nse Seasonally flooded

Nsa Saturated (S)

Nt Temporarily flooded

Ni Intermittently flooded

Na Artificially flooded

WaterDep: (+/-, or >pit depth)**Saturat<30:** yes or no**WaterPH:** to 0.1 pH units**WaterEC:** (uS/cm)**Drainage:**

E Excessively drained

Es Somewhat excess. drained

W Well drained

Wm Moderately well drained

Ps Somewhat poorly drained

P Poorly drained

Pv Very poorly drained

F Flooded

SoilMoist: Dry, Moist, Wet (field cap. to sat.), Aquatic (>10cm, perm water)**LowMottDep:** depth, Absent, Peat, or ND, chr=2 or less**LowMatrDepth:** depth, Absent, Peat, or ND, chr=1, no mottling, full gley**HydricSoil:** Present or Absent**Thaw Depth (cm):****CryoTurb:** Present or Absent**SurfOrg:** depth of top layer (cm)**CumOrg40:** total org in top 40**DomMineral40:** dominant mineral text. in top 40 cm

RE Extrem. Rocky (>60% crs; >2 mm)

R Rocky (SaGr + 15-60% rocks)

S Sandy (grSa to l Sa; <15% gravel)

L Loamy (CL to SL)

C Clayey (SC to C)

O Organic (used if no mineral)

DomText40: dominant text. (O or M) < 40cm**SurfaceFrag:**

0 none

S Stony (<0.1%)

Sv Very Stony (0.1-3)

Se Extremely Stony, (3 – 15%)

R Rubbly, (15 – 50%)

Re Very Rubbly (>50%)

RockDepth(>15%): cm**SoilpH:** to 0.1 units from paste at 10 cm**SoilpH30:** from paste at 30 cm depth**SoilEC:** uS/cm from paste**FrostBoil(%cov):** visual estimate**Ecotype Chemistry:**

A acid (pH<=5.5)

C circumneutral (5.6—7.3)

B basic (≥7.4)

E brackish (EC>800, <16000)

S saline (≥=16000 uS/cm)

Soil Sample: y/n, sample collected**SoilSampleDepth:****SampMeth (Sampling Method):**

P pit

L plug

A auger

C corer

E bank exposure

S surface

M metal probe

LM plug + probe

LA plug + auger

SoilClass2003: NRCS taxonomy 2003**VegCompleteness:** c, p, d**VegClass(L IV):** Viereck Level IV**Cutpoint: alternative veg class****Ecotypevegstr:** see codes**DisturbClass:** see codes**EcoType:** sequential coding for Physiograph, DomMin40, SoilMoist, Soil Chemistry, Veg Structure
DominantPlants:

Notes

SOIL PROFILE FORM**Lithofacies:**

B Blocky (angular>380 mm, >60%)

R Rubble (angular, 2-380 mm, >60%)

S Stony (rounded, >250 mm, >60%)

G Gravel (rounded, massive, >60%)

Gfm Gravel, with fine, massive, 15-60%

Gl Gravel (2-250 mm), layered

Sm Sands, massive

Si Sands, inclined

Sl Sands, layered

Soi Sands with org, inclined

Sr Sands, rippled

Sor – sands with org, inclined

Sgm Sands w/tr gravel, massive

Sgmt Sands w/tr gravel, turbated

Om Organic, massive

Ol Organic, layered (> 10% organic)

Olt Organic, layered, turbated

Oa Organic, limnic

Fm Fines massive

Fom Fines with organics, massive

Fomt Fines with org., massive

Fgm Fines w/tr gravel (tr-15% gravel)

Fl Fines, layered

Fr Fines, rippled

For Fines with organics, rippled

Fcm Fines with clay, massive

Fcl Fines with clay, layered

Fa Fines with algae, limnic

Horizon: used NRCS codes

Master horizon

O, A, AB, A/B, AC, E, EA, BA B, BC

Cr, R

Horizon suffixes

a, b, c, d, e, f, ff, g, h, i, j, jj, k, m, j, o, p, q,

r, s, ss, t, v, w, y, z,

TopDepth;**BotDepth:****Boundary: (combine, e.g. As)****Distinctness:**

A Abrupt (<2 cm)

C Clear2–5 cm

G Gradual (5–15 cm)

D Diffuse (>15 cm)

Topography:

S Smooth, W Wavy

I Irregular (deeper than wide)

B Broken

Textural Abbreviations**Fine fraction**

s sand

vcos very coarse sand (1–2 mm)

cos coarse sand (0.5–1 mm)

ms medium sand (0.25-0.5 mm)

fs fine sand (0.1—0.25 mm)

vfs very fine sand (0.05–0.1 mm)

ls loamy sand

l loam

sil silt loam

si silt (0.002–0.05 mm)

c clay (<0.02 mm)

Coarse fragments (>2mm)

boul boulder (> 60 cm)

st stone (25 – 60 cm)

cob cobble (7.5 – 25 cm)

gr gravel (0.2 – 7.5 cm)

Coarse fragment modifiers

sg 0 to 15 %

g 15 to 35 %

vg 35 to 60 %

eg 60-90 % (exgSiL)

G >90%

Organic Soils

Oi slightly decomposed

Oe intermediate decomposition.

Oa highly decomposed

Peat Types (Peat):

G Graminoid or sedge

Gf Gramin., fine (<2 mm wide)

Gc Gram., coarse (>2 mm wide)

Gh Gramin.-Herb

A Allocthonous (drifted)

Mf feathermoss

Ms SphaG

Md = dicranum/Polytrichum

Ml = Live mosses

W = woody

S = Sedimentary (algal, coprogen.)

CrsFragSizeMax:**Coarse Fragment Shape:**

Av very angular,

A angular,

As subangular

Rs subrounded,

R rounded,

Rw well rounded

ColorMatrix: Munsell chart**ColorMottle:** Munsell chart**Mottles (combine.g., ffd)****Abundance:**

f few (< 2% area)

c common (2 – 20 %)

m many (> 20 % area)

Size:

f fine (< 2 mm)

m medium (2 to 5 mm)

c coarse (5 - 20 mm)

v very coarse (20 – 76 mm)

e extremely coarse (>76 mm)

Contrast: (change in value, chroma)

f faint (hue, chroma similar)

d distinct (value 2-4, >1 chroma)

p prominent (value > 4)

Structure:**Grade**

m massive

sg single grained

w weak (barely visible)

m moderate (easily observable)

s strongly (distinctly visible)

Size

vf very fine (<1mm)

f fine (1 – 2 mm)

m medium (2 –5mm)

c coarse (5 – 10 mm)

vc very coarse (>10 mm)

Type

gr granular

pl platy

pr prismatic

clr columnar

abk angular blocky

sbk subangular blocky

w wedge

Consistence:

L loose

R friable

F firm

P plastic (roll >4 cm long)

S sticky

H Hard

O Soft

C Cemented

Roots and NonMatrix Pores:**Abundance**

f few (< 1/unit area)

c common (1-5/unit area)

m many (>5/unit area)

Size

vf very fine (<1mm)

f fine (1 – 2 mm)

m medium (2 –5mm)

c coarse (5 – 10 mm)

vc very coarse (>10 mm)

Unit Area depends on root size:

For fine roots 1 cm²For medium/coarse 1 dm²For coarse 1 m²

Terrain Units BEDROCK

Bxw	Bedrock, weathered (undiffer.)
Sc	Sedimentary, carbonate (limestone, dolostone)
Sn	Sedimentary, noncarbonate (shale, siltstone, conglomerate)
Sm	Sedimentary, mixed
Vfy	Volcanic-felsic-young
Vfo	Volcanic-felsic-old
Vmy	Volcanic-mafic-young (Quatern.)
Vmo	Volcanic-mafic (dark)-old
Vp	Volcanic-pyroclastics
If	Intrusive-felsic
Im	Intrusive-mafic/ultra mafic
Nc	Metamorphic-carbonate
Nn	Metamorphic-noncarbonate
Mcn	Metamorphic-mixed carb/noncarb
COLLUVIAL DEPOSITS	
C	Colluvial Deposits
Ch	Hillslope Colluvium
Cl	Landslide Deposit
Cu	Slump Deposits
EOLIAN DEPOSITS	
Esa	Eolian Active Sand
Esi	Eolian Inactive Sand
FLUVIAL DEPOSITS	
Fu	Fluvial, undifferentiated
Fd	Delta Floodplain
Fdra	Delta Active Channel Deposit
Fdri	Delta Inactive Channel Deposit (High-water Channel)
Fdoa	Delta Active Overbank Deposit
Fdoi	Delta Inactive Overbank Deposit
Fdob	Delta Abandoned Overbank Dep
Fpm	Meander Floodplain
Fmr	Meander Channel Dep (riverbed)
Fmrac	Meand Course Active Chan. Dep.
Fmrif	Meander Fine Inactive Chan Dep.
Fmo	Meander Overbank Deposit
Fmoa	Meander Active Overbank Dep
Fmoi	Meander Inactive Overbank Dep
Fmob	Mean. Abandoned Overbank Dep
Fb	Braided Floodplain
Fbr	Braided Channel Dep (riverbed)
Fbrac	Braided Course Active ChanDep.
Fbrif	Braided Fine Inactive Chan Dep.
Fbo	Braided Overbank Dep (complex)
Fboa	Braided Active Overbank Deposit

Fboi	Braided Inactive Overbank Dep
Fbob	Braided Abandoned Ovrbank Dep
Fhl	Headwater Lowland Floodplain
Fto	Old Terrace (lower terraces)
Ff	Alluvial Fan
GLACIAL AND NON-G. DEPOSITS	
FGp	Alluvial Plain Deposits
GLACIAL DEPOSITS	
Gmo	Older Moraine
Gmy	Younger Moraine
Gto	Older Till Sheet
Gty	Younger Till Sheet
GLACIOFLUVIAL DEPOSITS	
Gfo	Glaciofluvial Outwash
GfK	Kame Deposits
GLACIOLACUSTRINE DEPOSITS	
GL	Glaciolacustrine Deposits
L	LACUSTRINE DEPOSITS
MAN-MADE DEPOSITS	
Hfg	Fill, gravel
Hfo	Fill, overburden
Hfp	Fill, peat
He	Excavations
MARINE DEPOSITS	
Mb	Beach Deposits
Mba	Active Beach Deposit
Mbi	Inactive Beach Deposit
Mbb	Abandoned Beach Deposit
Mda	Active Coastal Dune
Mdb	Inactive Coastal Dune
Mta	Active Tidal Flat
Mti	Inactive Tidal Flat
Mtb	Abandoned Beach Deposit
Mp	Coastal Plain Deposit
Mps	Sandy coastal plain deposit
Mpf	Fine coastal plain deposit
GLACIOMARINE DEPOSITS	
MG	Glaciomarine Deposits
ORGANIC DEPOSITS (Org >40cm)	
Of	Organic Fens
Ob	Bogs
WATER	
Wr	Rivers and Streams
Wh	Headwater River
Wrln	Lower Perennial, non-glacial
Wrlg	Lower Perennial, glacial
Wrun	Upper Perennial, Non-glacial
Wrug	Upper Perennial, Glacial
Wl	Lake and Ponds

Wldcr	Deep Connected Lake, Riverine
Wldcm	Deep Connected Lake, Morainal
Wldir	Deep Isolated Lake, Riverine
Wldim	Deep Isolated Lake, Morainal
Wlscr	Shallow Connected Pond., River.
Wlscm	Shal. Connected Pond., Morainal
Wlsir	Shallow Isolated Pond., Riverine
Wlsim	Shallow Isolated Pond., Morainal
Wm	Marine
Wmn	Nearshore Water
We	Estuarine
Welt	Tidal Ponds (affected by tides)
Wert	Tidal River (brackish)
Weld	Brackish Deep Lake
Wels	Brackish Shallow Lake
Wh	Man-made Waterbodies
Whid	Drainage Impoundment
MACROTOPOGRAPHY CLASSES:	
C	Top, Crest, Summit Or Ridge
Sh	Shoulder Slope
Steep Slopes	
Sb	Bluff or Bank (unconsolidated)
Sbs	Steep bluff south facing
Sc	Cliff (rocky)
Sbr	Riverbanks
Su	UPPER SLOPE (convex, creep)
Suc	Concave (water gathering)
Suv	Convex (water shedding)
Sup	Plane
Sl	LOWER SLOPE (concave)
Slc	Concave (water gathering)
Slch	Nivation hollows, Snowbanks,
Slv	Convex (water shedding)
Slp	Plane
T	TOE Slope
D	Drainage or Water Track
B	BASINS OR DEPRESSIONS
Bd	Drained Basin
Bk	Kettle
F	FLAT-FLUVIAL RELATED
Fn	Nonpatterned
Fm	Flats margins (transition)
Fc	Channel, swale or gut,
Fi	Interfluv or flat bank
Fl	Levee
Fb	Bar (point, lateral, mid-channel)
Fs	Crevasse splay
Ft	Terrace
Ff	Flood Basin (behind levee)

L	LAKES AND OCEAN
Wi	Islands Present
Ls	Smooth FlatLake Margin
Fwb	Wave cut bench (shore)
Fwt	Wave cut terrace (shore)
R	RIVER OR STREAM
Rp	Deep Pools (>1.5 m)
Rs	Shallow Runs (<1.5 m)
Ri	Riffles,
Rr	Rapids
E	Eolian Patterns
El	Eolian linear dunes
Ep	Eolian parabolic dunes
Hm	Human modified
MICROTOPOGRAPHY CLASSES	
N	NONPATTERNED
MOUNDS (ice and peat related)	
Mi	Ice-cored mounds
Mpm	Peat mounds
Mir	Ice-shoved ridge
Mid	Ice-rafted debris
Mrm	Rocky Mounds (soil covered rocks)
Mw	Mounds caused by wildlife
Mh	Mounds caused by humans
MI	Tree mounds (dwnd logs/root balls)
Mu	Undifferentiated mounds (distinct)
DRAINAGE or EROSION RELATED	
Dt	Water tracks (non-incised)
Df	Feather pattern (in fens)
Dr	Ripples
Dd	Flow dunes
Ds	Scour channels-ridges
EOLIAN RELATED	
Es	Small dune
Eb	Scour depression
W	WATER
Wi	Islands present
ECOTYPE VEG STRUCT Code:	
B	barrens, PV
M	meadow (w/ moist=a, marsh)
MK	salt-killed meadow
DS	dwarf scrub (<20cm)
LS	low scrub (20—150cm)
TS	tall scrub (>150cm)
BF	broadleaf forest
MF	mixed forest
NF	needleleaf forest
WR	River (flowing)
WL	Lake (still water)

WN	Nearshore (marine)
(For water: e.g., RWR, CWL)	
VEGETATION CLASSES (IV):	
Bbg	Barrens (<5% veg)
Bpv	Partially Vegetated (5–30)
Fbobb	Open Paper Birch–Balsam Poplar
Fboc	Open Black Cottonwood
Fmcwsw	Closed Blck Cottonwd–Wh Spruce
Fmcwso	Open Black Cottonwd–Wh Spruce
Fncss	Closed Sitka Spruce
Fnoc	Open Mixed Coastal Conifer
Fnos	Open Sitka Spruce
Fnows	Open White Spruce
Fnwmc	Mixed Conifer Woodland
Fnwss	Sitka Spruce Woodland
Haf	Aquatic Fresh Herb
Hab	Aquatic Brachish Herb
Hama	Marine Algae
Hfm	Moist Forb Meadow
Hfmc	Ferns
Hfw	Wet Forb Meadow
Hfwhh	Halophytic Herb Wet Meadow
Hgdl	Elymus (Leymus)
Hgmb	Bluejoint Meadow
Hgwg	Fresh grass marsh
Hgwfs	Fresh sedge marsh
Hgwst	Wet sedge meadow tundra
Hgws	Wet sedge-willow tundra
Hgwhg	Halophytic grass wet meadow
Hgwhs	Halophytic sedge wet meadow
Hgwk	Salt-killed wet meadow
Hafm	Common marestail
Stca	Closed Tall Alder
Stoa	Open Tall Alder
Stcw	Tall closed willow
Stow	Tall open willow
Slcb	Low closed Shrub Birch
Slcbw	Low closed shrub birch-willow
Slcbe	Closed Shrub Birch-Ericaceous
Slce	Closed Low Ericaceous Shrub
Slcw	Low closed Willow
Slow	Low open Willow
Slobw	Open Shrub Birch-Willow
Slobe	Open Shrub Birch-Ericaceous
Sloeb	Open Low Ericaceous Shrub Bog
Sdee	Crowberry Tundra
Sdwg	Halophytic willow-graminoid
W	Water

The reporting of plot characteristics is limited. After the fieldwork, office measurements, and data management are completed, an annual report is produced that documents field activities and describes the types and amount of data that were collected. In addition, an Appendix Table should be created listing PlotID, Date, observers, location coordinates, and some other variables of particular interest to provide a hard copy listing of general plot information.

4.6 Personnel Requirements and Training

The work should be done by a trained ecologist with knowledge of vegetation and soils and a technician with a small amount of training to set up the plots and help with some of the routine data measurements.

4.7 Operational Requirements

Plot setup and description is done once at the initiation of the monitoring effort. In subsequent monitoring, there is a small effort required to relocate and maintain the plot markers. During the first monitoring round, the plot set up and documentation takes about 3/4 hr per plot. For 40 plots per study area, this requires about 4 days for two people to set up the plot network.

Equipment needs are listed in Table 4-1. Total cost of equipment is \$500.

The startup cost of plot establishment and documentation is about \$30,000 for about 120 plots in three study area. Maintenance costs in subsequent monitoring require about \$10,000 for the entire plot network.

4.8 References

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**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 5

**Tides and Storm Surges
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

5 Tides and Storm Surges

This Standard Operating Procedures manual for measuring high tide and storm surge levels across the salt marsh is designed to quantify changes in water levels at one location within each study area. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

5.1. Measurable Objectives

Specific objectives of the water level monitoring are to:

- 1) Determine daily heights of high tides;
- 2) Determine timing, height, duration, and frequency of storm events; and
- 3) Determine stage-return intervals for high-water events.

5.2 Sampling Design

The sampling of water levels is designed to use the initial stratification of sampling at three of the six coastal subsections that have a high abundance of salt marshes. At each study area, one pressure transducer is installed to record water levels every 30 minutes. Because the datalogger is capable of 40,000 readings, the datalogger can record data for 2 years. Although this can miss high stage by as much as 15 minutes and 5 cm, this is a good compromise between precision and downloading frequency. The battery should be replaced every 4 years. Locations of the water-level recorders, however, are designed only to quantify stages of high tides and are not sufficient to record the total tidal range and quantify mean tide levels. To allow practical access, the

instruments are installed in small tidal channels that are above the low tide range. Installation of recorders in deep water offshore is impractical because of the large tidal fluctuation, turbid water that makes retrieving bottom-fast instruments difficult, and the occurrence of winter ice that prevents year-round tethering to floats that can facilitate retrieval.

5.3. Field Methods

5.3.1 Water-level Recorder

A variety of manual and electronic gages are commercially available in different lengths and measurement intervals, including manual staff gages and electronic gages. As of December 2010, the preferred instrument for the SWAN network is a submersible pressure transducer (Solonist 3001 or In-Situ Aquatroll) that measures the pressure generated above the sensor. This instrument is able to record continuously and at high frequency over long periods, requires little maintenance, is rugged, relatively inexpensive, and can be deployed out of sight of visitors and away from damage by bears. The disadvantages are that it is affected by barometric pressure, can be affected by fouling of the sensor, and calibration can drift over time. The data are of sufficient quality for quantifying tidal fluctuations and stages of large events, but are not of sufficient quality for detecting small changes in relative sea level over long periods. Because the data recorded are pressure readings, a water-level recorder should also be installed above ground in one of the study areas to record barometric pressure.

5.3.2 Installation

Site selection for the water-level recorder is problematic. Ideally, the recorder is installed in deep water that has good visibility, low currents, and is easily retrievable regardless of weather. These conditions are rare in the SWAN study areas. Consequently, the recommended location is a shallow tidal channel that has permanent standing water even at low tide. Unfortunately, this placement negates the ability to obtain data from across the full tidal range and the data are useful only for recording the water level for high tides and storm surges. Although the ability to calculate mean sea level is lost, the priority parameters are high tides and storms that allow calculation of hydroperiod, and characteristics of storm events.

The water-level recorder is housed in a 2" diameter by 24" long, steel pipe (Figure 5-1) welded onto a 48" long, 5/8" rebar. The pipe is prepared by drilling numerous 3-mm holes around the top of the pipe to allow water exchange. The pipe is capped with a screw-on cap or plug to protect the pipe. A second housing is constructed of 1.5 in. CPVC pipe to help protect the sensor. The CPVC pipe is also perforated with 1/4 in. holes drilled through the pipe. When in place, the CPVC pipe and sensor hangs vertically against a pin at the bottom of the pipe. The pipe (without the sensor) is driven into the mud at the bottom of the tidal channel so that the top of the pipe is below the standing water at low tide. Mud is removed from the pipe to allow the sensor to hang freely from the cap when installed. Finally, the elevation at the top of the cap is surveyed relative to one of the benchmarks. The depth below the cap at which the sensor is hanging is subtracted from the cap elevation to determine the elevation of the sensor. If the sensor needs to be moved in the future due to channel migration or disturbance, a resurvey of the new installation to a benchmark will ensure compatibility of the data over time.

Water-Level Monitoring

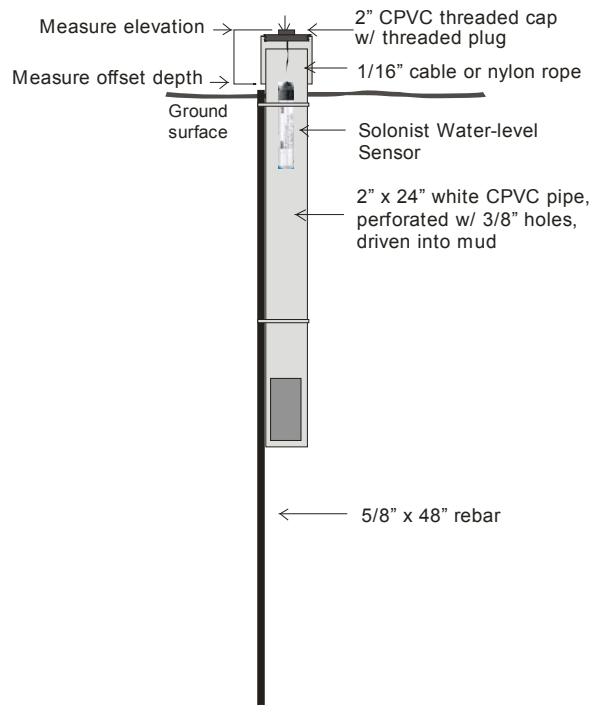


Figure 5-1. Metal pipe and rebar housing for water-level datalogger.

Additional barometric pressure sensors (In-situ Baro TROLL) should be installed at an easily accessible place for later compensation of water pressure records. One barometric pressure sensor can serve both Silver Salmon and Chinitna Bay and a second can serve Hallo Bay. A good site is to suspend the sensor at a 1.5 m height against the stem of a tree covered with abundant branches. The tree provides shade for the internal temperature sensor and is inconspicuous to people and bears. Locations of current instrumentation is noted in Figures 3 and 4 of the protocol narrative.

Table 5-1. Equipment needed for water-level monitoring

Item	Number
Water level recorder/temperature sensor (In-Situ Level TROLL 500)	1 per study site
Water level recorder/temperature/salinity sensor (In-Situ Aqua TROLL 200)	
Water level recorder (In-Situ Baro TROLL) for barometric pressure and air temperature	1
In-Situ adapter for downloading recorder or PC ToughBook	2
In-Situ software for downloading	1
Laptop computer, water proof case, charger	1
2" steel pipe, 24" long	1 per study area
Wooden block, 2 x 4 x 12" for pounding pipe	1 per study area
2 lb. Sledge hammer for pounding pipe	1
Rebar, 5/8" by 4 ft for securing pipe	1 per study area
Nylon rope, 1/4 inch by 12" for suspending sensor	1 per study area
Long-handled spoon for cleaning mud from pipe	1
Autolevel	1
Tripod	1
Rod	1
Camera for documentation	
GPS	
PocketPC	
PocketPC form in Excel or Access-compatible database for maintenance log	

5.3.3 Downloading

The pressure transducer is downloaded in the field with a laptop computer using special downloading software according to the operator's manual by the sensor manufacturer (In-situ 2010). The datalogger is retrieved from the housing, washed with freshwater, and dried with a towel. The cap is unscrewed from the sensor to expose the IR port, the sensor is inserted in the downloading adapter, and the data are offloaded. The data are offloaded to a file with the sensor name and date (e.g., SISA_watlvl_20jul07). Afterwards the sensor is relaunched and the internal sensor date is checked. Mud is cleaned out of the pipe if needed. The sensor is reinstalled in the pipe and the cap threaded back on. At this time maintenance is done to repair the housing if needed. The event is then documented with a set of standard parameters (Table 5-2) and the site is documented with photos.

Table 5-2. Data collected to document maintenance activity at data loggers.

Field	Type	Description
StationID	Text	Code for the station
Plot ID	text	Code for the plot ID adjacent to the installation
Observer	Text	Name of observer
Date/Time	Data/time	Date and time: year-month-day, twenty-four hour time
Lat-wgs84	Number	Latitude from GPS is decimal degrees, WGS84 datum
Lon-wgs84	Number	Longitude from GPS is decimal degrees, WGS84 datum
Sensor	Text	Sensor model
Depth	Number	Depth of 1 st sensor above or below ground (positive above ground)
Action	Text	Action taken: installed, download complete, download partial, download failed, modified, removed
Relaunch	Text	Was sensor relaunched: y, n
Blinking	Text	Is sensor LED blinking, y,n (confirms relaunch successful)
Battery	Text	Battery status, new, 90%, 50%, 25%, dead, dead & replaced
Photos	Text	Photos taken: y, n
Notes	Text	Notes on any problems that might affect data

5.4 Data Management

Data management involves field data entry of maintenance log, daily backup, office data transfer, manipulation and calculation, storage and archiving, and metadata documentation. These tasks are described briefly below.

Field data entry should be done on a handheld field computer (PocketPC) equipped with spreadsheet software (Pocket Excel) or onto a field data form. The file should be labeled with the study area and theme and person's initials (e.g., SISA_Download_Log_mjtj). The data file should be located in a folder on a flash memory card and not in volatile RAM memory. If problems develop, the data can be collected in a field notebook. The data fields and relevant metadata are provided in Table 5-2.

Backup of data for both the download maintenance log and download sensor data should be done at the end of each field day and backed up in two places. First, the file from the handheld computer should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix "Z_", which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul) should be added to the file name, which differentiates each daily backup. Data in the laptop from the sensor download should be backed up on two flash memory cards or thumbdrives. Back in the office, the data from the maintenance log are transferred into the master database in Microsoft Access and proofed for permanent storage and archiving.

Data from the water-level recorder need to be converted to depth measurements. The data are collected as water pressure, which is sensitive to barometric pressure. Water level is then

calculated using the water pressure data and the barometric pressure data using specialized software provided by the sensor manufacturer (In-situ 2010). The data should be stored into four sets of fields that include the raw downloaded data, the barometrically corrected raw data, a final set of data with relative depths, and a final set of data converted to elevations above mean sea level. Any data corrections or deletions are done to the final data and the raw field data is maintained as an archive.

Data from the temperature data loggers need to be reviewed for quality. The raw data are charted for each station and examined for outliers that may indicate a sensor problem. The potential erroneous measurements are flagged. Errors can arise from freeze up of the sensor, sensor calibration problems, or erroneous spikes in the data. Conversion of depths to elevations should be done if the surface elevation of the sensor can be determined. This can be done by obtaining high-quality differential GPS measurements of the housing height or by surveying the elevation of the housing to a benchmark with known elevation.

Unlike other data sets, the water level data is maintained in proprietary In-situ data management software. Because large numbers of records are recorded by the dataloggers, the volume of data is too large to be maintained within Access. The original data from each download, however, should be exported to a text file for archiving.

Metadata documentation is needed for both the maintenance log (see Table 5-2) and the downloaded sensor data. Full description of the sensor data is provided by the sensor manufacturer. The metadata should be included in the documentation of the download_log table in Access.

5.5. Analysis and Reporting

5.5.1 Data Analysis

Data analysis includes four aspects for the water-level data: (1) graphing of the final data, (2) summarizing the observation of peak stage for each day, (3) identification of storm events, and (4) determining the frequency distribution of peak stages. Charts of the raw data obtained at 30-min intervals are plotted with graphic or spreadsheet software. A separate graph is made for each station. The peak stage for each day is summarized by creating a pivot table with year, day, and maximum observation. These daily observations can be used to calculate mean daily high water (MDHW). Calculation of the MDHW can be used to identify storm events that exceed MDHW by 2 standard deviations. The number and dates of the storms are compiled, along with weather data for those periods from the nearest weather station; Homer (years 1939 to present) for LACL and Kodiak (1949 to present) for KATM. Weather frequency analysis can be conducted to evaluate extreme events, exceedance probabilities, and return periods using standard analytical techniques for hydrologic data (Stedinger et al. 1993).

5.5.2 Reporting

The results of the water-level and temperature data for each period can be presented in several ways. First, graphs should be presented of final data for each study area. Second, a chart of peak stage return intervals should be provided. Third, the mean monthly and annual level of peak stages should be presented either in tabular or graphic format and the data from all study areas can be included for comparison.

5.6 Personnel Requirements and Training

The installation of the water-level sensor can be done by 2 persons following the methods described above. Downloading and manipulation of data can be done by a technician that has become familiar with the specialized software. The technician should become totally familiar with the software and downloading procedures in the office before fieldwork is undertaken. A second person helps with site maintenance and adds to safety when operating in bear country.

5.7 Operational Requirements

Annual workload is greatest in the first year of installation. This work includes equipment manufacturing, training to use the software and downloading procedures, and deployment of the sensors. Annual work load is 40 person hours the first year for installation, and 40 person hours annually thereafter for downloading and data management, and 160 person hours every ten years for the major reporting effort.

Field installation should be done in mid-July in conjunction with the other salt marsh field efforts. Subsequent downloading is broken down into two regimes. The first is downloading the water-level recorder and barometric pressure recorder twice yearly (early and late summer) at the Silver Salmon study site by summer resident NPS personnel. The second regime is to download the water-level recorder at the two remaining remote sites during the summer every three years.

Equipment needs are listed in Table 5-1. Total cost of equipment (excluding laptop) is \$5,000. This total includes buying a duplicate set of water-level recorders in year 4 so that the original dataloggers can be swapped out and returned to the factory for battery change and maintenance.

Startup cost is ~\$3,000 for personnel time and ~\$3,000 for equipment. Annual maintenance costs thereafter run ~\$3,000 a year, except the major 10-yr reporting period which will cost ~\$15,000.

5.8. References

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Stedinger, J. R., R. M. Vogel, and E. Foufoula-Georgiou. 1993. Frequency analysis of extreme events. Pages in D. R. Maidment, ed., Handbook of Hydrology. McGraw-Hill, Inc., New York.

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 6

**Sediment and Water Characteristics
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

6 Sediment and Water Characteristics

This Standard Operating Procedures manual for measuring sediment accumulation and soil-water characteristics is designed to quantify changes in sediment thickness and soil-water pH and EC at each vegetation monitoring plot. While the 10-yr sampling interval is not sufficient for detecting changes in pH and EC, the measurements are useful to document soil-water chemistry at the time of vegetation sampling. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

6.1 Measurable Objectives

The specific objectives for the sediment accumulation and water characteristics measurements are to:

1. Determine the mean rates of accumulation over time;
2. Determine water depth above or below the surface
3. Characterize soil water pH and EC at each sampling period
4. Compare differences in sediment accumulation rates between geomorphic units and vegetation types;
5. Compare differences in soil-water characteristics among vegetation types; and

6. Use the sediment accumulation data to evaluate factors affecting vegetation changes.

6.2 Sampling Design

The sampling is done at permanent plots as described in SOP-4. At each plot, sampling is done at a single location at a corner of the vegetation plot. The sampling well and sediment wedge are sampled immediately next to each other.

6.3 Field Methods

6.3.1 Sediment Accumulation

Measurement of sediment accumulation in the field involves four steps: (1) cutting and removing a soil wedge with a sharp knife, (2) placing a scale and label on the wedges, (3) photographing the wedge, (4) replacing the wedge and sprinkling a colored, very fine sand over the soil surface as a stratigraphic marker, and (5) determining sediment accumulation from the photograph back in the office. The wedge is replaced and tamped in even to the existing ground surface. During a sampling revisit the wedge is cut from the same approximate spot. This technique is sufficiently reliable for large (>1 mm) sedimentation events, but will not be useful for detecting trace deposition.

The data file for the sediment-water characteristics has a check field for the sediment accumulation sampling. This field is simply to confirm that the photograph is taken of the soil wedge used for the sediment measurement. If a color sand layer is left from previous sampling, the depth of accumulated sediment above the marker is measured to the nearest 0.5 m with a ruler. If no marker is evident, measurements are made back in the office when photos from previous periods are available.

In the office, the recent photo is compared to photographs from the same plot taken in previous years. Ideally, a stratigraphic marker, such as the colored fine sand deposited in the initial year is visible. Otherwise, an identical marker horizon is identified on the photographs and the thickness of the soil above the horizon is measured on both photos (a reference tape, with the soil surface at 0 cm, must be shown in each; Figure 6-1). The difference in thicknesses is the amount of sediment accumulated over the time period. The change in thickness is divided by the change in time to obtain an accumulation rate. Deeper horizons can be used to measure erosion if material is lost. The use of preexisting marker horizons has been found successful in resampling on the Yukon Kuskokwim and Colville Deltas, but deformation of the buried horizons by root growth and freeze-thaw processes can modify the horizon by as much as 1-2 cm (M.T. Jorgenson, *unpublished data*). At Hallo Bay, buried volcanic ash from the 1912 eruption of Novarupta, and at Chinitna Bay and Silver Salmon, a thin ash deposit from the recent eruption of Redoubt (28 March 2009) provide distinctive marker horizons.



Figure 6-1. Photograph of soil plug cut from the ground surface. A recently deposited, thin silt layer near the surface shows differential accumulation of silt and sand and distinctive horizon at 2-cm depth provides a useful marker horizon for future comparison (photo . HABA_T2_1012sol02_2008_M_S.jpg).

6.3.1 Water Depth

The first step is to prepare a small-diameter monitoring well with a 1-in x 18-in soil probe at each permanent plot. This method is preferred over establishing a permanent well because the sampling is done only once every 10 years and fresh soil-water enters the well-hole at the time of sampling. Initially, the holes at all the sites along the transect are probed at the same time, a couple of hours before the sampling is done. This advanced preparation allows the small holes to fill to equilibrium level before sampling of water depths. After sampling is done the cylindrical soil plugs can be dropped back down the hole. When water is at or above the surface, no well is needed.

Table 6-1. List of equipment needed for measuring soil-water characteristics.

Equipment	Number
Electrical conductivity (EC) meter, broad range	2
EC calibration solutions, ~1000 and 20,000 $\mu\text{S}/\text{cm}$	2
pH meter	2
pH calibration solutions	2
Distilled water	0.5 L per transect
Squirt bottle	1
Sample vial	2
1 sampling cup, 10 ml capacity	
Soil probe, 1" diameter, 18" long	1

Handle for probe	1
Extension rods for probe	2
1 m of clear plastic tubing, 1/4" diameter	1
Squeeze bulb for tube	1
Measuring tape, metric	2
Large, serrated knife, 12" long	1
Colored fine sand, (from hobby shop)	
Small sticky notes	
Marking pen	
Handheld data recorder	1
Flash Memory Cards	1
Charger and cable	1

Water depth is measured with a measuring tape when water is above the sediment surface. When water is below the surface, 3/8-in teflon tubing is used to determine depth in the small hole. The field technician blows through the tube and listens for bubbling, which indicates that the tubing is immersed in soil water. The sampler should move the tube up and down to narrow the depth at which the tube just touches the water. The tube is then pinched with the fingers at the point where the tube crosses the ground surface and the distance between the fingers and the end of the tube is measured to the nearest cm with a measuring tape. The measurement is recorded as positive when water is above the surface and negative when below the surface. If no water is present, 999 is entered in field.

Table 6-2. Data fields, units, and descriptions of soil-water data.

Field	Unit	Description
PlotID	Text	Name of adjacent vegetation plot, e.g., SISA_T1-100
Observer	Text	Last name of observer
WatDepth	cm	Depth of water, positive above ground, negative below ground
MaxObsDep	cm	Maximum observation depth if water is not present
WatEC	μS/cm	EC of the water measured with a meter
WatpH	pH	pH of the water measured with a meter
SoilEC	μS/cm	EC of the soil paste measured with a meter
SoilpH	pH	pH of the soil paste measured with a meter
SedPhoto	text	Was photo taken of sediment wedge with ruler: y or n.
SedThick	mm	If a stratigraphic marker, such as colored sand, is evident from previous sampling period, measurements are made at 3 places and the approximate average is entered
Notes	Text	Information about oddities that may help interpret data. Notes are also used for documenting calibration solution. For calibration, PlotID is tagged with "cal", the reading is entered in the appropriate field above and the concentration of the standard is entered in the notes field.

6.3.2 Soil-Water EC and pH

The electrical conductivity (EC) and pH are measured from surface water or water taken from the well, if water is present. To extract water from the well, a small amount of water is sucked up into the plastic tube with a squeeze bulb or with the mouth. This extraction should be done twice. The first time the water is discarded as rinse from the tube and the second time the water is drained into a small plastic vial (~10 ml). EC is measured with an electrical conductivity meter and probe that is capable of measuring across the full range from 0 to 40,000 $\mu\text{S}/\text{cm}$. EC meters that measure the full range usually are of higher quality than inexpensive field instruments. The probe is immersed in the water and read after the reading has equilibrated (usually within 10 sec). The reading is entered into the handheld data recorder using $\mu\text{S}/\text{cm}$ as the unit. Note that some meters convert larger readings to mS/cm . If so, the reading must be converted in the field to $\mu\text{S}/\text{cm}$ to avoid confusion associated with changing units. The pH is then taken with a separate probe and measured to the nearest 0.1 pH. After the readings, the probes should be rinsed with distilled water stored in a small squirt bottle. Inexpensive, rugged pH meters are available that are sufficiently accurate for this measurement. More expensive probes are not recommended because of the abuse they incur during sampling of a wide range of media in the field.

If water is not available from dry soils, a saturated paste is made for determination of EC and pH. The paste is made by wetting the soil with distilled water until the soil just begins to flow. The surface should glisten but there should only be a negligible amount of free water standing at the surface. The soil paste is stirred to mix the water into the soil. The paste should stand at least 2 minutes before measurement. For measurement, the probes should be gently pushed into the paste until the sensor end is fully immersed. After measurement, the probe should be cleaned off and rinsed with distilled water.

Before sampling each day, the accuracy of the EC and pH meters must be checked using calibration solutions. Calibration readings are entered into the database as a calibration site (e.g., StationID is SISA-T1-cal). For EC, the calibration solutions should be approximately 1,000 and 20,000 $\mu\text{S}/\text{cm}$. If the meter reading is off by 3% or more, the meter should be calibrated to the standard. For pH, the calibrations solutions should be 4.0, 7.0 and 10.0. If the meter is 0.2 or more pH units different from the solution standard, the pH meter should be recalibrated according to manufacturer instructions. The measurement by the instruments of the standard solutions are recorded in the database. When recording, "Cal-date" is entered in the PlotID field, the measurements are recorded in the WatEC and WatpH fields, and the value for the calibration solutions are entered in the Notes field.

6.4 Data Management

Data management involves field data entry, daily backup, office data transfer, storage and archiving, and metadata documentation. These tasks are briefly described below.

Field data entry should be done on a handheld field computer (PocketPC) equipped with Access-compatible software (e.g., Pocket Excel, ABCD). The file should be labeled with the study area, theme, and person's initials (e.g., SISA_Soil_Water_mjtj). The data file should be located in a

folder on a flash memory card and not in volatile RAM memory. If problems develop, the data can be collected in a notebook. The data fields and relevant metadata are provided in Table 2.

Data backup should be done at the end of each field day and backed up in two places. First, the file from the handheld should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix “Z_”, which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul) should be added to the file name, which differentiates each daily backup. Back in the office, the data from the main data entry file is transferred into the master database in Microsoft Access and proofed for permanent storage and archiving.

Data should be stored in the master Access database once the data are correctly calculated and proofed. After all the data sets from the other field components are stored in the master Access database, the database should be archived on two separate media, a CD and on a separate server. The data reside in a separate Access database table and linked to the Plot database table with the PlotID.

6.5 Analysis and Reporting

6.5.1 Data Analysis

Data analysis involves three efforts: (1) development of descriptive statistics of sediment accumulation rates by study area and over all study areas; (2) analysis of differences in sedimentation rates among geomorphic units and vegetation types after post-stratification of the plots; and 3) using the data to evaluate factors affecting vegetation change. Descriptive statistics include tabular summaries of the mean, minimum, and maximum accumulation rates.

6.5.2 Reporting

The reporting will include two levels of reporting effort. After the fieldwork, office measurements, and data management are completed, an annual report is produced that documents field activities and describes the types and amount of data that were collected. This effort is intended to produce a brief interim report. The second level is a summary report that provides methods, and presents the results of descriptive statistics on annual status of the salt marsh components, graphic presentations, and statistical analyses of change.

6.6 Personnel Requirements and Training

The work can be done by a technician with a minimal amount of training. Few measurements are actually made in the field.

6.7 Operational Requirements

Annual work load for fieldwork is ~40 person hours each summer and 40 person hours for data management and reporting for the two consecutive years that fieldwork is done within the 10-yr monitoring interval. For the third year, when major reporting is done, the work load for data analysis and reporting is 160 person hours. Total work load every 10 years is 240 person hours.

Field measurements should be done in mid-July in conjunction with the other salt marsh field efforts.

Equipment needs are listed in Table 6-1. Total cost of equipment is \$500.

Startup costs are minimal and annual fieldwork costs runs ~\$3,000 a year for the two monitoring years, and ~\$14,000 for the third year of multi-year analysis and reporting. Approximate 10-yr costs for a complete monitoring cycle is ~\$20,000 for equipment and personnel time.

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 7

**Soil Temperature
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

7 Soil Temperature

This Standard Operating Procedures manual for measuring soil temperatures is designed to quantify changes in soil temperatures for one wet and one dry plant community at each study area. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

7.1 Measurable Objectives

Specific objectives for monitoring soil temperatures are to:

- 1) Document soil temperatures in two vegetation types, a wet type and a dry type;
- 2) Compare differences in soil temperatures between the two vegetation types; and
- 3) Determine changes in soil temperatures for the two vegetation types over time.

7.2 Sampling Design

Within each study area, one soil temperature datalogger is established in each of two vegetation types that represent the endpoints of the environmental gradient across the salt marsh: a lower, wet, halophytic sedge community, and a higher, dry, grass community that are common on all transects. The dataloggers are installed along one of the transects that has both vegetation types within each study area. Overall, there is one replicate each of the two vegetation types in each of the three study areas for a total of six dataloggers. This minimal effort is designed to replicate

soil temperatures for two very different, but dominant vegetation types, yet minimize the equipment expense and monitoring costs.

7.3 Field Methods

Inexpensive soil-temperature data loggers are commercially available for measuring soil temperatures on an hourly basis over periods of years without maintenance. For SWAN, submersible water-temperature data loggers (U22-001) manufactured by Onset Corporation are used for wet sites because they are completely waterproof and the battery life and data storage are reported to last 5 years. For dry sites, a dual-channel datalogger (U23-004) is used because it can get both shallow (-10 cm) and deep (1 m) soil temperatures and it is not at risk of flooding and damage.

Equipment that is needed is listed in Table 7-1.

Before installation, the data loggers are programmed with each site ID and recording interval using HOBOWare software (Onset 2010). The SiteID is simply the study area, component, and number (e.g., SISA_SoilTemp1). The recording interval is set to 2 hrs, because this is sufficient to capture minimum, maximum, and mean temperatures in slowly responding soil temperatures, and allows 5 yrs of data capture within the limits of the data logger's memory. The housing of the data logger is labeled with the SiteID.

Soil Temperature Monitoring

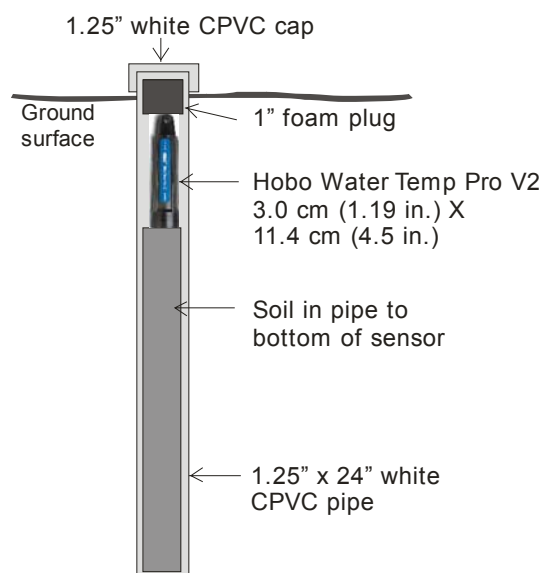


Figure 7-1. Schematic of temperature datalogger housed in protective casing.

Table 7-1. List of equipment needed for monitoring soil temperatures in SWAN.

Equipment	Number
HOBO® U23-004 Temperature/External Temperature Data Logger	3
HOBO® Water Temp Pro v2 Data Logger U22-001	3
Optic USB Base Station BASE-U-4	2
HOBO Waterproof Shuttle U-DTW-1	2
Large knife	
Tile probe	
Teflon tubing, 3/8 inch	
CPVC pipe, 1.25" diameter x 2 ft long	
CPVC cap, 1.25" diameter	
Wood board, 2 X 4 X 12"	
Sledge hammer, 2 lb.	
Fine String	
Foam insulation, closed cell, 1" long x 1.25" diameter.	

The data loggers are installed within a 1.25-in diameter, white, CPVC pipe casing to facilitate access and to prevent damage by bears. At each site adjacent to a vegetation monitoring plot, the pipe casing is installed by driving the plastic pipe into the ground so that the top is flush with the ground surface. The pipe is backfilled with soil to within 14 cm of the surface. Fine string is tied to the datalogger to aid retrieval and the data logger is inserted into the pipe. A small cylinder of

closed cell foam is slipped into the pipe to insulate the data logger from surface temperature fluctuations, with the string extending onto the top of the foam. The cap then is pressed firmly onto the top of the pipe. The cap is labeled with the station number (e.g., 1 or 2). A photograph is taken of the installation with the vegetation plot marker visible in the photograph. Finally, the cap is covered with a thin layer of plant litter similar to what is typical of the surrounding area. Installation is documented in a data logger maintenance log using the fields listed in Table 7-2.

Table 7-2. Data collected to document maintenance activity at water-level and soil data loggers.

Field	Type	Description
SiteID	Text	Code for the station
Transect	Text	
Date/Time	Data/time	Date and time: year-month-day, twenty-four hour time
Observer	Text	Name of observer
SensType	Text	Sensor Type, WATLVL, SOILTEMP, BAROMETER
SensModel	Text	Sensor model number
SERIALNUM	Text	Serial number of sensor
TimeInterv	Number	Sampling interval in hours
SENS-DEP1	cm	depth (-) or height (+) above/below gnd, cm
SENS-DEP2	cm	depth (-) or height (+) above/below gnd, cm
SENSWATDEP	cm	depth (-) or height (+) of water above/below sensor tip, cm
CASEWATDEP	cm	depth (-) or height (+) of water above/below top of casing/housing,
GRNDWATDEP	cm	depth (-) or height (+) of water above/below ground-sediment surface, cm
Action	Text	Action taken: installed, download complete, download partial, download failed, modified, replaced, removed
Relaunch	Text	Was sensor relaunched: y, n
Blinking	Text	Is sensor LED blinking, y, n (confirms relaunch successful)
Battery	Text	Battery status, new, 90%, 50%, 25%, dead, dead & replaced
Photos	Text	Photos taken: y, n
Notes	Text	Notes on any problems that might affect data

For downloading of the data loggers, the data loggers are merely swapped out with a new set of data loggers after a 3- or 4-yr period. This method allows installation of data loggers with new batteries, downloading of the data loggers to a computer in a more secure environment, and the return of the data loggers to the factory for battery replacement and refurbishing. Back in the office, downloading of data off the data loggers is accomplished by hooking an optic adapter to a computer and in conjunction with specialized software according to manufacturer's instructions (Onset 2010). During downloading, the internal SiteID, date, and battery level are checked.

7.4 Data Management

Data management involves downloading of the data loggers (described under methods), field data entry of maintenance log, daily backup, office data transfer, manipulation and calculation, storage and archiving, and metadata documentation. These tasks are described briefly below.

Field data entry of the maintenance information should be done on a handheld field computer (PocketPC) equipped with Access-compatible software (Pocket Excel). The file should be labeled with the study area and theme and person's initials (e.g., SISA_Download_Log_mjtj). The data file should be located in a folder on a flash memory card and not in volatile RAM memory. If problems develop, the data can be collected in a notebook. The data fields and relevant metadata are provided in Table 7-2.

Backup of data for both the download maintenance log and downloaded sensor data should be done at the end of each field day and backed up in two places. First, the file from the handheld should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix "Z_", which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul), should be added to the file name, which differentiates each daily backup. Data in the computer from the sensor download should be backed up on two flash memory cards or thumbdrives. Back in the office, the data from the maintenance log are transferred into the master database in Microsoft Access and proofed for permanent storage and archiving.

Data from the temperature data loggers need to be reviewed for quality. The raw data are charted for each station and examined for outliers that may indicate a sensor problem. The potential erroneous measurements are flagged. The temperature data are then copied to another field with a calibration offset if needed. Although sensors can be calibrated before installation, they can also be adequately calibrated by examining the temperatures during water-phase transitions during spring and fall, sometimes called the "zero curtain". Normally, the temperature at phase-transition should be at $\sim -0.2^{\circ}\text{C}$. If the difference between the measured temperature and 0.2°C is $>0.2^{\circ}\text{C}$, the difference is added to the temperature in the corrected temperature field. Calibration with the zero curtain values is preferred because sensors can drift over time making initial calibration invalid.

Data should be stored in the master Access database once the data have been reviewed and calibrated. After all the data sets from the other field components are stored in the master Access database, the database should be archived on two separate media, a CD and on a separate server.

Metadata documentation is needed for both the maintenance log (see Table 7-2) and the downloaded sensor data. Full description of the sensor data is provided by the sensor manufacturer. The metadata should be included in the documentation of the datalogger_log table that is used for both the soil-temperature and water-level data loggers in Access.

7.5 Analysis and Reporting

7.5.1 Data Analysis

The soil-temperature data are analyzed four ways: (1) graphing of data for each individual station; (2) summarizing data by mean daily, monthly, and annual values, (3) calculating of thawing and freezing degree days for each site, and (4) comparing mean annual temperatures, and annual freezing and thawing degree days between vegetation types, and (5) evaluating changes in temperatures over time. Changes in mean annual temperatures should be evaluated using a general linear model with repeated measures, using study area and vegetation type as categorical variables, and the annual temperatures as the repeated measure.

7.5.2 Reporting

The results of the soil-temperature data for each period can be presented several ways. First, graphs should be presented of hourly data for each study area. Second, tabular summaries should be presented on mean monthly and annual temperatures. Third, the mean annual temperature of each site should be plotted. Fourth, the mean annual temperatures should be averaged across the three study areas for each vegetation type. Fifth, the statistical results from testing of the significance of changes in mean annual temperatures should be presented in tabular format.

7.6. Personnel Requirements and Training

The installation of the data loggers can be done by one person following the methods described above. The work can be done by a technician. Downloading and manipulation of data can be done by a technician that has become familiar with the specialized software. The person should become familiar with the software and downloading procedures in the office before fieldwork is undertaken. Statistical analysis should be done by a qualified statistician or ecologist in consultation with a statistician. Reporting is done by an ecologist.

7.7. Operational Requirements

Annual workload is greatest in the first year of installation. This work includes equipment manufacturing, training to use the software and downloading procedures, and deployment of the sensors. Annual work load is 40 person hours the first year for installation, 40 person hours every 3 or 4 years for downloading and data management, and 160 person hours every 10 yrs for the major reporting effort.

Field installation should be done in mid-July in conjunction with the other salt marsh field efforts. Subsequent downloading is done every 3 or 4 years, during mid-summer.

Equipment needs are listed in Table 7-1. Total cost of equipment (excluding laptop computer) is ~\$5,000. This total includes buying a duplicate set of water-level recorders in year 4 so that the original dataloggers can be swapped out and returned to the factory for battery change and maintenance.

Startup cost is ~\$3,000 for personnel time and ~\$3,000 for equipment. Annual maintenance costs thereafter run ~\$3,000 a year, except the major 10-year reporting period which will cost ~\$15,000.

7.8. References

Onset. 2010. HOBOWare getting started using HOBOWare with HOBO data loggers. Onset Corporation, Bourne, MA. 15 pp.

**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 8

**Vegetation Cover
Version 1.0 (December 2010)**

Revision History Log:

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Procedures:

8 Vegetation Cover

This Standard Operating Procedures manual for vegetation cover is designed to quantify changes in the abundance of each plant species within each study area. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

8.1 Measurable Objectives

Specific objectives for monitoring vegetation cover are to:

- 1) Quantify the mean cover of plant species and growth forms within each study area using the systematically distributed plots;
- 2) Determine changes in mean cover of plant species and growth forms by study areas using the systematically distributed plots;
- 3) Classify the plant communities, or vegetation types, across all study areas using the data from both systematically and subjectively established plots;
- 4) Quantify the mean cover of plant species and growth forms by vegetation type using data from all plots and all study areas; and
- 5) Determine changes in mean cover of plant species and growth forms by vegetation type using data from all plots and all study areas.

8.2 Sampling Design

Plots are systematically distributed every 100 m along transects that have been equally distributed across each study area. An additional 1–3 plots are subjectively established along each transect in distinctively different vegetation types not sampled by the systematic plots to increase the sample size for uncommon types. These uncommon vegetation types are identified by the dominance of species not evident in the systematic plots or have a distinctive spectral signature on the imagery that varies from the common vegetation. This design generates a total of 30–40 plots per study area.

A power analysis (protocol narrative, Section 4) indicated that a minimum of 30 systematic plots per study area would need to be sampled in order to detect overall change in the cover of a dominant species among study areas. The current number of plots for Silver Salmon, Chinitna Bay and Hallo Bay are 23, 20, and 35, respectively, and are somewhat fewer than desired. The power analysis also indicated that a minimum of 15 plots per plant would need to be sampled in order to detect change in the cover of a dominant species within community types. For dominant vegetation types in the coastal flats (e.g., *Carex ramenskii*-*Stellaria humifusa*; *Carex glareosa*-*Carex ramenskii*; *Carex lyngbyaei*-*Cicuta virosa*) and on beach ridges (e.g., *Achillea millefolium*-*Carex gmelinii* and *Lathyrus maritimus*-*Senecio pseudoarnica*), we have established between 10-13 plots per study area, slightly fewer than the desired sample size. During future sampling, additional plots may need to be established in the undersampled study areas and plant community types.

To assess data quality and precision, 3 to 5 plots should be resampled during each field visit by separate observers. The duplicated plots are denoted in the SiteID by the addition of "dup" to the SiteID. The precision of the point-sampling technique is quantified by comparing the differences in cover among observers for the various plant species and growth forms. In particular, reliable identification of sedge leaves and mosses is difficult during point sampling. The amount of change detected over time can then be compared to the precision of the technique.

8.3 Field Methods

Sampling is done within a 4 x 10 m plot. Before sampling, the sampling person should inspect the plot to become familiar with the species and plant parts likely to be encountered in the plot. Any species for which the sampler is not totally confident in identifying should be collected, including belowground parts, for a voucher specimen. Specimens should be collected in flower or fruit, if possible. All species are given a tentative name, even if it is unknown (such as "tinyforb1"), for recording, and the specimens placed in a bag for later pressing and identification. The dominant non-vascular plants should also be tentatively identified and collected.

Table 8-1. List of equipment needed for 2 or 3 people to sample vegetation at one plot.

Equipment	Number
Meter tape, 10 or 25 m	2
Rebar, 3/8 x 2 ft	2 per plot
Camera	1
Flash memory card for camera	1
Camera batteries	2
CPVC pipe, 3/4" x 2 m	2
CPVC coupling, 3/4", glued to one end for connecting pipes, pipes are marked every 20 cm	1
Laser pointer, waterproof	3
Aluminum rod to hold pointer, 5/16" x 4 ft	2
Laser pointer holder, holds point to rod	2
Handheld computer (pocketpc) with two memory cards	1
Charger for PPC	1
Extra memory card for backup in field office	1
Program for recording point data	1
Plastic collection bags, 1 gal.	10 per study area
Plastic collection bags, 1 qt.	100 per study area
Plant press, extra newspapers	1
Marking pen	2
Identification sheet set	2
Flora of Alaska (Hultén 1968) for vascular plants	1
Plants of the Pacific Northwest Coast (Pojar and MacKinnon 1994) for common lichens and mosses	1
Hand lens	2

Vegetation cover in the plot is sampled using the point-sampling technique (Mueller-Dombois 1974, Elzinga et al. 2001). Cover is determined by sampling at 100 points systematically distributed across the plot. This method requires sampling 20 points spaced 20-cm apart along a 4-m-long rod, which is placed perpendicular to the plot direction. The rod is moved at 2-m increments (1, 3, 5, 7, and 9 m from 0 m end stake on the transect) across the plot after sampling of each rod-length is completed. Cover at each point is sampled with a vertically oriented laser pointer (pointed downward) mounted on an aluminum rod (Figure 8-1). After determination of what plants are intercepted at each layer by the laser pointer, the rod is moved 20 cm to the next point. Exact positioning is not critical and introduces an element of randomness. Because multiple layers are recorded at each point, plant cover often exceeds 100% per plot.



Figure 8-1. Point-intercept sampling at Silver Salmon Creek, July 2007. Ecologists (left, center) call out species present at a point along a PVC rod placed at 1, 3, 5, 7, and 9 m intervals from the 0 m endpoint of the plot (on transect, marked with pin flags). A laser pointer mounted on an aluminum rod is used to determine species “hits”. A third person documents each species ‘hit’ with a hand-held computer.

Cover at each point is determined by noting the plant species intercepted at each layer through the canopy. For trees and tall shrubs, which are rare in coastal vegetation, the laser can be pointed upward to sample the canopy. When live vegetation is not encountered, a note is made for litter or soil alone. Soil or litter at points with live vegetation is not counted to avoid the time and large counts associated with counting litter layers in varying states of decomposition, and there is always soil or sediment below litter. Water is noted, whether or not vegetation is present above or below the water, because water coverage is an important changing variable.

Accurate determination of some species, particularly sedges and mosses, is difficult during point sampling. To reduce this problem the plot should be inspected before sampling to identify all the species that are likely to be encountered during sampling. Voucher specimens should be collected when the species can not be positively identified. Species that are likely to be confused during sampling should be carefully examined to determine key leaf characteristics needed to differentiate species. With some taxa, it may be necessary to identify only to genus. Errors are unavoidable and the observer is encouraged to do the best they can to minimize error. If problems become evident during later data analysis, the problem can be resolved by lumping problematic species into broader taxonomic categories (e.g., genus or growth form).

The data are recorded on a handheld computer with special software for recording "hits." As one person samples with the pointer, another person records the data. During recording at each point, the recorder taps pre-programmed keys labeled with each six letter species code. The code uses the first three letters from the Latin genus and species names. When the pointing person finishes calling out the codes for all layers encountered at a point, the person calls out "next" and the recorder taps the enter key to complete the record and establish a new one. The program also has keys for growth forms of unknown species and there is a "notes" field for recording tentative names, if a specimen has been collected, and for additional plot-level observations. The database is programmed to record all "hits" at each point on one record, space-delimited, along with sample point number (1 to 100) and the PlotID. This program allows parsing of the data and attaching a layer number to each "hit". The recorder helps the pointer keep track of the sample point number to avoid skipping or duplication of a point. After 100 points are obtained, the program prompts the sampling to end. All the plot data for one study area are collected within a single file. If extra qualified help is available, two people can point sample while one person records ("powerpointing"; Figure 8-1).

Field taxonomy uses Hultén (1968) because it is a high-quality published flora and provides an unchanging reference for synonymy in the database. Care must be taken, however, to identify taxa to the subspecies level to the extent possible to better match changing synonymy. Up-to-date synonymy can be linked in the database. Taxonomy for non-vascular plants should use that of the NRCS Plants Database. The field guide "Plants of Coastal British Columbia" (Pojar and MacKinnon 1994) is a useful guide covering most of the plants encountered in the salt marshes.

8.4 Data Management

Data management involves downloading of the handheld computer, daily backup, office data transfer, voucher specimen identification, data management and calculation, storage and archiving, and metadata documentation. These tasks are described briefly below.

Field data entry of the maintenance information should be done on a handheld field computer (PocketPC) equipped with specialized sampling software. The file should be labeled with the study area, theme, year, and person's initials (e.g., SISA_Veg2007mtj). The data file should be located in a folder on a flash memory card and not in volatile RAM memory. If problems develop, the data can be collected in a notebook. The field names used in the field program are renamed to more explicit names for the Access database that better link to other data tables, and several fields are added and populated in the office after compilation of the field files, including StudyArea, Year, SiteID-Year, Species_Code, and Collected. The data fields and relevant metadata are provided in Table 8-2.

Backup of data is done at the end of each day. The file from the handheld computer should be copied to a second memory card on the handheld computer or to internal nonvolatile memory. At this time, the prefix "Z_", which causes the file to drop to the end of the directory listing to avoid erroneous opening, and the suffix with the date (e.g., 19jul) should be added to the file name, which differentiates each daily backup. Back in the office, the data from the main data-entry file are transferred into the master database in Microsoft Access and proofed for permanent storage and archiving. The original field files are archived in a separate directory.

Table 8-2. List of fields, and their units and descriptions, used for collecting vegetation cover data.

Field	Office	Unit	Description
PlotID	StudyArea		Landscape unit, study area, added in office
	SiteID		Plot or station identifier
	Year		Year, four numbers, added in office
	SiteID-Year		Created in office after sampling, added in office
UniqID	PlotPoint		Combined plotID and point and layer
Point	Point		Point number for sample of 100 points in plot
Plntcount	Layer		Layer in hit sequence at one point, added by handheld computer
Plntcode	Field_code		six letter veg code assigned during sample, space delimited
	Species_Code		Final six letter code after voucher ID and QA/QC, added in office
Pctcov	Cover		Cover value for individual hit (1 hit = 1%)
	Collected	Text	Yes or no, temporary code name, obtained from notes in office
Note	Notes	Text	Key characteristics of collected plant or other observations that affect the species ID

Voucher specimens are stored in a field plant press at the end of each day. Specimens may be identified that night to aid sampling the next day, or back in the office. Plants are identified to subspecies to the extent possible by an in-house plant taxonomist, or can be brought to a specialist at the University of Alaska herbarium. After identification, the records in the database are updated or corrected.

Data should be stored in the master Access database once the data have been reviewed. After all the data sets from the other field components are stored in the master Access database, the database should be archived on two separate media, a CD and on a separate server. The SiteID field in the "Veg_Point_Count" table is linked to the Plot Data table.

8.5 Analysis and Reporting

8.5.1 Data Analysis

Vegetation data are summarized to percent-cover values for both the systematic subset and the total set. The data are cross-tabulated to summarize the "hits" by plot and by species to provide a repetitive percent-cover index for each species. Total cover often exceeds 100% because of overlapping layers of vegetation.

For the systematic set of plots, the percent-cover data are cross-tabulated to summarize species cover by study area and across all study areas. This calculation is performed independently of vegetation type and provides an overall metric for assessing change for individual species. This data set can then be used for testing for significant changes with a general linear model with repeated measures, using the study area as the variable and year as the repeated measure.

For the total data set that includes the additional, subjectively placed, plots, the data are treated similarly as above to generate percent cover by species and plot. These data are used to classify vegetation types and analyze for change by vegetation type.

Vegetation classification is a multi-step procedure and suitable procedures are well described in McCune and Grace (2002). First, the data are organized in a matrix by species and by plot using the Pivot routine in Excel when linking to the Access database. Second, communities are classified using the TWINSpan or other clustering routine in PC-ORD software to sort data by plot and species and to hierarchically cluster the plots. Communities can be differentiated at the 75% information remaining level. Third, the data are analyzed by nonmetric multidimensional scaling (NMS) to identify structural relationships in the data set. The NMS analysis can be run in the "autopilot" mode that finds the optimal solution for number of runs, best solution for each dimensionality, and testing for significance. The Sorensen distance measure is typically used. Fourth, the sample plots are plotted according to the distance measures for the first two axes and labeled according to the TWINSpan cluster they are identified with. The clusters for each TWINSpan-class are plotted on the NMS axes and reviewed to identify outliers for each cluster. For each outlier, the species-cover tables are reviewed to identify the reason for the outlier and a decision is made whether to keep the outlier, eliminate the outlier, or reclassify it. Once the plant communities are established, each plot is assigned a community name that is based on its dominant species and a diagnostic species that differentiates the community from other similar communities. While salt marsh vegetation tends to be extremely patchy and challenging to classify, the classification techniques help identify which classes are similar and overlapping and which are very distinctive. This set of analyses has been performed with the initial dataset from the study areas (Jorgenson et al. 2010) but may need to be rerun for future sampling dates to assess whether the plot composition has shifted from one plant community to another.

The vegetation data from all the plots are then used to analyze changes by vegetation type. This approach is similar to the analysis done for the systematic subset, except that the analysis is done by vegetation type instead of by study area. While vegetation type for an individual plot is likely to change over time, the initial vegetation classification provides a grouping closely related to initial environmental conditions and provides a basis for evaluating where changes are most notable.

The advantage of this dual approach (i.e., analysis by study area and vegetation type) is that plant species in differing coastal environments have differing environmental tolerances, disturbance regimes, and successional pathways, and are also likely to respond differently to climate change. Thus, analysis by vegetation type is much more powerful for evaluating the response of individual species and includes uncommon vegetation that would not be sampled by systematic sampling alone. Analysis by study area can identify trends over time for each species; the area of inference consists of the three study areas.

8.5.2 Reporting

The results of the vegetation data for each period can be presented several ways. First, tabular summaries should be provided for percent cover of each species by plot. Second, descriptive statistics should be summarized by study area and vegetation type. Third, results of the vegetation classification should be presented in tables that sort related species by vegetation type. Vegetation classes identified on a chart of the NMS results help visualize the similarity and distinctness of the various vegetation types. Fourth, the changes over time can be tested for significance by general linear models with repeated measures, with the study area or vegetation type used as the variable for the two data sets, and time (year) as the repeated measure. Fifth, the

data from all the plots from all the years can be analyzed with NMS to identify changes in plot distribution in "species space," or successional patterns (McCune, B., and J.B. Grace. 2002).

8.6 Personnel Requirements and Training

Vegetation sampling is done by a qualified plant ecologist with sufficient local knowledge and a technician. The ecologist point samples, while the technician records. A technician with plant knowledge can be trained to identify the 50 to 100 species that are to be sampled. Data management can be done by a technician. Statistical analysis should be done by a qualified statistician, or an ecologist in consultation with a statistician. Reporting is done by an ecologist.

8.7 Operational Requirements

Annual workload is greatest in the first year due to the time required to set up the plots. Annual work load for field preparation and fieldwork to sample 60–80 plots per year is 300 person hrs, and ~600 hrs over 2 yrs for the complete sampling. About 120 hrs are needed every year after sampling for plant identification, management, and annual reporting. In the third year after a complete sampling round, 400 hrs are needed for the major analysis and reporting effort.

Sampling should be done in mid-July during peak biomass. Equipment needs are listed in Table 8-1. Total cost of equipment (excluding laptop computer) is \$300.

Annual sampling and reporting costs are ~\$30,000 for the first two years and ~\$25,000 for the major 10-yr reporting.

8.8. References

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**Salt Marsh Monitoring Protocol for the
Southwest Alaska Network (SWAN)**

Standard Operating Procedure (SOP) # 9

**Photo Interpretation of Landscape-level Change
Version 1.0 (December 2010)**

Revision History Log:

Version No.	Revision Date	Author	Changes Made	Reason for Change

Procedures:

9 Photo-interpretation of Landscape-level Change

This Standard Operating Procedures manual for assessing landscape-level change is designed to determine the abundance of ecotypes within each study area through photo-interpretation of a time-series of aerial photographs and high-resolution satellite images. The broader ecotype classification, based on geomorphic and plant community characteristics, is necessary because the classification of plant communities as defined from the field surveys is insufficient to adequately represent the range of ecological conditions (e.g. non-vegetated tidal rivers) evident on the imagery. The Protocol uses the technique of point-sampling on a systematic grid instead of digitizing map polygons because it is much quicker and more appropriate for highly patchy terrain. Objectives, sampling design, methods, and analysis and reporting procedures are described below.

9.1 Measurable Objectives

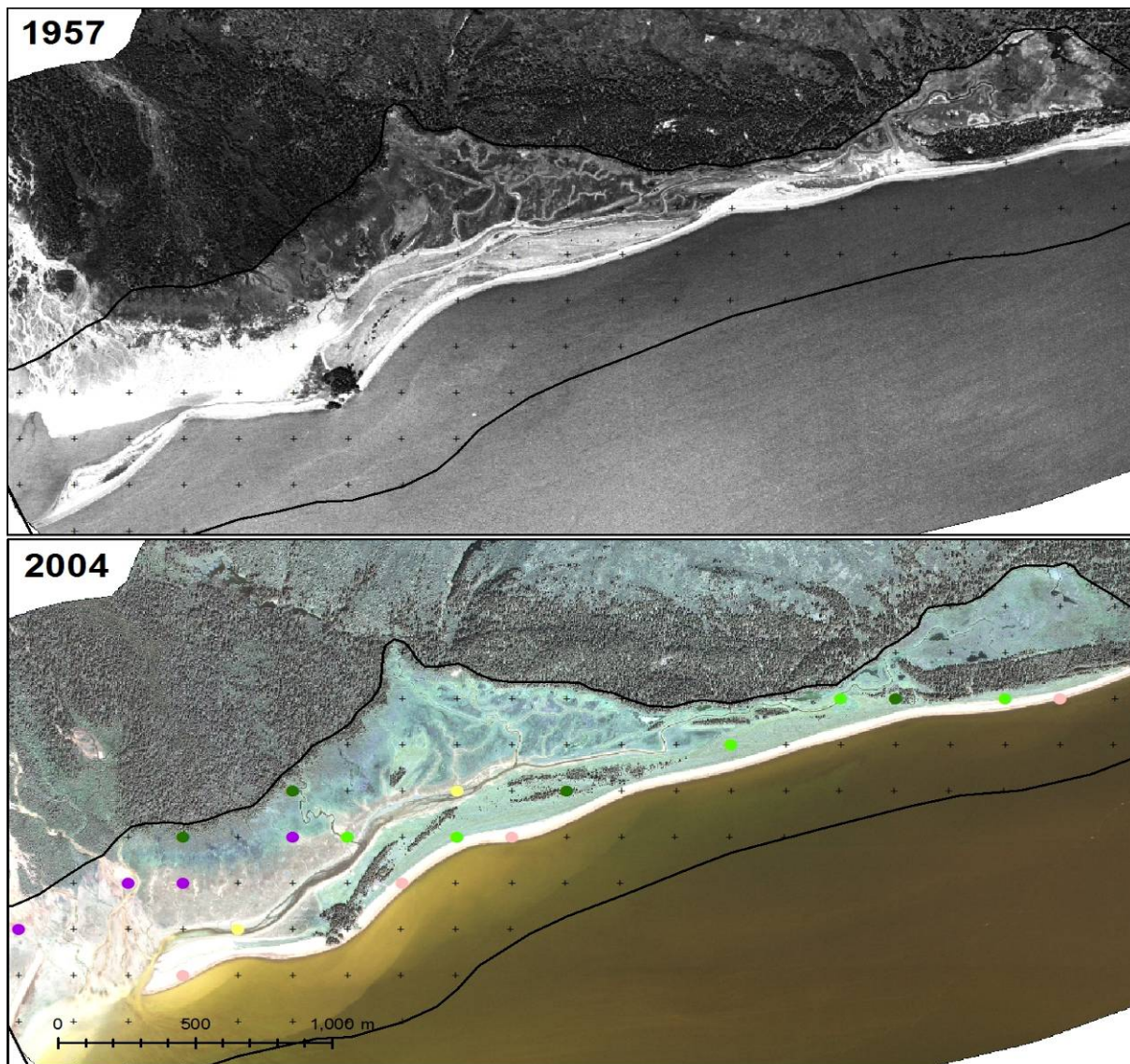
Specific objectives of the monitoring component to assess landscape-level changes in the abundance of ecotypes are to:

- 1) Establish a systematic grid for photo-interpreting changes at sampling points over a time series of imagery;
- 2) Develop a ecological classification that incorporates physiographic, geomorphic, chemistry, and vegetation characteristics;
- 3) Quantify the distribution and abundance of ecotypes based on point sampling;

- 4) Summarize the changes over time; and
- 5) Classify the change into specific geomorphic or ecological processes

9.2 Sampling Design

The work is designed to quantify the types and abundance of the ecotypes within each study area, which represent the primary level of sample stratification. The sampling uses a 200-m grid with a random start established with a GIS. The sampling is designed to allow a generalized linear model with repeated measures to be used for testing differences in ecotype abundance across three sites among multiple years. The study areas include Silver Salmon, Chinitna Bay, and Hallo Bay, but could be expanded in the future to include Tuxedni Bay (LACL) and Swikshak Lagoon (KATM), among other areas. The grids have already been established for each site (Jorgenson et al. 2010) and an example of the sampling grid overlaid on an 1957 airphoto and a 2004 IKONOS high-resolution satellite image is presented in Figure 9-1. Future photo-interpretation of ecotypes from newly acquired imagery will be completed every 10 years.



Landscape Changes 1957-2004

- | | | | | | |
|-----------|------------------------------|--------|--------------------------------|--------------|-------------------------------|
| + | none | orange | channel erosion and deposition | light green | sedimentation and succession |
| red dot | shoreline erosion | yellow | channel deposition | olive green | shoreline deposition-success. |
| red dot | shoreline erosion-deposition | purple | sedimentation | bright green | early succession |
| pink dot | shoreline deposition | blue | beaver dam | dark green | late succession |
| brown dot | channel erosion | cyan | paludification | | |

Figure 9-1. Example of sampling grid (black cross-hairs) used to assess landscape-level changes at Chinitna Bay. Points where change occurred between two time periods (e.g., 1957 & 2004) are color-coded with type of change.

9.3 Methods

The abundance of the various ecotypes are determined by point sampling of the relative cover of the ecotypes on historical aerial photographs and future high-resolution satellite images. The sampling grids include 276, 109, and 249 points at Silver Salmon, Chinitna Bay, and Hallo Bay, respectively. At each grid point, the ecotype is determined through photo-interpretation. The interpretation uses a ecological classification system (Table 9-1) developed from relationships among geomorphic unit, soil texture, drainage, soil chemistry, and plant community developed from cross-tabulation of environmental characteristics sampled at the permanent monitoring plots (Jorgenson et al. 2010). Descriptions of the geomorphic units are provided in Table 9-2. The monitoring plots also serve as reference plots for helping control the accuracy of the photo-interpretation. The photo-interpretation is done on-screen using ArcGIS software at an approximate scale of 1:1000, and the ecotype at each point for each of the three periods is entered into an attribute table. Attributes for each point include site, ecotype55, ecotype80, ecotype05, change55-80, change80-05, change55-05, and notes. Where change is evident among periods, the change is attributed in the change fields (e.g. "change55-80") to a specific geomorphic or ecological process defined in Table 9-3. New fields will need to be added for future analyses.

The photo-interpretation attempted to differentiate all ecotypes using photo-signatures available from field survey plots. Many ecotypes, and their associated plant communities, have distinct plant structures and spectral signatures that allow reliable classification (e.g., Coastal Sandy Moist Circumacidic Beachgrass-Umbel Meadow versus Coastal Sandy Moist Circumacidic Alder Shrub). Other graminoid dominated ecotypes, however, are hard to differentiate (e.g., Coastal Loamy Brackish Wet Lyngbye Sedge Meadow versus Coastal Loamy Brackish Wet Lyngbye Sedge-Herb Meadow) and interpretation is less reliable. This should be recognized when discussing the type and magnitude of the change during reporting.

Analysis of landscape changes is affected by the spatial resolution and spectral characteristics of the imagery. For the available historical imagery, the spatial resolution is sufficient (1.0 m, except 4.0 m for the 2005 IKONOS image for Hallo Bay) was not a major factor. The spectral characteristics, however, are very different. Small differences in vegetation composition or waterbody margins are difficult to discern on B&W air photos, whereas, differences in vegetation and soil moisture are readily evident on the CIR air photos. The true-color IKONOS has intermediate spectral variation. Consequently, large changes in vegetation structure (e.g., from meadow to forest) can be reliably detected, but small shifts in composition of meadows are difficult to detect. Similarly, the margins of deep water with vegetated margins can be easily detected and mapped, while the margins of shallow water with muddy margins are indistinct and the accuracy of detecting change is reduced. During the photo-interpretation, the interpreter should be conservative and assume no change unless the photo-characteristics indicate distinct differences in signatures among years.

9.4 Data Management

Management of the GIS data has three aspects: (1) version control of changing GIS files, (2) metadata documentation, and (3) storage and access control to the files. The first two tasks are managed by the ecologist or remote-sensing specialist that creates the GIS data layers, and the last task is managed by the network data manager.

Over time, additional information acquired from field studies may create the need to modify the ecological classification. If the classification system changes, older files may need to be revised to maintain consistent mapping and classification among time periods. Consequently, the file names for the various GIS data layers should be tagged with a date or version number. The plant community abundance layer should be labeled with park network, theme, year, projection, and date version was completed, with date format in yyyyymmdd (e.g., SWAN_Coastal_Veg_2004_AlbaK83_20071201). Metadata for each GIS data layer should be compliant with FGDC metadata standards and can be entered within the metadata form in ArcCatalog. The form indicates which fields are mandatory for FGDC compliance.

Table 9-1. Classification of coastal ecotypes based on relationships among geomorphic units and plant communities with salt marsh study areas in SWAN.

Geomorphic Unit	Soil Texture	Drainage	Soil Chem.	Plant Community	Ecotype
Active Coastal Beach, Active Coastal Dune	Gravel, Sand	Excessive-Well	Saline-Brackish	Barren Beach	Coastal Gravelly Saline Barrens
	Sand, Gravel	Excessive-Slightly Ex	Circum-acidic	<i>Lathyrus maritimus-Senecio pseudoarnica</i>	Coastal Sandy Dry Circumacidic Beach-pea Meadow
Inactive Coastal Beach, Inactive Coastal Dune,	Sand	Slightly Excessive-Well	Circum-acidic	<i>Picea sitchensis-Angelica lucida</i>	Coastal Sandy Circumacidic Moist Sitka Spruce Woodland
				<i>Elymus arenarius-Angelica lucida</i>	Coastal Sandy Moist Circumacidic Beachgrass-Umbel Meadow
	Sand	Well	Circum-acidic	ND	Upland Sandy Moist Willow Tall Shrub
	Sand, Gravel	Slightly Excessive-Well	Circum-acidic	<i>Alnus sinuata-Dryopteris dilatata</i>	Upland Sandy Moist Circumacidic Alder Shrub
				<i>Calamagr. canadensis-Lupinus nootkatensis</i>	Upland Sandy Circumacidic Moist Bluejoint-Lupine Meadow
				ND	Upland Sandy Circumacidic Moist Sitka Spruce Woodland
Active Tidal Flats	Loam-Sand	Slightly Poor-Very Poor	Saline-Brackish	<i>Barren Mudflat</i>	Coastal Loamy Flat Barrens
				<i>Barren Tidal Channels</i>	Coastal Loamy Channel Barren
	Loam	Mod. Well-Very Poor	Saline-Brackish	<i>Carex ramenskii-Stellaria humifusa</i>	Coastal Loamy Saline Wet Ramenski Sedge Meadow
			Brackish	<i>Carex glareosa-Carex ramenskii</i>	Coastal Loamy Brackish Wet Sedge-Grass Meadow
		Mod. Well-Somewhat Pr.	Brackish	<i>Elymus mollis-Plantago maritima</i>	Coastal Loamy Brackish Wet Elymus-Forb Meadow
			Slightly Brackish	<i>Elymus mollis-Carex lyngbyaei</i>	Coastal Loamy Slightly Brackish Wet Elymus-Sedge Meadow
Inactive Tidal Flats	Loam	Poor-Very Poor	Brackish	<i>Carex lyngbyaei-Calam. Deschampsioides</i>	Coastal Loamy Brackish Wet Lyngbye Sedge Meadow
	Loam-Organic-rich	Very Poor	Slightly Brackish	<i>Carex lyngbyaei-Cicuta virosa</i>	C. Organic-rich Slightly Brackish Wet Lyngbye Sedge-Herb Meadow
			Brackish	<i>Carex mackenziei-Eleocharis kamtschatica</i>	Coastal Loamy Brackish Wet Mackenzie Sedge Meadow
Abandoned Tidal Flats, Inactive Tidal Flats	Loam-Org-rich	Slightly Poor-Very Poor	Circum-acidic	<i>Myrica gale-Salix fuscescens</i>	Lowland Organic-rich Circumacidic Wet Sweetgale Low Shrub
	Organic-rich	Very Poor	Circum-acidic	<i>Calamagrostis canadensis-Equisetum fluviatile</i>	Lowland Organic-rich Circumacidic Wet Bluejoint Meadow
Isolated Shallow Estuarine Lake	Water	Very Poor-Flooded	Saline-Brackish	<i>Hippuris tetraphylla-Triglochin maritimum</i>	Coastal Saline Maretail Marsh
		Flooded	Brackish	Estuarine Water	Coastal Brackish Ponds
			Circum-acidic	<i>Hippuris vulgaris-Sparganium angustifolium</i>	Lacustrine Circumacidic Maretail Marsh
Tidal River	Water	Flooded	Circum-acidic	Tidal River	Tidal River
Nearshore Water	Water	Flooded	Saline	Estuarine Water	Coastal Tidal Channels
			Saline	Nearshore Water	Nearshore Water

Table 9-2. Classification and description of geomorphic units for salt marshes along Cook Inlet, AK.

Geomorphic Unit	Description
Barrier Islands and Spits (Mi)	Undifferentiated gravelly or sandy barrier islands, spits connected to the mainland, and bay barriers. They typically are linear features parallel to the coast, although spits may have more variable orientations.
Active Sandy Beach (Mba)	Wave eroded and deposited sandy material on sloping beaches fronting open water. Surface varies from barren to vegetated by early successional plants
Coastal Overwash Fans (Mo)	Gravelly to sand sediments deposited in fan-shaped to linear lobes formed by breaching of beaches and dunes during large storm events. The material typically grades from coarse to fine perpendicular to the shoreline.
Coastal Active Dune (Mda)	Very fine to fine sand deposited in wind-blown dunes parallel to the coast and downwind from sandy beach deposits. Active dunes have <3 cm of organic matter within the top 30 cm, indicating frequent deposition. Beach-pea meadows predominate.
Coastal Inactive Dune (Mdi)	Very fine to fine sand deposited in wind-blown dunes parallel to the coast and downwind from sandy beach deposits. Inactive dunes have >3 cm of organic matter within the top 30 cm, indicating infrequent deposition. Sitka spruce woodlands, willow tall shrub, alder shrub, and bluejoint meadows predominate.
Active Tidal Flat (Mta)	Areas of nearly flat, barren mud or fine sand that are periodically inundated by tidal waters. Tidal flats occur on seaward margins of deltaic estuaries, lagoons, leeward portions of bays and inlets, and at mouths of rivers. Tidal flats may vary widely in salinity depending on tidal flooding and influx of fresh water. Active flats have <3 cm of organics within the top 30 cm, indicating frequent deposition. Beachgrass and Ramenskii sedge vegetation predominate.
Inactive Tidal Flat (Mti)	Similar to active tidal flats, but flooded only during large storms. The sediments are only slightly brackish and the surface usually is well vegetated. The silty sediments have >3 cm of organics within the top 30 cm.
Abandoned Tidal Flat (Mtb)	Similar to active tidal flats, but rarely flooded by storms. The flats often have been uplifted by tectonic events. The sediments are non-saline and the surface usually is well vegetated. The silty sediments have >10 cm of organic matter formed by non-halophytic vegetation within the top 30 cm. Sweetgale low shrub, and Bluejoint meadow predominate.
Tidal Lagoons (Wetl)	Shallow estuarine water protected from open water by barrier islands and spits. Water is slightly brackish to brackish depending on the input of freshwater.
Tidal Ponds (Wetp)	Coastal ponds that are flooded periodically with saltwater during high tides or storm surges. Salinity levels often are increased by subsequent evaporation of impounded saline water. The substrate frequently is silt with some clay and fine sand, and occasionally contains peat.
Tidal River (Wetr)	Permanently flooded river channels that are affected by daily tidal fluctuations and have correspondingly variable salinity. The channels generally experience peak flooding during spring breakup and lowest water levels during mid-summer.
Tidal Active Chan. (Wetca)	Regularly flooded, dendritic, small channels (guts) on tidal flats. Typically they have muddy sediments and lack vegetation.
Tidal Inactive Channel (Wetci)	Irregularly flooded, dendritic, small channels (guts) on tidal flats affected only by storm events. Typically they have muddy sediments, are fresh to slightly brackish, and are vegetated by nonhalophytic vegetation that are slightly salt tolerant. Permanently flooded waterbodies within inactive channels are mapped as Tidal Ponds.
Nearshore Water (Wmn)	Marine water near the shoreline. Winds, tides, river discharge, and sea ice create dynamic changes in physical and chemical characteristics. Bottom sediments vary from wave cut bedrock, to gravel, to mud. During winter the water is covered with ice floes.
Shallow, isolated lakes (Wlsi)	Shallow isolated lakes and ponds are freshwater bodies that are not affected by tides or storm surges. These may occur on abandoned tidal flats and beaver impounded drainages at the margins to the tidal flats.

Table 9-3. Classification of geomorphic and ecological processes associated with landscape change of coastal ecosystems.

Change Type	Description
None	No change in ecotype.
Shoreline Erosion	Change from land to nearshore water.
Shoreline Erosion-Deposition	Change from land to nearshore water, and back to nearshore water.
Shoreline Deposition	Change from nearshore water to land.
Channel Erosion	Change from land to tidal river or tidal gut.
Channel Erosion and Deposition	Change from land to tidal river or tidal gut back to land.
Channel Deposition	Change from tidal river or tidal gut to land.
Sedimentation	Change from vegetated ecotype to barren land or earlier successional ecotype.
Beaver Dam	Change from land to water caused by a beaver dam.
Paludification	Change from water or marsh ecotypes to wet meadow ecotypes.
Sedimentation and Succession	Change from vegetated ecotype to barren land, and back to vegetated ecotype.
Shoreline Deposition and Succession	Change from water to barren land and then to vegetated land.
Early Succession	Change from barren land to an early successional ecotype with meadow or shrub vegetation.
Late Succession	Change from an early successional ecotype (meadow and shrub) to forested ecotype.
Tidal Fluctuation	Change from nearshore water to tidal flat in offshore areas, or vice-versa due to normal tidal fluctuation. While this change is distinctive on imagery, it was ignored and the barren tidal flat was assigned to nearshore water because it is not a persistent change.

9.5 Analysis and Reporting

9.5.1 Analysis

After completion of the photo-interpretation, analyses are performed, including 1) summary of abundance of ecotypes types by study area and period (imagery for each site may vary by a few years for each period); and 2) hypothesis testing to evaluate the significance of changes among years, with each study area being a replicate.

9.5.2 Reporting

Reporting of methods and results should be done every 10 yrs, after new imagery is acquired. The report should include figures showing the new imagery with a thematic overlay of vegetation types with the points symbolized by different colors, as shown in Fig. 9-1. Charts of the mean areal extent of each ecotype across the three study areas should be included in the report. Results of hypothesis testing also should be provided in tabular form.

9.6 Personnel Requirements and Training

The mapping of ecotypes should be done by a qualified plant ecologist or landscape ecologist familiar with the study areas. This work can be done in-house by qualified NPS staff or by contracting with a specialist. Once the photo-interpretation of vegetation types is completed, the analysis of change can be done by a statistician or an ecologist with guidance from a statistician.

9.7 Operational Requirements

The work is done for the initial baseline images at the start of the monitoring effort and may be expanded to include historical photography. The initial effort for photo-interpreting vegetation ecotypes requires ~80 person hours for the three study areas combined for each time period. Statistical analysis requires ~24 person hours and reporting ~40 person hours per time period. No fieldwork is required.

Facility and equipment needed for the work are limited to a computer, ArcMap GIS software for mapping, statistical software for analysis, and word-processing software for reporting. The cost for each time period for photo-interpretation of vegetation types, analysis, and reporting is approximately \$15,000 per time period.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
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