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Monitoring vegetation structure and composition at multiple spatial scales in the Central Alaska Network

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Important Note: This sampling protocol consists of this Protocol Narrative and the Standard Operating Procedures (SOPs) listed below. At the current time, this protocol has been field tested only in Denali National Park and Preserve. As a result, all of the particular examples of spatial and temporal aspects of sampling contained herein are from Denali. We propose that the same steps will be followed in order to apply these procedures in the other two network units: Wrangell-St. Elias National Park and Preserve and Yukon-Charley Rivers National Preserve.

Standard Operating Procedures for Vegetation Monitoring Program in the Central Alaska Network.

SOP 1:	Preparation of equipment and supplies for fieldwork
SOP 2:	Training field crews
SOP 3:	Creating sampling materials in GIS in preparation for fieldwork
SOP 4:	Preparing for a field sampling bout
SOP 5:	Navigating to sample points using GPS
SOP 6:	Establishing and marking permanent monitoring plots
SOP 7:	Recording physical and biotic characteristics of vegetation plot
SOP 8:	Documenting a permanent plot using digital photography
SOP 9:	Performing soil sampling procedures
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I. Background and Objectives

Issue being Addressed and Rationale for Monitoring Vegetation Structure and Composition

Primary producers (plants, algae and autotrophic bacteria) form the foundation of every terrestrial and aquatic ecosystem. The fundamental properties, energetic pathways and structural attributes of an ecosystem are all directly influenced by the rate and manner in which solar energy is converted to carbon-based chemical energy. Changes in the composition or functional attributes of the primary producers within a system result in myriad downstream consequences, including fundamental changes in the movement of energy through the ecosystem, the nature of trophic interactions within the system and the niche characteristics and habitat volumes for different elements of the biota. Monitoring vegetation is thus crucial to detecting and understanding ecosystem changes over time.

In addition to providing the energetic foundation for all ecosystem functions, vegetation is unique in that it also defines the habitat structure for most other forms of life. As a result, the differences in the faunal communities that exist between tundra and forest habitats in interior Alaska, for example, are a function of both the differences in the forms of chemical energy (i.e. primary production) that are available and the differences in structural properties of the habitat that exist between these two vegetation types. Even a cursory comparison of the different sets of birdcalls emanating from the tall bands of willows along a subalpine stream course versus those coming from an adjacent *Dryas*-covered tundra ridge will attest to this. Similarly, the mammalian and avian faunas of forested habitats in interior Alaska differs from the faunas found in neighboring alpine meadow sites, in large part because of the differences in vegetation structure found at these two types of sites.

The vegetation, in turn, is controlled by ecological factors primarily, but not solely, related to the physical environment such as insolation, temperature, precipitation, substrate type and quality, and disturbance regime. Plant-animal interactions such as herbivory are another important factor in controlling vegetation patterns and processes on the landscape, particularly during times of high animal densities. Two examples from Alaska are: the effects on vegetation of periodically very high hare densities in interior Alaska (Smith et al 1988, Bryant et al 1994), and the considerable changes to spruce forests caused by spruce-bark beetles in south-central Alaska a few years ago (Niemela et al 2001, Van Hees & Holsten 1994).

Understanding the changes in the distribution and abundance of different elements of the vegetation is central to monitoring the ecosystems of the Central Alaska Network parks. We believe that vegetation monitoring can serve as a “keystone” monitoring component that will facilitate the integration of other monitoring elements because of the central role of vegetation within the ecosystem, and the close cause and effect relationships between vegetation and the distribution and relative abundance of most other biological components of our ecosystems. In addition, the strong causal relationship between environmental parameters (such as climate and lithology) and vegetation attributes makes vegetation a sensitive bio-indicator of environmental changes.

In addition to the central role that vegetation plays in the ecology of central Alaska’s parks, the organisms that form the vegetation (including vascular plants, bryophytes and lichens) represent

a significant proportion of the biodiversity that the N.P.S. is charged with protecting. Conservatively, the parks in the Central Alaska Network contain more than 1000 vascular plant species and more than 1000 species of nonvascular plants. Changes in the vegetation of these parks would thus result in potentially significant alterations of fundamental patterns of biological diversity resident there. This monitoring protocol samples the landscape in order to monitor these significant aspects of the biological diversity resident in Park lands, which is crucial to detecting any emerging threats to this natural heritage.

Another critical management concern related to vegetation that this monitoring program will address is the threat to intact ecosystems from non-native species. Currently, exotic plants are confined to areas of the landscape of the network parks that have been directly disturbed by humans. As additional exotic species are introduced, and resident exotics expand their ranges, this relatively minor problem could evolve into a major threat to the integrity of Park ecosystems. The species composition measurements that will be recorded as a part of this program will serve as an "early warning" of any such potential threat of exotic plant invasions.

Recent research suggests that global climate change will profoundly affect Alaska's climate in the future (Ager 1997, Chapin et al 1995). Because the distribution and abundance of vegetation in the far north is so strongly controlled by the physical environment, the consequences of climate change in the Central Alaska Network parks are likely to be profound. Indeed, a review of recent scientific literature reveals that the there are numerous indications that these changes may already be detectable (Sturm et al 2001, Barber et al 2000, Chapin et al 1995, Suarez et al 1999). Additionally, evidence from the pollen record at the end of the glacial maximum during the Pleistocene suggests that a transition between vegetation community types can occur rapidly, within 100 years (Post 2003). The potential for profound changes due to climate warming include increased levels of insect herbivory (Fleming & Candau, 1998), changes in fire (Stocks et al 1998, Landhausser & Wein 1993) and other disturbance regimes with profound influences on vegetation (Rupp et al 2000, Scott et al 2002); widespread melting of permafrost and concomitant changes to vegetation (Jorgenson et al 2001, Osterkamp et al 2000, Osterkamp et al 1998); potential increase in exotic plant species invasions (Dukes & Mooney 1999); and changes in vegetation structure due to warmer temperatures and longer growing seasons, such as the spread of forest, or shrub encroachment into alpine areas (Johnstone & Chapin 2003). A primary goal of the vegetation monitoring program is to provide data to Park management concerning how the effects of all of these perturbations affect Park ecosystems, and at what spatial scale such changes are detectable.

An emphasis on sampling environmental gradients at multiple scales

The vegetation of the Central Alaska network is composed of a mosaic of ecosystems, varying along a gradient from temperate rainforest to arctic tundra. The distribution of the many plant communities that make up the landscape of each park is controlled by the interaction of climate, topography, substrate, and site history with regional biotas. These determining factors vary considerably across the landscape and thus we find a diversity of plant communities and vegetation types that vary across all spatial scales. The scale of these patterns varies from very small-scale patterns caused by micro-topography within individual sites to patterns on the scale of the landscape that are driven by differences in regional climatic factors.

The considerable diversity of vegetation types and communities that occur in the network includes tussock tundra on solidly frozen permafrost in the interior of the Toklat Basin, lush mixed forest in the Chugach Mountain lowlands, tall cow parsnip and forb meadows in the subalpine zone south of the Alaska Range crest, and well-drained *Dryas* tundra rich in species endemic to Beringia in the high alpine zone of the mountains north of the Alaska Range crest, and in the central interior highlands. The diversity that occurs within this network represents a considerable fraction of the community diversity resident in all of Alaska.

One basic example of the direct environmental control of vegetation structure is that the ecological distribution of tree species closely follows gradients in growing season air and soil temperature. A measure known as mean July isotherm is very predictive in modeling the limit of trees on the Alaska landscape under present conditions (MacDonald et al 1998). As a result, closed forest does not generally occur in alpine areas above about 3000 feet in elevation. However, we also know that historical and geographical factors interact with this strict ecophysiological control of plant distributions – and in many places the treeline has not reached its maximum possible elevation (based strictly upon climatic factors) due to barriers to seed dispersal, the relative recency of deglaciation, or other factors.

On another spatial scale, we can also observe differences *within* broadly defined vegetation types themselves that occur across the large climatic and edaphic gradients that exist within the network. That is, although "white spruce forest" is found near Denali Park headquarters, in the Yukon River lowlands of Yukon-Charley Rivers NP, and also in the Copper River basin far to the east, the characteristics of these spruce forests vary considerably according to the different ecological conditions that occur in each of these three different regions of the network. The structure and composition of the forests in these areas are also affected by the historical and paleoecological factors that have influenced the development of the regional floras in each of these distinct regions of the park. Differences in forest structure and composition that are the product of these gradients, in turn, would likely result in divergent responses to any changes in ecological conditions over time among forest types in these three different areas. For this reason, monitoring one stand of "white spruce forest" in one given area of the park would not necessarily provide monitoring data applicable to all our white spruce forest types.

It is possible for trained observers to describe vegetation patterns that occur over the landscape of interior Alaska, and to hypothesize about the factors that cause these patterns. Tools such as landcover maps and satellite imagery offer additional ways to observe and describe vegetation patterns in a very general way. However, to understand and reliably detect important changes in the vegetation patterns and processes that occur on the landscape, it is vital to make on-the-ground quantitative measurements of key attributes of the vegetation in a systematic way. These field measurements allow us to quantify and understand the specific nature of the relationships between vegetation patterns and their primary driving variables, and to monitor how these relationships may change over time. Significant changes in the species composition or structure of the vegetation of an area may occur before these changes are reliably discernable in a satellite image or vegetation map. Changes in remote sensing platforms over time add a further complication to relying on remotely-sensed images to detect changes that are occurring on the ground.

The important factors that control vegetation patterns on the landscape vary along measurable gradients principally related to topography, edaphic conditions, and climate. These large scale gradients cause variation in more immediate environmental gradients such as soil properties, temperature, moisture, snow cover, growing season length, and related factors. Therefore, to understand the distribution and abundance of a vegetation parameter on a landscape scale, and how it changes over time, it is critical to effectively sample these ecological gradients. A sampling design that only samples a small quotient of any major ecological gradient would not detect changes in the underlying relationships between the "standing crop" of vegetation on the landscape at any one time and the factors that have shaped the major patterns in this standing crop. The focus of our long-term vegetation monitoring strategy is on detecting and understanding changes in the primary ecological *relationships* between landscape and vegetation, not simply describing the properties of the standing crop at any given point in time.

The approach to monitoring that we have developed is based on the observation that many of the physical and biological resources in Denali vary along gradients at three discernable spatial scales:

- Regional-scale gradients: variation in resource attributes caused by large scale phenomena such as variation in macro-climate regime, differences among geological terranes, and variation due to differences in ecological history (i.e., glaciated versus unglaciated).

- Meso-scale gradients: variation in resource attributes along major environmental gradients correlated with topography, such as slope, elevation, aspect, and individual site history.

- Micro-scale gradients: variation in resource attributes along very small-scale gradients such as microtopography, differences in within site vegetation communities, and differences in within site vegetation structure.

A primary goal of this design is to sample the range of variation in physical and biological parameters that exist along each of the gradients outlined above. For instance, regional-scale gradients in resource attributes will be understood by analyzing the variation in measured parameters among numerous mini-grids in different ecoregions. Meso-scale gradients will be understood by analyzing the variation in measured parameters within individual mini-grids. Variation along micro-scale gradients will be captured within individual sites in a mini-grid.

Historical Development of Vegetation Monitoring in the Central Alaska Network

The only ongoing, long term vegetation dataset from the three Central Alaska park units (which total approximately 14.235 million Ha, or 26 % of all N.P.S. lands) was the vegetation component of the prototype Long Tern Ecological Monitoring program in Denali, which was initiated in 1992. Vegetation work in the other network parks was limited to sporadic research or impact assessment studies and vascular plant inventory efforts. The development of a network-

wide program for vegetation monitoring evolved directly from the prototype program in Denali, which is described below.

From the beginnings of the prototype Long Term Ecological Monitoring program in Denali in 1992, detection of change in the vegetation of the park was recognized as a fundamental aspect of the program. The original program design concept was organized around the idea of watersheds as integrating features of the landscape (Thorsteinson and Taylor 1997). Vegetation monitoring began on permanent plots arrayed on an elevational gradient in the Rock Creek watershed, a south-facing watershed spanning current treeline located near park headquarters. Measurements on the plots would occur on two time scales. Measurement of the fundamental attributes of composition and structure of the vegetation would occur every decade. Measurements to assess growth and reproduction of white spruce (*Picea glauca*), phenology of selected herbaceous and shrub species, and berry production would occur annually.

In the original design, 5 watersheds spread throughout the park were to be included in sampling. The costs of such expansion were high, and eventually it became obvious that costs of the original design were beyond available funding. The original design relied on plots selected by judgment, thereby precluding inference from the studied plots to a broader area. The original design was also primarily focused on a single issue—global climate change. Several years into the monitoring effort, the implications of these limitations were clearer and became significant concerns. These concerns stimulated a major reevaluation and revision of park objectives for vegetation monitoring.

The primary lessons that emerged from this reevaluation process were threefold:

1. The objectives for the vegetation monitoring program needed to be reviewed and then clearly and explicitly stated for the program to meet the needs of park management and to finalize a scientifically-sound protocol tailored to meet those needs.

2. The design of the initial vegetation monitoring project in the Rock Creek drainage was too spatially limited to provide meaningful information concerning the vegetation cover of the park. The spatial scale of the program needed to be recalibrated to the scale of the park landscape, rather than the scale of an individual small drainage basin.

3. The design of the vegetation monitoring program needed to be based upon a statistically-rigorous, randomized approach to sample allocation to ensure that valid design-based inferences could be made from the monitoring data.

Vegetation monitoring objectives were reformulated. In this process, the objectives were organized into two scales--extensive and intensive. The revised objectives also addressed a considerably broader array of issues than the initial prototype program.

In 1998, the idea of using a systematic grid as the framework for detection of change in vegetation (and other ecological attributes) was suggested by outside reviewers (McDonald et al. 1998). Our initial reaction was skeptical—we assumed a grid would not feasible. After further consideration, however, the idea became attractive to us for several reasons. Collocation of plots

would move us toward the important goal of integrating data sets, and the probability design would avoid bias and allow broad-scale inferences to be made. The design would also be robust to unanticipated changes in ecological conditions. These advantages were enough to spur further investigation of the grid idea.

Thus, beginning in 1998, the USGS and NPS, in a joint research effort, began explorations of a systematic design for meeting the revised monitoring objectives. We focused our attention initially on investigating the potential applicability of a major national monitoring program that uses a systematic design to detect change in forest ecosystems--the U.S. Forest Service's (USFS) Forest Health Monitoring (FHM) program. Could their design and methods be applied in Denali, thereby saving us protocol development costs and providing seamless integration with a nationwide data set? We learned that the spatial and temporal scales of the questions asked by the USFS did not match the scales of the questions of interest to Denali, so the FHM design and methods could not be directly applied. We therefore experimented with modifications to the design and field methods to better address Denali's specific objectives (Helm 2001).

Preliminary Exploration of the Systematic Grid Design for Denali

At the time the grid idea was first broached, University of Alaska Fairbanks vegetation ecologist Dr. Dot J. Helm was working on development of vegetation sampling design and methods for Denali, under the auspices of a cooperative agreement with the USGS-Alaska Science Center. During her tenure on the project (1998-2000), she was involved with preliminary exploration of the grid idea, and with development of sampling methods to be used at each point. The results of her work are summarized in Helm (2001).

Once we had decided to test the grid idea, Helm focused her preliminary work on whether the design and procedures of the Forest Health Monitoring (FHM) Program of the U.S. Forest Service could be adapted to Denali's goals. The FHM Program uses a grid, with spacing of 27 km between points. Sampling at each point uses a cluster design with 4 plots, to reduce travel costs and capture more of the variation at each point. Our experiences with the FHM methodology helped us to understand that our objectives were different from their objectives, mainly in terms of spatial and temporal scales. In FHM, the spatial scale of interest is much larger (large regions of the country vs. one albeit large park), and the temporal scale much shorter (annual estimates of change vs. decadal or longer estimates of change). This realization spurred us to evaluate other grid spacing and sample unit arrangements.

The major tradeoffs involved in selecting a grid spacing concern getting enough points to be able to say anything but not so many points that you cannot afford it. Decisions about the grid spacing, and the level of sampling that occurs at each point, also relate to the scale of the questions being asked.

We recognized that GIS analysis and simulations could be very helpful to selection of grid spacing. Helm (1999) took a ballpark look at how grids of various sizes would sample the ecoregions and subsections in Denali. Starting with the 27 km spacing of the FHM grid, which would include 34 points, she found that this spacing was too sparse—several ecoregions were missed entirely. Intensifying the FHM grid twice (18 km and 9 km), did a much better job at

covering the different ecoregions, but had far more points than could be reasonably sampled (110 and 334 points, respectively). She speculated that something like a 12 km grid would be usable, but that correlations between adjacent points should be investigated.

McDonald et al. (2000) conducted a computer exercise to mimic sampling of basal area (of trees) and investigate grid spacing and its effect on variance and bias of estimators. In this first exercise, they tested grid spacings of 2.5 to 20 km. The average number of points encompassed by these grids ranged from 54 (20 km grid) to 5,868 (2.5 km grid). During this simulation, they found no obvious "jumps" in the precision of the estimators to aid in selection of grid size.

Goeking et al. (2000) looked at how using grid spacings ranging from 100 m to 20 km would capture the biophysical diversity of Denali's environment. They compared the proportional representation of ecoregions and subsections, topography (as represented by slope, elevation and aspect), and land cover among grids of various sizes. They used simulations to also examine the variability in representativeness at each grid size. They found that elevation was the only characteristic accurately represented in the 20-km grid, suggesting that the 20-km grid size was too coarse to adequately represent the variety of environments in Denali. They concluded that a 10-km grid would represent the actual distribution of vegetation types in the park, and that this spacing was probably the balance-point between logistical constraints and meaningful data.

Up until this point, we had been working with the assumption that a single plot, or a cluster of subplots (as in the FHM program) would sample each grid intersection. The idea of locating a cluster, or "mini-grid" of 25-36 points at each grid intersection was first suggested by Carl Roland in December 2000. Each mini-grid would be sampled from a base camp over a 1-2 week period. The impetus for the mini-grid idea was two-fold.

1. A design that grouped points together would facilitate accomplishing more work per unit of access cost because the sample unit into which travel is required is the "mini-grid" rather than an individual point. Because within any given geographic region, vegetation is more strongly controlled by local site factors such as slope, aspect and elevation than by geographic location, per se, we could still assemble useful data across important ecological gradients by working more intensely within a 6.25 km area, as opposed to spreading primary plot locations more widely.

2. We could acquire reasonably detailed information about each mini-grid that would allow analyses of gradients and patterns *within* each mini-grid. This approach reduces concerns that with relatively few primary points (grid intersections) the underlying relationships between vegetation and topography could not be effectively captured within the design.

Roland used a map showing the 20-km Park-wide grid to show what the mini-grid design might look like. The number of mini-grids in the design was reasonable (~60), and it was clear that a variety of access means, including walking, access from the park road, helicopter, rafting and fixed-wing aircraft, could be used. With this diagram, the logistic feasibility of the grid design seemed less daunting and worth further study.

At this point, the design became a multi-stage design: The first stage consists of the 20-km grid intersections. The second stage consists of the mini-grid. The number of points and spacing to be used in the mini-grid was decided upon by a process of trying to optimize two (competing) sets of objectives: one set of objectives was ecological and the other set was logistical in nature. On the ecological side of the equation, we sought to distribute points in a way that captured significant meso-scale variation in landscape and vegetation attributes broadly indicative of the landscape mosaic of the study area. In other words, we hoped to effectively sample the primary gradients (such as slope, aspect, elevation and vegetation type) that occur within each study area. In addition, we wanted to achieve the maximum spacing between points to increase the "independence" of the observations made at each of the plots within the mini-grid. On the logistical side of the equation, we wanted to include the maximum set of points feasible within a sampling bout of 7 to 10 days in duration, and to balance the desire for increased spacing of sample points with the amount of time that would be required to walk between them.

We decided upon an arrangement of 25 points, spaced 500 m apart (i.e., 5 rows of 5 points each). This provided enough points to describe the variation in vegetation that is encountered in a 2 km^2 area, and 500 m was determined to be a reasonable distance between points that reduced the likelihood of over-sampling local patterns, but also allowed for reasonable travel time between points by crews traveling on foot. With any more points or longer distances between points, we would spend all our time traveling and not be able to complete sampling in the time allotted.

The mini-grid idea fit perfectly with the hierarchical approach, and with our desire to detect changes at multiple scales. The regional gradients caused by broad-scale factors such as climate, geology and ecological history, would be captured by comparing mini-grids, while meso-scale gradients related to topography and individual site history would be captured by comparing points within mini-grids.

There was another practical reason that made the mini-grid approach attractive. Under a single-stage Park wide design consisting of plots at the grid intersections, all plots would need to be visited to estimate parameters across the park. If the program did not survive long enough to visit all the grid intersections, any data collected would be essentially useless. With the two-stage approach, each mini-grid could stand on its own and provide valuable data for a given study area, so even if all mini-grids were not visited, usable long-term data would have been collected.

Spatial and Temporal Scales for Vegetation Monitoring

We separated the objectives for long-term monitoring of vegetation into two categories based on their spatial scale: "extensive-scale" objectives, and "intensive-scale" monitoring objectives. A key difference between these two categories relates to the area of statistical inference associated with the objectives. Landscape-scale objectives are those monitoring parameters for which we seek to make direct inferences about changes in broad-scale patterns on the landscape of the park. A goal of our landscape-scale monitoring objectives is to detect changes occurring over areas the size of ecoregion subsections. Data collected to meet these objectives would allow us to make statements such as:

"In an estimated 25 percent of forested sites in the "Interior boreal mountains – outer ranges" ecoregion subsection, paper birch has been replaced as the dominant forest tree species by white spruce over the past 20 years. This apparent conversion of broadleaf to conifer forest has been restricted to sites below 1000 m in elevation, however, and has not been observed on sites above this elevation".

The rationale that will allow us to make general statements like this is that for the extensive-scale objectives, each point on the landscape will have an equal probability of entering the sample population; hence the area of inference associated with the analysis of these data will be the entire region. An important benefit of this spatially extensive sampling frame will be the ability to make area-based estimates concerning the prevalence of a given change in condition or attribute of the vegetation on a region-wide basis.

In contrast, the monitoring activities in the "intensive" sites will generally be more time consuming than those performed as part of the extensive sampling protocols. In addition to the measurements of vegetation structure and composition that will be performed at the extensive sites, process variables such as growth and reproduction and phenology of selected species will be quantified in the intensive monitoring sites. In addition, more detailed observations of particular parameters relating to specific management concerns (such as revegetation and the abundance of exotic plant species) will be made at some the intensive monitoring sites.

In contrast to the park-wide sampling frame used for assigning sample sites to meet the extensive objectives, the "intensive" scale sites will be chosen with specific constraints upon their location. As a result, the area of inference associated with the analysis of data from the intensive sites will be reduced in some cases, and often limited to a more localized area relative to the landscape–scale data. The necessity for constraints in locating the intensive-scale sites arises from our need to access them quickly and easily because we will be performing a larger number of more time-consuming tasks in the intensive sites. Because of these limitations on the area of inference associated with the intensive sites, effort must be made to avoid locating these monitoring stations in atypical sites so that the data gathered there are applicable to the largest fraction of an individual Park possible. Additionally, we will still need to integrate randomization procedures into the siting of the intensive sites. Randomization would remove potential biases from the plot selection process and increase the area of inference of the data collected in the "intensive" sites. The focus of this report is on the landscape-scale, or extensive set of objectives. The intensive scale objectives and the design for meeting those objectives will be treated in a future document.

The spatial scale at which we seek to detect changes in the vegetation cover of the park is directly related to the temporal scales at which those changes may feasibly be detected. Inherent in a park-wide sampling frame is the need for allocating considerable logistical and personnel efforts to gather data from across the diverse and remote park landscape. Because the annual appropriation for the monitoring program is divided among a suite of components, there is a limited amount available each year for any one of the components. This fiscal limitation means that sampling the vegetation of the park landscape must be accomplished over a period of several years, rather than within any single year. Due to the large size of the park and difficulties of access into it, it is impossible to devise a landscape-scale sampling plan that would be both meaningful and feasible to accomplish within a single year.

As a result of these fiscal and logistical constraints on the program, we have identified a suite of landscape-scale vegetation monitoring objectives that are compatible with a sampling interval of multiple years. In general, the objectives that we have identified for monitoring vegetation at a landscape scale are fundamental properties of the vegetation cover that we would expect to show detectable changes only over decadal time intervals, with relatively less inter-annual variation. Highly labile vegetation attributes, such as annual variation in phenology or reproductive effort were specifically excluded from the landscape-scale monitoring objectives because they were considered to be prohibitively expensive to accomplish at the large spatial scale. Parameters that are too expensive to monitor at the landscape scale, but are nevertheless considered vital to the vegetation monitoring effort will be included in the *intensive scale* vegetation monitoring objectives.

Extensive-scale Measurable Vegetation Monitoring Objectives

We now describe the nine extensive-scale monitoring objectives in the vegetation component of the CAKN vital signs monitoring program. These objectives relate mainly to vegetation characteristics, but also include several objectives relating to other ecological attributes (e.g., evidence of forest insects, soil characteristics, landscape appearance). This set of objectives, although developed through the vegetation component of the program, reflects the desire for an integrated monitoring program.

Objective #1—Structure of the Vegetation

Monitor changes in the structure of the vegetation cover of the Central Alaska Network parks at a landscape scale.

Vegetation "structure", as we define it, means the relative abundance (in both vertical and horizontal dimensions) of the different species and growth-form classes that constitute the vegetation cover. Growth form classes that we recognize include the following: tree, shrub, dwarf shrub, forb, graminoid-sedge, graminoid-grass, moss, and lichen. The vegetation structure of a site, therefore, will consist of quantitative data: cover values by species (within different height strata) for each of the sample sites. In addition, the quantitative data will be used in combination with other observations to classify the vegetation of each site according to the Alaska Vegetation Classification (Viereck et al 1992).

Specifically, the measurable objectives for monitoring vegetation structure at a landscape scale are:

1.1 Detect changes in the absolute and relative abundances of the different growth-form classes that form the vegetation cover of the park.

1.2 Detect change in the abundance and composition of the dominant species in the vegetation cover.

1.3 Detect change in the distribution and abundance of discrete vegetation types on the

landscape of the parks.

Cover data from successive sampling iterations will be compared to determine whether change has occurred in the vegetation structure of the site during the intervening period, and what the nature and direction of that change has been

Objective #2— Species Composition of the Vegetation

Monitor changes in the taxonomic composition and diversity characteristics (including species-area relations) of the vegetation cover of the Central Alaska Network parks at a landscape scale.

This objective includes vascular plants, bryophytes (mosses and liverworts) and macro-lichens. Along with vegetation structure, taxonomic composition is a basic element of the botanical resource of the Park. Changes in plant species composition are similarly strongly correlated with a broad spectrum of other vital aspects of the ecosystem including forage quality, habitat use patterns, nutrient cycling and successional status (to name a few). In addition, the most basic taxonomic unit in resource conservation is the species, and it is therefore incumbent on the Park to monitor changes in species distribution and abundance to meet this conservation imperative. Furthermore, specific management concerns such as the invasion of exotic plant species and the conservation of rare native plants require a landscape-scale framework (such as can be provided by the LTEM program) within which to institute more targeted and intensive monitoring activities. Monitoring species composition is also important because of "keystone" ecological functions only performed by certain species. The absence of a keystone species has been shown to have cascading and unpredictable effects throughout a natural system. Similarly, specific mutualistic relationships (dependent on particular species) can have very important consequences for the integrity of the system. Potential examples of this are specific plant-pollinator relationships (important for rare invertebrates), secondary host plants of forest pathogens (*Ribes*, for instance), and obligate mutualistic associations with ecosystem implications (N-fixers, mycorrhizae,).

Specifically, the measurable objectives for monitoring the taxonomic composition of the vegetation are:

2.1 Detect changes in the species composition of the vegetation (this consists of comparisons of species *lists* at $time_1$ vs. $time_2$ vs. $time_3$).

2.2 Detect changes in the species-richness characteristics of the vegetation (this consist of comparisons of the *number* of species per unit area at $time_1$ vs. $time_2$ vs. $time_3$)

2.3 Detect changes in selected measures of diversity of the vegetation at several spatial scales (using comparisons of calculated indices of diversity at $time_1$ vs. $time_2$ vs. $time_3$)

Our characterization of the species composition of a site will thus consist of two essential elements: a complete list of the taxa that occur there and a set of quantitative metrics of

species:area relationships for the site, including selected numerical diversity indices and typical species-area curves.

Objective #3—Density and Basal Area of Selected Tree Species

Monitor the density (number of individuals per unit area) and basal area of tree species at a landscape scale.

These measurements are important because they will give us rough measures of the productivity (basal area) and population structure (numbers of individuals within different size classes of a species) for tree species, which strongly affect other components of the ecosystem.

Specifically, the measurable objectives for monitoring density and basal area of tree species are:

3.1 Detect changes in the absolute and relative densities of the different tree species at a landscape scale.

3.2 Detect changes in the basal area of tree species at a landscape scale (this metric can also be expressed in both absolute and relative terms).

Absolute density is the estimated number of trees per unit area, relative density is the relative contribution of each different tree taxon relative to the overall density of trees on the landscape (one species may stay the same in an absolute sense, but still become relatively more prominent due to diminution of other taxa in a local area). Obtaining the information listed above will be an integral part of mapping each permanent plot, as the DBH and location of each tree and tall shrub will be recorded for these purposes.

Objective #4—Annual Growth of Spruce (using dendrochronological techniques)

Monitor changes in the patterns of annual growth of spruce trees at a landscape scale over time

This objective will be met by extracting increment cores from a subset of trees in the vicinity of each permanent vegetation monitoring plot. These cores will be prepared and measured to quantify patterns in the annual growth of spruce trees over several hundred year periods, depending on the age of the tree.

Specifically, the measurable objectives for monitoring annual patterns of tree growth are:

4.1 Quantify the variation in the annual growth increments of spruce at a landscape scale (along principal environmental gradients).

4.2 Detect changes in the relationship between landscape variables and spruce annual growth.

Using increment cores to study the patterns of variation in annual growth of spruce trees on the landscape gives us a unique opportunity to extend the monitoring program backwards in time.

The analysis of increment cores containing ring width information dating back to the 1600s (some of which were obtained during the pilot study!) will allow us to examine the current patterns of spruce growth within a much larger temporal context. Over time, we will assess whether the patterns we see today in annual spruce growth are within the historic range of variation observed over the Park landscape. In addition, annual growth in spruce has been found to be a sensitive indicator of certain climatic variables, which make these data potentially valuable for understanding how climate has historically varied across the diverse landscape of the Park.

Objective #5—Forest Insect Damage

> *Monitor changes in the degree, extent and distribution of selected forest insect damage at a landscape scale.*

Land management agencies were caught off-guard by the spruce-bark beetle "outbreak" that occurred in south-central Alaska recently. The National Park Service, and others, had virtually no baseline data regarding the presence, abundance and distribution of forest insects or their indicators. As a result, we were unprepared to provide the public and decision-makers with valuable background information on this phenomenon. We believe that it should be the responsibility of the monitoring program to provide background data concerning issues such as this.

Specifically, the measurable objectives for monitoring insect damage are:

5.1 Detect change in the number of forested plots affected by selected insect species over time.

5.2 Detect change in the severity or intensity of insect damage to trees in forested plots over time.

5.3 Detect change in the bole and canopy characteristics of study plots over time (in relation to insect activity).

If the climate continues to warm, it stands to reason that major changes in the distribution and abundance of insect species will occur in our area. It is well known that the growth and development in many insect taxa is largely temperature dependent; therefore the distribution and abundance of many insects is likely controlled by factors related to temperature-related climatic factors. Major changes in the population dynamics of phytophagous insects would be expected to have potentially profound influences upon the Park's ecosystems. The relatively low level of insect pressure on northern plant populations (due to short growing seasons, killing frosts, and extreme cold weather events) may mean that these populations are genetically "unprepared" for high levels of phytophagy from insects. This might set the stage for dramatic changes in the vegetation should higher temperatures reduce generation times and increase over-winter survival rates for insects in interior Alaska.

Objective #6—Soil Attributes

> *Quantify the variation in primary soils attributes such as fertility, texture, soil temperature and pH at a landscape scale and monitor changes in these attributes over time.*

Specifically, the measurable objective of monitoring soils attributes is to:

6.2 Quantify variation in soils attributes (including temperature, fertility, pH, and texture) on the park landscape and detect changes in these attributes over time.

Soil attributes are of central importance in understanding the distribution and abundance of plant species across the landscape. Soil attributes mediate virtually all environmental influences upon the vegetation in one way or another. In the absence of data quantifying basic attributes of soils, such as soil reaction (pH), texture, organic matter and relative fertility, it would be very difficult, if not impossible to really understand any of the major relationships between vegetation and the primary environmental gradients, or any changes that would occur in these relationships over time. Soils represent the major interface between physical drivers of our ecosystems and the biota. The soils information we will collect represents a necessary baseline and context for understanding variation in other attributes of the ecosystem.

Objective #7—Active Layer Depth and Occurrence of Thermokarst

> *Monitor the depth of the active layer at a landscape scale, also monitor evidence of thermokarst processes at a landscape scale.*

Specifically, the measurable objectives for monitoring active layer depth and evidence of thermokarst at a landscape scale are to:

7.1 Detect changes in the mean depth of the active layer on the park landscape.

7.2 Detect changes in distribution and abundance of thermokarst on the park landscape.

A major finding of the Bonanza Creek LTER site over the past decade has been an increased rate of thawing of permafrost causing increased area affected by thermokarst processes: Approximately 37.5% of Caribou-Poker Creeks Research Watershed has unstable or thawing permafrost. At least 2.1% of the permafrost in this watershed has retreated in the last 90 years due to climate warming. It appears that 1.2% of the permafrost in the watershed did not recover after the forest fires early in this century.

While it would be prohibitively expensive to monitor the distribution of permafrost per se at a landscape scale, it is less difficult to monitor area the depth of the active layer because this can be measured using inexpensive soil probes at each vegetation plot. In addition, thermokarst is evident at the ground surface through geomorphic changes, and associated other evidence. The distribution of such evidence may also be efficiently monitored on the extensive plot network for the vegetation monitoring program.

Objective #8—Fuels

> *Monitor changes in the amount, distribution and character of fuels (particularly the duff layer and woody debris) on the landscape of the Central Alaska Network parks.*

Specifically, the measurable objectives for monitoring fuels are to:

8.1 Detect changes in the total amount of fuels on the landscape of the network.

8.2 Detect changes in the type, size and position (vertical distribution) of fuels.

8.3 Detect changes in the depth of the duff layer and litter layer on the park landscape.

Fuels data will emerge from data collected to meet other objectives, including monitoring of vegetation structure and soils attributes. One method quantifying the fuel attributes is part of the vegetation structure measurements: cover of both live vegetation and dead debris and litter will be a part of these measurements. This will provide cover and vertical distribution by classes of fuels: litter, woody debris, and standing dead wood by height stratum. Additional measurements relating to the depth of the duff layer will be made at each extensive vegetation sampling site as part of the soil sampling objective.

Objective #9—Using Georeferenced photo points as a tool to monitor landscape change

> *Monitor changes in the "appearance" of the vegetation and of the landscape through time*.

Meeting this objective involves creating a geo-referenced network of permanent photo points dispersed throughout the landscape that will allow for the documentation of landscape scale changes in the vegetation of the park.

Two types of photo points will be documented through the landscape-scale monitoring of vegetation:

9.1 Photo points directly associated with the sampling of the extensive plots that will document vegetation changes on the scale of the site to the local area.

9.2 Photo points chosen for their usefulness in panoramic or larger-scale documentation of the appearance of the landscape at various points through time.

Quantitative data are crucial to monitor changes in the vegetation of the Park over time. However, for certain important attributes including treeline dynamics, a picture (particularly a high resolution, geo-referenced picture specifically framed to capture important vegetation attributes) may truly be worth a thousand data points. Over the past several years we have worked on a project to reproduce some historical photos that have taken in Denali over the years, this work has shown the value of repeated photography for documenting and understanding landscape change over time.

II. Sampling Design

The sampling design for this program is an unstratified, multi-stage systematic grid design based on a random start. In this design, a set of "mini-grids" consisting of 25 points (5 rows of 5 points spaced 500 meters apart) are located on a lattice of "macro-grid" points that are spaced 20 km apart. A 200 m^2 permanent vegetation plot is installed at each of the 25 mini-grid points, and measurements of various parameters are made within this vegetation plot. Although the underlying design is based on a Park-wide sample allocation, for cost and logistical reasons we have reduced the actual initial sampling area to a large subsection of each Park, which we refer to as the initial sampling window (see Figure 1 for an illustration of the sampling widow for Denali). We could thus expand the sampling area to include the *entire* extent of each Park using the same underlying sampling design, if it becomes feasible to do so in the future.

In addition to the 20 km base systematic grid sample, we will intensify sampling in limited, easily accessible areas of each Park that are of high management interest. The reason for this intensification is to obtain higher spatial resolution in the monitoring program for areas that are of particularly high concern to management. In Denali, this area of sampling intensification is the immediate road corridor area (see Figure 2). In a buffer zone extending 3 km on both sides of the road, we have added all of the mini-grids from the 10 km Park-wide systematic grid sample to intensify the spatial resolution of the program in this area. There are 10 additional mini-grids in this intensive sampling area, in addition to the five mini-grids from the base 20 km systematic sample .

In this sampling design, then, we have two simple, *overlapping* areas of statistical inference: 1) the sampling window within which we are measuring all mini-grids on the 20 km systematic grid (this window covers about 1.289 million Ha); and 2) the smaller road corridor intensification area (which contains 170,854 Ha) wherein we have intensified the macro-grid to include the 10 km mini-grids. Inferences concerning the whole sampling window (#1) will be made using the *only* the (31) primary 20 km mini-grids that it contains, whereas inferences about the road corridor will be made using only data from the 10 mini-grids in that area. There are five mini-grids that occur in both of these samples.

<u>Rationale for Selecting this Sampling Design Over Others</u>

The idea of using a systematic grid for the Denali vegetation monitoring program was first suggested by statistical consultants Lyman McDonald and Trent McDonald of WEST, Inc. during a visit to the park in 1998 (McDonald et al. 1998). The idea was to locate plots or transects or other sampling units for various attributes of the ecosystem in a grid system spread over the entire park. This approach would give us a probability sample, avoid bias, and by collocating sampling for various components of the program, provide a method for integrating data sets. The approach would also use permanent sample units, which have important advantages in long-term monitoring (discussed below), over temporary sample units.

One advantage of grid designs is their efficient description of spatial pattern (Cole et al. 2001). In other designs, much information about spatial pattern is discarded: samples come from the same or different sites. Information about the relationship among sites is lost. Because detecting

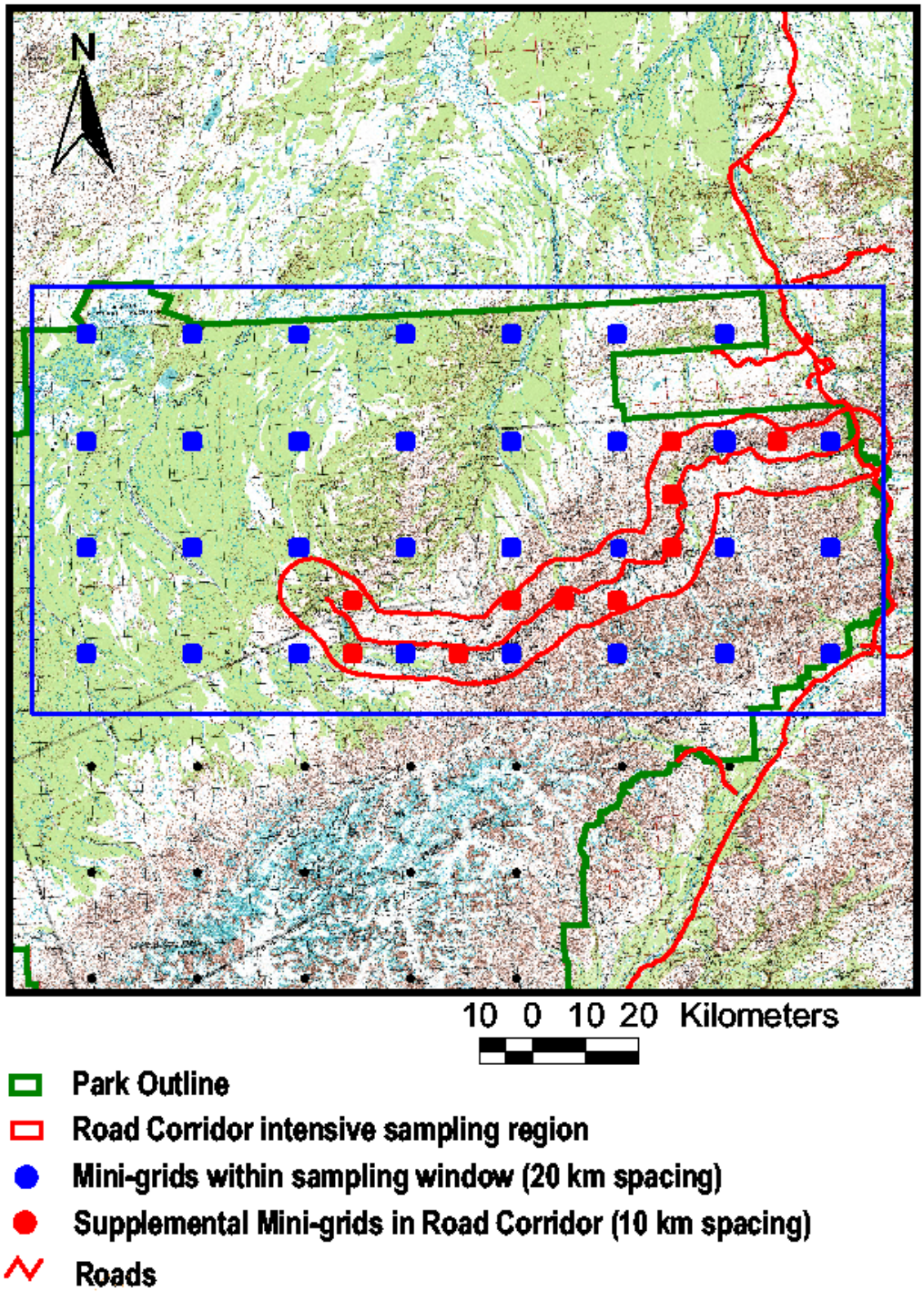


Figure 1. Map of Denali National Park and Preserve showing the spatial arrangement of sampling locations for the vegetation monitoring protocol.

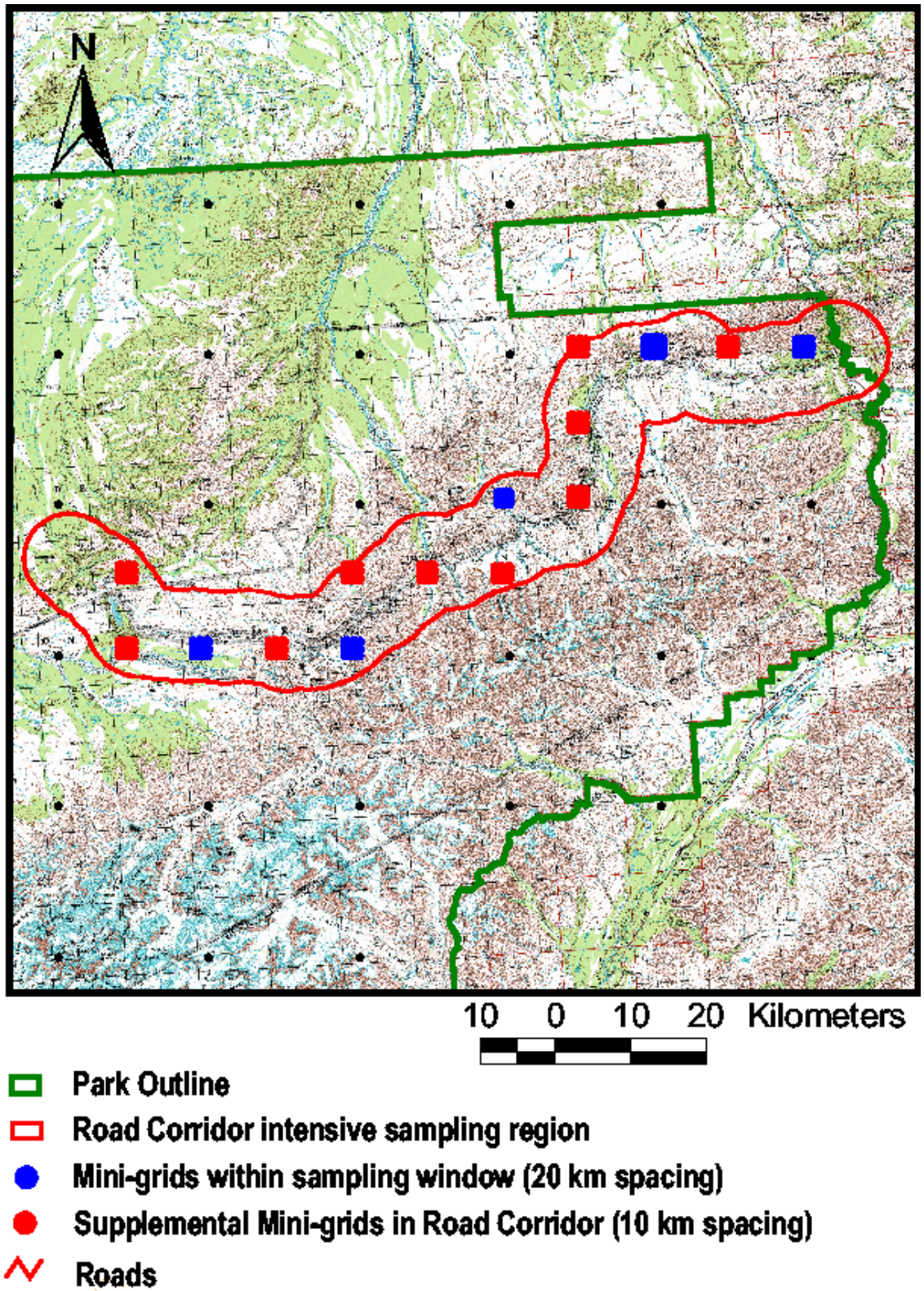


Figure 2. Map of northern region of Denali National Park and Preserve showing detail of the Road Corridor intensive sampling region.

changes in spatial patterns is a primary goal of the program, the systematic grid design is favored. The multi-stage grid design is also suitable for detecting changes in spatial patterns at a range of scales. In this regard, one of the strongest features favoring the grid design relates to its application in a hierarchical approach to monitoring. In the hierarchical approach, several scales of sampling intensity are nested to match spatial and temporal scales of ecological process and change, and to economize. At the broadest spatial scales, the park would be sampled with remote sensing using a base grid over the whole park. At what we have come to call the extensive scale (the topic of this report), a moderate number of grid intersection points are visited where measurements meaningful at regional scales are made. A small number of the extensive sites are used for intensive measurements too expensive or time-consuming to consider measuring at all sites. Use of the grid in a hierarchical framework was considered key to creating an integrated program.

The use of the systematic grid eliminates certain important types of bias in the process of sample site allocation, and frees the program from the constraints imposed by current understanding or projections of change. That is, by not constraining the sampling plan based on our own preconceptions, it will potentially be more versatile and robust over time. The grid sampling approach will also allow us to make aerially-based inferences concerning changes in vegetation structure over time over the entire landscape of the sampling window. In other words, we will be able to make an estimate of the percentage of the Park in which a particular condition, or change in condition over time, occurs.

Three other concepts were implicit in the grid design. The first was that the design is robust for detecting unanticipated changes. Whether this feature is advantageous depends on your point of view. Many monitoring programs are targeted toward detecting specific changes (e.g., pollution events or population dynamics of a single species). Targeted programs are relatively easy to design, and they are efficient because sampling can be optimized for the change of interest. However, because these programs are targeted, they are not good at detecting unanticipated changes. If detection of unanticipated or unpredictable changes is one of the reasons for monitoring, then the design issues are more complicated. A grid design is appropriate because it makes no assumptions about where changes might occur, and spreads sampling effort evenly over the sampling frame. The grid design essentially allows you to hedge your bets about future changes that cannot be predicted based on current understanding.

Why is detecting unanticipated changes important? Our knowledge of ecosystems and how they change through time is improving, but there is much we do not know, particularly at the "extensive", or landscape scales that we have decided to target. Ecological changes we cannot foresee may be the ones we need to be the most concerned about. Current guidance about what to monitor follows the drivers-stressors-effects- approach, which leads to targeted monitoring. Certainly this is important to include in the monitoring program. However, having something to catch the unforeseen changes also seemed important.

The second concept embodied in the grid idea was a philosophy about stratification. Stratification is often desirable because it reduces variation in estimated variables. When estimates are more precise, change detection is facilitated. In long-term studies, however, stratification must be used with care, because if the strata change, the data become difficult or impossible to use for their intended purpose. In ecological studies, vegetation type is one of the most used variables for stratification. Clearly, stratifying on vegetation type over long periods of time would not be prudent. We were assured that while stratifying beforehand would not generally be desirable, post-stratification could be used during data analysis. Post-stratification has the advantage of being flexible.

A third attractive attribute of the systematic design was that it represented an effective and relatively simple, straightforward way of dispersing samples evenly across the landscape. Simple random sample allocation procedures could result in the "clumping" of samples by random chance, necessitating choosing among potential samples. Other sample allocation approaches would have required that we partition the park prior to allocating samples and make *a priori* decisions regarding the allocation of sample effort among these different partitions. The systematic approach offered a relatively "clean" way around those complexities. To effectively sample the macro-scale gradients in resource attributes across the Park, we needed to have the maximum dispersion of samples across the landscape. The systematic grid provided that dispersion of samples at the Park-wide scale. The primary theoretical danger of a systematic design is that it could intersect some underlying repeating pattern on the landscape coincident with the systematic sample intervals. Our preliminary experiences in executing this design in the field suggest that this is not a danger for the parameters of interest in Denali National Park and Preserve.

We decided upon a multi-stage systematic grid design, with random start because it offered a variety of logistical and analytical benefits for the long term monitoring program. The benefits of this proposed approach include:

1. Clustering of sample points into mini-grids concentrates landscape-scale sampling efforts within confined study areas that require lower access cost per data point and that require fewer overflights and trips into wilderness as compared to a single-stage grid approach.

2. Allows for statistically valid conclusions concerning changes in resource attributes due to sample randomization.

3. Effectively samples both regional and meso-scale gradients in resource conditions, thus allows modeling of ecosystem attributes along these gradients.

4. Constructs a sampling frame that is not tied to any preconceived notions of how changes in the ecosystem and bird assemblages will occur.

5. Allows for area-based estimates of the status and trends in resource conditions, and for the estimation of the variation in spatial and temporal scales.

6. Provides a multiple-scale sampling frame that allows for collocation and integration of monitoring efforts occurring at various scales.

7. Allows for the detection of change, not only in the status of particular resources, but of changes in the underlying relationships between those resources and environmental and geographic gradients.

8. Takes advantage of permanent plots to improve precision and allow the components of net change to be assessed, facilitating understanding of cause-effect relationships.

9. Retains information about spatial relationships that would be lost in other designs.

Another important aspect of the proposed design is that it is logistically feasible, and affordable, within current and planned future budgets for the program.

The Importance of Permanent Plots

As mentioned earlier, permanent plots have certain advantages over temporary plots in long-term studies. Revisiting the same plots at different points in time reduces plot-to-plot variation. This produces more precise estimates of change, than if different plots are visited on each sampling occasion.

In vegetation sampling, use of permanent plots also allows measurement of the components of net change. When trying to understand the causes of change, this feature of permanent plots is highly desirable, and a defining advantage over temporary surveys (Scott 1998). In a forest, for example, use of permanent plots allows measurement of recruitment (establishment of new trees), growth of existing trees, and mortality between sampling occasions. Thus, information on the components of net change in basal area of trees in the sampling frame is available. Use of temporary plots would only allow estimation of changes in basal area, with only indirect measures of growth and mortality contributing to that change.

While permanent plots are advantageous, there are certain problems that must be dealt with. For the plots to actually be permanent, they must be marked in a way that they can be relocated. This adds time and cost to the initial sampling visit, and there can be technical difficulties (e.g., permafrost). The advent of GPS has made the use of permanent plots much more feasible.

<u>Population being Monitored</u>

The populations being monitored under this design include all of the vascular and nonvascular plant taxa that occur in the area of terrain contained within the sampling window illustrated in Figure 1. However, our approach to monitoring is area-based as opposed to being based on specific populations of interest. So, for example, we will obtain considerable information concerning the population of white spruce that occurs within the study area (including estimates of density, basal area, cover, population size-class structure by species, among others) , but the focus of the monitoring is not this population per se, but the area within which this population

occurs. Indeed, if white spruce were to disappear from the study area entirely, the sampling design would remain exactly the same. Our area-based focus is different from many monitoring programs focused on single species, wherein the design is tailored to capture the maximum amount of information regarding the population dynamics of multiple species. In these instances, changes in the distribution and abundance of the focal species often necessitate changes in the locations for monitoring these species, or in the design of the program for monitoring them. We do not anticipate changing location or design of the vegetation monitoring protocols regardless of what changes are observed within the study area (within reason). In fact, we have attempted to design a robust set of protocols that will apply across all vegetation types extant within the Park. As a result, if landscape change occurs, and (for example), an area currently occupied by tundra becomes forest over time, we will not be in a position that requires us to change the suite of measurements that occur at the site because of this change in vegetation condition. We expect populations to enter and disappear from the sample universe over time, with landscape change.

Site Selection

We describe the site selection procedure that was followed for Denali in this section, which would serve as the model by which site selection would occur in each of the network units. The sampling frame for the mini-grid design is unstratified and originally consisted of the entire area within the boundary of Denali National Park and Preserve. The foundation of the sample selection procedure for this design was a grid of virtual points with 100-m spacing covering the entire park. This systematic "base" grid was generated using ArcInfo software using a random location as the starting point, and contained 2,488,319 points within the park and its' immediate vicinity. All sampling points that will be measured for the long-term monitoring program in Denali will come from this randomly-drawn systematic grid.

The sample selection procedure for the mini-grid design occurred in five steps:

1. The first step, described above, was generating the 100-m base grid across the entire Park. Each subsequent step involved selecting subsets of points from this 100-m base grid from a random start.

2. The second step of sample selection consisted of a making a random selection (a subset of the 100 m base grid) that formed a "macro-grid' of points spaced 10 km apart in an even grid pattern across the park (every 100 th base grid point from a random starting point). This 10-km park-wide grid included 255 points (see Figure 3).

3. In the third step, a "mini-grid" sample was drawn at each of the 10-km grid intersections, consisting of a lattice of 25 points, spaced 500 meters apart in five rows of five points (see Figure 4). The 10-km grid points formed the southeast corner of each of these mini-grids.

4. The fourth step of the sample selection procedure involved selecting a subset of these 255 mini-grids in the 10-km grid, to form the 20-km Park-wide systematic grid. To do this we chose the Rock Creek mini-grid as the "seed" for selecting the 20 km grid

points. The Rock Creek mini-grid encompassed the most of the plots established for the original design of this program, thereby integrating the initial monitoring sites into the new, landscape-scale approach for the program. With the selection of the Rock Creek point, the final layout for the 20-km Park wide systematic grid was in place

5. The fifth and final step of site selection was to intensify sampling within the road corridor buffer in response to Park management's desire for increased data-resolution from this region of the Park. To do this, we added *all* of the mini-grids on the parkwide 10 km systematic grid that fell within this buffer to the sample.

Originally, our intent was to pursue a Parkwide level of inference for this monitoring program, which is why the site selection routine described above is for a Park wide sampling frame. However, during an evaluation of the proposed design, Park management requested that the length of the return interval time for resampling the mini-grids be reduced, and that sampling be intensified in areas of high management concern. In order to respond to these requests, it became clear that implementation of the entire Park-wide 20 km grid would be impossible, at least in the initial phase of the program. In order to reduce return intervals and intensify sampling within the road corridor of the Park, a spatial restriction (or "sampling widow") was put on the 20 km Park wide systematic grid that is described above. In addition, we increased the sampling intensity in the Park Road corridor to include all 10 km points in a buffer extending 3 km from the Park Road in all directions (as described in step #5 above).

As a result of restricting initial sampling efforts to the sampling window and intensifying sampling within 3 km of the Park Road, we have two overlapping areas of statistical inference within this design (see sampling design section for a description).

Sampling Frequency

There were two primary sets of trade-offs that had to be considered during the development of this monitoring program that pertain to sampling frequency. First, because of limited resources, we needed to arrive at a reasonable compromise between spatial and temporal sampling intensity. Our focus was on developing a multi-scale effort that included the capability of making landscape-scale inferences. Inherent in undertaking measurements that include this very large spatial scale, was the need to constrain how often plots were revisited (as was discussed in the objectives section above). The second challenge inherent in designing an effective long-term monitoring program for vegetation was the need to balance a desire for frequently repeated samples in order to detect potential changes in a timely way, and the unavoidable effects of trampling that these sampling procedures have on the vegetation. If we were to sample too frequently the program would simply be measuring its own impacts to the plot network. If we sample too infrequently, the program is in danger of becoming irrelevant to evolving management concerns. We decided that a minimum return interval of six years was necessary in order to minimize the potential for adversely affecting the vegetation of the permanent plots through repeated trampling. This return interval allows us to accomplish a 20 km systematic grid of mini-grids across more than half of the Park area.

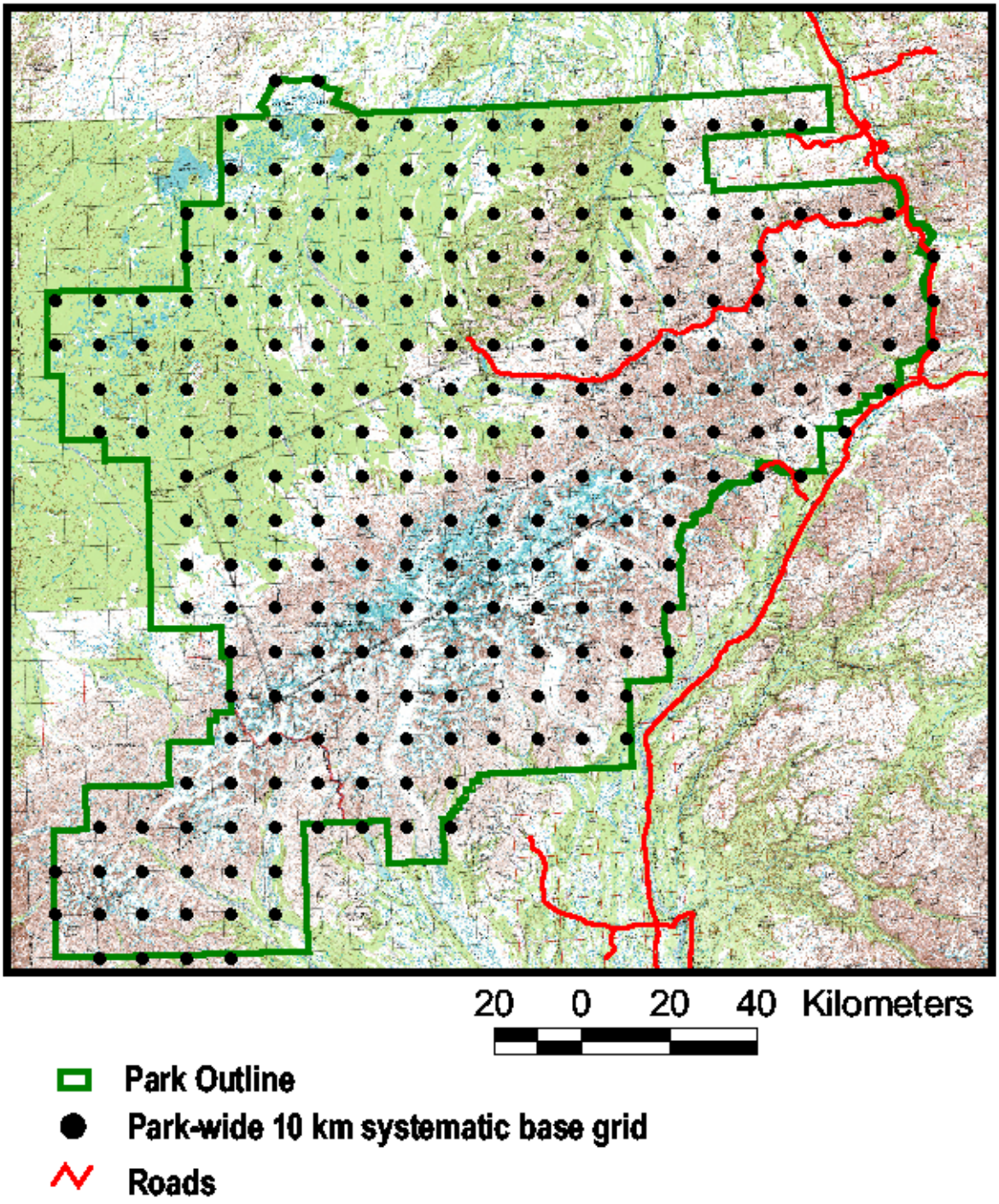


Figure 3. Map of Denali National Park and Preserve showing the spatial arrangement of sampling locations on the 10 km systematiic base grid sample.

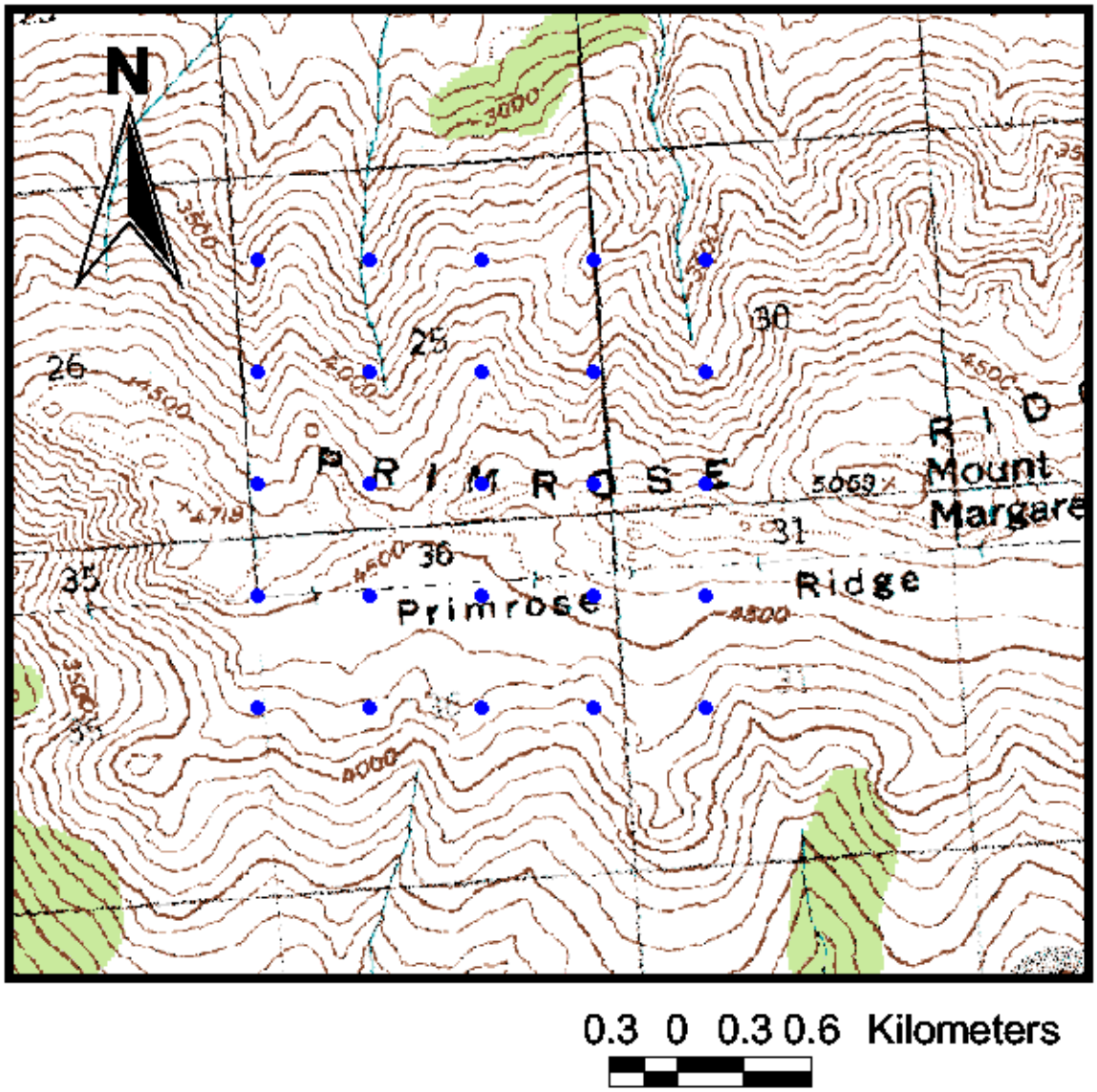


Figure 4. Example of a single mini-grid sampling area, showing spatial arrangement of sample locations.

One iteration of sampling using this design in Denali would require six years to complete from start to finish, with two vegetation crews performing field sampling each year. Complete measurement of an average of seven mini-grids per year will be the goal for the program, so that six field seasons should be an adequate amount of time to complete all 40 accessible mini-grids in the sample. Thus the temporal design for this program will be a simple interpenetrating rotating panel design (shown in Table 1). There will be six panels consisting of seven mini-grids each, and each panel will be measured during one year. Thus it will require six years to complete one iteration. Upon completion, the rotation will begin again from the first panel. We will begin sampling with panel one in 2006, upon final acceptance of this protocol for vegetation monitoring.

Table 1. Schematic showing the panel rotation scheme for the CAKN vegetation monitoring program in Denali NP & P. The member ship of the seven panels will be determined at random, with constraints limiting them to a mix of access and phenology categories. An "X" indicates the panel listed during the given year will be sampled.

Year >>>

Mini-Grid Name	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Panel 1 – 7 Mini-Grids	X						X					
Panel 1 – 7 Mini-Grids		X						X				
Panel 1 – 7 Mini-Grids			X						X			
Panel 1 – 7 Mini-Grids				X						X		
Panel 1 – 7 Mini-GridsX					X						X	
Panel 1 – 6 Mini-Grids						X						X
Cumulative number of Mini-Grids sampled	7	14	21	28	35	41	41	41	41	41	41	41
Number of Mini-Grids measured twice	0	0	0	0	0	0	7	14	21	28	35	41

III. Field Methods

Field Season Preparations, Field Schedule and Equipment Setup

Prior to the field season each year, beginning in April or May, the field workers must review this entire protocol, including all of the SOPs. It is important that each member of the field crew is thoroughly familiar with the elements of the design and standard operating procedures for this program. There are numerous tasks that must be performed to ensure a smooth and efficient field season, including generating and copying sufficient data sheets for the year, making appropriate logistical plans, and purchasing necessary equipment and supplies to provision the field effort. These procedures are described in SOP'S # 1 through 4.

Preparing for field sampling bout

Due to the large number of procedures performed as part of the vegetation monitoring field sampling effort, considerable preparations are necessary in order to effectively accomplish this suite of tasks. This is particularly true due to the remote nature of the fieldwork, and the high cost of transport to field sites. All materials and equipment must be brought with the crew, and there are rarely opportunities for retrieving misplaced or forgotten items. The suite of tasks involved in preparing for a field sampling bout include preparation of maps and GIS materials (described in SOP #3), performing planning functions in Pathfinder Office for GPS work (described in SOP # 1), and assembling all of the equipment and supplies required for this effort. The full set of tasks required to appropriately prepare for a vegetation field sampling trip are laid out in SOP #4.

Field sampling methods

The following procedures are performed in the field:

Plot layout and marking

The permanent plot design is a circular plot 16-m in diameter that encompasses an area of about 200 m^2 (Fig. 5). The plot is formed by laying out two tape measures, perpendicular to each other and crossing at the plot center monument. Plot layout procedures are described in SOP #6. The center point for each permanent plot is one of the 25 random points that constitute the mini-grid sample, as described above. Four separate 4-m² quadrat placements are located within the plot, one on each "arm" of the transects that radiate from the plot center (Fig. 5). Around the central 16-m diameter plot is the peripheral tree coring plot, which is an 8-m "doughnut" encircling the permanent plot (Fig. 6).

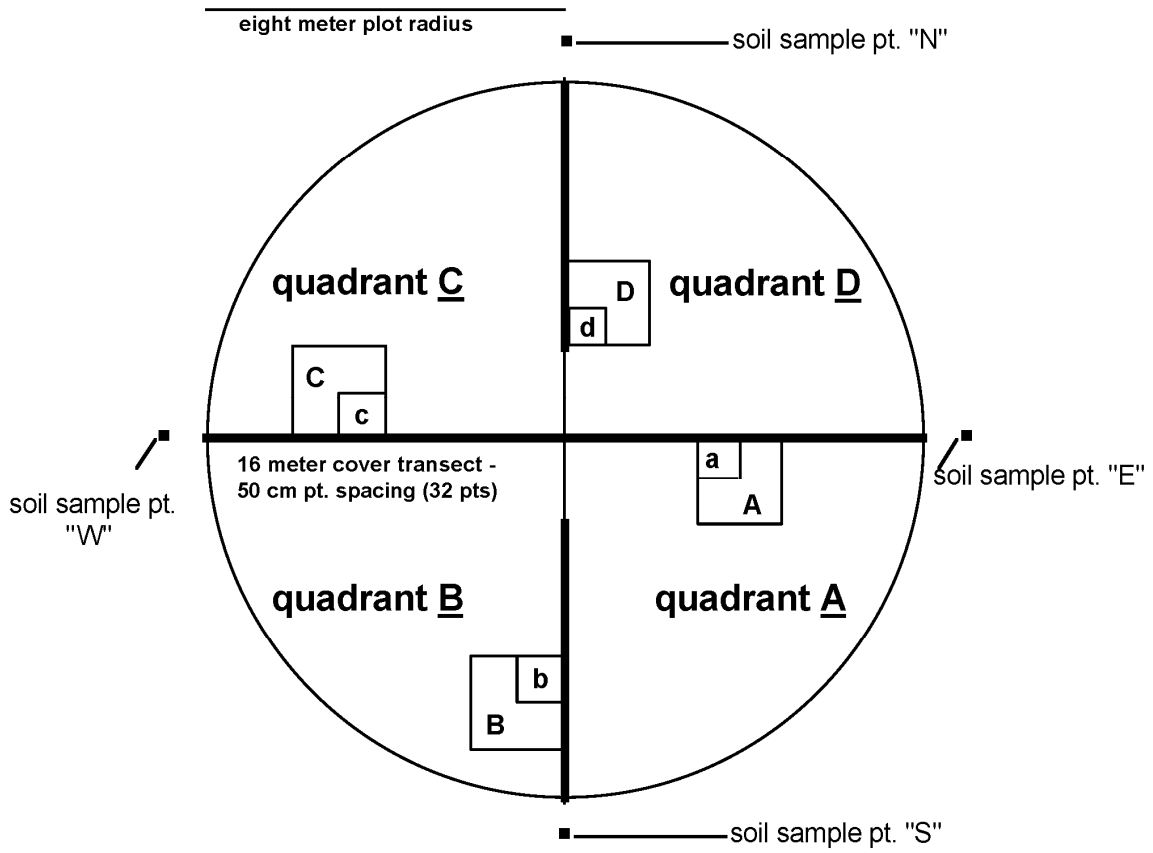
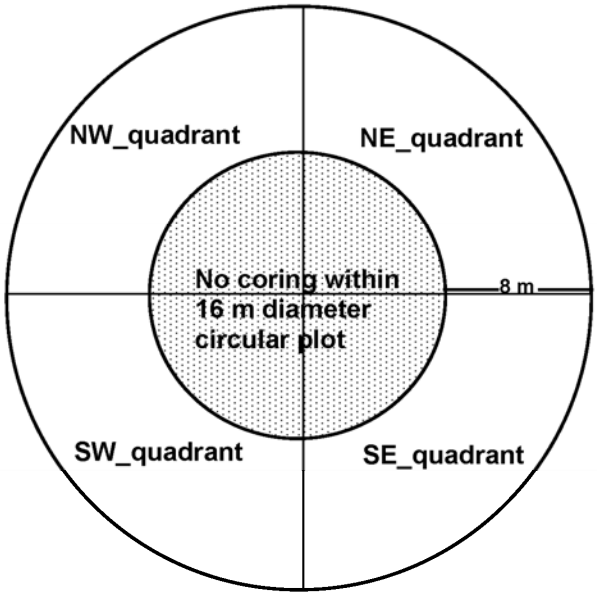


Figure 5. Diagram showing the layout of the vegetation plot, including transects, quadrat placements, and soil sampling points. These plots are 16 m in diameter and encompass about 200 m^2.

We chose to use a circular plot shape for several reasons. The circular plot is easily and quickly installed through the use of two intersecting transects that describe the diameter of the circle. Square and rectangular plots require that four measuring tapes be positioned (one along each perimeter of the plot). In addition, using the circular plot, only the center point needs to be permanently marked. Mapping of trees within the plot is facilitated, because only a single

azimuth and distance (from plot center) needs to be recorded for accurate mapping. Finally, a circular plot shape reduces edge effects because the perimeter: area ratio for the plot is at the minimum value. This enhances the consistency of the measurements made within the plot, by ensuring a greater degree of homogeneity within each individual plot, all other things being equal.



The largest diameter spruce tree in each of the quadrants (NE, SE,SW, NW) is cored, measured, mapped, and assessed for condition and vigor.

Figure 6. Diagram showing the configuration of the tree coring plot, which is located around the periphery of the permanent vegetation plot in an 8 m concentric circle.

Plot centers are permanently marked through the use of small, pre-stamped markers that have a magnet under the cap. These markers are low to the ground, protruding less than 30 cm above the surface. These permanent markers consist of a 3.5” round head affixed to a fluted aluminum staff pounded into the ground (Fig. 7). They closely resemble in size and appearance the USGS

Figure 7. Plot monument used for marking permanent vegetation monitoring plot centers.

benchmark markers. The magnet increases our ability to relocate these markers for future sample iterations through the use of magnetometers. These markers were selected through a process of consultation with the park wilderness coordinator, and are very unobtrusive on the landscape. We have had complete success in relocating these markers through the course of the pilot study for this program.

Acquiring Plot Digital Photographs

High quality photographs provide a tangible archive of information concerning the landscape and vegetation of the park at a given point in time. Comparing photographs taken at a single point over time can provide a very valuable window into how change has occurred on the landscape. The spatially extensive approach that we are taking provides an unparalleled venue for acquiring geo-referenced, high quality images that are also married to an array of quantitative data. We photograph each plot from a minimum of four separate angles, and take a photograph of each quadrat. In addition we opportunistically acquire landscape photographs and other images that

document patterns of variation within each mini-grid and permanent plot. The procedures for performing plot photography are described in SOP #8.

Recording Plot Descriptive Data

A variety of data regarding the attributes of the permanent plot are recorded. Procedures for recording these observations are described in SOP #7. These include observations of both physical and vegetation features of the plot and its landscape context. Physical attributes recorded at each plot include: slope angle and azimuth, elevation, topographic position, disturbance regime, slope shape, drainage characteristics and evidence of frost action and fire. Biotic plot variables that are recorded include vegetation classification, landcover classification, dominant species, adjacent vegetation or ecotones, tallest tree and shrub heights. We also record observations of humans and wildlife sightings and/or wildlife sign in the vicinity of the plot. These descriptive data are also recorded for each of the four 4-m^2 quadrats within each plot. Recording these observations for each quadrat allows for both double-checking consistency of the observations and providing an indication of variation of these parameters within a plot.

Measuring the Cover Transects

Measurements of vegetation structure are fundamental to meeting the primary objectives for the vegetation monitoring program, but also provide useful information to other monitoring components, especially the faunal component. Vascular plant abundance and vegetation structure in the permanent plots are quantified using point intercept transects (see SOP # 10). These transects are performed along the two perpendicular tapes that define the plot. At 50 cm intervals, we use a specially-designed sampling staff (Fig. 8) with a combined densitometer and descending pin to record each intersection of vegetation biomass with the sample point along the transects among 10 vertical strata. This technique allows for the characterization of the vegetation both in terms of percent cover by species, but also in terms of the vertical arrangement of the cover. The use of the pin and point-densitometer reduces the large observer error of ocular estimates of cover, and the vertical component of the measurements adds a significant new dimension as compared to simple estimates of cover that do not take the vertical arrangement of the vegetation into account.

Making Species Composition observations

We record the species composition for vascular plants, bryophytes (mosses and liverworts) and terricolous (ground-dwelling) lichens according to the procedures described in SOP's #12 & #13. These measurements allow us to estimate the following parameters for each of the three elements of the vegetation (vascular plants, bryophytes, and macrolichens):

Figure 8. Examples of field workers using cover transect sampling staff designed for use in this program**.**

1. A comprehensive species list for each plot.
2. Frequency of occurrence of each species in the 1-m^2 quadrats.
3. Frequency of occurrence of each species in the 4-m^2 quadrats.
4. Mean species richness, and associated variance, in the 1-m^2 quadrats.
5. Mean species richness in the 4-m^2 quadrats.
6. Species richness of entire plot.
7. Calculation of a variety of diversity indices for the plot including evenness, Simpson's Index, and Shannon's index.

Cover of Cryptograms (Nonvascular plants and Macrolichens)

As described above, vascular plant abundance and overall vegetation structure in the permanent vegetation monitoring plots are quantified using the point-intercept method on the cover transects described above. Using this technique, the identity of each vascular plant intersected on a point was recorded. Unfortunately, it is not practicable to similarly identify each cryptogam species using this method, due to the difficulty of reliably identifying these taxa in the field. Therefore, moss and lichen cover were each recorded as a class on the cover transects, yielding total cover of each of these elements as opposed to individual species cover values. Because cryptograms are a dominant component of the vegetation cover, and ecologically important, we desired a similar level of information about them as for vascular plants. We estimate percent cover of each cryptogam species within the nested quadrat array to produce estimates of cryptogam species abundance, as described in SOP #13.

Tree Measurements

The abundance and community structure of tree species are quantified within each of the permanent vegetation plots according the following procedure (described in detail in SOP #14): all individuals of tree species 12 cm diameter at breast height or greater are measured for diameter, assessed for pathology and vigor and mapped within the plot (based on azimuth and distance from plot center); saplings (individuals less than 12 cm DBH, but taller than 1.37 m) are measured and tallied by species by condition class (live/dead); seedling (individuals less than 1.37 m in height) density is quantified by counting the number of individuals that occur in each 4-m^2 quadrat, which are then tallied by species and condition class. This set of observations allows us to make estimates of total density (stems per hectare) of trees among size classes and basal area of each tree species (total area (m^2) of bole per hectare at breast height), which are the two primary methods of characterizing stand structure for forest communities. It also provides information on the prevalence and distribution of a set of indicators of "forest health", including insect activity, pathogens, physical damage and related factors.

Increment Coring of Spruce

We conduct tree increment coring within the 8-m wide doughnut-shaped surrounding the 16-m diameter plot (see SOP #15). The largest individual spruce tree in each of four quadrants of this increment coring plot (Fig. 6) is cored as low to the ground as is feasible (usually between 20 -40 cm above the ground). A "penetrating" core (one that bisects the entire diameter of the tree bole) is removed so that two separate measurements of annual growth can be measured for each year. Cores are mounted on standard wooden mounts, sanded and prepared for counting (see SOP #20). The number of annual rings in each core is counted, whereupon the individual annual rings are measured with an electronic micrometer, which automatically logs the ring widths. Ring width data are then analyzed using Cofecha® statistical software, and the cores are re-measured as necessary.

Soils Observations

Soils observations and samples are acquired at each of four soil observation points arrayed around the perimeter of each vegetation plot, according to the procedure outlined in SOP #9 (see Fig. 5 for sampling locations). The following parameters are recorded at each of the soils observation points: soil temperature at 10 cm below surface, surface cover, and depth of the litter, moss, living mat and organic horizons. In addition, a soil sample is taken at each point and integrated to form a single composite sample for the plot. The soil samples are frozen upon return from the field until the end of the field season. Soil samples are sent to the U.A.F Palmer field station Soils Laboratory (see SOP #19). The samples are then weighed, dried, and weighed again to determine field moisture percent. The dried samples are then sieved to <2mm, and the fractions of the soil in each size class (<2mm, >2 mm) are weighed (SOP #19). The following parameters of the soil sample are determined: moisture content, pH, soil texture, % carbon, and % nitrogen (using autoanalyzer methodology - SOP #19).

IV. Data Management

<u>Database Design</u>

Digital vegetation data are stored in an MS Access database with filename *CAKN_Vegetation.mdb* which resides primarily on the YUGA server *165.83.59.10* in the *vegdata* folder. The database design was originally developed for the Denali LTEM vegetation monitoring program in 2001 (original file name DENA_ltem_vegetation.mdb). This Microsoft Access® database for storing and analyzing data collected under this design is consistent with NPS data management standards. The design of the database is an integral part of the data acquisition, storage, analysis and communication process for this program. We worked with Angie Southwould, database programmer with the Alaska Support office of the NPS in the design of the database for this program (the details of this database, including descriptions of each field and query are described in SOP #22). By taking full advantage of the relational capabilities of the software, the database design allows us to reduce the time required for recording and entering data, and expeditiously summarize the data in a variety of different ways quickly and easily. The use of automatic entry of certain important identification field values through the use of nested sub-forms within the database allows for quality control and the

automation of several important database functions. In addition, digital images recorded at each sample site are entered into the database structure and may be viewed from within the database. Data entry procedures are described in SOP #23.

The general structure of the database, including both tables and relationships, is shown in Fig. 9 and a detailed database diagram, showing all relationships and tables is provided in Appendix A. The descriptions of each field in the database are documented in SOP # 22. There are three primary types of tables in the database:

1. **Reference tables**, which contain attribute data on individual records such as species and are denoted with the prefix “ref_”.

2. **Data tables**, into which the actual field data are entered (e.g., cover transects, species composition, tree measurements, etc.) and are denoted by the prefix “tbl_”.

3. **Cross-reference tables**, which are the products of combinations of data tables and reference tables, which are denoted by the prefix “xref_” in the database structure.

The design of the database allows for entry of numerous iterations of observations from a single point in space (the permanent plot).

Data model

The database for this program contains of a variety of tables, queries and forms to handle data entry, validation, export, and analysis. Figure 9 shows the relationships among the primary tables in the database. The sample event table, *tbl_sample_event*, serves as a focal point in the data model by tying 14 separate data tables to appropriate grid sampling point numbers in the table *tbl_sample_point*. Grid sample points are in turn related to appropriate mini-grids in *tbl_grid*. The field *sample_event_num* serves as the primary key for *tbl_sample_event* and as the foreign key in each of the 14 data tables. Values for *sample_event_num* consist of a concatenation of the grid code, two-digit sample point, four-digit year, and Julian date. For example, "GORG_CR07-2002198" represents the "Gorge Creek" mini-grid, point 7, sampled on the 198th day (July 17) of 2002. A sample event is defined as a single trip to a single point in the sample design. Thus this field ties together the spatial and temporal aspects of sampling for the program.

Data in the tables *tbl_cover_transect_data* and *tbl_plot_species_collection_data* are based spatially on both mini-grid points and transects. For these data, transect information is related via the field *sample_transect_num* in *tbl_sample_transect* which is in turn related to *tbl_sample_event* via the unifying *sample_event_num* field.

Currently (Oct. 2004), the *CAKN_Vegetation.mdb* database houses the primary DENA mini-grid sampling data that the CAKN anticipates applying to several vital sign monitoring protocols. This information is contained in both *tbl_grid* which records critical information about each mini-grid and *tbl_sample_point* which records site-specific information about each of the 25 points in each mini-grid. At this time (Oct. 2004), the CAKN_Birds.mdb database for the Network's passerine monitoring vital sign is the only other database utilizing the DENA mini-

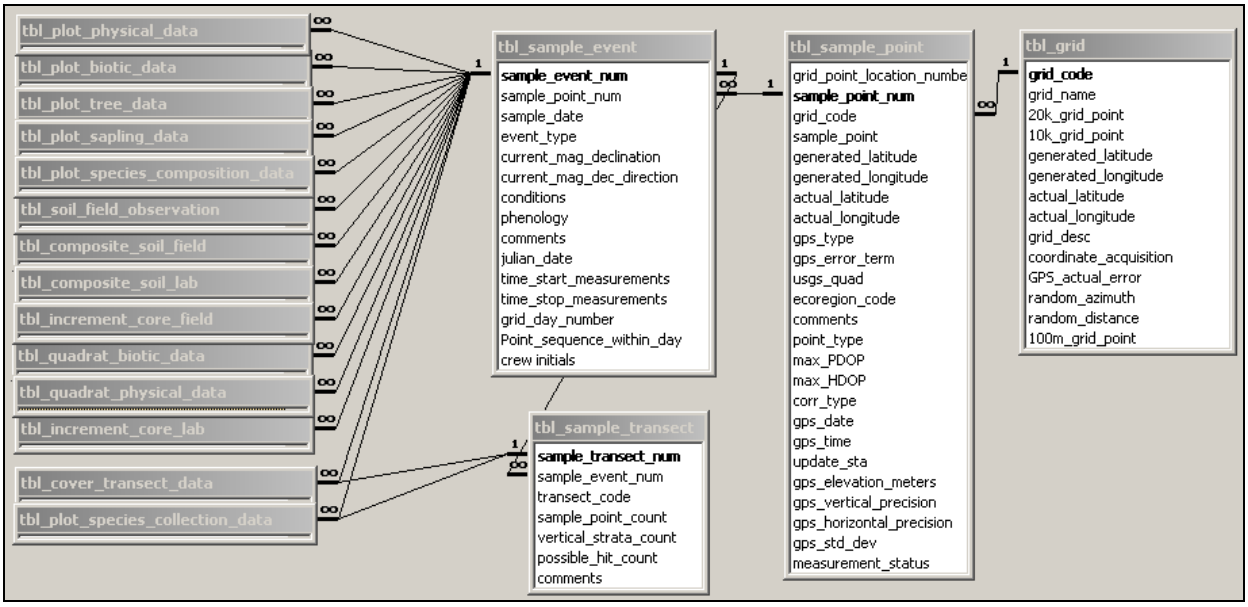


Figure 9. The general structure of the vegetation monitoring database used for this program.

grid sampling scheme. This is accomplished via linking *tbl_grid* and *tbl_sample_point* to the CAKN_Birds.mdb via the MS Access Linked Table Manager. As additional databases are built to utilize the DENA mini-grid (as well as similar mini-grids for YUCH and WRST), a revised database strategy to centralize the mini-grid information will be designed and implemented.

Data entry and validation

Entering the vegetation data into the database occurs once the field season is completed, the initial trip reports describing the progress of field work during the season have been prepared, and all of the equipment has been cleaned, repaired and stored for the off-season, and final determinations of species identities from the field collections have been made. Data entry and validation for this program progress according to the steps outlined in SOP #23.

Data archival procedures

All of the data from this program, including hard copies and electronic format data will be archived in accordance with standards described in the Central Alaska Network data management plan. This includes storage of original materials in fireproof safety cabinets and repeated back-up copies of all electronic media.

V. Data Analysis

Vegetation data collected through this program follow a path from initial field data collection to data entry, and through data analysis, to data summary tables and figures (Fig. 10). After data are collected in the field, they are entered into a Microsoft Access database described above. The database is uploaded to a web server running StatServer with a library of custom S-PLUS functions for performing a suite of analyses, also called analytics. A user can then use a web

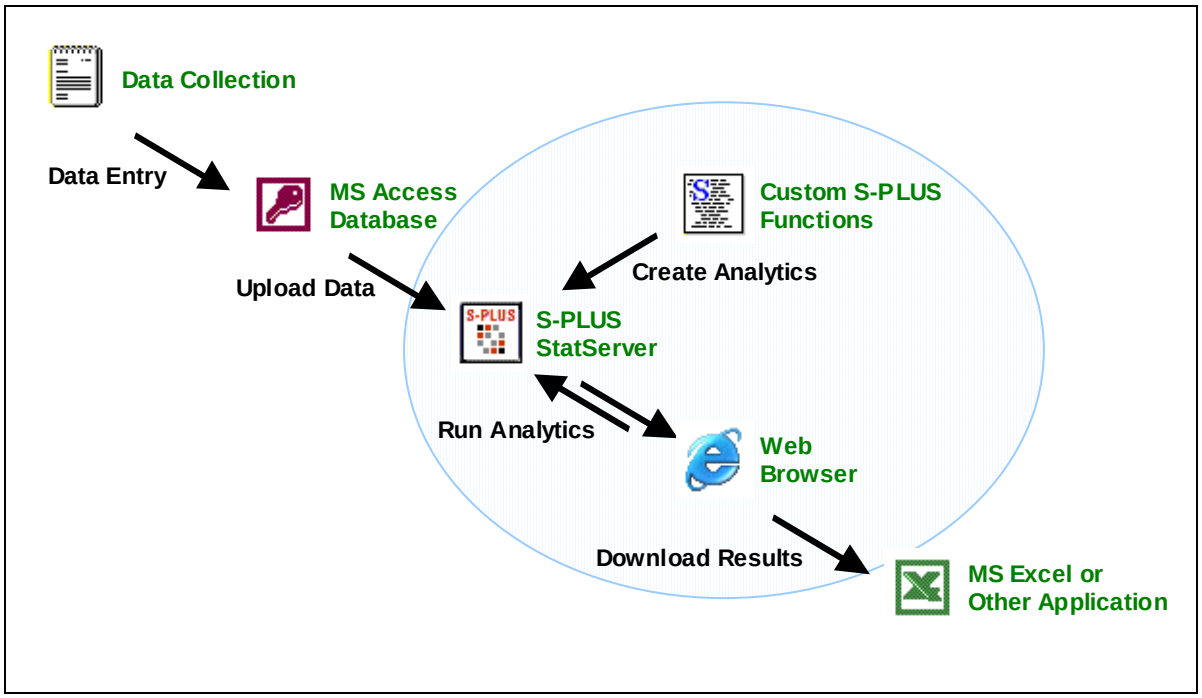


Figure 10. Schematic showing vegetation monitoring data collection and analysis sequence for the Central Alaska Network monitoring program.

browser to visit the data analysis website, select an analysis to run, enter the specific details of the analysis, and download the results in one of several file formats. The user may then open the results in the appropriate application to perform further analyses or create graphical displays. The data analysis SOP #24 details the stages and procedures circled in Figure 10.

We define three broad (and closely inter-related) categories of data analysis for this program:

1. Analyses of the *status* of vegetation resources. This set of analyses includes description of spatial distribution and abundance of vegetation resources and the analysis of relationships among vegetation parameters and physical or geographic predictor variables. These analyses are performed on vegetation data collected within a single sample iteration (see sample design section). These analyses allow us to describe the distribution and abundance of vegetation resources along primary ecological gradients, and how different aspects of the vegetation covary across the landscape.

2. Analyses designed to detect changes in the status of vegetation resources and to detect directional trends in these changes. For this set of analysis to proceed, it is necessary to have at least two sample iterations for a given set of sample points (for change in status) and at least three or more sample iterations (to detect a *trend*).

3. Analysis of sampling variation in the vegetation data. In order to perform this category of analysis, it is necessary to perform specific tests of sampling protocols designed to address observer variation, which includes assessing the results from multiple observers done at the same time. This set of analyses is important in order to make estimates of the

precision of the estimates of the status of vegetation resources, a key component in the power of this program to detect change over time.

The first step in performing data analysis in any of these three categories is producing summaries of the raw data at the various spatial scales of interest to this program. For example, the raw cover transect data (which consist of hundreds of point observations in the database) must be condensed to provide the researcher with mean percent cover by taxon (or group of taxa such as growth form) for a specific spatial scale such as individual plot or group of plots. We have used StatServer®, a web-based version of S-Plus to perform the vital function of condensing and summarizing the field data from this project. StatServer is more completely described in Appendix L.

StatServer® Data Summary Routines: The Link between Database and Data Analysis

We have designed a set of statistical routines, using StatServer® software, to facilitate summarizing and analyzing the vegetation data acquired for the vegetation monitoring program. These routines allow us to perform a large number of calculations and data summaries quickly, without actually entering the database that is used to store the data for the program. This web page also allows for quick and effective sharing of project data over the internet. Users can access a flexible set of tools to inspect the patterns of variation in measured variables across all of the spatial scales using the majority of the monitoring data we have collected during this pilot study. The statistical software that these routines use is based on the S-Plus statistical software program. Procedures for performing summaries using this tool are described in SOP# 24.

VI. Reporting

Timely and comprehensive reporting of the results of our work is a key component of this protocol. In keeping with the spatially-nested design of this program, we have devised a hierarchical structure for reporting the results of this monitoring program that includes reports that will be delivered on varying time cycles. There will be four types of reports for communicating the results of this program:

1. Sampling Trip reports, which will detail the events of particular sampling trips and provide the reader with a summary of the logistics and accomplishments of the field crew during each field trip. In general, a trip report describes the progress of the sampling of an individual Mini-Grid (see Appendix B for an example of one of these reports). Instructions for preparing a trip report are provided in SOP #25.

2. Annual summary reports will describe the results from sample plots and entire mini-grids sampled in a given year. Each year we will produce a set of reports that summarize data collected for *each point* that was sampled, and will summarize the data for an entire mini-grid, examining larger scale patterns in the data. These reports will contain sets of identical data summary tables and graphics that display the results of the year's fieldwork from different sampling areas, and discussion of these results (procedures for preparing these reports are detailed in SOP #26).

3. Comprehensive status reports communicating the results of this program will be prepared on longer cycles, as sampling is completed in major geographic regions of the study area. For example, there are 11 mini-grids that have sample plots that fall into the Yukon-Kuskokwim bottomlands Ecoregion within the sampling window. Once all of these mini-grids are completed, we will prepare a report summarizing the information collected in this Ecoregion, describing the primary vegetation patterns and relationships between physical environment and vegetation that were observed during this sampling. Once the entire 35 accessible mini-grids were completed (a full sample iteration of the Program) a report describing the results for the entire area would be prepared (descriptions of these reports are presented in SOP #27).

4. The final type of reports envisioned for this program are *ad hoc* reports treating results for a specific data stream in more depth and detail than is possible in the other report formats outlined above. Because of the large volume of data collected for this project, we will actively seek collaboration with scientists who can work up project data more thoroughly than will be possible in reports that summarize data from the entire program. Two examples of this type of in-depth ad hoc analysis and reporting are currently occurring within the project on the following data streams: increment core data and nonvascular plant diversity data. We contracted with Dr. Martin Wilmking to analyze the tree ring data collected for this project in 2002 to assess patterns of white spruce growth in relation to climate (this report is provided in Appendix C of this document). Nonvascular plant lead technician James Walton, is completing an M.S. thesis using project data to develop predictive models of community composition and diversity of the nonvascular flora of Denali.

During the first iteration of sampling for this program, the reports described above will focus on describing the status of vegetation resources that is revealed through this work. Once the second iteration of sampling has begun, the focus of these reports will be on changes in the status of vegetation resources among iterations, and reports from subsequent sampling iterations would then also focus on trend detection.

VII. Personnel Requirements and Training

One important lesson learned from the prototype Denali LTEM program is the need for each part of the monitoring program to have a Principal Investigator. This is what we mean by the category of "Scientific Leadership." In our view, there must be someone in charge of the program, and this person is the Principal Investigator. The Principal Investigator is responsible for defining the monitoring objectives and questions and then carrying out data collection, analysis, reporting and interpretation. To carry out these types of responsibilities, the position must be filled with someone working at a high level, at the GS-11 level or above.

<u>Roles and Responsibilities:</u>

The principal investigator is the lead ecologist for implementing this monitoring protocol, and is supervised by the Supervisory Wildlife Biologist for Denali National Park and Preserve. Because of the need for a high level of training and consistency in implementing the protocol,

the project manager will usually be the person responsible for the training of field crews, and will usually, although not always, be a member of the field crew. The data management aspect of the monitoring effort is the shared responsibility of the project manager and the CAKN data manager. Typically, the project manager is responsible for data collection, data entry, data verification and validation, as well as data summary, analysis and reporting. The data manager is responsible for data archiving, data security, dissemination and database design and assistance with data management and database design. The data manager, in collaboration with the project manager, also develops data entry forms and other database features as part of quality assurance and automates report generation. The data manager is ultimately responsible that adequate QA/QC procedures are built into the database management system and appropriate data handling procedures followed.

Field Crew Responsibilities:

The essential component for the collection of high-quality data on vegetation are well-trained and highly competent botanists. This cannot be overemphasized. The ability to differentiate among hundreds of plant species can only partially be taught, it is important that skilled botanists are hired to do this work. In addition, much of this work is performed in remote backcountry situations where encounters with grizzly bears, moose, fast-moving glacial streams, and inclement weather are to be expected. Each crew must have technicians who are experienced backcountry travelers.

There will be multiple field crews performing identical data-collection procedures in separate study areas under this program. Each crew will have a designated leader who will be responsible for the work being accomplished, the safety of the crews and logistical decisions. In addition, there will be a lead technician for each individual SOP on each crew. By identifying lead technicians for each SOP, we seek to accomplish two primary goals: first, to ensure the accurate and complete collection of data and maximize the consistency of the data acquired by the different crews; second, provide the opportunity for different crew members to have a higher level of "ownership" and responsibility within the program. Key to the success of this program over the long term is reducing, where possible, staff turnover. We believe that technicians with a greater degree of responsibility and ownership in the program will tend to stay with the program longer.

This lead technician for an SOP will be ultimately responsible for the following things:

1. Making sure that the proper field equipment, supplies, and data sheets (in the proper numbers or amount) are prepared and brought into the field for each sampling bout.

2. Ensuring that data are collected according to the SOP in the field, and making sure that no data go missing or uncollected. This does not necessarily mean that the lead person will personally collect all the data, just that they are responsible for it being done, and done correctly!

3. Carrying out the correct sample processing and follow-up procedures once the field work has been completed (for example, making sure that soil samples are put in the drying

oven, that plant samples are properly pressed, labeled and dried, that tree cores are dried, stored and processed correctly, etc.).

4. Overseeing data quality control during the data entry and error-proofing stages. Most of the errors that are introduced into ecological data sets occur through ***transcription*** errors rather than errors in the actual acquisition of data. It is critical that this error is minimized for the long term ecological monitoring program to be successful. The lead technician will be the point of contact for the data entry and the proofing of entered data for errors.

5. Documenting any problems or difficulties that are encountered with the data collection SOPs – the lead technician is responsible making suggestions on how a SOP or some aspect thereof (for example data sheet layout) can be improved in future years.

The lead technician should communicate with the project manager and the lead technician for the SOP from the other crews if there are any questions or problems encountered, or if clarifications are required, as the sampling proceeds. The following list shows the different SOPs for which there will be lead technicians assigned:

#5 - Navigation to plot, care of GPS units and batteries, map data and point location tables.
#6 - Plot layout – plot marking and GPS point acquisition.
#7 - Recording plot biotic and physical characters.
#8 - Plot photography – including transects, quadrats, landscape shots.
#9 - Soil samples; field observations of soil parameters.
#10 - Cover transects - care for sampling staffs, standardization of single letter codes for species.
#11 - Quadrat measurements – physical and biotic estimates, seedling counts.
#12 - Species composition vascular (& vascular plant collections).
#13 - Species composition non-vascular (& nonvascular plant collections).
#14 - Tree mapping and measurement, sapling measurement and counts, tree condition and vigor class, and tree insect and pathogen damage.
#15 & #16 - Tree increment coring and fuels measurements on cored trees.

VII. Operational Requirements

Annual Workload and Field Schedule

Seasonal technicians for the vegetation monitoring program will be hired to start work in early May each year. Training and preparations for field work will commence immediately, including aviation, bear safety and firearms training required in Alaska. Actual field sampling commences after crew training, usually in the mid- to late-June. Crews work on a “Maxi-flex” schedule that allows them to be in the field for 10-day sampling trips alternating with 4 days off throughout the period mid-June through mid-August while sampling occurs.

Facility and Equipment Needs

The following facilities are needed to support this work:

1. Office and storage space to support up to five seasonal technicians for a single Park.

2. Limited dry laboratory space with dissecting and compound microscopes for botanists to work on specimen identification.

3. Access to long term museum collections to curate and consult voucher specimens collected during this work.

Budget

Currently, the Principal Investigator for the program is the Denali Plant Ecologist, a GS-12 position shared between the Denali base budget and the Central Alaska Network monitoring program. For the purposes of this cost estimate, we have assumed that the salary costs for work of the Principal Investigator related to the vegetation monitoring program are paid by the park and the network monitoring program, but are not attributed to the operating budget of the vegetation monitoring project. Estimated annual operational costs for the vegetation monitoring program in Denali National Park and Preserve are $ 98,450, and include the following major categories:

1. Personnel.

2. Contracts required for specialized work such as soils analysis or specimen identification.

3. Travel (including logistical support of program).

4. Equipment (field sampling gear, GPS, cameras, etc…).

5. Supplies (sample bags, paper, batteries, etc…).

Table 2 shows the breakdown of the costs for this program among these major categories, and Table 3 provides a detailed annual personnel budget, by payperiod, for accomplishing this program.

Personnel — This sampling protocol requires two crews of three, each of which consists of a Crew Leader, and two Biological Technicians. Under this program one crew is led by the Principal Investigator and the other crew is led by the lead biological technician. The remaining technician positions will be filled either at the GS-5 or GS-6 level, depending on experience and qualifications of the candidates. We estimate the annual personnel costs associated with data collection to be $72,600 (see Table 3 for details).

Contracts — We rely on contracted services for specialized technical needs including specimen identification and soil sample analysis. These are annual costs that fluctuate, and the estimates provided here represent an average.

Travel.—We included two types of cost under travel: field per diem and transportation costs. Field per diem is currently $25 per day and covers the costs of food and incidental expenses of

employees. We estimated field per diem costs as the number of field days times the number of personnel, totaling $5,250—a relatively minor portion of the total budget.

Transportation to mini-grids is achieved by park vehicles, hiking, fixed wing aircraft, rafts and by helicopters. Use of the park vehicles is not extensive and has occurred within existing bounds of shared use, and we have therefore not included these as an annual operating expense. Use of park vehicles would be considered a subsidized expense for this program

When using the contract Fire Management helicopter, the costs to the monitoring program are charged on a per hour basis, typically $500/hour of use. Of the 7 mini-grids to be visited each field season, perhaps 3-4 will require helicopter transport. Typically, two trips are required to shuttle the crew in to a mini-grid, and two trips are required to shuttle the crew back out. The length of the flights will vary, but we estimated one hour per shuttle. With these assumptions, helicopter costs are projected to be $8,000 per season to accomplish this protocol.

Table 2. Estimated annual operating costs of implementing this protocol in Denali National Park and Preserve, separated by five cost components: Personnel, Contracts, Travel, Equipment, and Supplies..

Cost component	Description	Amount	Percent of Total
Personnel	See **Table 3 for details**	$ 72,600	**73%**
Contracts:			
	U..A. Museum Herbarium	$ 2,500	
	Other specimen identification	$ 3,500	
	Soils Analyses	$ 6,000	
Subtotal		$ 12,000	12.5%
Travel:	OAS costs	$ 8,000	
	Field Per Diem	$ 3,750	
Subtotal		$ 11,750	12 %
Equipment	(replacement)	$ 2,000	2%
Supplies	Paper for data sheets, etc…	$ 500	0.5%
Total Annual Budget		**$ 98,450**	**100%**

Table 3. Schematic showing staffing needs of vegetation monitoring program with two field crews and timing of their work:

Project Staff	Salary grade & Cost / PP	PP10	PP11	PP12	PP13	PP14	PP15	PP16	PP17	PP18	PP19	PP20	PP21	PP22	PP23	# PP	Total Cost
Crew 1																	
Project P.I.	GS-12	Data analysis & report	Data analysis & report	Data analysis & report	Train	Train/ Field work	Field work	Field work	Field work	Field work		Data analysis & report	Data analysis & report	Data analysis & report	Data analysis & report	NA	N/A
Tech. #1	GS-06 $1,400			Train	Train	Train/ Field work	Field work	Field work	Field work	Field work	Data tasks	Data entry	Data entry	Data entry	Data entry/ report	**12**	$16,800
Tech. #2	GS-05 $1,200				Train	Train/ Field work	Field work	Field work	Field work	Field work	Data tasks					**7**	$8,400
Crew 2																	
Lead Tech.	GS-07 1,600	Prep.	Prep	Prep. / Train	Train	Train/ Field work	Field work	Field work	Field work	Field work	Reports	Data entry	Data entry	Data entry	Data entry/ summary	**14**	$22,400
Tech. #1	GS-06 $1,400				Train	Train/ Field work	Field work	Field work	Field work	Field work	Data tasks					**8**	9,800
Tech. #2	GS-06 $1,400				Train	Train/ Field work	Field work	Field work	Field work	Field work	Data tasks					**7**	9,800
Est. Over-time																	**$ 5,400**
Total																	**$ 72,600**

Projecting future costs of helicopter usage to implement the design is difficult due to uncertainty about fuel costs, insurance costs, and the great number of other factors that influence per hour charges and availability fees. However, the costs to use the helicopter appear to represent a relatively small proportion—8.5%—of the overall budget. These costs are reasonable and allay our biggest initial concern with attempting a landscape-scale sampling design, which was that helicopter costs would be unsupportable.

Supplies.—We have allocated a small amount ($500) for the annual purchase of supplies. These include Rite-In-The-Rain paper, pens, pencils, sample bags, batteries, plant presses and paper, etc.

Equipment.—The initial equipment purchases required for implementing the vegetation monitoring protocol have occurred (during the pilot study phase). Equipment includes field gear (e.g., tents, stoves, sleeping bags, etc.) and scientific gear (e.g., tree increment corers, digital cameras, GPS, maps, compasses, soil probes, etc.). We have included $2,000 in the budget as an equipment replacement fund.

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