

Long-term Ecological Monitoring Program

Evaluation of a Study Design for Detecting Ecological Change in Denali National Park and Preserve at Multiple Scales

Volume 1

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“ . . . sampling over time and space is a problem . . . “

--Trent McDonald, in a phone conversation
with Karen Oakley, August 14, 2001,
reflecting on the basic problem we face in
designing a long-term ecological monitoring
program for a large national park like Denali

Executive Summary

Introduction

- Denali National Park and Preserve (Denali) protects and preserves a 2.4 million ha region in central Alaska. Since 1992, Denali has served as a testing ground for long-term ecological monitoring protocols.
- The overall goals of monitoring at Denali and other national parks are to support the protection and preservation of park resources through improved understanding of the dynamic nature of park ecosystems and through detection of changes in key indicators.
- Reviews of the Denali monitoring program in 1995 and 1997 raised concerns about statistical validity, spatial scale and relevancy to management needs.
- We present findings from an ongoing pilot study to develop new objectives and methods for monitoring ecological attributes of Denali at large spatial scales—scales up to and including the entire park. This study responds to the 1997 review and a desire to use a probabilistic sampling design including the entire park in the sampling frame.
- The sampling design described in this report is based on a systematic grid of points covering the entire park. An evaluation of this design is needed to inform upcoming decisions about the future direction of the Denali monitoring program. This report will form the basis for peer and management review, discussions and, ultimately, decisions about implementing the design.
- Our work on the grid sampling design began with vegetation, one of the primary components of the Denali monitoring program. Because the proposed design provided an obvious framework for looking at other ecological attributes, we explored the integrative potential of the design starting with songbirds.
- Successful long-term monitoring programs must be (1) relevant, (2) statistically credible, and (3) cost-effective. In the 9 chapters of this report we address all 3 elements for program sustainability.
- We created a draft website (<http://mercury.bio.uaf.edu/DenaliLTEM>) to complement this report. The website provides access to pilot study documents, plot photographs and to additional graphical summaries of the pilot study data.

Chapter 1: Monitoring Objectives

- Because data collected under the initial Denali program were not meeting park needs, the objectives for vegetation and songbirds monitoring at Denali have undergone significant revisions since the program began in 1992.
- The revised objectives reflect desires to:
 - Make design-based inferences valid for areas larger than those sampled;
 - Include the whole park in the sampling frame;
 - Monitor attributes with the potential to address a broad array of management concerns, including concerns that cannot be foreseen at this time, and
 - investigate relationships among physical and biological attributes and how these relationships change over time.
- Vegetation is considered a primary monitoring component because vegetation provides the energetic foundation of all ecosystem functions. Vegetation is also unique in that it defines the habitat structure for most other forms of life.
- Environmental gradients, particularly those related to topography, edaphic (soil) conditions and climate, are important to understanding vegetation patterns in Denali. These gradients must be effectively sampled to understand the patterns of variation of vegetation on a landscape scale, and how they change over time.
- Understanding and detecting changes in the primary ecological *relationships* between landscape and vegetation is the focus of our long-term vegetation monitoring strategy.
- Objectives of vegetation monitoring at Denali are divided into two categories: extensive-scale, and intensive-scale. The minigrid design was developed to meet the extensive-scale objectives. Parameters too expensive to monitor at the extensive scale will be included in the intensive-scale vegetation monitoring objectives (not addressed in this report).
- Recognizing fiscal and logistical constraints, we identified a suite of vegetation monitoring objectives compatible with a sampling interval of multiple years. These objectives address fundamental properties of the vegetation cover that we expect to show detectable changes only over decadal time intervals.
- The highest priority objectives for extensive-scale vegetation monitoring are to detect changes in the structure, composition and distribution of these vegetation attributes across the park landscape. Trees are an important component of

vegetation structure and will also be monitored. Physical attributes, including soils characteristics, will be monitored because of their strong relationships to vegetation patterns.

- Detecting changes in fauna populations is also a fundamental part of the Denali LTEM program. Songbird monitoring has been included since the beginning of the program.
- Because songbird distribution is strongly tied to habitat structure, songbirds provide a unique monitoring tool for assessing and detecting changes in the landscape. Of all vertebrates that occur in Denali, songbirds are probably the easiest and most economical to detect, and a single survey can cover many species.
- The original goals of bird monitoring programs in Denali were focused on detecting annual changes in bird populations. Because sampling routes were located for convenience, only a small suite of primarily forest-dwelling songbirds was being monitored. Birds in other habitats important in Denali (e.g., the alpine, scrub, wetlands) were not being monitored.
- The monitoring paradigm for birds has now shifted to place a higher priority on gathering information about the overall distribution and relative abundance of all birds within the park and to understanding how these patterns change over time.

Chapter 2: The Proposed Approach

- The idea of using a systematic grid for Denali monitoring was first suggested by statistical consultants Lyman McDonald and Trent McDonald of WEST, Inc. during a visit in 1998.
- The grid 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 over temporary sample units.
- Between 1998 and 2000, we conducted preliminary investigations of the grid idea, collaborating with Dr. Dot J. Helm (Vegetation Ecologist, University of Alaska Fairbanks) and Trent McDonald of WEST, Inc. We used GIS analysis, computer simulations and a limited amount of field sampling to settle on a grid spacing of 20-km for initial testing. This spacing would capture the diversity of Denali's environment with a reasonable number of points (~60 points).
- Our initial assumption was that a single plot would be located at each grid intersection. However, we were concerned that underlying gradients between vegetation and topography would be missed with this arrangement. Establishing a

- “minigrid” of 25 points at each grid intersection was proposed as a way to capture these meso-scale gradients. Access costs would also be reduced.
- By adopting the idea of the minigrid, the design became a two-stage design. The first stage consisted of the 20-km grid intersections. The second stage consisted of the minigrids.
 - For initial testing, we settled on a minigrid consisting of 5 rows of 5 points each, with 500 m between points.
 - Temporal aspects of the design are as important as the spatial aspects, and the two are related. The amount of space that can be sampled depends on how much time is available, both within and among years.
 - Within a year, the time available for sampling at Denali is limited by northern conditions. For vegetation, the sampling period is compressed to about 6 weeks; for songbirds, the sampling period is even more compressed—to about 3 weeks.
 - How to schedule revisits to plots among years is complicated by many factors. We continued simulation studies with Trent McDonald of WEST, Inc., to help develop a revisit plan for the minigrid design.
 - We currently propose a 10-year rotation in which each minigrid would be visited once. The park would be divided into 4 regions, and minigrids would be sampled by region. All minigrids in one region of the park would be visited before moving to the next region. We would also allow some flexibility in the exact sequence of revisiting minigrids to account for logistical constraints.
 - “Good sampling practices” are required in the National Park Service’s Inventory and Monitoring Program. The sampling approach proposed for Denali incorporates many of the national guidelines, including: use of a probability sample; defining the initial sampling frame as the entire park; using a grid to distribute sampling sites throughout the park; use of permanent plots; and collocation of sampling by program components.
 - Experiences of other monitoring programs using grid designs suggest that the 20-km grid spacing is in the right ballpark, that reliable data to inform management decisions are produced and that unexpected changes are detected.
 - The primary advantage of the systematic grid design is its structural simplicity. Data from systematic designs are easier to analyze as questions change over time. Other advantages are that the design:
 - Concentrates landscape-scale sampling efforts within confined study areas that require lower access cost per data point and fewer overflights and trips into wilderness as compared to a single-stage grid approach.

- Effectively samples both regional and meso-scale gradients in resource conditions, thus allowing modeling of ecosystem attributes along these gradients.
- Constructs a sampling frame that is not tied to any preconceived notions of how changes in the ecosystem will occur.
- Allows for area-based estimates of the status and trends in resource conditions.
- Provides a multiple-scale sampling frame that allows for collocation and integration of monitoring efforts for a variety of ecological attributes.
- Allows for the detection of change in the underlying relationships between resources and environmental gradients.
- Takes advantage of permanent plots to improve precision and allow the components of net change to be assessed, facilitating understanding of cause-effect relationships.
- Retains information about spatial relationships that would be lost in other designs.
- Appears to be logistically feasible, and affordable, within current and planned future budgets for the program.

Chapter 3: Field and Analytical Methods

- The permanent plot design for vegetation sampling is a circular plot 16-m in diameter that encompasses an area of about 200 m².
- We chose to use a circular plot shape because circular plots are easier to install and permanently mark than rectangular plots, and it is very easy to map trees in them. A circular plot shape reduces edge effects because the perimeter: area ratio for the plot is at the minimum value, and this enhances the consistency of the measurements made within the plot.
- The circular plot includes transects used for estimation of plant cover (including its horizontal and vertical dimensions), quadrats for area-based estimation of species occurrences and cover, mapping and measuring of trees, and soil depth sampling locations. Soil samples and tree cores are taken from areas just outside the circular plot. Plot centers are permanently marked with small, pre-stamped markers with a magnet under the cap.

- The vegetation sampling procedures and plot arrangement were chosen because they were simple, unlikely to require modification over the duration of this program and provide maximum repeatability among multiple generations of observers. The procedures were also chosen to be applicable across all landscape positions and vegetation types extant within the park.
- The procedures include internal overlaps such that data on important vegetation monitoring objectives (such as structure) will come from several sampling techniques. These overlaps will allow us to assess consistency of results and be sure that observed changes are real.
- Songbirds were sampled with standard variable circle plot methodology using protocols adapted for Alaska conditions and used in the recent Yukon-Charley Rivers National Preserve bird inventory. Distances to detected birds were estimated to allow detection probabilities to be calculated. This will allow densities of common species to be estimated.
- We have created a Microsoft Access® database for storing and analyzing data collected under this design that is consistent with NPS data management standards. The assistance of Angie Southwold, database programmer with the Alaska Support office of the NPS, was critical in the design of this database.
- We also created a set of web-based statistical routines, using StatServer® software, to facilitate summarizing and analyzing the minigrid data. Collaboration with Ed Debevec, biometrician with the Institute of Arctic Biology at the University of Alaska Fairbanks, was critical to development of the StatServer® website and analytical routes.
- Post-stratification of monitoring data is the key to our framework for detecting changes at larger spatial scales and along environmental gradients.
- Community metrics are also a key part of our analysis framework. They will allow us to monitor emergent properties of vegetation and songbird communities. These include diversity metrics and ordination techniques.

Chapter 4: Introducing the Vegetation Data

- The vegetation data presented in this report are from visits to 9 minigrids located in the northeastern section of the park during 2001 and 2002.
- The pilot study minigrids encompassed broadly different areas of the landscape, including the alpine-boreal gradient that typifies Denali. The pilot study minigrids also included different access methods (helicopter, foot travel).
- We completed sampling for vegetation at 96% of all possible points during this pilot study (including 2003). These pilot study experiences suggest that, despite

numerous challenges in terrain and weather, sampling vegetation using the minigrad design is logistically feasible.

- In keeping with the spatially-nested character of the design, we present examples of vegetation data from points, minigrads, and the landscape (all minigrads). In Chapter 4, we begin with the data collected at individual points. Understanding what the data look like at the point level provides a foundation for understanding how the data are used to describe meso-scale and regional scale variation in vegetation (addressed in Chapters 5 and 6, respectively).
- Examples of data from selected individual points are shown to illustrate the following:
 - Plot photographs,
 - Physical environment and soils data summaries,
 - Vegetative cover transect data summaries,
 - Vascular plant species composition data summaries,
 - Tree data, including plot maps of tree distribution, tree density and biomass measurements, and tree increment coring data.

Chapter 5: Individual Minigrads: Variation in Vegetation at the Meso-Scale

- In Chapter 5, we move to the next larger spatial scale of inquiry and present data for entire minigrads.
- We present examples of the data at the minigrad level to show the variability in measured parameters at the meso-scale level. The meso-scale level is designed to capture the main gradients associated with topography and soils, such as slope, elevation, aspect, site history and a suite of soil factors.
- To illustrate data at the meso-scale, we chose three minigrads as examples: a boreal minigrad (West Toklat); an alpine minigrad (Primrose Ridge), and a transitional (boreal-alpine) minigrad (Lower Stony Creek). Using data from all 25 points sampled in each minigrad, the physical and vegetative characteristics of each minigrad are described.
- Relationships between vegetation and physical attributes are then examined, focusing on 1) vegetation structure; 2) tree abundance; 3) vascular plant species richness; and 4) community composition.

- We identified significant variation in vegetation variables in response to environmental gradients in each of the minigrids discussed. The utility of the proposed design rests upon the ability to model variation in vegetation along the primary landscape gradients within the minigrids.

Chapter 6: Among Minigrids: Variation in Vegetation at the Regional Scale

- In Chapter 6, we move to the next larger spatial scale of inquiry and provide examples of how this design allows observations from minigrids to be used to make inferences at regional scales.
- We present comparisons of the ranges of variation *among* the nine minigrids for physical and vegetative attributes measured during the pilot study.
- We also show how post-stratification of the entire data set can be used to examine the relationships between specific environmental gradients and vegetation attributes at the regional scale.
- We show how comparisons of data among minigrids, and data combined across minigrids, can be marshaled to quantify and understand the variation in important vegetation variables in response to landscape gradients.
- The value of the proposed design is its ability to provide data that allow us to construct robust and general models relating variation in vegetation to underlying causal factors. Models constructed using data from successive iterations of field sampling may be compared to detect changes in these underlying ecological relationships.

Chapter 7: Introducing the Songbird Data

- We conducted bird surveys in 2001 and 2002 on the pilot study minigrids also visited by the vegetation crews. As described earlier, the pilot study minigrids were located in the northeastern region of the park, and included different habitats (alpine, transitional, boreal) and access methods (helicopter, foot travel).
- As for the vegetation crews, the songbird crews were able to access almost all points in the pilot study minigrids. Sampling songbirds with standard point count techniques using the minigrid design is logistically feasible.
- In keeping with the spatially nested character of the design, we present examples of songbird data from points, minigrids, and the landscape (all minigrids).
- As expected, songbird species composition at individual points was related to vegetation structure.

- As expected, songbird species occurrences varied between and among minigrids. Variation was greatest among minigrids that varied by environmental attributes such as vegetation composition and elevation. Minigrids similar in environmental characteristics shared more species.
- While preliminary, these data illustrate the potential for using songbird data collected on the minigrid system to track the relationships between bird communities and landscape structure in Denali.

Chapter 8: Estimating Costs for Implementation

- Recognizing and providing for the costs involved in long-term monitoring is critical to program success.
- Costs are often underestimated which can lead to important aspects of program operations, such as data management and reporting, being neglected. Overestimation of costs is also a problem, if it leads to abandoning an otherwise useful approach. Probabilistic sampling designs for large or difficult to access regions may not even be attempted because it is assumed that the costs are too high.
- From our pilot studies, we have been able to hone in on what the operational costs of implementing the proposed design in Denali will likely be.
- We estimate an annual budget on the order of \$95,000 for vegetation aspects of the program.
- Under this scenario, two field crews are deployed and a GS-9 Biologist is hired to cover some duties currently performed by the Principal Investigator. With this level of funding, 7 minigrids would be visited each year, and the Principal Investigator would be able to devote more time to data analysis and reporting.
- A key finding from this cost analysis is that the majority (75%) of the expense to implement the program is for personnel.
- Training represents 20% of personnel costs, emphasizing the importance of finding qualified employees and retaining them.
- Costs of transport to minigrids (helicopter) were a relatively minor portion (~9%) of the overall budget. A basic premise of the design was to minimize helicopter use, so this finding is not surprising. Future helicopter costs are difficult to predict, so future costs for getting to minigrids are somewhat uncertain.
- The costs of managing, analyzing, interpreting and reporting data are often the most overlooked and underestimated costs of monitoring. Realistic estimates are that these activities represent 30% or more of total costs.

- We found annual data management costs for minigrid design implementation difficult to quantify. Some costs are paid by other funding sources (i.e., park base, network, region, and national programs of the NPS and USGS). We are also still learning what it takes to analyze and report the monitoring data from this design. Thus, our current estimate for data-related costs is an underestimate and will need to be refined.
- Another important finding relates to “subsidized” costs. These include the salary of the Principal Investigator, administrative support, and data analysis and management support. Although the exact costs for these activities are difficult to pin down, simple recognition that these costs must also be supported is critical to the program’s long-term success.
- This ballpark estimate for annual costs and our analysis of program expenses should provide a solid basis for evaluating trade-offs as the process of refining a sustainable long-term monitoring program continues.

Chapter 9: Synthesis and Recommendations

- Our goal in writing this report was to solicit scientific and management feedback so the design can be strengthened and modified to meet park needs.
- We began this pilot study essentially “from scratch”. In the last three years, we have progressed on two parallel tracks:
 - Testing field methods and logistics under a wide variety of conditions and biotic communities with crews of seasonal technicians, and
 - Developing a foundation for analyzing and assessing multiple-scale monitoring data by creating a relational database and data analysis routines.
- Proposed objectives for the FY 2004 Work Plan related to the Minigrid design are:
 - Respond to peer and management reviews of this report.
 - Analyze and report on vegetation and songbird data collected in 2003.
 - Analyze vegetation data to address measurement error and other “detection of change” questions.
 - Write a study plan for field season 2004 and beyond in keeping with review comments and results of our continuing analyses.

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Introduction

Denali National Park and Preserve (Denali) protects and preserves a 2.4 million ha region in central Alaska (Figure I.1). Denali includes Mt. McKinley, the highest mountain in North America, and extensive lands surrounding it. In 1992, Denali was one of four parks nationwide to initiate a long-term ecological monitoring program. Denali was selected as a testing ground for monitoring methods appropriate for subarctic parks. Detection of change in key characteristics of the vegetation and animal communities of Denali is a fundamental objective of the park's Long-term Ecological Monitoring (LTEM) Program.

This report presents the latest findings on development of objectives and methods for monitoring ecological attributes of Denali at large spatial scales—scales up to and including the entire park. The purpose of this report is to present, in a single report, our findings from investigations conducted between 2000 and the present. In these investigations, we examined the utility of a systematic design based on a grid of points covering the entire park. We intend this report as a convenient vehicle for obtaining management and peer review of this idea. An evaluation is needed at this point to inform decisions about the future direction of the monitoring program.

An overarching goal of the Denali LTEM Program has always been to develop integrated information about the Denali environment. Our work on the grid idea began with vegetation, but the grid provides an obvious framework for looking at other aspects of the environment in a manner that will promote integration of data sets. To explore the integrative potential of the grid design, we started with songbirds, coinciding with a major review and revision of the landbird monitoring portion of the Denali LTEM program (McIntyre 2003). Thus, in this report, we also present findings about the applicability of the design for looking at songbird populations and for integrating datasets generally.

Hinds (1984) observed that successful long-term monitoring programs must be relevant, statistically credible, and cost-effective. Programs that neglect any one of these critical areas will face problems and likely fail. In this report, we address all three elements for sustainability. “Relevancy” begins with statements of objectives that demonstrate ecological relevancy and relevancy for park managers. Thus, we begin by explaining the monitoring objectives in Chapter 1. Statistical credibility is crucial to the creation of reliable data sets, and we describe the statistical approach we propose in Chapter 2. An evaluation of monitoring data provides a reality check on the relevancy of the objectives and on ability of the statistical design to deliver the goods: Will the data answer the questions we have? We therefore present pilot study data to show what the data to meet the objectives collected according to the proposed design look like (Chapters 4-7). Costs must be considered to ensure that all things (people, equipment, etc.) necessary to carry out the monitoring are accounted for and adequately supported. Costs must also be within the boundaries of the monitoring budget and supportable over the long-term. Thus, we present estimated costs for implementation in Chapter 8. By addressing these 3

elements for sustainability, we hope to build a solid foundation for long-term monitoring at Denali.

In this introductory chapter, we explain how the grid idea came to be the focus of our investigations; introduce the design and its major features; and, provide an overview of our pilot studies from 2000 to the present.

Background: How We Got Here

Although the park-wide design we describe in this report could apply to a variety of ecological attributes, our investigations were centered around and expanded from the vegetation monitoring component of the program. From the beginnings of the monitoring program 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 emerging 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 broader array of issues.

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 reactions were skeptical—we assumed a grid would not be feasible. After further consideration, however, the idea became attractive to us for several reasons. Collocation of plots would move us toward the elusive goal of integrating data sets, and the probability design would help us avoid bias and allow inferences. 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 grid 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).

For landbird populations, the original monitoring program, based on two independently operated projects, was limited to spruce forest and shrubby willow sites along the park road with all survey routes selected without a sampling design. Thus, the same concerns that arose for vegetation monitoring also arose for landbird monitoring. There was no clear reason why monitoring was focused solely on forest birds, as opposed to birds of subalpine and alpine areas, or birds of other areas (e.g., aquatic birds). There was no way to evaluate what portion of the park's bird communities was actually being monitored. These concerns led us in the same direction that the concerns about vegetation monitoring had led.

Introducing the Systematic, Two-stage Design

Although the proposed design, and the rationale for choosing it and its various features, will be discussed in detail in Chapter 2, a brief description is necessary at the outset. As mentioned earlier, the design is based on a systematic grid of points covering the entire park. In statistical parlance, the design is a systematic, two-stage design. The design is probability-based because the starting point of the grid was randomly selected. The fact

that all points within the park had an equal, randomly-determined probability of entering the sample population allows us to make inferences from the sites we visit to the rest of the park. This is a key feature of the design. Other key features are the use of permanent plots, and the lack of stratification of the sample prior to data acquisition. The rationale for these and other choices involving the design will be explained in Chapter 2.

As noted, the design has two stages. The first stage of the design consists of the points on the grid located at 20 km intervals (Figure I.2). Within Denali's 2.4 million ha, there are 66 points. At each of these points, sampling will occur for each attribute of interest in the second stage of the design. For vegetation, this second stage of the design is a "minigrid" of 25 points spaced 500 meters apart (i.e., 5 rows of 5 points) (Figure I.3). At each point, a single circular plot 16 m in diameter and encompassing 200 m² is established for the majority of vegetation measurements. For songbirds, the 25 minigrid points used for vegetation sampling provide convenient locations to also survey birds, via standard point-count methodology.

The two-stage minigrid approach 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 the systematic, two-stage 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 minigrids in different ecoregions. Meso-scale gradients will be understood by analyzing the variation in measured parameters within individual minigrids. Variation along micro-scale gradients will be captured within individual sites in a minigrid.

Because the focus of our initial effort has been on sampling minigrids, we have come to speak of the "minigrid" design—therefore, "minigrid" has evolved into the common name for the program. However, while the minigrid is the second stage of the design being investigated for vegetation and songbirds, the second stage could take a different form for other attributes. This flexibility is important for fitting together datasets from all components of the program.

To detect change at the points over time, the points are revisited to make repeat observations using identical methods. The exact scheme by which the points would be revisited is still being evaluated. Given the constraint of fixed budgets, there are obvious trade-offs between the temporal "intensity" of a sampling regimen (i.e., frequency of resampling) and spatial extensiveness of the sampling frame (you cannot have it all)! Recognizing this, the objectives for extensive-scale vegetation monitoring were specifically crafted to focus on fundamental parameters of the vegetation cover that, in general, are expected to change relatively slowly. This choice allows for longer return intervals before a given change would be detectable, and thus facilitates our goal of effectively pursuing a truly landscape scale monitoring approach for vegetation. For other attributes with different sets of objectives, revisits may need to occur more frequently and/or spatial extensivity may need to be less than for the vegetation program. The negotiation between return interval and spatial extent of the sampling frame will need to be performed based on the specific needs of each component of the program. The temporal aspects of the design—particularly how differences in sampling frequency will affect our ability to integrate the data—is an active area of investigation.

Now that the basic outline of the minigrid approach has been described, we turn to a brief description of our efforts to determine if the design is logistically feasible and if it will provide the data needed to meet our objectives.

Testing the Design: The Pilot Study

The grid design sounded good scribbled on the back of a napkin, but what would it be like on the ground? How many points would be needed? Could we actually get to the points? Could a single crew survey vegetation and songbirds during the same visit? Could we afford it? What would the data look like, and how would we analyze them? Would the data meet the objectives of the program? To begin to answer these questions, we embarked on a pilot study. Pilot studies are an integral part of designing long-term monitoring programs because they allow you to test your methods and design before making final decisions.

Our pilot study has had two thrusts. We began in the virtual world, using computer simulations to settle on a grid spacing that would be a balance between feasibility (what we could afford) while still providing enough points to sample the diversity of the park landscape. The second thrust of the pilot study has been to get out into the real world and collect data.

We began pilot studies of the Denali minigrid design in 2000 with the aforementioned simulations. Through this process, we were able to settle on the use of a 20 km x 20 km spacing between grid points. With this decision made, a grid was laid over the park, thereby defining the points to be sampled. This allowed us to begin field tests, which started in 2001.

We started by selecting 3 points to test the range of access methods that would ultimately be required to reach sample points throughout the park. The most likely access methods for the 66 points included foot travel, helicopter, fixed wing aircraft, and raft. In 2000, we were able to test foot travel and helicopter access methods by sampling the grid points located in Rock Creek, Savage River, and Wigand Creek (Figure I.4). The 3 points were all located in the northeastern section of the park, which includes the park road.

Rock Creek was chosen because it could be sampled by day trips from the park road. In addition, this minigrid overlaid the original sampling sites in the Rock Creek watershed. Comparing data from the minigrid to data from the original sampling sites would be a valuable exercise. The Savage River minigrid was chosen because it was near the road, but would require the crews to hike in with all the sampling and camping gear. Thus, Savage River grid would be a good test of logistical feasibility. The Wigand Creek grid was chosen because it would be accessed by helicopter. Sampling this minigrid would illustrate the logistical challenges of working within limitations posed by helicopter travel (e.g., weight, weather, budget, FIREPRO helicopter availability).

The three grids were also chosen with an eye toward including a range of the available habitats in the northeastern section of the park, including tussock tundra, spruce forest, subalpine shrublands, and alpine ridges and meadows. In the first year, we needed immediate answers to the basic questions of navigation and travel. We also needed to see how the methods worked in the various habitats of the park, and to see how variable the data were.

We successfully visited the 3 minigrids in 2001. In 2002, we therefore embarked on a slightly more ambitious sampling program and visited seven minigrids. The minigrids chosen for sampling in 2002 were also in the northeastern section of the park (Figure I.4). Our decision to focus the pilot study in this area was based partly on the need to collect baseline data in this area, which has been targeted for construction of new access. The park's need for data in the "North Side Access" area coincided with the minigrid pilot study in a way that benefited both efforts.

Thus, at this point in time, the minigrid effort has included simulations to assist in the selection of the design layout, and field work to test logistic feasibility and collect data. Here, we report on the results of the pilot study for the purpose of soliciting feedback on the proposed approach.

Denali Landscape-scale Monitoring Website

We have developed a website to facilitate communication and discussion of our work. This website serves our immediate need to make as much information as possible available about the minigrid pilot study to aid in its evaluation. The website complements this report by providing access to the wide variety of documents that record the history of our progress as well as the pilot study data.

The website also serves a long-term need to make the data from the Denali monitoring program readily available to multiple audiences. The landscape-scale monitoring framework we are proposing has broad spatial and temporal contexts. We anticipate that a large volume of information on the entire cross-section of park ecosystems will be generated. Our first priority is that this information will be of direct use to park management and its science and education programs. This information should also be of use to a much broader public as well. Starting a website during the early stage of the program demonstrates our commitment to making data available. It also allows us to learn what works and how we can improve this capability. We envision that this web site will grow and evolve over time and will eventually include numerous additional functions, such as interactive database queries and GIS interface capabilities.

The current home for the Denali Landscape-Scale Monitoring web site is the University of Alaska Fairbanks (UAF) (<http://mercury.bio.uaf.edu/DenaliLTEM>). We have been working with Dr. Eric Rexstad and Ed Debevec of UAF's Institute of Arctic Biology for several years developing web-based access to Denali monitoring data. As part of this effort, Ed Debevec helped us create a website to serve information, including documents, data, and photographs, about the landscape-scale monitoring effort. The site will be transferred to an NPS server during FY 2004.

The website has four divisions:

1. **Documents**: a page for retrieving relevant documents concerning the Denali landscape-scale monitoring program and its development;
2. **Photos**: a set of pages that allows the user to view plot photographs and images of the minigrids visited thus far;
3. **Data Summaries**: a set of pages that make available a wide variety of data summaries for vegetation and songbird data collected during our pilot field studies during 2001-2002; and
4. **Links**: a page that provides links to other resources concerning this program and Denali National Park and Preserve generally.

We encourage all readers to visit the website as a helpful adjunct to reading this report. The photographs are especially useful for understanding the scale issues involved (e.g., What does 500 m mean in the Denali landscape?), and the data summaries help show the variety of ways the data can be used.

Guide to this Report

This report is organized into 2 volumes. Volume 1 (this document) is the main body of the report. Volume 2 contains the majority of the figures and tables (a few small tables are embedded in Volume1). We chose this approach to document production because of

limited time for formatting and because the report was being prepared for the purpose of obtaining review.

Volume 1 includes 9 chapters.

- **Chapter 1: Monitoring Objectives.** Because sampling designs and methods must match the objectives, we begin by presenting the objectives of the vegetation and songbird components of the Denali LTEM program. To understand the development and appropriateness of the proposed design, a solid understanding of the objectives is required.
- **Chapter 2: The Proposed Approach.** In this chapter, we provide an overview of the sampling design we propose to meet the objectives. We discuss the rationale for a probability-based design, and describe the basic features of the design. We describe the process of coming up with the design and highlight the rationale for decisions leading to the design.
- **Chapter 3: Field and Analytical Methods.** Here, we describe the methods used to collect vegetation and songbird data, as well as the methods of data analysis. This chapter is a useful prerequisite to the following chapters, which present and discuss the pilot study data.
- **Chapter 4: Introducing the Vegetation Data.** In this chapter, we introduce the vegetation data by providing examples of data collected from individual points. This chapter provides familiarity with the data and lays the groundwork for the following two chapters, where we show how the data are analyzed at the meso-scale and regional scale.
- **Chapter 5: Individual Minigrids: Variation in Vegetation at the Meso-scale.** In this chapter, we look at how data from the 25 points within a minigrid are analyzed to describe variation in vegetation patterns at the scale of the minigrid. For this purpose, we chose three minigrids spanning the boreal-alpine gradient that typifies Denali, to use as examples: a boreal minigrid--West Toklat, a transitional minigrid--Lower Stony Creek, and an alpine minigrid--Primrose Ridge.
- **Chapter 6: Among Minigrids: Variation in Vegetation at the Regional Scale.** In this chapter, we move to the next scale of interest—the regional scale. Here, data from all minigrids sampled in the pilot study are considered. We compare the ranges of variation among the sampled minigrids, and we demonstrate how post-stratification can be used to examine relationships between environmental gradients and vegetation at the regional scale.
- **Chapter 7: Introducing the Songbird Data.** In this chapter, we present an overview of our experiences and initial findings from bird surveys on the pilot study minigrids. Although the findings are preliminary, the data help demonstrate

the potential for the minigrid design to produce integrated information about change in Denali ecosystems.

- **Chapter 8: Estimating Costs for Implementation.** Cost is the Achilles Heel of any long-term monitoring program. A realistic assessment of the costs to collect and analyze the data is necessary. One of the values of the pilot study is the opportunity to determine what (personnel, equipment, travel, etc.) is needed to perform the work, and the costs of those things. In this chapter, we describe a ballpark budget for implementing the minigrid design. This ballpark estimate provides a basis for evaluating trade-offs as the process of refining a sustainable long-term monitoring program continues.
- **Chapter 9: Synthesis and Recommendations.** We conclude the report with a chapter to emphasize key points in this report and lay out our immediate plans for activities in FY 2004.

Your Feedback Needed

We conclude the introduction by asking readers for their input on the ideas presented in this report. Input on the objectives, the overall design and its various features, the data, and the tacks we have taken to data management and analysis is needed. We also need to hear about important aspects of design we may have neglected or not addressed. The feedback we receive on this report will help Denali and other parks make decisions as we move from pilot study mode to implementation.

Sara Wesser, Inventory and Monitoring Coordinator for the NPS-Alaska Region, is coordinating the review process for this report. Please remit comments to her by [to be determined].

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Chapter 1. Monitoring Objectives

Because sampling designs and methods must match the objectives, we begin by presenting the objectives of the vegetation and songbird components of the Denali LTEM program. To understand the development and appropriateness of the proposed design, a clear understanding of the objectives is required. To understand the objectives, however, the context for the objectives is also necessary information. Here, we delve into the frameworks for the objectives and how the frameworks and objectives have evolved.

The overall goal of the Denali LTEM program is to protect park resources by providing ecological context for resource preservation decisions (Oakley and Boudreau 2000). This goal is met through monitoring activities that (1) provide timely information to decision makers to determine if ecological status and trends require a change in management, and (2) improve understanding of Denali ecosystems (Oakley and Boudreau 2000). These broad goals for the Denali LTEM were set prior to the advent of the National Park Service Vital Signs Monitoring Program¹, which has established national goals for monitoring. Although the wording is somewhat different, the Denali goals have the same intent as the national goals to (1) provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management, and (2) provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments. The proposed monitoring objectives and design described in this report address primarily the latter goal related to understanding the dynamic nature of park ecosystems.

The organizational framework of the Denali LTEM program is ecological. Vegetation is one of four broad program components—the others are physical environment, aquatic systems, and fauna. Vegetation is recognized as a critical program component because of the value of vegetation for its own sake, and for the central role that vegetation plays in the ecosystem. Songbirds are part of the fauna component of the Denali LTEM program. Only two faunal groups were targeted in the original design of the program: landbirds and small mammals. Landbirds were included because they include many migratory species and are important component of the park's biodiversity. Specific monitoring objectives are set within each of the four broad program components.

In this chapter, we describe in detail the frameworks and objectives for vegetation and songbird bird monitoring, and their evolution.

Vegetation Objectives

The objectives for vegetation monitoring as part of the Denali LTEM program have gone through several iterations since the initial proposal. In all iterations, the objectives have

¹ Denali is now included in the Vital Signs Monitoring Program as a part of the Central Alaska Network. The other parks in this network are Yukon-Charley Rivers National Preserve and Wrangell-St. Elias National Park and Preserve.

included, as a highest priority, a desire to detect significant changes in the structure, composition and distribution of the vegetation. Other objectives have included measurement of growth and reproduction of white spruce (*Picea glauca*), the dominant tree species in the park, annual berry production, annual phenology of selected species, tracking fires, and detecting changes in biodiversity (loss of rare species or introduction of exotic species). The major difference between earlier and later versions of the objectives concerns the scale at which the objectives be addressed. Another critical difference relates to the relative importance of vegetation monitoring within the LTEM program overall. Being recognized as one of four major components of the LTEM program has allowed the development of comprehensive vegetation monitoring objectives.

The objectives described here are the most recent version, and were first iterated by Carl Roland, Plant Ecologist for Denali, in March 2000, in a comprehensive objectives document (Roland 2000). These objectives reflect review of the original objectives and data, input from the 1995 review of the entire LTEM program and the 1997 external peer review of the vegetation protocol, and a conscious effort to address the concerns expressed in those reviews about the original vegetation monitoring program. They also reflect input received during the Central Alaska Network Scoping Workshop held in April 2002. Overarching considerations in the development of the revised objectives were desires to:

- Switch from model-based to design-based inferences thereby allowing statements to be made with confidence and allowing inference to areas larger than those sampled;
- Include the whole park in the sampling frame to allow meaningful statements about status and change in vegetation to be made with confidence;
- Monitor attributes with the potential to address a broad array of potential management concerns, including concerns that cannot be foreseen at this time; and,
- Provide the opportunity to investigate relationships among vegetation and landscape variables and how these relationships change over time.

Why Monitor Vegetation?

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. The primacy of this process forms the linchpin for many aspects of the science of ecology, including our understanding of the movement of energy through ecosystems, the nature of trophic interactions within a system and the characterization of niche characteristics and habitat volumes for different elements of the biota.

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. food) 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 fauna of forested habitats in interior Alaska differs from the fauna found in neighboring boreal meadow sites, in large part because of the differing vegetation structures 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. The effects of plant-animal interactions such as herbivory can be another important factor in controlling vegetation patterns and processes on the landscape, particularly during times of high animal densities. Two recent examples from Alaska are: the effects on vegetation of very high hare densities in interior Alaska over the past three years, and the considerable changes caused by spruce-bark beetles in south-central Alaska a few years ago.

Understanding the factors that control the distribution of the vegetation, and those that control the rates and attributes of key vegetation processes is thus central to understanding the ecosystems of Denali National Park and Preserve. We believe that vegetation monitoring can serve as a “keystone” monitoring component that can 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 close causal relationships between environmental parameters (such as climate and lithology) and vegetation attributes make these attributes sensitive bio-indicators of environmental changes.

Why Environmental Gradients are Important to Understanding Vegetation Patterns in Denali

The vegetation of Denali National Park and Preserve is composed of a mosaic of taiga and tundra ecosystems. The distribution of the different plant communities that make up the landscape of the park is controlled by the interaction of climate, topography, substrate, and site history with the regional biotas of the park. 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 park includes tussock tundra on solidly frozen permafrost in the interior of the Toklat Basin, lush mixed forest in the Cook Inlet 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.

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. 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 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 park. That is, although “white spruce forest” is found near park Headquarters, in the Cook Inlet lowlands, and also in the Kuskokwim River drainage far to the west, 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 park. 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.

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 most any 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 captures only a fraction of a major ecological gradient (elevation, for example) would not provide adequate data for our purposes. To detect changes in the relationship between variation in vegetation and underlying landscape gradients, samples must be analyzed across the entire gradient in question. Understanding and detecting changes in the primary ecological *relationships* between landscape and vegetation is the focus of our long-term vegetation monitoring strategy, not simply describing the properties of the standing crop at any given point in time.

Spatial and Temporal Scales for Vegetation Monitoring at Denali

We separated the objectives for long-term monitoring of vegetation into two categories based on their spatial scale: “extensive-scale” objectives, and “intensive-scale” 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 interannual 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. We decided that attempts to include such parameters could be fatal to the overall goal of sampling the vegetation at a landscape 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.

We now describe the 10 extensive-scale monitoring objectives in the vegetation component of the Denali LTEM 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, human use, landscape appearance). The objectives, although developed through the vegetation component of the program, reflect the desire for an integrated program.

Extensive-scale Vegetation Monitoring Objectives

Objective #1—Structure of the Vegetative Cover

Monitor changes in the structure of the vegetation cover of the park 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 (Vioreck et al 1992).

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

1. Detect changes in the absolute and relative abundances of the different growth-form classes that form the vegetation cover of the park.
2. Detect change in the abundance and composition of the dominant species in the vegetation cover.
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—Composition of Vegetative Cover

Monitor changes in the taxonomic composition and diversity characteristics (including species-area relations) of the vegetation cover of the park 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:

1. Detect changes in the species composition of the vegetation (this consists of comparisons of species *lists* at time₁ vs. time₂ vs. time₃).
2. Detect changes in the species-richness characteristics of the vegetation (this consist of comparisons of the *number* of species per unit area at time₁ vs. time₂ vs. time₃).
3. Detect changes in selected measures of diversity of the vegetation at several spatial scales (using comparisons of calculated indices of diversity at time₁ vs. time₂ vs. time₃).

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 (m² of tree bole/unit 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:

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

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:

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

1. Detect change in the number of forested plots affected by selected insect species over time.
2. Detect change in the severity or intensity of insect damage to trees in forested plots over time.
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 overwinter survival rates for insects in interior Alaska.

Objective #6—Human Use

Monitor changes in the evidence of human use of the landscape of the park.

By documenting evidence of human use at the sites on an extensive-level plot network (such as: a trail nearby, vegetation trampling, camp fire ring, garbage present) it should be possible to make area-based statements concerning particular types of human use of the landscape, and how those uses may change over time. This would serve as a “strategic” or background level of detection of such changes analogous to the way the

species composition data will serve as a background level for exotic plant species distribution. Human impacts will need to be studied in a “tactical” sense by performing targeted trail monitoring in heavy use areas, but we envision the extensive plot network as providing a landscape-scale context for intensive measurement activities relating to specific impact concerns.

Specifically, the measurable objectives for monitoring evidence of human use of the landscape are to:

1. Detect changes in the distribution patterns in physical evidence of human use of park landscape.
2. Detect changes in the severity and distribution of vegetation impacts due to human use of the landscape of the park.

Objective #7—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:

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 #8—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:

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

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 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 #9—Fuels

Monitor changes in the amount, distribution and character of fuels (particularly the duff layer and woody debris) on the landscape of the park.

Specifically, the measurable objectives for monitoring fuels are to:

1. Detect changes in the total amount of fuels on the landscape of a park.
2. Detect changes in the type, size and position (vertical distribution) of fuels.
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 soil 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 #10—Landscape Appearance

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:

1. Photo points directly associated with the sampling of the extensive plots that will document vegetation changes in the plot area.
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 with Dr. Les Viereck on a project to reproduce some historical photos that he has taken over the years in the park, this work has shown the great value of repeated photography for documenting and understanding landscape change over time.

Focus on Using Landscape-Vegetation Models for Monitoring

The essential goal of this component of the Denali LTEM program is to detect changes in the properties of the vegetation cover of the park over time, as described in the objectives presented above. However, another primary goal is to collect vegetation and associated data about the park landscape that will allow for quantitative modeling of the ecological relationships that control the variation in vegetation parameters (including diversity, community composition and vegetation structure) on the current landscape. These two basic goals for the program are intimately related. In fact, we believe that, in a sense, the primary indicators of interest to this monitoring program are actually the underlying relationships between vegetation parameters and landscape variables (such as elevation, slope, aspect, etc...), rather than simply the mean values of the “standing crop” of vegetation.

In practice, this focus on modeled landscape-vegetation relationships means that we will collect data in such a manner as to facilitate the examination of the monitoring data along ecological gradients. We will therefore attempt to assess whether vegetation changes have occurred by determining whether the nature and/or magnitude of a *relationship* between the dependent vegetation parameter of interest and an independent physical variable has changed, not necessarily just whether the overall mean of the vegetation parameter has changed.

A simple example of the type of analysis we anticipate would be a comparison of the slope of the regression line that predicts tree density based on plot elevation during

sample iteration 1 vs. the same regression line developed from data collected during sample iteration 2. This is a qualitatively different sort of analysis than simply asking whether the overall mean tree density for an entire area is different in time 2 vs. time 1. Essentially, the approach we advocate involves using what we know about significant landscape control of vegetation parameters (represented by modeled quantitative relationships from previous sample iterations) to detect and assess any changes in vegetation that may be occurring on the landscape. However, the comparison of overall mean density is a simpler analysis, which we will still be able to perform with the data we collect.

In the subarctic, the physical environment is largely responsible for controlling vegetation patterns on the landscape. Furthermore, because of the low solar angle and other factors, topographic variables are crucial mediators and determinants of the nature of the physical environment of a site in the far north. Thus, if changes in physical parameters occur, these changes will presumably be clearly reflected on the landscape by changes in vegetation, and furthermore any such changes will occur unevenly across the landscape, their character and magnitude mediated by the topographic attributes of different parts of the landscape. As a result, our approach to monitoring vegetation in the subarctic is focused on discerning what changes, if any, occur in the underlying relationships between easily measured landscape variables and the vegetation parameters of interest. This approach is predicated on the observation (and preliminary data presented later in this document) that there are strong and conspicuous correlations (and often causal relationships) between the vegetation parameters of interest and landscape variables. If variation in vegetation attributes was different, such as if it were primarily randomly variable, or ordered mostly by biotic interactions unrelated to the landscape, or perhaps variable along inconspicuous and not easily measured environmental gradients, this approach would be unwarranted and highly problematic. That is, there would be significant difficulties in taking an approach focusing on monitoring vegetation along principal topographic gradients.

Another reason for our emphasis on using modeled relationships to detect vegetation change is that significant changes in vegetation could realistically occur at a landscape scale between two sampling events that actually result in no net difference in the population mean reflected in the data. For example, a warming and/or drying trend in interior Alaska could cause treeline to migrate upwards in elevation in the park, causing increases in the density of spruce within Denali. However, this same climatic shift might also engender changes at lower elevations, such as drought stress or increased insect activity, that act to reduce spruce density within the park. In this instance, if one were to simply test for changes in overall density of spruce at a park-wide scale, the mean values would cause one to reject the hypothesis that changes had occurred in spruce density over the sample interval. On the other hand, the equations describing the relationship between spruce density and elevation would likely be dramatically different between the two sample iterations. We believe that using a more nuanced approach to data analysis that relies on modeled fundamental relationships is likely to substantially increase our ability to both detect change and to understand the ecological dimensions of any changes. In many cases a simple change in mean abundance of a vegetation variable at a park-wide

scale is of considerably less import, ecologically, than observed changes in fundamental relationships that would be understood only through the process of comparing models derived from subsequent sample iterations.

We believe that using monitoring data to develop quantitative models that predict vegetation variables based on a suite of measured physical attributes will not only allow us to better understand the current vegetation ecology of the park, but also allow us to better detect changes that occur in the vegetation cover of the park over time. In addition, these models will help place any observed vegetation changes into their ecological context, and help managers understand the potential consequences of these changes.

Songbird Objectives

Just as the objectives of the vegetation component have gone through a significant development and refinement as the program has evolved, the objectives for the landbird monitoring component have also evolved. McIntyre (2003) provides a complete history of the landbird monitoring component of the Denali LTEM program, documenting a major shift in the program emphasis coincident with development of a draft Avian Conservation and Management Plan for Denali. The initial landbird monitoring projects, point counts conducted by the Alaska Bird Observatory (ABO) and mist-netting for the Monitoring Avian Productivity and Survivorship (MAPS) program conducted by the Institute for Bird Populations (IBP) focused on detecting population changes in a suite of forest-dwelling species. These objectives grew from an overall concern for declining populations of neotropical migrants (Weicker and Benson 2002). Unfortunately, both projects were designed and conducted independently of each other. While these projects had related goals, the lack of a probabilistic design and a focus strictly on a limited number of common songbirds, resulted in the meaning of the data being unclear. The 1997 peer reviews raised many questions about the validity of the initial landbird monitoring effort.

In an effort to determine what types of bird monitoring programs are needed at Denali, both for park-wide and region-wide monitoring, Denali staff are in the process of developing the Denali Avian Conservation and Management plan. This plan, which is currently in preparation, includes several goals of specific relevance to shaping the bird monitoring in the LTEM program. These goals include putting more focus on understanding the ecological dynamics of birds on the landscape and documenting the presence, breeding status, habitat characteristics and when applicable, the relative abundance of bird species in Denali.

Within the context of the Denali Avian Conservation and Management plan, the monitoring paradigm has shifted by placing a higher priority on gathering information about the overall distribution and relative abundance of birds within the park and to understanding how these patterns change over time. While this is a major shift from the original goals of the bird monitoring programs conducted by ABO and IBP, the data collected by ABO using point counts is very useful for planning new surveys within the minigrid sampling design. Within this new framework, we need to test the applicability

of tools such as using presence/absence data and change in bird assemblages, in addition to monitoring of individual species populations.

The Role of Bird Monitoring in Denali and on the Minigrids

At least 115 species of bird breed in Denali. Another 50 species pass through the area during migration. Monitoring birds at Denali requires a well-designed, multi-faceted approach. The term monitoring takes on many different meanings, and bird monitoring programs may include a wide variety of activities including monitoring population trends of specific species (e.g., Trumpeter Swans), monitoring reproductive characteristics of specific species (e.g., Golden Eagles and Gyrfalcons), or monitoring the occupancy of nest sites at specific locations.

In relation to the minigrid sampling design, songbirds provide us with a unique monitoring tool for assessing and detecting changes in the landscape. Of all vertebrates that occur in Denali, songbirds are probably the easiest and most economical to detect, and a single survey can cover many species (Hutto and Young 2002). Because the Denali LTEM program is interested in understanding change at the landscape scale, songbirds are a logical choice for inclusion in the minigrid design. (Keep in mind, however, that the minigrid system may not be applicable for monitoring other species such as Golden Eagles, Gyrfalcon, Trumpeter Swans, Harlequin Ducks, and other species that occur at very low densities). Songbirds include a wide variety of species that occupy many different habitats over many different environmental gradients. They often respond quickly to changes in their environments (Hutto and Young 2002, Jones and Bock 2002) and many species of songbirds are easy to survey using field-tested methodology. In the minigrid sampling, songbird birds may represent a unique response variable in relation to changes in vegetation (the explanatory variable). According to Hutto and Young (2002), habitat association data can help us move beyond long-term population trend monitoring, which most of us equate with “monitoring”.

Because the minigrid sampling design is based on a landscape approach, the design provides us with opportunities to develop distribution maps for many species of birds in Denali. Further, using the minigrid sampling system for monitoring other species and aspects of bird populations may be applicable in the future. For instance, establishing constant-effort mist netting stations in conjunction with point counts on specific minigrids may provide information on demographics of specific species (including those listed as species of concern by the Boreal Partners in Flight working group).

Perhaps one of the most exciting aspects of integrating the songbird monitoring with the vegetation monitoring on the minigrids is the opportunity to develop and test hypotheses regarding the distribution and abundance of songbirds in relation to vegetation structure and composition. Different species exhibit affinities for specific habitats, while others are more general in their habitat associations. Examining changes in the structure of bird communities in relation to changes in vegetation structure and composition provides us with a unique opportunity to examine ecological patterns and processes at high latitudes.

The Benefit of Monitoring at Permanently Marked Points

Monitoring at permanently marked points for long-term monitoring guarantees that the same points are sampled every time, ensuring that variation among years is due to variation in bird occupancy or activity at the point, and not to variation in point location (Hutto and Young 2002). Having permanently marked points also benefits the collection of environmental data including vegetation data and tracking changes in these variables over time.

The Role of Habitat Structure in Regulating Songbird Distribution Patterns

Some of the most obvious patterns in bird communities are those relating species to habitats (Wiens 1989). Species with specific habitat requirements may shift in their distribution and local abundance as habitat structure changes over time (Noon et al. 1979). However, many factors interact and influence the structure of bird communities including competition, density, predators, prey abundance and availability, parasites, events on migratory routes and wintering areas, and weather events. Because most of the songbirds in Denali are migratory, our sparse knowledge of the ecology and population biology of these species during migration and winter is a particularly conspicuous gap that may complicate the interpretation of results of our study. In a long-term study of bird community dynamics at Hubbard Brook (New York), researchers found that each species population was potentially limited by one or more of these factors, and that the relative importance of these factors differed among species, such that the dynamics of each species was driven by a different combination of factors (Holmes et al. 1986).

Suggesting that we identify the factors controlling songbird distribution in Denali without addressing these other factors is simplistic and dangerous. This pilot study is being used to assess the applicability of the minigrids and integrating sampling locations with other monitoring components. Two important components of any bird monitoring program are count data and demographic data (Marzluff et al. 2000, Hutto and Young 2002). While we are not including a demographic study in the bird monitoring effort at this point, we have not ruled out incorporating demographic studies into the minigrid design. Overall, we are using the minigrids as a starting point to describe the distribution and relative abundance of many species of songbirds, and we assume that these data will provide the foundation for generating hypotheses regarding the dynamics of songbird populations in Denali. Further, these data sets will provide insight into the spatial and temporal variability of bird communities in a naturally fragmented and naturally disturbed landscape. Most contemporary studies of the effect of landscape characteristics and structure and bird communities revolve around forest management and resource extraction (Drapeau et al. 2000, Jokimaki et al. 2000).

According to Wiens (1989) “greater insight into the effects of all these factors is likely to emerge, however, if studies of avian habitat associations are conducted at several locations over several years, and if they are founded on careful consideration of features of the natural history of the birds and their environments”. The minigrid sampling design

provides us with a means to examine avian-habitat associations in relation to Wien's suggestion.

Spatial and Temporal Scales for Songbird Monitoring

Multi-scale analyses permit the examination of scale-dependent patterns and interrelationships among scales (MacFaden and Capen 2002). Only a few bird studies, however, have addressed the consistence of variability in bird communities across different spatial scales (Jokimaki et al. 2000). The minigrid sampling design provides us with a platform for examining avian habitat relationships at scales ranging from micro-habitat to broad landscapes. This sampling design allows us the flexibility of examining the role of landscape structure on both the spatial and temporal variation in bird populations (Jokimaki et al. 2000). We assume that once we adequately model the spatial distribution of songbirds, we can then monitor distribution and abundance over time, and predict future changes based on changes in landscape variables and components (following Buckland and Elston 1993).

Many bird monitoring programs are focused on detecting population trends over time. This usually requires repeated sampling at the same points at a specific time interval (i.e., every year, every two years) to obtain the sample sizes and statistical power needed to detect change and estimate trends. Our primary objectives for this component of the songbird monitoring do not include monitoring population trends, rather we focus on more extensive questions concerning distribution, habitat associations, and changes in the composition of bird assemblages across the landscape over time. However, we can also test our ability to monitor some species of songbirds by resurveying points on a sample of minigrids at selected intervals over time (Carlson and Schmiegelow 2002).

Extensive-scale Songbird Monitoring Objectives

The goal of this pilot project is to assess point counts and distance estimation for monitoring the spatial and temporal variation in songbird assemblages in Denali. This phase of monitoring songbirds (and near-songbirds when applicable) aims to obtain data to provide information on birds across Denali's landscape and has several long-term objectives including:

1. Describe the distribution (spatial patterns) and develop indices of relative abundance (including species richness) of songbirds.
2. Describe and assess the variability, both spatial and temporal, of songbird assemblages.
3. Investigate spatial and temporal variation in species richness and community composition to better understand the ecological patterns and underlying processes that produce them.

4. Determine the ecological processes that produce the observed variability (asks the question about bird-habitat relationships both at the local and landscape scale).
5. Determine the scale(s) that these processes manifest.
6. Describe how songbird populations and communities respond to changes in vegetation and climate.
7. Measure species diversity at three levels:
 - a. Sampling station (alpha diversity; how species interact in the same environment).
 - b. Between sampling stations (beta diversity; how species respond to heterogeneity along environmental gradients; species turnover rate).
 - c. Over the entire sample set (gamma diversity; total bird diversity index).

Obtaining high quality data on the composition and structure of the vegetation communities within the minigrids is one of the major advantages of co-locating the songbird sampling and the vegetation sampling. Vegetation structure often affects the abundance and distribution of songbirds, and the data collected by the vegetation crew will be valuable for understanding the role of landscape structure on songbird distribution and abundance in Denali.

Chapter 2: The Proposed Approach

The purpose of this chapter is to describe in more detail the proposed design, specifically its evolution and the rationale supporting it. The process of developing a monitoring program involves many choices, or decisions, all of which involve trade-offs. Thus, the rationale behind the choices is important to understanding if the “correct” design decisions have been made. Here, we present our thinking about the choices made in the development of the proposed approach: a randomized, systematic, two-stage sampling design.

The first choice was whether to have a sampling design at all, so we begin there. We then lay out general sampling design considerations as context. We turn then to the evolution of the grid idea at Denali, starting with the introduction of the idea in fall 1998. Our initial investigations concerned grid spacing, so we then discuss how we came to choose the 20 km grid as the basis for data collection to meet the extensive-scale objectives. We then discuss our current thinking about sampling in time—the temporal aspects of the design. Experiences of other monitoring programs using systematic grid designs are related. We conclude with a general discussion of the advantages and acknowledgements of the limitations of the design.

First Things First: Why Have a Sampling Design at all?

The first and most fundamental decision was whether to have a sampling design at all. In the original Denali LTEM program concept, all study sites were selected by judgement in (presumably) representative locations, at both the park level (5 watersheds), and watershed level (sites within a watershed). This sentinel site approach is not technically a sampling design. The approach has considerable appeal because it is cheaper and logistically simpler. However, data from sentinel sites cannot be used to make inferences to broader areas, and bias is a problem. Thus, the first decision was to pursue a design grounded in probability theory. The primary benefit of having a sampling design is the ability to make statements with a known level of confidence about park conditions, and changes in those conditions. The confidence comes from knowing that we did not let our biases influence the areas we studied, and from having a measure of the reliability of estimates.

Related to the decision to pursue a probability design was a desire to understand changes occurring over the whole park--to get to that elusive, landscape-scale level of understanding. Why do we care about the whole park? We care about the whole park because the National Park Service is charged with protecting the whole park, for the benefit and use of this and future generations. Thus, even though the thought of trying to understand changes occurring over an entire 2.4 million ha area is intimidating, it seemed to us that should be the starting point. Knowing that a number of national monitoring programs attempt to understand environmental changes over continent-wide scales using probability designs provided an indication that this was not necessarily an impossible task (Olsen et al. 1998).

The pursuit of the landscape-scale relates also to the issue of bias: If we selected sites based on their presumed representativeness, how do we know that in fact the sites are representative of the entire 2.4 million ha park? How do we know that what is happening on our selected sites is also happening elsewhere? We don't. Some surprising (sobering) examples can be found to illustrate how our assumptions about the distribution and abundance of organisms or habitats in the environment can be wrong. The best way to test our assumptions is to take a sampling approach.

The NPS Inventory and Monitoring Program guidance now directs monitoring programs to use "good sampling practices" so that the data meet the purpose for which they were collected and withstand scrutiny by critics (<http://www.nature.nps.gov/im/monitor/>). The NPS has developed guidelines for long-term monitoring sampling plans because the basic assumption is that a sampling approach will be used (Table 2.1). The sampling approach proposed for Denali incorporates many of the recommended guidelines, including: use of a probability sample; defining the initial sampling frame as the entire park; using a grid to distribute sampling sites throughout the park; use of permanent plots; and collocation of sampling by program components.

Because the NPS has chosen to emphasize the use of probability designs, we could have skipped directly to discussion of the specific design considerations. We wanted to mention this important philosophical viewpoint right at the beginning to emphasize the significance of this high-level policy decision. Many environmental monitoring programs continue to use non-sampling approaches with high cost and logistical considerations being the primary reasons for not attempting a sampling approach. The NPS decision reflects the agency's commitment and willingness to commit financial resources to obtain credible data about park resources.

Sampling Design Considerations

Now that we have discussed the reasons for taking a sampling approach, we can move on to discussing specific sampling design decisions. First, the sampling design process takes place within the context of the overall program design process, which includes the setting of objectives.² Preliminary objectives need to be stated before sampling design can be discussed. In addition, the specific analytical methods that will be used to detect changes (and thereby meet the objectives) must also be kept in mind. The entire planning process is both stepwise and iterative. The steps are sequential, but problems encountered in later steps require revisiting decisions made in earlier steps.

Basic sampling design decisions include determining the following:

1. What is the population of interest?
2. What is an appropriate sampling unit?
3. What is an appropriate sampling unit size and shape?

² Numerous references discuss the overall monitoring program design process, e.g., Elzinga et al.1998, Parr et al. 2002, Caughlan and Oakley 2001.

4. How should sampling units be positioned in space?
5. Should sampling units be temporary or permanent?
6. How many sampling units should be sampled?
7. How often and when should sampling units be sampled?

(Elzinga et al. 1998). Monitoring protocol development typically requires research to answer these design questions. Some design decisions are relatively easy to make based on work by others published in the scientific literature. Other design decisions require experience in the particular environment. For example, migratory bird arrival and singing patterns for a given area need to be determined to properly schedule surveys. The size and spacing of plots for sampling vegetation depend on the vegetation patterns in the given ecosystem.

In Chapter 1 we discussed the vegetation and songbird monitoring objectives. In general, the program objectives relate to detecting changes in broad scale features of the ecosystems. That is, this is not a thematic program (restricted to one particular issue or topic, e.g., air pollution). The program has multiple objectives and multiple components; it is an omnibus program. This complicates the design process because it is not possible to optimize the design for every objective or component. The design must accommodate sampling of a wide variety of ecological attributes.

The Grid Idea is Broached

The idea of using a systematic grid for the Denali LTEM 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.

The grid suggestion occurred at an opportune time because the park was reconsidering its monitoring objectives based on dissatisfactions with the program as it had developed in Rock Creek. The key question was how to get out of Rock Creek into the rest of the park. Initial reactions to the grid idea, however, were wary for the standard reasons. As always, cost and logistical constraints of getting to randomly selected points for sampling seemed insurmountable. Would a grid to cover all of Denali's 2.4 million ha be so sparse that there would not be enough points to be meaningful? Could we afford to visit all the points in a denser grid needed to obtain meaningful data? How could a single random point chosen from very large grid cell polygon effectively represent the myriad of gradients in community structure and composition that occur within that polygon?

The primary initial concern with the use of a park-wide systematic grid was that the various important ecological gradients that control vegetation at the meso-scale would

not be captured within the park-wide sampling approach. For example, if the particular random point selected within a given grid cell fell on a north-facing slope, the measured values for our parameters of interest for that grid cell would be radically different than if the point happened to fall on a south-facing slope. Because we expect ecological changes to occur differently both among regions of the park and also differently along the continuum of meso-scale gradients *within* those regions (grid cells), we believed it was critical to allocate samples along gradients at the meso-scale to monitor vegetation effectively. Thus, capturing the variation *within* each of the grid cells (that is variation at the meso-scale) was a major concern during the development of this sampling design.

Another hurdle the proposed design faced was that ecologists often stratify sampling frames and locate sampling sites in areas within “homogeneous” areas of habitat. This is especially true when the purpose of sampling is, for example, to ground-truth a vegetation map. It took time and a process of evaluation of alternatives to come around to the idea of sampling vegetation at random points without stratification.

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). 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 entire park 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.

The primary alternatives to systematic sampling are (1) not sampling at all (which we have already considered and discarded as an option) and (2) simple or stratified random sampling. Ideally, we should have considered these other random sampling methods as an alternative to systematic sampling, but the truth is, we did not. Once the advantages of the systematic grid became clearer, we were eager to try it out and never truly considered simple or stratified random sampling as alternatives.

An 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 changes in spatial patterns is a goal of the program, the systematic grid design is favored. The 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 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 ingrowth (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.

Another aspect of permanent plots that needs to be considered in the context of long-term monitoring is that they can wear out due to the impacts of frequent measurement. This became an issue in the Rock Creek drainage on the small mammal monitoring plots, sampled on several occasions each year over the past 11 years. Using permanent plots on the scale of the entire park, the frequency of revisits will not be often enough for measurement impacts to be an issue.

As part of our pilot studies in 2000, we visited, or attempted to revisit, plots on the McKinley River floodplain that had been marked in 1956 by Les Viereck and by Dave Densmore in 1976 (Helm 2001, Viereck 2003). This experience was invaluable for understanding the difficulties in marking and relocating “permanent” plots in various Denali habitats.

Preliminary Exploration of the Grid Idea 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 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 representativity 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 minigrid of 25-36 points at each grid intersection was first suggested by Carl Roland in December 2000. Each minigrid would be sampled from a base camp over a 1-2 week period. The impetus for the minigrid idea was two-fold.

- 1) More work could be accomplished per unit of access cost because the sample unit into which travel is required is the “minigrid” rather than an individual point.
- 2) We could assemble fairly detailed information about each minigrid that would allow analyses of gradients and patterns within each minigrid. This approach reduces concerns that with relatively few primary points (grid intersections) the underlying relationships between vegetation and topography could not be examined.

Roland used the 20-km grid to show what the minigrid design might look like (Figure I.2). The number of minigrids in the design was reasonable (~60), and it was clear that a variety of access means, including walking, 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 two-stage design: The first stage consists of the 20-km grid intersections. The second stage consists of the minigrid. The number of points and spacing to be used in the minigrid 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 minigrid. 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.

For purposes of testing, we settled upon an arrangement of 25 points, spaced 500 m apart (i.e., 5 rows of 5 points each). This seemed like enough points to describe the variation that might be encountered in a 2 km² area, and 500 m seemed a reasonable distance between points. 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 minigrid 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

minigrids, while meso-scale gradients related to topography and individual site history would be captured by comparing points within minigrids.

There was another practical reason that made the minigrid 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 minigrid could stand on its own and provide valuable data for a given study area, so even if all minigrids were not visited, usable long-term data would have been collected.

With the minigrid idea, however, comes the further complication of tradeoffs between the number of grid intersections (i.e., the number of minigrids), and the number of points in a minigrid. Ideally, we want to get to as many minigrids as possible, arguing for fewer points per minigrid. However, we also want a clear picture of variation within each minigrid, arguing for more points per minigrid. For the purposes of a pilot study, however, the idea of a grid spacing of 20-km with the 25-point minigrid seemed a reasonable place to start. Our preliminary investigations led us to this basic design.

Temporal Considerations

Our preliminary investigations focused mainly on distribution of sample units in space. Equally important in any long-term monitoring program is the question of how sampling events are distributed over time. As always, we must expect there to be trade-offs. As we have already seen, there are significant time-space interactions. The amount of “space” we can sample depends on how much “time” is available for sampling. Time is an issue both within a year, and among years.

Within a year, the amount of time available for sampling depends on a number of factors, including the characteristics of the resource being sampled. For vegetation at Denali, for example, the timing when sampling can be performed is compressed to about 6 weeks due to northern plant growth cycles. Similarly, for land birds, the timing of sampling is even more compressed—to about 3 weeks. Unfortunately, the ideal timing for plant and vegetation sampling do not overlap, so our aspirations for interdisciplinary crews for minigrid visits to measure both plants and birds had to be abandoned.³ Separate crews and visits for each monitoring component will likely be the norm, rather than the exception.

The main difference between long-term monitoring and other studies is the intention to look at changes over many years—decades to centuries. How to schedule revisits to plots is complicated by many factors, including the potential for fluctuating or reduced budgets to reduce or postpone planned visits. However, the ideal plan for revisits is a critical part

³ We have however retained the idea of using some technicians, skilled in both bird and plant identification, on both crews. This approach is more efficient because it reduces the amount of time devoted in the pre-field season to hiring. It makes the jobs more appealing because the jobs last longer, therefore attracting more skilled applicants.

of the overall design. To help develop a revisit plan for the minigrid design, we continued our simulation studies with Trent McDonald and associates at WEST, Inc. Before diving into the results from these studies, it is worthwhile to review general revisit design concepts.

McDonald (2003) reviewed designs used in monitoring programs and suggested a standard nomenclature for use in describing revisit designs. The *panel* is a group of sample units that will always be sampled on the same sampling occasion or time period. The *revisit design* refers to the plan for how sample units will be visited through time. The *membership design* refers to how sample units become members of a *panel*. The *cycle* is the number of occasions required to visit all panels that will ever be sampled an equal number of times.

In simplest terms, revisit designs are characterized by:

- The number of panels they include;
- The number of occasions each panel remains in the sample before being rotated out; and
- The number of occasions each panel is rotated out of the sample.

Although there are an infinite number of revisit designs, McDonald (2003) found that there were 4 basic designs in use by monitoring programs. These included:

1. The “Always revisit” design. The same panel is visited on every occasion.
2. The “Never revisit” design. Each panel is only visited once.
3. Intermediate designs. Each panel is revisited for x occasions, then not visited for y occasions. For example, each panel is visited once, then not visited for 5 occasions.
4. Split panel designs, where each panel has its own revisit schedule. For example, Panel #1 is on the “Always revisit” design, and all other panels are on the “Never revisit” schedule.

Common methods for composing panels (the membership design) include judgement samples, simple random sampling, and systematic sampling. If a systematic sample is taken and divided among the panels, this is called an interpenetrating design.

McDonald (2003) reviewed the advantages and disadvantages of these basic revisit designs and membership designs. He concluded that split panel designs have the most potential to meet the sometimes competing objectives in most environmental monitoring programs. He noted however that determining the optimum allocation of effort among the panels in a split panel design is difficult and deserving of further study.

In simulations for revisit designs for the two-stage minigrid approach, McDonald and Nielson (2001) and Nielson and McDonald (2003) investigated a range of sampling plans including the “always revisit” design mentioned above and several interpenetrating designs with or without the split panel option. As in the previous simulations aimed at determining optimum grid spacing, hypothetical white spruce presence and basal area were used as attributes. Several analysis approaches were also tested in combination with the various revisit designs.

Nielson and McDonald (2003) found that an interpenetrating split panel rotation design with one panel of sites visited every field season, and 3 other panels visiting on a rotating basis every three seasons provided estimates of status with low bias and acceptable levels of precision. For detection of trend under this design, a two-phase regression procedure was the best analysis method. Another conclusion from this work was that reducing the number of points in minigrid (as long as there were at least 9 points per minigrid) to allow more minigrids to be visited each season would improve power to detect trends.

The simulation study focused on designs that would allow estimation of both status and trend in the monitored attributes at the park-wide scale, and the recommended design did the best job when data on both status and trend were needed. This exercise helped clarify that determining status, on an annual basis, was not one of our goals, at least for vegetation attributes.

The objectives of the landscape-scale vegetation monitoring program were carefully chosen, and focused on detecting changes in basic attributes of the vegetation cover at relatively large spatial scales. Changes in the chosen parameters are expected to occur at decadal or longer intervals of time. The parameters that are measured in the network of plots are fundamental properties of our ecosystems that, barring massive and unforeseeable perturbations, will not exhibit detectable levels of change in the space of a few years. For example, treeline will probably not migrate up the north side of the Alaska Range in the space of five or six years. The dynamics of such a potential change would occur over at least a decade before they would be detectable at the landscape scale. *The landscape-scale vegetation monitoring program is not designed to make annual or even bi-annual estimates of resource conditions at a park wide scale.* The funds and manpower for such an effort are not available.

The temporal context at which we seek to detect changes in the parameters of interest to the vegetation monitoring program was critical to choosing the sample return interval for the program. We have decided upon a return interval of ten years for the long-term vegetation monitoring program for a combination of scientific and logistical/cost considerations. *Thus, for making park-wide estimates of resource conditions, we consider a single sample iteration to be ten years in duration.* On average, we anticipate performing field sampling at six minigrids per year. At this point in time, there are 50 minigrids that are accessible for actual sampling, with 16 others that are located in extremely dangerous or inaccessible terrain. At a rate of 6 minigrids per year, we should be able to complete one full sampling of the park in an average 8.3 years. That is the

amount of time required to sample the park for park-wide inferences concerning vegetation parameters to be possible.

We plan on accomplishing the task of sampling the park landscape in a targeted manner that will allow for regional estimates of vegetation parameters to be made on a much shorter scale of time. For example, we will accomplish sampling of the 19 minigrid samples located in the northeastern quadrant of the park first, which will allow us to develop estimators for the abundance and distribution of measured vegetation parameters for this entire region of the park (Figure I.2). This will be complete within the first four years. We will then accomplish sampling of the remainder of the minigrid samples for the northwest, southeast, and southwest quadrants of the park in succession. This will allow for estimates to be made for landscape-scale estimates of vegetation parameters to be made for coherent segments of the park in a stepwise fashion. Once all of the samples in each quadrant are completed, we will have the ability to make park-wide estimates of the vegetation parameters.

Once sample iteration has been completed in its entirety, we anticipate a one to two year hiatus in field sampling for concerted examination, analysis and interpretation of the data prior to initiation of the next sampling iteration. This will be possible given a ten-year return interval and an average full sample iteration that requires 8.3 years to complete. This iteration will progress in the same sequence as the first sample, by completing the minigrid samples in the northeast quadrant of the park first and progressing in a sequential fashion to each of the remaining quadrants. Thus, the first opportunity to assess regional-scale changes in the vegetation cover of the park will occur at approximately year 13 or 14, once the second sampling iteration for the northeast quadrant of the park has been completed. Obviously, it will be possible to evaluate any changes within individual minigrid samples that may have occurred following the eleventh field season.

Because of logistical and cost considerations, it will most likely not be practicable for the samples selected for measurement each year to be drawn entirely at random. We must have the flexibility to respond to circumstances beyond our control regarding the timing of sampling the set of grids. For example, helicopters may be largely unavailable on a given year, which would necessitate an allocation of effort to minigrids that are accessible in other ways that year. The myriad logistical considerations that go into performing remote backcountry field work in Alaska must be acknowledged, and if the design is predicated on a strict random sample grid selection would very likely doom the program. Samples in any given year must be chosen to meet a multivariate set of circumstances that includes differences in peak phenology across the landscape, balancing access costs and staff availability, and opportunistic logistical situations. The straightjacket of random selection of sample timing would likely cause more analytical problems than it would solve in the long run.

Other Monitoring Programs Using Grid Designs

We are aware of several other monitoring programs with similar environmental objectives that have used or are using grid designs. Knowing something about how these programs have fared is useful to consider as we continue to design the Denali program. Interestingly, one of the first examples we found of a program using a grid design was from the National Park Service. The other examples we found of programs using systematic grid designs are major, continental and national-scale programs (mainly for forests) operating in Europe and the United States.

Sequoia-Kings Canyon National Parks Vascular Plant Inventory

Graber et al. (1993) reported on a vascular plant inventory of Sequoia and Kings Canyon National Parks, conducted between 1985 -1990. They visited 1-km grid intersections to document vascular plant species presence in 0.1 ha circular plots. One rationale for this design was to collect information on the presence of plants, animals, substrate and other ecological features to provide the basis for describing and understanding species-environment and species-species relations. They acknowledged that the design was a compromise among several objectives, so their progress towards some objectives was less efficient than if they had designed specific studies. However, they concluded that the combined approach was more economical than using a series of independent study designs.

Over the 5 years of the study, 517 plots (out of a total 3,500 possible plots) were visited. The total cost of the inventory (including field work and data management) over 5 years was \$265,300, or \$513 per plot. Although they started to examine small mammal presence on the plots, they found that the plant work disturbed the plot and interfered with small mammal trapping.

An important finding from this study concerned the occurrence and distribution of exotic plant species. They found 42 species not previously recorded in the parks, of which 11 were alien species. All of the newly recorded species were found at low elevation sites where dense chaparral conditions and a limited trail network had limited botanical exploration. This finding was unexpected, and provided important new information about exotic plants in these parks. This is an example of why having a design that calls for visits to sites that are not easy to get to is so important.

While this study employed a grid to determine sampling sites, the study was not able to achieve its initial sampling plan. Only 14% of the grid intersections were actually sampled. The grid intersections sampled were chosen to disperse sampling effort in varied topographic regions within the parks. Thus, the design might best be described as a quasi-systematic, stratified design. The choice of a 1-km grid was ambitious and not achievable within the constraints of the project. However, the study demonstrated the value of employing random sampling to select study locations and that getting to remote and difficult to access sites is possible.

Nationwide Programs in the United States

In the United States, the U.S. Forest Service has been the prime user of systematic grid designs, in both the decades-old Forest Inventory and Analysis (FIA) program, and the more recent, aforementioned, Forest Health Monitoring (FHM) program. The Environmental Monitoring and Assessment Program (EMAP), developed by the Environmental Protection Agency, also used a systematic grid design. EMAP was envisioned as a comprehensive program involving measurement of many different ecological attributes. However, not all aspects of EMAP are still operational. The operational programs, such as EMAP Estuaries, use systematic grid designs. In fact, the systematic grid was one of the defining features of EMAP.

Forest Inventory and Analysis Program.--The FIA program began over 80 years ago with the goal of maintaining a current inventory of renewable forest resources in the U.S. The FIA program is nationally coordinated but implemented regionally, with contiguous geographical regions as survey units. These survey units represent the target populations. They use a two-phase approach. A systematic grid with a random start is used to locate the first phase sample points, which are evaluated using aerial photographs. Phase two involves ground sampling at a sub-sample of the Phase one points, also selected systematically with a random start. These are permanent plots. The revisit cycles vary among regions—for example, plots in the southern U.S. are visited every 6-8 years, while plots in the western U.S. are visited every 10-14 years.

Forest Health Monitoring Program.--The FHM program began within the framework of EMAP in the early 1990s (Mangold 1998). A portion of the FHM program is aimed at detection monitoring, with goals of estimating with known confidence the current status, changes and trends in selected indicators of forest ecosystem conditions on a regional basis. The FHM program uses permanent plots selected with a systematic grid survey design (Scott et al. 1993). The grid is hexagonal, with plots located 27 km apart. In some regions, local forests have chosen to intensify the grid to provide more detailed local information that is compatible with the overall program. One of the most important features of the program is that it is standardized so that data are comparable among and within regions and contribute to a national assessment. Now that the program has been operational in some parts of the country for more than a decade, they have begun to assess changes.

Many of the attributes measured on the FHM grid relate to crown condition, and in this respect, this program is very similar to the Forest Condition Monitoring program in Europe, described below. The permanent plots on the FHM grid represent the synoptic portion of the program—data from the plots provide a broad-scale overview of forest health across regions on an annual basis. Another portion of the program, the Evaluation Monitoring Phase, takes a closer look at problematic situations based upon the Detection Monitoring Phase. The FHM detection monitoring program has been implemented in ~27 states, and it is intended that eventually all states will be included.

Currently, a merger of the FIA and FHM program is underway. Both programs have the same design, and they are trying to use the same plots. FIA may also go to an annual cycle, like FHM.

Pan-European Forest Condition Monitoring

In Europe, 38 countries are participating in forest condition monitoring under a program established in 1984. The Forest Condition Network operates under the auspices of two international cooperative programs concerning transboundary air pollution⁴, and data from the program are used to inform decisions about emission controls. The program appears to have a good reporting record, and may be one of the world's largest and most successful biomonitoring systems.

The network has 2 levels: The Level I Network is a 16 km grid, which includes 5700 plots across the 38 countries in the program. The Level I Network provides an annual picture of broad-scale trends in crown condition throughout Europe. The Level II Network involves intensive monitoring on 860 permanent plots (on selected sites) spread throughout Europe. The Level II Network provides data on stress factors that might be involved in changing crown conditions observed in the Level I Network.

The Level I Network of the European forest condition program is similar to the proposed Denali grid. In the Level I Network (16 km) grid, crown condition of trees is measured at each grid intersection. The 16 km grid is considered the minimum density; many countries, however, have adopted use of denser grids, including 4 km, and 1 km grids. Kohl et al. (1994) examined the precision of crown condition estimates for Switzerland for grid densities of 1 km, 4 km, 8 km, and 16 km. They found that a sharp deterioration in precision at the sparser grid densities (12 km and 16 km grids). The loss of precision found in the 8 km grid was not enough to justify the 75% greater sample size required to survey the 4 km grid. These results about grid spacing from Switzerland seem particularly relevant to Denali. Denali (2.4 million ha), is about half the size of Switzerland, (4.1 million ha), but has similar topographic relief and similarly few tree species.

Although the measurements made at each Level I Network site are few and restricted to tree condition, the Level I Network has been used to assess other ecological conditions related to forest condition. For example, Landmann et al. (1999), working in France, reported on forest insect and disease surveys conducted in the Level I Network permanent plots and compared to forest and insect disease surveys conducted according to classical "off-plot" surveys. They found that the permanent plot surveys complemented the findings from the off-plot surveys, particularly for temporal variations in insect and disease damage, but were less informative about the spatial variations (due to the sparse network). The value of the permanent plots related to the ability to follow individual trees through time, and to distinguish among causes of tree mortality (i.e.,

⁴ These are the: United Nations Economic Commission for Europe (UN/ECE) Convention on Long-range Transboundary Air Pollution, and the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests).

drought, frost, insects, air pollution). This study is illustrative of the ability of a permanent plot network to provide insights into cause-effect relationships involved in ecological change (Scott 1998).

The French insect and disease study is also an example of how the permanent plots provide a framework for detailed studies by investigators that complement the broad-scale information coming from the network. Data from the Level I and Level II Networks are also publicly available and widely used by investigators looking at specific questions (e.g., effect of weather). The most recent report from the Forest Condition Network cited some 23 studies using Level I and Level II data to analyze causes of forest damage. The value of the Forest Condition Network data has increased by merging them with other external data sets (e.g., meteorological data).

The most recent report from the Forest Condition Network highlights how the value of the network data has increased through time. Although originally established, and still primarily concerned with air pollution, the program's data are now being used to answer questions about a broader range of issues not on the radar screen when the program began in the early 1980s (EC-UN/ECE 2000). These include biodiversity, climate change and carbon sequestration.

Implications for Denali

In the Sequoia-Kings Canyon study, the grid spacing was based on assumptions about how many plots the investigators could visit in a single year (300 plots) and complete the inventory within 10 years. They also considered what grid size would capture variation in the topography of the parks. Using these caveats, they chose to use the 1-km grid spacing. They significantly overestimated how many plots could be visited in a single year (100 actual vs. 300 estimated). In this regard, a small pilot study might have been helpful to selecting a grid size that was both logistically feasible and ecologically meaningful. Because there were far more grid intersections in the grid than could be sampled, they were unable to achieve many of the advantages of a systematic design.

The U.S. Forest Service, with its FIA and FHM programs, has demonstrated a long-standing commitment to employing statistically valid survey designs. The U.S. Forest Service and European Forest Condition Network examples show that it can be done, even when the areas involved are quite large. Another recurring feature among these programs is the hierarchical approach, where the synoptic, permanent plot-grid work is used to inform more detailed investigations related to the cause of changes. One aspect where the Denali program differs is the temporal scale. Both the FHM and European Forest Condition Network produce annual estimates, and the Denali program expects to operate on a much longer time scale.

In terms of grid spacings, the 27 km grid used by FHM and the 16 km grid used in Europe, suggest that 20 km spacing for Denali is in the right ballpark. However, the findings of Kohl et al (1994) and Goeking et al. (2000) both suggest that grid spacing of 10-12 km range would be ideal. Intensifying the grid to that level, however, greatly

increases the number of grid intersections. The number of points per minigrid would most likely have to be reduced (given no additional resources for sampling) to include that many minigrids.

The European Forest Condition Network seems to illustrate many of the desirable features we would like to see in the Denali program. This European network appears to produce reliable data that are well respected and used to inform critical decisions about emission controls. The European network has also demonstrated that the value of the data has increased over time, and that the systematic grid design has been useful for detection of unexpected changes.

Advantages and Limitations of the Proposed Approach

We have already referred to some of the advantages of the proposed approach, but we thought it would be worthwhile to summarize again here. We need to also point out some of the limitations.

Limitations

While the systematic grid eliminates certain important types of bias from sample site selection, it introduces another type of bias into the design that relates to using a two-dimensional sampling frame to allocate samples in a three dimensional environment. Steep slopes cover, per unit of ground area, less map area than flat areas, in an amount proportional to the steepness of the slope. Therefore, sloping areas are somewhat less likely to be selected than flat areas when using a two-dimensional grid as the sampling frame. Thus, there is an inherent sampling bias against sloping areas of the landscape in a systematic grid laid over a two-dimensional map, relative to their prevalence on the landscape.

There is an additional statistical concern with using a systematic sampling plan, which is that each sample event technically represents a sample size of one; there is no “true” replication within the design. However, if the population is randomly-ordered without an underlying periodic pattern, it is generally accepted that simple random sampling estimators of population parameters may be used. The amount of variation in vegetation structure relative to our feasible sampling intensity is an additional (and seemingly unavoidable) concern related to sampling such a huge area with relatively limited resources.

The extensive grid may not be sufficient for monitoring any particular individual species whether it is an exotic weed or native endemic. This scale of monitoring will be designed for broad trends in species diversity and community composition.

The number of minigrids that can be visited in a single season is an important constraint and produces the design’s most important limitations. We will not be able to make statements about the vegetation of the park as a whole until the program has been operating for at least a decade. Breaking the park into 4 regions will also influence our picture of the park as a whole. In this respect, the design is similar to the approach used

in FHM where data are primarily analyzed and reported by region. The only way to produce park-wide estimates will be to lump data by time (all plots visited in the decade).

The design will not be good at detecting changes that happen quickly. If our assumption that most changes that we are aiming to detect happen slowly, this will be okay. If some changes happen more quickly, we may wish we had done something else. However, this tension is inherent in accepting the task of landscape-scale monitoring under the constraint of limited budgets. If the choice were made to monitor large sections of the landscape using quantitative ecological techniques, the trade-off with temporal intensity would appear to be inevitable. In other words: “sampling over time and space is a problem”.

Advantages

Desirable design characteristics for long-term monitoring include the notion of simplicity to allow adaptability and flexibility over time (Overton and Stehman 1996). In this case, simplicity refers to the structure of the sampling design. Compared to stratified designs, the systematic design does not have a lot of structure to it and should therefore produce data that are easier to analyze over a long period of time.

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 areally-based inferences concerning changes in vegetation structure over time over the entire landscape of the park. 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.

The benefits of proposed approach include:

1. Concentrates landscape-scale sampling efforts within confined study areas that required 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 appears to be logistically feasible, and affordable, within current and planned future budgets for the program. (We will discuss the costs in greater detail in Chapter 8.)

Chapter 3. Field and Analytical Methods

Having laid out the overall design approach in the preceding chapter, we turn now to a more detailed discussion of methods: the field methods used to collect data at each point in a minigrid, the database structures used to store and ready the data for analysis, and the analysis procedures developed thus far. We begin with a more detailed explanation of the procedures used to define the systematic grid that is the foundation of the design. We then describe the field and analytical methods used for vegetation and songbirds. The specific procedures for vegetation and songbird sampling, described at the level of detail needed for executing them, are found on the project website. Here, we explain the procedures generally, but focus on the rationale for and history of our experiences leading to the chosen methods.

Procedures Used to Create the Sample Grid

As discussed in Chapter 2, the sampling frame for the minigrid design was unstratified and consisted of the entire area within the boundary of Denali National Park and Preserve. Thus, every point on the landscape within the boundary had an equal probability of entering the sample population for the monitoring program. The foundation of the sample selection procedure for this design was a grid of virtual points with 100-m spacing covering the 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 vicinity. All sampling points that will be measured for the long-term monitoring program will come from this randomly-drawn systematic grid.

The sample selection procedure for the minigrid design occurred in four steps. The first step, described above, was the selection of the 100-m base grid. Each subsequent step involved selecting subsets of points from this 100-m base grid. The second step of sample selection consisted of a randomly-selected subset of the base grid that formed a “macro-grid” of points spaced 10 km apart in an even grid pattern across the park (i.e., every 100th base grid point from a random starting point). This 10-km park-wide grid included 255 points (Figure I.2). In the third step, a “minigrid” 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 (Figure I.3). The 10-km grid points formed the southeast corner of each minigrid. The fourth step of the sample selection procedure involved selecting a subset of these 255 points in the 10-km grid, to form the 20-km park-wide grid, as described below.

Logistical and cost considerations will prohibit the repeated sampling of 255 points across the park. Therefore, we selected a subset of the 255 points in the 10-km grid for final inclusion into the proposed landscape-scale monitoring design. As discussed in Chapter 2, we decided that a 20-km “macro-grid” spacing resulted in the maximum number of samples feasible for this program to sustain in the long-term. This selection of the 66 points included in the 20-km grid represented the final step in the sample selection procedure (Figure I.2).

Examining the randomly generated 10-km grid, we observed that one of the minigrids encompassed much of the Rock Creek drainage near park headquarters. Rock Creek was the original study site for the long-term monitoring program. For this reason, we selected this 10-km grid as the “seed” for the park-wide 20-km grid network, thereby integrating the initial monitoring sites into the new, landscape-scale approach for the program. With the Rock Creek point chosen, the final layout for the 20-km park-wide systematic grid was in place.

Although the 255 minigrids in the 10-km systematic grid will likely never be sampled due to costs associated with acquiring such a large and intensive sample, the 10-km grid provides the park with a valuable dimension of flexibility in the design of the long-term monitoring program. Specifically, this larger set of samples allows for the intensification of monitoring efforts in selected areas of the park of elevated management concern, while maintaining a rigorous, and consistent, probability-based sample design. We believe that this dimension of the design provides flexibility for future integration of other long-term data sets with the park-wide monitoring effort.

An example of this flexibility is the “North Side Access” biological reconnaissance of the Toklat Basin ecoregion that began in 2002, with funding received from the NPS Natural Resource Protection Program (NRPP). We used additional funds for this special project to increase the sampling intensity of our pilot study efforts within the Toklat Basin to seamlessly include all 10-km grid points in this ecoregion. We envision several benefits from this approach:

- 1) It provides a consistent sample design based on a rigorous, probability-based, and park-wide sample selection procedure, and identical sampling and analysis protocols can be used.
- 2) It increases the value of the project data because we are able to make direct comparisons with similar data gathered across the park, thus placing these data on a particular region in a broader spatial context.
- 3) The long-term monitoring program data collected in the ecoregion are similarly enhanced due to increased sample sizes in this critical region of the park.

The additional set of plots that are measured as a part of other studies, such as the Toklat Basin project described above, would in most cases be excluded from the baseline set of inferences at the park-wide scale. Including these additional sites would skew the area-based estimates that are envisioned for the park-wide level of inference. However, at scales smaller than the whole park our sample sizes for detecting change on the landscape would be increased. In addition, the benefits of short-term projects like the Toklat Basin study can be magnified by the integration of these data into the park’s long term monitoring data sets.

Vegetation Methods

We will now provide an overview of the specific methods that were used for making observations and measurements of vegetation in the field. The goal of the following section is to describe these methods, and also to provide the context on how and why this particular set of methods was chosen. This link between the objectives of the program (described in Chapter 1) and specific methodologies chosen to meet these objectives is critical to the success of the program. For readers interested in the step-by-step field operating procedures for each of the data streams acquired during this study, descriptions of methods at this level of detail are provided in Landscape Scale Vegetation Monitoring Handbook, which can be found on the project website.

The first section of this chapter describes the specific field methods that were used to quantify vegetation and physical variables. We then discuss the underlying approach to selecting methods that we had during the development of this program, including the criteria that were used to weigh different possible approaches and methods. Following the discussion of field methods, we address data management and analysis. We describe the database design we created, and a set of web-based analytical routines for vegetation data using StatServer® software. We conclude by describing analytical methods, followed by a summary of our progress to date on developing methods for long-term vegetation monitoring.

Vegetation Field Methods

The field methods listed here under the heading “vegetation” methods include methods for acquiring a broader array of data than simply that for vegetation. This suite of data is currently acquired by the vegetation crew, and used in analysis of the vegetation data, but should also be of broad interest and use to each of the other monitoring components. Basic physical attributes of the sites are quantified using this set of protocols, including topographic, geomorphic, and soils-related attributes of the sample points, GPS data, and the acquisition of a large set of geo-referenced digital images of each point and the landscape context of each study area. We provide synopses of the most important field methods for the vegetation program below. Table 3.1 provides a cross reference between the objectives for the program and the particular field procedures that we have devised to meet them.

Plot layout and marking

The permanent plot design is a circular plot 16-m in diameter that encompasses an area of about 200 m² (Figure 3.1). The plot is formed by laying out two tape measures perpendicular to each other and crossing at the plot center monument. A photograph of a plot being sampled in the alpine zone of the Rock creek drainage is shown in Figure 3.2. The center point for each permanent plot is one of the 25 random points that constitute the minigridded 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 (Figure 3.1). Around the central 16-m diameter plot is the peripheral tree coring plot, which is an 8-m “doughnut” encircling the permanent plot (Figure 3.3).

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). We learned by experimenting with modified Whittaker plots how difficult and time-consuming it can be to set up rectangular plots in Denali shrub and forest habitats. 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.

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 (Figure 3.4). They closely resemble in size and appearance the USGS 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. In addition, we have had considerable experience with attempting to relocate “permanent” vegetation plots marked with rebar and metal conduit in various Denali vegetation types. These experiences have taught us that that a longer-lasting, more easily found, and unambiguously identifiable monument was needed for this program to succeed in the long-term. Our decision to use mapping-grade GPS technology for acquiring plot position data was also informed by past efforts at plot location in the park.

Plot Photographs

The use of photo documentation of existing conditions is a critical element of this program. 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 minigrid and permanent plot.

Plot Descriptive Data

A variety of data regarding the attributes of the permanent plot were recorded on the point data sheet. These included 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 were recorded include vegetation classification, landcover classification, dominant species, adjacent vegetation or ecotones, tallest tree and shrub heights. We also recorded observations of human use in the area (Objective #6), wildlife sightings, and/or wildlife sign in the vicinity of the plot. These descriptive data were also recorded for each of the four 4-m² quadrats within each plot as well. 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.

Cover Transects

Early in the development of monitoring objectives, we realized that measurements of vegetation structure would be a critical element of the landscape-scale monitoring effort. Structure measurements 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. For these reasons, a significant effort was focused on developing methods for quantifying vegetation structure that we use for this program. Dr. Dot Helm, vegetation ecologist with the University of Alaska Fairbanks, was instrumental in assisting with the development of the protocol for sampling vegetation structure (see Helm 2001).

Our goal was to characterize the horizontal distribution of vegetative cover, as is traditionally done, but also to quantify the vertical dimension of vegetative cover. Because of the long-term nature of this monitoring effort, we focused on techniques that would reduce observer variation to a minimum. Based on a survey of the literature and personal experiences, we decided to focus on point-intercept methods for quantifying cover, using a set of vertical strata at each measurement point. During 1999 and 2000, we performed a variety of tests of this technique, including variable point spacings, transect lengths and transect arrangements (Helm 2001). Based on this earlier work, we decided upon a set of three cover transects per permanent plot, with sample points spaced 50 cm apart, and plant cover to be quantified (by species) in 10 vertical strata: 0-10 cm above the ground; 10 - 20 cm, 20 - 30 cm, 30 - 50 cm, 50 - 99 cm, 1.0 - 1.5 m, 1.5 - 2.0 m, 2.0 - 3.0 m, 3.0 - 4.0 m, and >4.0 m. The selection of the vertical strata breakpoints was based on review of breakpoints used in other vegetation and animal habitat studies in Alaska. The strata were chosen to be of value for both vegetation and faunal objectives. We describe the specific technique we developed for quantifying vegetation structure below.

Vascular plant abundance and vegetation structure in the permanent plots, necessary to meet Objectives #1 and #2, were quantified using point intercept transects. These

transects were performed along the two perpendicular tapes that define the plot. At 50 cm intervals, we used a specially-designed sampling staff (Figure 3.5) with a combined densitometer and descending pin to record each intersection of vegetation 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.

Species Composition

Determining species composition for vascular plants, bryophytes (mosses and liverworts) and terricolous (ground-dwelling) macrolichens is needed to meet Objectives #2 and #3. Species composition for the aforementioned plant groups was recorded for each entire permanent plot according to the following procedure: Each species present in the first 1-m² quadrat (located in quadrant A – see Figure 3.1) was recorded; any additional species in the larger, 4-m² quadrat were then recorded. Figure 3.6 shows a photograph of field workers performing quadrat measurements. This process was repeated for each of the subsequent 3 nested 1-m² and 4-m² quadrat placements. Following the searches in the quadrats, each quadrant was searched for additional species (not already found), which were recorded, noting the quadrant in which they were first observed. This process results in a complete list of vascular, bryophyte and terricolous macrolichen species that occur in the plot in a way that retains the relationship between area sampled and species observed. These measurements allow us to estimate the following parameters for each of the three elements of the vegetation (vascular plants, bryophytes, and macrolichens):

- 1) A comprehensive species list for each plot;
- 2) Frequency of occurrence of each species in the 1-m² quadrats;
- 3) Frequency of occurrence of each species in the 4-m² quadrats;
- 4) Mean species richness, and associated variance, in the 1-m² quadrats;
- 5) Mean species richness in the 4-m² 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.

In addition to these metrics of community composition and diversity, the design and methods that we have employed allow for the construction of species-area curves at each spatial scale. We can examine the differences in “minimum area” among plots, plant communities, or entire minigridded samples. The concept of minimum area in vegetation

sampling refers to the minimum amount of area that needs to be sampled to characterize the species composition of a site. Species acquisition curves are typically asymptotic, and minimum area is usually defined as an amount of area beyond (to the right) of the inflection point in this curve. Assessing minimum area concerns is facilitated by our method of gathering observations that describe the gradual accumulation of species occurrences in the nested quadrats with each incremental increase in area sampled. For example, if we only searched the entire plot to determine community composition, we could not examine the relationships between species richness and sampled area *within* the 200-m² plot. During this pilot study, we have found that this relationship varies profoundly across the landscape of the park. We believe the capabilities for examining species-area relationships provided by this sampling regimen furthers our understanding of the patterns in overall species richness even among very large sections of the park landscape. This will be discussed further in the vegetation results chapter of this report.

Cover of Cryptogams (Nonvascular plants and Macrolichens)

As described above, vascular plant abundance and overall vegetation structure in the permanent vegetation monitoring plots were 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 cryptogams are a dominant component of the vegetation cover, and ecologically important, we wanted a similar level of information about them as for vascular plants. We estimated percent cover of each cryptogam species within the nested quadrat array to produce estimates of cryptogam species abundance. In combination with the frequency of occurrence data derived from the quadrats for nonvascular species, this represents the best method for recording abundance of cryptogam species we can devise, although it is not necessarily optimal because of the potential for observer differences in the estimation of species abundances. We plan to experiment with micro-scale point intercept methods for quantifying cryptogam cover within the plots. However, because we are already recording nonvascular species occurrences using the quadrat array, the cover estimates do not add a considerable amount of time to the field operations.

Tree Measurements

The abundance and community structure of tree species (Objective #3) were quantified within each of the permanent vegetation plots according the following procedure: all individuals of tree species 12 cm diameter at breast height or greater were 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) were 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-m² quadrat, which were 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 (m²) 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 (Objective #5 – forest insect damage).

Increment Coring of Spruce

We conducted tree increment coring (Objective #4) within the 8-m wide “doughnut” surrounding the 16-m diameter plot. The largest individual spruce tree in each of four quadrants of this increment coring plot (Figure 3.3) was 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) was removed so that two separate measurements of annual growth can be measured for each year. Cores were mounted on standard wooden mounts, sanded and prepared for counting. The number of annual rings in each core was counted, whereupon the individual annual rings were measured with an electronic micrometer, which automatically logged the ring widths. Ring width data were then analyzed using Cofecha® statistical software, and the cores remeasured as necessary.

Soils Observations

A variety of soil measurements are required to meet Objective #7. The soil protocol we developed was reviewed by Dr. Mark Clark of the USDA-Natural Resources Conservation Service (NRCS) and author of the soils map for Denali National Park and Preserve (Clark in prep.). Soils observations and samples are acquired at each of four soil observation points arrayed around the perimeter of each vegetation plot (see figure 3.1). The following parameters were 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 was taken at each point and integrated to form a single composite sample for the plot. Field pH was measured for this sample using a pHtestr® field pH meter. The soil samples were frozen upon return from the field until the end of the field season. The samples were then weighed, dried, and weighed again to determine field moisture percent. The dried samples were then sieved to <2mm, and the fractions of the soil in each size class (<2mm, >2 mm) were weighed. Soil samples were sent to the U.A.F Palmer field station soils laboratory, where the following parameters were determined: pH, soil texture, % carbon, and % nitrogen (using autoanalyzer methodology).

Active layer depth (Objective #8) was quantified through the use of a 1.5 m heavy-duty soil probe, which was thrust into the ground in two locations in each of the four quadrats within the plot. The mean of these eight soil depth observations were averaged to obtain the mean soil depth for the plot. This measurement equates to active layer depth in permafrosted terrain.

Our General Approach to Selecting Vegetation Field Methods

We selected the suite of quantitative field techniques described above to acquire the data about the vegetation structure and composition required to meet the objectives outlined for the monitoring program. The suite of techniques that were selected, which included nested quadrat arrays for species composition, vertically-integrated point-intercept transects for vegetation cover, and tree measurement and mapping, among others, are well-tested techniques that have been used repeatedly in the peer-reviewed ecological literature. We combined this set of methods into a novel plot system designed specifically for the range of variation in vegetation communities that occur across the park as well as the logistical constraints imposed by the landscape-scale spatial approach that we have adopted.

We believe that the substantial logistical and analytical complications associated with the large spatial and temporal scales we are attempting to sample impart certain distinct limitations upon the sampling techniques available to this program. Specifically, the program must, of necessity, rely upon multiple generations of field technicians over time. For the conclusions based on the data to be valid, a premium must be placed upon “transferability” of the protocols among generations of field staff. As a result, simplicity and repeatability are particularly important attributes of the techniques selected for the program. While new and emerging technologies and techniques are often very useful (and seductive), the benefits of their use must be weighed against the possibility that they will require further modification and revision over time. In general, we have opted to rely on a set of simple, highly transferable, and well-tested techniques and data acquisition protocols, with a minimum reliance upon rapidly evolving technology for actual data acquisition. One exception to this rule is our use of mapping-grade differential GPS technology for documenting permanent sample point locations.

The field methods that were selected for the landscape-scale vegetation monitoring pilot project were selected according to the following criteria:

- 1) The techniques selected must provide data appropriate to meet the objectives of the program.
- 2) The procedures and plot arrangement must be flexible enough to be used across the park landscape, and applicable across all landscape positions and vegetation types extant within the park.
- 3) The field techniques utilized must provide the maximum repeatability among multiple generations of observers and over long periods of time.
- 4) In general, techniques should be as simple and field-tested as possible thus less likely to require modification over the duration of this program.
- 5) Techniques must be cost-effective and accomplished relatively expeditiously, in keeping with the need to sample large numbers of plots within a given season.

In addition to these criteria, we wanted to adopt a combination of techniques that provided internal overlaps in the information collected on vegetation parameters. We thought that it was critical to have several different data streams concerning particularly important parameters. These overlaps will allow us to assess the consistency of our results among different data acquisition procedures. For example, there were five separate data streams that provided information concerning the abundance, distribution and species composition of tree species (Objectives #2 #3, #4, #5, #9, and #10):

- 1) Abundance data, by species, derived from cover transects allows for estimation of percent cover of trees, by species, as well as estimation of the total tree leaf-area index (LAI) for a plot;
- 2) The percent cover of trees is recorded (albeit by ocular estimate) for each of the four quadrats. The occurrence of each species within each quadrat is also recorded, thus allowing us to make estimates of the *frequency of occurrence* of the different tree species, another estimate of abundance;
- 3) The number of tree seedlings, by species, by condition class (live/dead) are *tallied* within each 4-m² quadrat, which allows for estimates of seedling density (individuals < 1.37 m in height);
- 4) Each individual tree that occurs within each plot is mapped and measured for diameter at breast height. These measurements allow us to estimate basal area (square meters of tree bole per hectare) and density (number of tree stems per hectare); and,
- 5) Trees in an 8-m radius around the plot are cored, mapped and measured, providing additional estimates of tree size, density and growth patterns over time.

While this degree of overlap may appear high, we believe it is important to have several different lines of evidence concerning the important ecological variables associated with (in this case) tree abundance and distribution on the landscape. If each of these independent lines of evidence confirm a particular change in status (for instance, a change in the abundance of tree biomass within a certain minigrid, ecoregion or elevation stratum of the park), we would have much more confidence that the observed change is actually a real one, and not one due to sampling or measurement error. In addition, each of the different data acquisition protocols provides information on different facets of the question of tree distribution and abundance on the landscape. These different facets have different ecological implications for different elements of the biota, and should be useful for other components of an integrated monitoring program.

Because this sample design is for long-term monitoring, the techniques that we adopted for it could not be optimized for any *one* vegetation or plant community type, as would be done for a short-duration research project. Instead, the methods selected needed to be more broadly applicable across a range of types, including the range of variation spanning dense forest to sparse alpine tundra. In the time horizon envisioned for this

monitoring program (decades to centuries), we made the assumption that any given cover type observed at an individual plot at a given point in time could (at least theoretically) eventually change into any other type. Thus we believe it is desirable to have a single plot design that would not require us to change sampling methods based upon changes in the sample population.

The crucial dimension of a long time horizon for this program necessitated trade-offs in the size and spatial arrangement of the various techniques that were adopted. For example, we decided upon a set of four 4-m² quadrats within each plot for quantifying plant species composition. This quadrat size is likely much larger than necessary for tundra plant communities, where the plants are small and tightly packed and smaller quadrat sizes are usually used. Performing species occurrence observations in such large quadrats within tundra vegetation requires considerable time and focus. However, lowland plant communities, which typically have much coarser plant and vegetation patch sizes, generally *require* the larger quadrat size to effectively capture variation in species composition. To solve this conundrum, we opted to use the more inclusive 4-m² quadrat size, but also included nested 1-m² quadrat within each of these 4-m² quadrats to capture more of the fine-scale variation that occurs within tundra plant communities. This solution allowed us to use a single plot configuration to effectively sample a range of different ecological situations. The set of observations we measure are identical at all plots because using variable sets of plot layouts or techniques according to current vegetation would necessitate making changes in techniques over time for given sampling locations. This would create thorny analytical problems should large changes in vegetation occur. In fact, it could prove fatal to our ability to make design-based inferences across the landscape if conditions or patterns change significantly over time.

The approach to plot design that we are proposing for the landscape-scale vegetation monitoring program also relies to a certain degree upon “over-sampling” to maximize the quality of the data acquired. For example, we enumerate all species that occur in each of four 4-m² quadrats within each 200-m² permanent plot. For the majority of vegetation types, this level of sampling intensity would not be required to obtain relatively precise estimates of species composition and species-area relationships (assuming a highly trained crew). We have chosen to collect data on 4 quadrats to reduce the likelihood that the occurrence of a given species in a plot during a given sample iteration is missed. In addition, upon completion of the recording of species occurrences in the quadrat array, we perform a search of the entire 200- m² plot to note species present in the plot that were not observed in the quadrats. We believe that by sampling at this level of intensity, we are ensuring a higher quality of data is collected for the program.

Database Design

We have created a Microsoft Access® database for storing and analyzing data collected under this design that is consistent with NPS data management standards. The design of the database is an integral part of the data acquisition, storage, analysis and communication routines for this study. We were very fortunate to have the assistance of Angie Southwold, database programmer with the Alaska Support office of the NPS in

the design of the database for this program. 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, yet still expeditiously summarize the data in a variety of different ways quickly and easily. The use of data entry masks for key fields, and 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.

The structure of the database, including both tables and relationships is shown in Figure 3.7. 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.

In designing the database, which occurred in tandem with development and testing of the field data collection methods, we consistently strove to maximize the flexibility of the data structures to retain the maximum array of capabilities for exploring and summarizing the data. This fit with the principle underlying this program to “expect the unexpected”. In other words, we did not want to set up a narrowly-defined set of data structures that would limit our ability to reorganize and reexamine the data according to either new hypotheses, or new ways of looking at the data that evolve over the envisioned long-term duration of the program. In addition, we intended that the vegetation data serve as one of several “cornerstones” of the monitoring program that should serve the needs of other components (such as the faunal monitoring components). The analysis requirements of other monitoring components may require the data to be summarized differently than would be done for strictly vegetation purposes. By striving for flexibility in data structures, we hope that we can provide data summaries in numerous different formats that will suit the needs of other monitoring components.

A simple example of the benefits of the relational database structure is the following: the database contains a reference table with one record for each plant taxon that has been observed in the entire study. In this reference table, each taxon has a six-letter species code in the key field for the table. This table contains attributes about each species, including its taxonomy and synonyms, growth habit, nativity, conservation status, and geographic range, among others. All of the actual data tables (such as species composition, cover transects, etc...) are related to this reference table through the six-letter species code. Thus by the simple entry of the species code, we are able to summarize data not only by species, but by growth form (tree, shrub, forb etc...),

geographic range and all of the other related attributes contained in the taxon reference table.

The relational nature of the database provides powerful additional capabilities to support our ability for detecting changes in the biota over time. We might be able to detect changes in the abundance of a particular *class* of plants long before it would be possible to detect changes in any given species that is a member of that class. For example, a significant drying trend in interior Alaska could result in an increase in grass abundance on the landscape. If this increase in grass abundance was divided evenly among 10 species, it would be much easier to detect a change in the abundance of the class as a whole, than to detect the much smaller incremental changes in abundance of any individual grass species. Such analyses are greatly facilitated by the relational database structure adopted for these data. Furthermore, for the purposes of (for example) faunal components of the monitoring program, the ecological attribute of importance may precisely be the increase in “grass”, not so much the individual species identities within this stratum.

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 during this study. A large volume of data has already been acquired during field sampling for this program. For example, the cover transect data table currently contains 33,693 records and the species composition table contains 17,163 records, after just two seasons of pilot sampling. We decided it was critical to create a set of automated data summary procedures that would facilitate the examination and exploration of our data. We worked with Ed Debevec, a biometrician with the Institute of Arctic Biology at the University of Alaska who created a set of web-based data summary routines that can be performed by anyone with access to the following website (which is currently passworded): <http://fnemd-1.iab.uaf.edu/statsserver/>.

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 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.

Vegetation Analytical Methods

A primary attribute of the approach that we have taken in the development of this program is to maximize the potential for detecting changes in the fundamental attributes of the ecosystem, across several spatial scales, without making *a priori* assumptions about the direction or magnitude of such potential changes. For this reason, we discarded

the model-based approach inherent in the original design in favor of a more flexible monitoring design not predicated on any single hypothesis regarding anticipated changes on the landscape, nor dependent upon the “representativeness” of any given set of judgement-based set of plot selection procedures. Thus, in developing the analytical approach for this program, we sought to further maximize the flexibility in exploring and analyzing the data we have acquired to quantify and assess patterns of variation in measured parameters in a variety of ways. Table 3.2 provides an overview of the nested spatial scales of interest to this proposed monitoring program, with examples of how data collected according to this design would be examined to detect changes in selected vegetation parameters.

We begin our discussion of analytical methods with the topic of post-stratification, which is a linchpin in our framework for monitoring vegetation changes at larger spatial scales and along important environmental gradients. We then discuss the various community metrics for monitoring emergent properties of vegetation communities in the park. We describe our use of “equivalent latitude”, which is an index of potential solar radiation for landscape surfaces, which varies as a function of slope, aspect and latitude. We conclude this section with a summation of our progress thus far in developing an integrated set of field and analytical methods for this program.

The following principles form the foundation for the analytical approach that we have developed for this program.

First, we sought the ability to calculate parameter estimates at each of a hierarchically nested set of spatial scales, including the following:

- 1) At the individual 200-m² plot level,
- 2) Among groups of plots (ecological strata) within each minigrid sample,
- 3) Across all of the plots in an entire minigrid sample (values across all 25 plots),
- 4) At the “regional” level (incorporating data from across several minigrids); and
- 5) At the “park-wide” level (or the entire sample)

Second, the randomization procedures underlying this design allow for post-stratification of plot-derived data at all of the above spatial scales, that is, plots may be pooled together based on observed values, regardless of the minigrid of origin, to investigate patterns of ecological variation.

Post-stratification of Plot-based Data

Our ability to detect changes at the spatial scales #2 and #4 in the above list is founded on the concept of post-stratification of monitoring data. This simply means to form “strata”, or groups of plots, after the actual sampling has been conducted. We pool data from groups of plots to generate estimates for segments of the landscape, based on a set of plot grouping variables. The following geographic and ecological attributes may be used to pool plots to form strata for the purpose of examining observed variation in vegetation parameters on the landscape: elevation, slope angle, aspect, equivalent latitude (an index

of potential solar radiation described later in this section), soil depth, ecoregion subsection, slope position, vegetation type, and drainage characteristics of a site. The mean and variance of measured vegetation parameters within each set of grouped plots (or “strata”) may be calculated (see equations below). Table 3.2 shows a few examples of the proposed uses of post-stratification within the design.

Also inherent within the design and data collection procedures is the ability to pool species-based observations based upon numerous different sets of common attributes. In other words, for all of the species-based measurements that are performed in the field (including cover transects, tree measurements, species composition, etc...) the data for distinct *groups* of species may be pooled together to generate estimates. For example, cover may be expressed by species, but also summarized across all species within the following groups: growth form, plant family, genus, family, biogeographic range category, endemic status, and life history traits (annual perennial, biennial). In this way, by utilizing the relational capabilities of the database, we are able to generate abundance, frequency, density and other estimates for informative *groups* of species.

Equations

As described above, for any vegetation attribute, we wanted the ability to calculate a parameter estimate for a single plot, multiple plots within a single grid, and multiple plots within multiple grids. Two series of generic equations that we use to derive these estimates are given here: one series for attributes that contain variability within each plot (the plot was subsampled thus the value for the plot often represents a mean observed value) and another series for attributes that were completely measured on a plot.

An example of a parameter with variability within each plot (“plot sub-sampled” in equations below) is the number of species observed in the 4-m² quadrats – because there are four such quadrats in each plot, the expressed value for this parameter for a plot is the *mean* number of species per 4-m² quadrat. On the other hand, the density and basal area of trees within the plot does not contain variability, because each tree within the plot is mapped and measured, and thus there is a single observation for the plot for these parameters. Thus the parameter is said to be “completely measured” in the equations given below.

Definitions

$$\begin{array}{ll}
 h = \text{stratum}; & h = \{ 1, 2, \dots, H \} \\
 i = \text{minigrd}; & i = \{ 1, 2, \dots, G \} \\
 j = \text{plot within minigrd}; & j(i) = \{ 1, 2, \dots, n_i \} \\
 k = \text{quadrat within plot within minigrd}; & k(i,j) = \{ 1, 2, \dots, m_{ij} \} \\
 y_{ijk} = \text{datum from } k^{\text{th}} \text{ quadrat in } j^{\text{th}} \text{ plot in } i^{\text{th}} \text{ minigrd (plot subsampled)} \\
 y_{ij} = \text{datum from } j^{\text{th}} \text{ plot in } i^{\text{th}} \text{ minigrd (plot measured completely)}
 \end{array}$$

(1) Attribute mean for plot j within minigrd i :

Plot Subsampled
$$\bar{y}_{ij} = \frac{1}{m_{ij}} \sum_{k=1}^{m_{ij}} y_{ijk}$$

$$\text{var}(\bar{y}_{ij}) = \frac{s_{ij}^2}{m_{ij}}, \text{ where } s_{ij}^2 = \frac{\sum_{k=1}^{m_{ij}} (y_{ijk} - \bar{y}_{ij})^2}{m_{ij} - 1}$$

(2) Attribute mean for plots in stratum h within grid i :

Plot Subsampled
$$\bar{y}_{h(i)} = \frac{1}{n_{h(i)}} \sum_{j \in H} \bar{y}_{ij}$$

$$\text{var}(\bar{y}_{h(i)}) = \frac{s_{h(i)}^2}{n_{h(i)}} + \frac{1}{n_{h(i)}} \sum_{j \in H} \frac{s_{ij}^2}{m_{ij}}, \text{ where } s_{h(i)}^2 = \frac{\sum_{j \in H} (\bar{y}_{ij} - \bar{y}_{h(i)})^2}{n_{h(i)} - 1}$$

Plot Completely Measured
$$\bar{y}_{h(i)} = \frac{1}{n_{h(i)}} \sum_{j \in H} y_{ij}$$

$$\text{var}(\bar{y}_{h(i)}) = \frac{s_{h(i)}^2}{n_{h(i)}}, \text{ where } s_{h(i)}^2 = \frac{\sum_{j=1}^{n_{h(i)}} (y_{ij} - \bar{y}_{h(i)})^2}{n_{h(i)} - 1}$$

(3) Attribute mean for stratum h across multiple grids:

$$\bar{y}_h = \frac{1}{n_h} \sum_{i \in H} \bar{y}_{h(i)}$$

$$\text{var}(\bar{y}_h) = \frac{s_h^2}{n_h} + \frac{1}{n_h} \sum_{i \in H} \frac{s_{h(i)}^2}{n_{h(i)}}, \text{ where } s_h^2 = \frac{\sum_{i \in H} (\bar{y}_{h(i)} - \bar{y}_h)^2}{n_h - 1}$$

Community ecology-based approaches

One important aspect of our approach to vegetation monitoring is a solid grounding in community ecology. While we are interested in detecting individual species, and classes of species responses to environmental gradients and change, we are also interested in monitoring key emergent properties of communities of organisms. This approach involves the goal of quantifying (or at least describing) variation in community structure and composition over time and space. To meet this goal of a community-based monitoring approach, we turn to traditional methods of analysis in community ecology: measures of community composition, diversity, and relative dominance including diversity indices and ordination techniques.

Diversity measures.-- We used the following metrics to characterize and study the distribution of plant species richness on the park landscape: mean species richness at the following nested scales: 1 m²; 4 m²; 200 m² plot; entire minigrid (25 plots); multiple minigrids. These values are calculated for each of the following components of biodiversity: vascular plants, bryophytes, terricolous macro-lichens, as well as meaningful subsets of these categories (such as Alaska-Yukon endemic plant species). In addition, we used species occurrence data to calculate the following indices of community diversity:

- 1) **D = Simpson's diversity index for infinite population** = $1 - \sum (P_i * P_i)$
where P_i = importance probability in element i (element i relativized by total across all plots)
- 2) **H = Diversity** = $-\sum (P_i * \ln(P_i))$ = Shannon's diversity index
- 3) **E = Evenness** = $H / \ln(\text{Richness})$

Whereas the mean number of species per unit area (the species richness metrics described above) provides an important estimate of species richness, it may fail to account for species turnover among sample units, or *total* species richness for a given set of samples. For example, two minigrids may contain an identical mean of 20 species per 200-m² plot, but have considerably different levels of overall plant diversity depending on how much turnover in species exist within each minigrid. One of these minigrids might contain only 20 total species (if the same 20 species occur in each plot within the minigrid), whereas the other minigrid sample could potentially contain up to 500 species (if there were complete turnover among plots; 20 species x 25 plots = 500 total species). To examine the species-area relationships across all spatial scales, we utilize calculated cumulative species-area curves to directly assess the relationships between the amount of area sampled and the number of species observed at each increment of area sampled.

Ordination of community data.--To explore the relationships between vegetation structure and composition, and the physical environment, we have used detrended correspondence analysis (DCA), an ordination technique based upon reciprocal averaging (Hill 1979). Plot-level cover data, by species, were ordinated with DCA. DCA scores

were then regressed against physical variables to assess important relationships between variation in vegetation and these causal factors. In addition, simple occurrence data (frequency of occurrence in 4-m² quadrats and 200m² plots) were also ordinated and used in regression analyses to examine patterns in species composition across key environmental gradients within the study area.

Equivalent Latitude: The Potential Solar Radiation of a Site

Equivalent latitude (EQ) is an index of potential solar radiation for a topographic surface; it varies as a function of slope angle, aspect and latitude (Lee 1962). This variable has been used to predict the distribution of plant communities and permafrost in Alaska (Dingman and Koutz 1974, Roland 1996). The equivalent latitude of a surface represents the latitude at which a level surface would receive an equivalent amount of solar radiation as the sloped surface in question (exclusive of atmospheric attenuation of radiation). Thus the equivalent latitude of a flat surface equates to the latitude of the site, and north-facing slopes have higher values of EQ, whereas south-facing slopes have lower values of EQ. The equivalent latitude for a site is calculated with the following equation:

$$EQ = \arcsin [(sink * \cos H * \cos L) + \cos K * \sin L]$$

(where... K = slope in degrees, H = deviation from true north, L = Latitude)

Summary of Vegetation Methods Development to Date

The focus of the methods development during this pilot study has been crafting an integrated set of field and analytical methods designed to meet the objectives laid out in Chapter 1 of this report. In addition, we have sought to create the larger infrastructure for carrying this program well into the future, including the creation of numerous data structures and analysis routines capable of handling large volumes of ecological data from several iterations of field sampling for monitoring. We have also created a web site for communicating the scope, background and results of this work to a wider audience. To date, then, we have accomplished the following steps toward making a viable long-term ecological monitoring program:

- 1) Created a park-wide, two-stage systematic grid sample (set of points) based on a random starting point, which resides in the park GIS;
- 2) Created an original plot design for the program with procedures for measuring the fundamental aspects of the vegetation cover of the park necessary to meet the program objectives;
- 3) Designed a normalized relational database structure using Microsoft Access® software to store and effectively analyze vegetation data, including data from several iterations of sampling from a park-wide two stage systematic grid sample;
- 4) Field tested the set of sampling procedures to assess their logistical practicability;

- 5) Constructed a comprehensive set of data summary and analysis routines, that operate independently from the data storage database and are served on the world wide web to allow for numerous users to access the data from a variety of locations;
- 6) Developed a prototype website to be used for the dissemination of information concerning the landscape scale monitoring program.

Songbird Methods

Songbird Field Methods

Birds were sampled with variable circle plot methodology (Buckland et al. 2001) using protocols field tested by the Yukon-Charley Rivers National Preserve bird inventory (Swanson and Nigro 2003). We also developed our data forms and data base structures using the Yukon-Charley bird inventory database as a template for our data forms and data base structures.

In 2001 and 2002, we sampled birds for 8 minutes at each point. (In 2003, we changed our methodology to reflect sampling periods across North America and sampled birds for 10 minutes at each point). We conducted point counts from 0230 and 0930 Alaska Standard Time, between 8 June and 30 June, in 2001 and 2002. These are the census periods recommended by Boreal Partners in Flight to maximize detection of species breeding in interior Alaska. We did not conduct any censuses during heavy rain or when winds exceeded 15 kph.

A single observer conducted the census at each point. One observer conducted all censuses for Crew A in 2001 and 2002. In 2002, two observers in crews B and C were regularly rotated throughout the minigrids to minimize observer bias.

Upon arrival at the sample point, the observer measured a 125 m radius circle using a laser range finder to aid with distance sampling. The recorder took a series of measurements including the name of observer and recorder, date, start time, stop time, temperature, sky conditions, wind direction, overall background noise, insect levels, slope, and aspect. All data were recorded on standardized data sheets.

We began censusing birds approximately one minute after arriving at or establishing the sampling point. The observer called out all birds detected within 150-m of the sampling point and the estimated horizontal distance between the observer and the detection. The recorder documented these data on the standardized data form. Based on previous work conducted in Yukon-Charley Rivers National Preserve (Swanson and Nigro 2003), we conducted each census for at eight minutes per station and broke the census time into two periods, 0-5 min. and 5-8 min. (In 2003, we conducted each census for 10-minute and broke the census period into four intervals: 0-3 minutes (to correspond to the National Breeding Bird Survey sampling period), 3-5 minutes (to correspond to the historic off-

road point count program in Alaska), 5-8 minutes (to maintain consistency with 2001 and 2002 data), and 8-10 minutes. For each observation, we recorded species, estimated distance (10-m intervals to 125 m), and type of detection (audio, visual, fly-by). Additionally, we recorded all birds observed or heard as we traveled to each sampling point. Data collected between points are not useful for estimating density, but are valuable for describing the number of species observed on each minigrid.

No observer training was completed in 2001. The observer, Carol McIntyre, for the two minigrids in 2001 was competent both in identification of birds by sight and sound, and had training extensively in distance sampling in 1998 and 1999. We completed a two-week training period in May 2002 in cooperation with the Alaska Bird Observatory (ABO). All observers completed the training that included identification of birds, particularly songbirds and near-songbirds, by sight and sound, and distance sampling training. At least two crew members were trained to use handheld Garmin, Trimble, and Rockwell PLGR handheld global positioning system (GPS) units.

Wind direction, wind speed, the direction that a singing bird is facing, and the intensity of the song or call are all factors that influence an observer's ability to estimate the distance to birds. The most critical element in using distance estimation is being able to accurately estimate the distance of the closest birds, usually those within 60 meters of the observer. This requires that all observers be highly trained using distance estimation. Observers should be trained and tested annually to maintain consistency in estimating distances.

Sampling points were established at three minigrids in 2001 (Rock Creek, Wigand Creek, and Savage River) and seven minigrids in 2002 (Primrose Ridge, East Chitsia, East Toklat, West Toklat, Lower Stony, Gorge Creek, and Cabin Peak) (Figure I.4). The bird crew or the vegetation crew established sampling points (latitude and longitude) using a geographic information system (GIS) and then located these points in the field using a highly precise handheld global positioning system (GPS) unit (Rockwell PLGR or a Trimble Geo-Explorer). We marked each sampling point with a uniquely numbered survey marker that was permanently placed in the ground.

Songbird Analytical Methods

We transcribed data from field data sheets to a Microsoft© Excel spreadsheet. We are currently working with Doug Wilder, Database Manager for the Central Alaska Network, to develop an Access relational database for these data. The database will be similar to that developed for the avian inventory for Yukon-Charley (D. Wilder, pers. comm.); however, it will be tailored for integration with the Denali vegetation-monitoring database. The unique plot marker assigned to each sampling point joins all tables and databases. Data will be managed following guidelines set up by the Denali Long-term Ecological Monitoring Program and the Central Alaska Network Monitoring Program. All raw and digital data will be stored and archived in Denali and Fairbanks.

An analysis plan for the bird sampling data will be written during fall 2003, coincident with development of improved data management structures and documentation. The

analysis plan will include use of the program DISTANCE (Buckland et al. 2001) to calculate detection functions and estimate bird densities. Once the analysis plan is written and peer-reviewed, analyses of all pilot study collected in 2001, 2002 and 2003 will be completed.

For the purposes of this report, simple calculations were performed using Microsoft© Excel. Total detections were calculated for each species by point, minigrid, and all minigrids. Frequency of occurrence was calculated for minigrids as the number of detections divided by the number of points surveyed (i.e., we were not able to survey all 25 points in each minigrid).

Chapter 4. Introducing the Vegetation Data

We now turn to an examination of the field data that we have amassed during the first two seasons of this pilot study. A primary initial focus of this pilot study effort was to determine the logistical and cost feasibility of the proposed monitoring design. That is, could we effectively execute this design on the ground and carry out all of the protocols in a safe and timely fashion? Once we resolved the questions regarding the feasibility of this undertaking, scientific questions regarding the “quality” and utility of the data acquired were the primary focus. We treat both of these sets of questions in Chapters 4-6, with our goal being to provide the reader with a tangible and complete understanding of the monitoring data acquired through this study design.

For the proposed design to be successful, the data collected must effectively capture the important attributes of the park vegetation cover at the different spatial scales of inquiry outlined in the Chapters 1-3. In addition, because this program is focused on examining changes in resource attributes along environmental gradients, the design must be effective at capturing significant relationships between landscape variables and the vegetation attributes of interest. We will examine the pilot study data to allow the reader to assess the efficacy of the design in capturing important vegetation variables as well as significant relationships between the vegetation parameters and causal environmental factors.

Overview of the Vegetation Data

In keeping with our goal of providing the reader with the most useful cross-section of our results for the purpose of assessing the utility of the proposed design, we had to make choices concerning which data would be presented. Since a critical element of the proposed program is the spatially-nested character of the design, we present examples of results at each of the following spatial scales for monitoring that are envisioned within the design: 1) individual sample points (this chapter); 2) entire minigrids (Chapter 5); and 3) across all minigrids (Chapter 6).

The primary goal of Chapters 4-6 is to present a cross section of the results of the pilot study to assess the potential utility of this design for landscape-scale vegetation monitoring. For readers interested in viewing a more complete array of the vegetation and physical data than presented here, we have posted a comprehensive set of data summaries resulting from this work on the draft program website (<http://mercury.bio.uaf.edu/DenaliLTEM/>).

We begin Chapter 4 with a brief discussion of the logistics and practical feasibility of the design informed by field work from the first *three* years of the pilot study (since we have recently completed field work for 2003, we have additional information on the logistical aspects of the program). Upon completing the discussion of feasibility studies, we turn to present data from the first two field seasons of this project.

In the remainder of Chapter 4, we present results summarized for individual points within the minigrad design (e.g. data from single vegetation monitoring plots). The purpose of this chapter is to describe the complete scope and variety of data that are made available by the proposed monitoring design. Understanding how the data from an individual point are acquired and summarized is a necessary prerequisite to evaluating the more substantive presentation of observed variation in vegetation parameters among points, and larger segments of the landscape, that is presented in Chapters 5 and 6. In the following chapters that describe our results across larger spatial scales of interest, we will present information from selected subsets of the data streams. However, we felt it was crucial to first provide a complete accounting of the various data that were acquired in each plot.

In Chapter 5, we describe variation in measured physical and vegetation parameters within three separate minigrads, each representing a different fraction of the park landscape: a boreal minigrad (West Toklat), a transitional minigrad (Lower Stony Creek), and an alpine minigrad (Primrose Ridge). The examination of data at the scale of complete minigrads is important because these data represent the “meso-scale” gradients targeted during the development of the objectives for this monitoring program, as discussed in Chapter 1.

In Chapter 6, we examine summaries of the entire data set acquired during the pilot study through the use of post stratification. This level of analysis will allow us to make general statements about the relationships between vegetation and important underlying causal factors on the landscape of the park, and to detect whether these relationships change over time. Because we make the explicit assumption that vegetation change will occur differently in different segments of important environmental gradients, this level of analysis is crucial to detecting and understanding change at the landscape scale. To explore the potential utility of this approach, we selected two primary ecological gradients to examine for purposes of this report: elevation and soil depth. We conclude Chapter 6 with a discussion of how the data presented in the Chapters 4-6 may be used to accomplish the goals of this long term monitoring program – to detect changes in the cover of the vegetation cover of the park at a landscape scale.

Overview of Field Sampling and Logistics

We conducted fieldwork on 12 minigrads during the period 2001-2003 (Table 4.1). By design, the 12 pilot study minigrads encompassed broadly different areas of the landscape (including diverse alpine, transitional, and boreal areas) and access methods (helicopter, foot travel). We completed sampling on 287 out of 300 possible points (96%) on these minigrads. We surveyed all 25 points at nine minigrads. Sampling was not completed for all points in only three minigrads, Tributary Creek, East Chitsia, and Gorge Creek, in which 24, 20, and 18 points were measured respectively. Of the thirteen points that were not sampled, eight were inaccessible due to steep and dangerous terrain (seven points at Gorge Creek and one point at Tributary Creek), and likely will never be reachable. Extreme weather was a factor preventing completion of sampling at one minigrad (East Chitsia). Of the 300 points among 12 minigrads that were sampled, only five points were

not sampled that were actually possible to sample, which represents a success rate of greater than 98 percent! Clearly, the sampling program that we have embarked upon is logistically feasible.

The points that we have sampled thus far have included high alpine scree slopes, closed spruce-birch forests, very dense alder thickets on steep slopes, and *Eriophorum* tussock bogs on permafrost terrain. Considerable diversity in landscape positions and vegetation types was observed both within and among the twelve minigrid samples that have been measured thus far during this study. However, these twelve minigrids can be broadly separated into three general categories:

- 1) **Boreal minigrids** (Wigand Creek, East Chitsia, East Toklat West Toklat, Upper Wigand Creek and Lower East Fork);
- 2) **Transitional minigrids** that encompass both boreal and alpine sites (Rock Creek and Lower Stony Creek); and,
- 3) **Alpine minigrids** (Upper Savage River, Primrose Ridge, Tributary Creek and Gorge Creek).

In 2001 the crew for this project consisted of two GS-06 seasonal technicians and the project principal investigator, with help from Karen Oakley on the Upper Savage River sampling trip. In 2002 the project fielded two full crews with three members each, including the project P.I. The field crew in 2003 consisted of three seasonal technicians. Each summer, then, each vegetation field crew performed sampling at three minigrids. The first year the following measurements were performed: plot description and physical variables, photo documentation, vascular and nonvascular species composition, cover transects, tree measurements and mapping. Two sampling regimens were added to this basic set of observations for the 2002 season: the soils measurements and the tree coring protocols. These additional sampling routines were also successful, and were continued in 2003.

We used helicopter transport to access five of the study areas (Wigand Creek, Lower Stony, East Chitsia, East Toklat and West Toklat) and hiked in to another three of the areas (Upper Savage River, Gorge Creek and Primrose Ridge), establishing base camps from which sampling was conducted. The Rock Creek minigrid was accessed by day hikes from the park headquarters area, where the crew was stationed. The success of field crews in completing sampling in spite of the variety of access challenges and considerable diversity of landscapes encountered during this pilot study bodes well for the long-term viability of this approach. The results of the feasibility aspects of this pilot project conclusively showed that the chosen arrangement of samples (25 points spaced 500 m apart) was practicable for the suite of variables that we chose to measure. Detailed trip reports describing ten of the grid sampling trips are provided on the project website.

Point Data: Examples of Data Summaries from Individual Plots

In this section, we present a conspectus of the different types of data that are recorded in each plot. This section is included to convey the diversity of monitoring metrics available through the proposed design. These data consist of summaries for a variety of individual plots that were measured during the pilot study. We selected an array of plots that best express the utility of the different data streams. The importance of the information conveyed in this section is not the actual data values that we present. Rather, our goal is to provide the reader with an understanding of the various methods for summarizing and presenting physical and vegetation data that are available through this design. For this reason, we selected examples of data from across the different minigridded samples that were measured during the pilot study. We selected plots that best highlighted the different data streams.

The following sections detail the purpose of each data stream, with specific examples from our pilot study work. The data streams treated here are as follows, organized by our data collection protocols: plot photographs, physical and soils data summaries, cover transect data summaries, species composition data summaries, plot maps of tree distribution, tree density and biomass measurements, and tree increment coring data.

Plot Photographs (Objective #10)

Repeat photography is a valuable tool for examining ecological changes on the landscape over time, particularly for stationary resources such as vegetation. Examining a series of photographs taken at the same point at intervals over many years serves as a unique enhancement to quantitative analyses of ecological data. It also serves as a permanent archive of the appearance of the landscape at each sampling interval through time. The best sets of plot photographs accomplish the following objectives: the images capture the vegetation mosaic within the plot itself (both of each quadrat placement and the entire plot) and show the landscape context of the plot and any major ecotones in its vicinity. In addition to serving as means of evaluating changes in vegetation cover over time, the plot photographs perform the added functions of facilitating re-location of the plot for future sample iterations and as a tool for helping with data quality control. For example, if the data from an individual quadrat appear to be unusual or questionable, we can examine the photo of the quadrat to determine the accuracy of the data. Similarly, plots that prove to be outliers in the data analysis phase may be revisited “virtually” through the use of plot photographs.

We provide one full set of photos from a single permanent plot to demonstrate the potential that acquiring this large set of georeferenced images provides the long term monitoring program in Figures 4.1 through 4.9. These photographs were taken in the Lower Stony Creek minigridded at point #21. This photo set provides extensive information concerning the vegetation of the plot and its landscape context that could not be captured in any other way. The position of the forest edge in relation to the plot, the stature and composition of the surrounding vegetation, as well as the measured vegetation within the plot, and the larger scale views across the local landscape all provide a useful data that

can be used for direct comparisons once these photo points have been repeated during the next sample iteration.

Physical and Soils Characteristics (Objectives #7 and #8)

In this section we provide examples of a cross section of the physical and soils attribute data recorded in this study. To display these data, and give an indication of how they vary within a minigrid, we present a cross section of values recorded from eight points in the Lower Stony minigrid in table form. These sample points were selected as examples because they represent the variation in these attributes observed within this particular minigrid sample, and because we have a relatively complete set of data for these points. Physical data recorded at eight points in the Lower Stony minigrid are shown in Table 4.2, and plot descriptive data for the same group of plots are shown in Table 4.3. Field observations of soils attributes are provided in Table 4.4 and values from the laboratory soils analyses are provided in Table 4.5.

A primary reason for collecting this detailed set of physical and soil attribute data is to allow us to quantify relationships between vegetation parameters and these environmental factors – how does vegetation vary along the gradients represented by these physical variables? It is our intention to use statistical modeling techniques to evaluate the strength and nature of the relationships between the various measured physical parameters and vegetation.

In addition to providing the context for understanding and monitoring the variation in vegetation on the landscape, the physical and soils data themselves represent useful monitoring metrics that will be evaluated to detect whether changes have occurred in the park ecosystem over time. For example, changes in the distribution of permafrost on the landscape of the park should be reflected in changing values for numerous soils attributes that we measure (Tables 4.4 and 4.5), including soil depth (= active layer depth), mean soil temperature, soil moisture, and eventually soil carbon and nitrogen levels as mineralization would be expected to increase with the thawing of permafrost at a landscape scale.

Vegetation Structure (Objectives #1, #2, and #9)

The vegetation cover data form a cornerstone for the proposed vegetation monitoring program. These data allow us to make estimates of a variety of important vegetation parameters including absolute and relative measures of abundance, structure, diversity and the vertical arrangement of the vegetative cover. The structure of our database design allows for a large array of ways to examine data from the cover transects, through pooling data according to various species attributes including growth form, geographic range and taxonomy (family, genus). We present a few examples of these data summaries based on cover transect data in this section. All of the data summaries that are presented here are derived from routines that are available on the StatServer® web page for the project. In presenting these data, we start with the most basic types of data

summaries and present a set of increasingly specific summaries of the data, to show the flexibility of this approach to collecting cover data.

The most basic, generalized set of summary statistics of the cover transect data provide rough estimates of the diversity and overall density of the vegetation of a site. The cover.transect.summary StatServer® analytic summarizes the following attributes of vegetation structure based on the data from the three cover transects measured at each plot:

- 1) total number of species encountered on the cover transects, which is a measure of relative species richness of the dominant vegetation cover of the plot (typically only relatively abundant taxa are captured through this point-based sampling approach).
- 2) the mean and variance in the number of species encountered *per point* along the transect, which provides a measure of the species “packing” observed within the plot - low numbers of species per point reflect a vegetation cover that consists of patches of relatively homogeneous vegetation, whereas higher numbers of species observed per point indicate a vegetation with more species growing in close proximity.
- 3) the mean and variance in the number of “hits” at each point along the transects, which provides a relative measure of the biomass of the overall standing crop of vegetation because the more “hits” encountered on the transects, the higher the overall biomass, other things being equal.
- 4) the mean and variance in the number of “hits” recorded above 30 cm above the ground at each point along the transects, this value provides a measure of the amount of biomass in the vegetation in the vertical strata above 30 cm – which could be important for wildlife, for example as hiding cover for mammals, or nesting habitat for birds.

Table 4.6 shows the values for these basic cover transect summaries for the same eight plots in the Lower Stony minigrid for which physical data summaries were provided.

The information derived from the cover.transect.summary analytic allows for comparison of general attributes of the cover data derived from numerous plots quickly and easily. The utility of these data for monitoring is to increase our ability to detect community-level shifts in attributes of the vegetation cover including relative dominance, total biomass and related factors. Clearly, for example, changes in the biomass of vegetation observed above 30 cm have important implications for the ecosystem, if it is detectable at larger spatial scales than just the individual plot.

We will now move on to additional data summaries that provide more specificity about the vegetation cover of the individual monitoring plots than the generic data provided in the cover.transect.summary analytic. All of the cover analyses described below were

performed using the “[veg.cover.summary](#)” analytic from the StatServer web page. In the interests of space, we will present a set of examples from a single plot to show the kinds of data summaries available through this set of analytic routines.

The next level of the cover data analysis includes summarizing cover by what we call “transect cover elements”. This level of analysis uses the [veg.transect.summary](#) function to derive estimates of percent cover by the following different elements that we encounter while performing the cover transects in the field:

- 1) vascular plants
- 2) bryophytes (mosses and liverworts)
- 3) lichens (terricolous macrolichens)
- 4) organic debris – dead organic materials including litter, and standing dead organic debris such as dead tree branches, tree snags, etc...
- 5) mineral - rock gravel, bare mineral soil
- 6) water

This analytic pools cover for all observations based on the value in the “transect_cover_element” field of the “ref_taxon” table of the database (see database design Figure 3.7). Thus, for example, all observations of vascular plant species that occur in the cover transects in a plot are pooled together to generate an estimate of the total cover of vascular plants in the plot, as a class. Figure 4.10 shows a graph of the vertical cover profile for all of the *transect cover elements* observed in Lower Stony minigrid point #11. The value of these data for meeting the objective of monitoring vegetation structure is considerable. Specifically, in future, these abundance estimates can be compared to the same estimates derived from future sample iterations to test whether there have been significant changes in the total cover of basic elements of the park’s landcover. For example, a decrease in vascular plant cover coupled with an increase in “organic detritus” would be expected to occur with mortality of trees in a plot. If such a change in the cover signatures between two sample iterations were observed, we would inspect the plot photographs and analyze the tree measurements from the plot to either build support for or to refute such hypotheses generated by the cover analyses.

It is certainly to be expected that individual plots will show changes in their cover signatures over time, the real question for the landscape-scale monitoring program is whether larger segments of the landscape are showing *directional* changes in cover. In other words, are there general patterns of cover change that are occurring at the scale of an entire minigrid sample, or region of the park? One minor way that we will be able to address such questions is to *tally* the number of plots that show an observed change versus the number that do not show it. Subsequent sections of this report will describe other analytical approaches to these landscape-scale questions, beyond simple tallying of individual plots.

Another level of data summary available from the cover transects is the estimation of cover by individual species, or groups of species. This level of analysis parses the cover data represented by the transect cover element category “vascular plants” shown in

Figure 4.10 into cover by the individual component species that form this class. Using our methods, vascular plant cover data can be expressed by species, or species may be pooled together to examine cover by growth form, range category, or other species pooling variables. For example, Figure 4.11 shows the *total* cover (irrespective of vertical position) of the vascular plant species observed on the cover transects at Lower Stony minigrid point #11. Figure 4.12 shows the vertical profile of the plant cover, although with species data pooled to express cover by growth form classes for the same plot.

The ability to detect changes in the abundance and vertical or horizontal distribution of plant species and groups of plant species is a major focus of the proposed monitoring program. The fundamental sample unit for characterizing these vegetation attributes is the individual sample plot. Plot-based data, such as those presented above, may be grouped to examine whether differences observed at the scale of individual plots, is in fact occurring more generally across the park landscape. For instance, with two iterations of samples, we could ask the question whether the overall abundance of white spruce (in terms of cover) showed an increase, decrease, or had remained constant across a given sample interval. These plot-based data would serve as the building blocks for any attempt to detect changes or to examine larger scale patterns in the vegetation cover of the park.

Species Composition: Vascular and Nonvascular Species (Objectives #2 and #3)

The primary set of methods for recording the species composition of the vegetation monitoring plot are the quadrat measurements, in which the occurrence of each vascular plant, bryophyte and macrolichen species within a set of nested areas are recorded. This set of observations provides a wealth of information concerning the vegetation of a site, including the identity of the species that occur there, the species richness characteristics of the vegetation, species:area relationships in the vegetation, and frequency of occurrence of all of the species within the vegetation.

The most basic result of the species composition observations are simple lists of species that were observed in a plot at a given sample event. A further refinement of this list of species occurrences is the frequency of occurrence of these species in the nested quadrat array for each plot. Using this technique, we can estimate the frequency of occurrence at three spatial resolutions: within the 1 m² quadrats, within the 4 m² quadrats, and within the entire 200 m² plot. Tables 4.7 and 4.8 show examples of species frequency tables for vascular, bryophyte and macrolichen taxa observed in Rock Creek minigrid point # 19. These data provide a measure of the “perfusion” of the species observed in the plot through the vegetation mosaic. A frequency of “1” in the 1 m² quadrats (meaning the species was observed in each one) in a plot represents the most common level of species occurrence. Species that were only observed in the quadrant searches of the entire plot (200 m²), and not in either of the quadrat observations have “0” frequency in the quadrat columns, but receive a “1” in the plot frequency column. The plot frequency value for a

species may only vary from “1” when multiple plots are considered, thus for this single plot all species have a frequency value of “1”.

The species frequency data are an important tool for monitoring the abundance and distribution of less abundant elements of the flora. The cover transect measurements provide information about the structure of the vegetation cover, and the *dominant* species within the vegetation. However, few species of particular management concern such as rare and endemic taxa or exotic plants are captured by the level of intensity of the cover transect sampling protocol, unless they occur at a high level of abundance, which is unusual. Because the species composition observations are area-based (rather than point-based, as the cover transects are) many more species are captured using these techniques. The species frequency signatures of the vascular plants and cryptogams derived from different sample events may be compared to detect changes in the abundance or distribution of these species over time. For example, these measurements should allow us to determine whether a particular taxon is “invading” areas of the landscape by becoming established in plots where it had previously been absent.

The frequency data may also be summarized by classes of species to detect changes in the abundances of sets of species of concern. For example, Table 4.9 shows the frequency of occurrence of species endemic to Alaska among all the points sampled in the upper Savage River minigrid. Changes in the frequency of an entire class of species of management concern over time, such as endemics or exotics, would certainly be important to detect. These data will allow us to monitor changes of this nature on the landscape of the park.

In addition to providing data concerning individual species abundance and distribution, the species composition data also allow for monitoring of important community-level attributes of the vegetation. The measurements we have been made during the course of this work strongly show that species richness of the vegetation varies dramatically across the landscape of the park. Certain landscape positions have very high diversity while large areas of the landscape are relatively depauperate. Furthermore vascular plants, macrolichens and bryophytes show different patterns of variation in response to landscape variables. Presumably, then, significant shifts in the environmental factors that control these community patterns would cause changes in species richness patterns on the landscape. These changes in community composition would almost certainly have cascading other effects upon many other organisms, including symbionts, parasites and commensals. The species composition measurements would allow us to detect such changes in these fundamental ecosystem properties. Table 4.10 shows a values for several species diversity metrics, calculated for each of the 25 points in the Lower Stony minigrid sample. These metrics include the mean number of species observed in the 1 m² quadrats, 4 m² quadrats and the total species richness of the individual plots. The calculated values of Shannon’s diversity index and Simpson’s diversity index are also presented.

The species acquisition curve is another method for quantifying species richness of the sampled areas. Plotting the net addition of new species with each increase in area

sampled allows us to examine the species-area relationships of different plots and vegetation types. This analysis allows us to determine the sampling adequacy of our chosen plot size and configuration for the different elements of the flora (e.g. vascular plants, lichens, mosses, and liverworts). It should always be the case that the asymptote of species acquisition has been reached when sampling in a given plot is terminated. That is, the number of species that is added with each new unit of area should not be increasing at a rapid rate. All of our analyses to date suggest that the 200 m² plot size is appropriate for all of the vegetation types studied thus far. In fact for most of the boreal types, the plots could be substantially smaller, and still capture the large majority of species in the site. Figure 4.13 shows the species acquisition curves for four classes of organisms for upper Savage River minigrid point #19 (the same plot for which species frequencies were provided earlier in this section). Note that for all of these types of organisms, the species acquisition curve has flattened significantly once 100 m² of area has been searched.

We have observed conspicuous and consistent differences in the slope and asymptote of the species accumulation curves among different vegetation types and segments of the landscape, across all spatial scales, during the course of this work. Therefore we believe that the species-area relationships themselves represent a facet of the vegetation cover worth monitoring (over and above the utility of assessing minimum sample area discussed above). Therefore we have devised a series of species-area analytical routines for the StatServer web page that allow us to quantify this relationship across all spatial scales of interest to the landscape scale monitoring program. These routines will be discussed in subsequent sections of this report that deal with the larger spatial scales of inquiry.

Tree Maps for Permanent Plots (Objectives #1, #3, #5, and #9)

Tracking the growth and condition of the trees that occur in each plot is important for detecting changes in health, structure, and composition of our forests over time. To accomplish this, it is important that field workers recognize each individual tree within each permanent plot, so that measurements are correctly attributed to particular trees at different sample iterations. To facilitate consistent recognition of individual trees within the permanent plots we created a mapping function in the StatServer® analytical tool kit to generate simple maps that portray the location, size, species and condition class of each tree in each permanent plot. This function uses the azimuth and distance from plot center to plot the location of each tree on a map showing the plot perimeter. The function assigns the tree different color dots based on the species. The relative size of each dot is determined by the diameter of the tree, and dead trees are indicated using an “x” though the dot. Figure 4.14 provides two examples of plot maps generated using data from the pilot study: Rock Creek point #2 and Wigand Creek point #23.

Plot maps will be provided to each field crew for subsequent iterations of sampling, along with a set of the plot photographs. In combination with the high-quality GPS locations

and magnetometers for locating the center monuments, the crews will have a full set of tools for locating plots and reinstalling them correctly for remeasurement activities.

Tree Measurements (Objectives #1, #2, #3, #5, and #9)

Detailed information concerning the size, location, canopy position, vigor and evidence of pathogens and/or physical damage was recorded for all of the individuals of tree species greater than 12 cm diameter at breast height (dbh) that occurred in the plots measured during the pilot study. Table 4.11 shows a summary of some of these data for trees observed in the Wigand Creek minigrid point # 23. The goal of collecting these data is to allow us to monitor the status and trends in vigor and community structure of forest communities at a landscape scale. Comparison of identical data from successive sample events should allow for detection of major trends in establishment, mortality and vigor in the forested areas of the park.

The tree data allow us to make estimates of the density and biomass of different size classes of trees. We use these plot level data to calculate the number of stems per hectare (density), the m² of tree bole per hectare (basal area) and the mean diameter of trees for each plot. Tables 4.12 through 4.14 present these data for Wigand Creek minigrid point #23. According to the design of this program, data from individual plots can be pooled together, to generate estimates of tree density, basal area and diameter over much larger areas of the park landscape. We have developed the statistical routines to calculate these area-based estimates at all of the spatial scales of interest, from within-plot to park-wide, and incorporated these routines into the StatServer functions web page.

Annual Growth of Spruce (Objective #4)

Where possible, we extracted increment cores from four spruce trees in the peripheral increment coring plot that surrounds each permanent vegetation monitoring plot. The number of rings in these cores was counted and each annual ring was measured. The data contained in the tree cores are unique in that they provide a window into the past that allows us to examine patterns of annual growth in spruce over centuries of time. The data contained in these cores also allow us to make estimates concerning the minimum age of particular stands of spruce trees occurring within the minigrid study areas. Understanding patterns in the ages of forest stands provides important information concerning the long term dynamics of vegetation on the park landscape, such as the periodicity of major disturbances, on the landscape.

Annual growth of spruce in interior Alaska is highly variable among years. The annual growth data that we have collected confirm this observation. We have calculated two metrics of annual growth for the cores that were sampled in 2002; raw annual ring width (Figure 4.15) and basal area increment (Figure 4.16). Ring width is simply the width of each increment of annual radial growth. This metric is useful because it allows us to quantify the mean growth of trees on an annual basis, and understand patterns in interannual growth over the life of a tree. However, raw ring width data can be misleading

when comparing tree growth across different trees because, on average, larger trees tend to have smaller rings. In addition, each increment of radial growth accounts for a larger production of wood in a large tree as compared to a small tree. For this reason, we standardized the annual growth measurements by calculating a metric called basal area increase (BAI), which represents the cubic cm of wood produced by a tree each year, and is a function of the tree's diameter and annual growth increment.

Annual growth in spruce in interior Alaska is strongly controlled by climatic factors including interactions between growing season temperature and precipitation. Our ability to accumulate a very large tree ring data set from across the park landscape through this project will allow us to better understand the variability in both spruce growth and climatic factors across this large area, and how these patterns have changed through time.

Establishment of spruce on the landscape of interior Alaska is highly episodic in nature. Generally speaking, establishment of stands of spruce occurs following major disturbance events, as opposed to through the gradual accumulation of seedlings. This is because these plants generally require a mineral seed bed for establishment of seedlings, which is only available immediately following major disturbances. We hope to better understand the periodicity of these disturbance events by quantifying the minimum age of forest stands across the park landscape through the increment coring protocol. As an example we calculated that the minimum ages for the four trees measured in the Lower Stony Creek minigrid point 16, were 252, 204, 89 and 301 years old respectively.

Human Use of the Landscape (Objective #6)

We record any sign of human use of the landscape at each permanent monitoring point, including the presence of roads, structures, camps, social trails, garbage, and observations of people within the study area. These occurrences may be tallied and expressed by frequency histograms across minigrids. These data for an individual point consist of a list of evidence of human use of the landscape. A matrix of different items of evidence of human use will be developed. This will allow us to create frequency histograms for different types of human sign for individual minigrids, and larger sets of sample points.

Discussion

The goal of this chapter of the report was to provide concrete examples from the array of different data streams that have been developed thus far for this project. We believe this introduction was necessary to provide context before launching into our examination of the substance of the field data that have been collected thus far. In the next chapter, we present more substantial analyses to show how well this design captures variation in important gradients within the vegetation of the park and relationships between vegetation and landscape variables.

Chapter 5. Individual Minigrids: Variation in Vegetation At the Meso-Scale

In the previous chapter, we provided examples of the data collected at each sample point with a survey of the suite of data summaries possible within this design. In this chapter, we move to the next larger spatial scale of inquiry envisioned for this monitoring design - the data for entire minigrids. The goals of this section are to present a selection of the data at the minigrid level and to show the variability in measured parameters at this spatial scale, focusing on variation within minigrids. For this purpose, we chose three minigrids, spanning the boreal-alpine gradient that typifies Denali, to use as examples (for map of minigrid locations, see Figure 5.1):

- A boreal minigrid--West Toklat,
- A transitional minigrid--Lower Stony Creek, and
- An alpine minigrid--Primrose Ridge

We selected three minigrids as examples of the data acquired at this spatial scale for purposes of this report. However, in the process of graphically presenting the pilot study data for these particular minigrid samples, we will include data from all of the minigrids that were sampled during the pilot study, wherever possible. This will provide the reader with a more complete picture of the range of variation in measured parameters captured by this design. Thus, while we will specifically discuss the data from the three example minigrids, the reader will have access to the broader context of the entire data set. Variation *among* the minigrids measured during the pilot study will be discussed in Chapter 6.

For purposes of this report, we have decided to focus on presenting data from the following primary data streams: physical attributes, vegetation structure attributes, vascular plant species community composition and species richness attributes, and tree attributes of the samples. These measurements represent the core aspects of the program and allow for a relatively complete examination and evaluation of the proposed monitoring design.

This chapter is separated into four sections – one for each of the example minigrids, followed by a discussion section at the end. For each minigrid, we discuss the physical and soil environment, and then treat the attributes of the vegetation observed in the sample. We then present the results of analyses of relationships between the physical environment and vegetation parameters for the minigrid sample. In the final section of this chapter we discuss the utility of these data for both understanding vegetation pattern and process on the current landscape and for detecting change in the landscape-vegetation relationships over the long term.

NOTE: In this report, we present the observed values for many parameters through the use of “box and whisker” plots (Figure 5.2). We chose this particular graphic format because it enables us to portray the median observation for the parameter, its’ range of

variation, and skewness in the pool of observations for all of the minigrids sampled in a single figure. This graphic representation thus quickly summarizes the variability in a given parameter within and among all of the samples in a single graph. It also shows “outlier” values for each minigrid sample, when they exist. The white line within the green “box” represents the median observation, and the box itself spans the upper and lower quartiles of the range of observations (it contains the middle 50 percent of the observed values for the parameter). The “whiskers” extend to the nearest observed value not beyond 1.5 times the interquartile range from the quartile limits. Outliers are represented by horizontal lines of values outside the whiskers (i.e., observations farther than 1.5 times the interquartile range outside the box). When examining these figures, bear in mind that the pool of observations used to construct them are 9 different sets of 25 separate values – one value for each sample point in each minigrid. Thus in figure 5.2, the range of observation in equivalent latitude for the minigrid sample depicted is between 12 and 82 degrees. These plots do not show the mean value for a parameter, so whenever a box and whisker plot was used, we provided the mean values for each parameter in the text.

A Boreal Minigrid: West Toklat

Physical Attributes

Topography and General Character

The West Toklat minigrid sample was located west of the Toklat River, approximately midway between VABM Toklat and the Stampede air strip (Figure 5.3). This area is approximately 6 km NW of the point where the Toklat River exits the Alaska Range mountains. The minigrid was arrayed along the flanks of a large east-facing bluff formed from Nenana gravels (for photos of the area, see Figure 5.4). Sample points were located in the following landscape positions: on the relatively level surface of the glacial drift outflow terrace at the base of the bluff, on the east-facing slopes of the bluff, and on the heavily permafrosted, gently north-inclined upper surface of the bluff feature.

This minigrid was generally boreal in character, although the open vegetation on the upper surface of the bluff was essentially treeless, probably due to a combination of permafrost soils and strong prevailing wind patterns in this area. Elevations of the 25 sample points ranged between 676 m and 838 m, with a mean plot elevation of 747 m (Figure 5.5a). Slope angles measured in the plots were generally very gentle with a mean of 5°, and ranging from essentially flat (1° slope) to moderately steep (22°; Figure 5.5b). The distribution of plot aspects observed within the minigrid were mostly north and east-facing, reflecting the overall tilt of the landscape to the north in this region of the park, and the influence of the large east-facing bluff bisecting the minigrid. (Figure 5.6a).

Equivalent latitude of the surfaces measured in this minigrid ranged between a low of 58.69° on point #10 on the upper surface of the bluff, to 80.08° at point #3, on a northeast-facing section of the bluff (Figure 5.6b). Mean equivalent latitude for the 25 points was 65.66°. Observed values of equivalent latitude for the sample indicate that, on

average, the topographic surfaces sampled in this minigrid receive less solar radiation than the norm for level surfaces at this latitude (due to the preponderance of north aspects in the sample).

Soils

Mean soil depth measured at the plots in the West Toklat minigrid averaged 27 cm (SE = ± 3 cm), with a minimum average soil depth of 18 cm, and a maximum average soil depth for a plot of 39 cm (Figure 5.7a). This narrow range of soil depths reflects the strong influence of permafrost in this area. In fact, we encountered no plots with deep active layers in this minigrid. Mineral ground cover classes (including rock, gravel and bare mineral soil) were essentially absent from this heavily vegetated lowland minigrid (Figure 5.7b). In contrast, the surface of the West Toklat minigrid was heavily mantled with organic detritus (which includes down wood, litter and standing dead material), accounting for an estimated 51 % cover ($\pm 7\%$) of the ground surface of the study area (Figure 5.8a). Mean litter depth averaged 1 cm, the depth of the living mat averaged 4 cm (Figure 5.8b), and mean organic soil horizon depths averaged 25 cm (Figure 5.9a) in this sample.

Mean soil temperatures for the West Toklat minigrid sample points varied between 1.1 ° C and 5.3 ° C, with a mean soil temperature for the entire sample of 3.1 ° C (Figure 5.9b). The range of variation in soil temperatures observed in this sample was narrow. This low variation in soil temperatures again reflects the relatively uniform, continuous nature of the permafrost in this region.

We took soil samples at 20 of the points within this minigrid sample. We were unable to obtain soil samples from five points because there was no mineral soil present at the soil sample points, only accumulated, lightly decomposed organic peat substrate. The soils from this grid were relatively fine textured, with a mean fine soil fraction (particles < 2mm) of 85.5% of the sample, and a minimum observed value of 41.7 % fine fraction, and maximum value of 100 % fine fragment (Figure 5.10a).

Soil textural analyses for sand:silt:clay percentages were performed on only 5 soil samples from the West Toklat minigrid sample, because of the large number of highly organic samples (and consequent low mineral sample volume available for testing). The average sand:silt:clay ratio for these samples was 34:47:19, reflecting silty, glacial drift-derived soils prevalent in this study area (Figure 5.10b). Mean moisture content of the West Toklat soil samples was very high at 62% water, with a minimum observed value of 32% water and a maximum water content of 82% (Figure 5.11a). Mean and median moisture content of the West Toklat soil samples was the highest for any of the minigrid samples, despite the fact that this area was sampled during a prolonged period of dry, warm weather. The influence of perched water tables in the permafrosted lowland sites also contributed to the wetter edaphic conditions observed there.

We observed relatively high accumulation of organic matter in the soils in the West Toklat minigrid. Carbon content ranged from four percent to 41 %, with a mean of 22%

soil carbon (Figure 5.11b). Nitrogen content ranged from 0.1 % to 1.6 %, with a mean nitrogen content of 1.0 % (Figure 5.12a). The soils in this study area, which are generally derived from glacial drift overlain by accumulations of organic materials of varying thickness, were markedly acidic, with a minimum observed pH of 3.94 and a maximum observed value of 5.13 (Figure 5.12b). The mean soil pH for the West Toklat minigrid sample was 4.50, indicating a markedly acidic soil environment.

Relationships among Physical Attributes

The West Toklat minigrid encompassed relatively slight variation in topographic variables such as slope, aspect, and elevation. This relative topographic homogeneity likely results in lower overall variability in other physical factors and habitat characteristics for plants. The overriding presence of permafrost throughout the study area further reduced the amount of variation in soils attributes. As a result, the strength of the correlations among the physical variables was generally less strong in this sample than in more variable sections of the landscape where geomorphic processes result in strong covariation of soils and landscape variables. A correlation matrix for the physical and soil parameters is shown in Table 5.1.

Several pairs of physical variables were strongly correlated in this sample. For example, plot elevation was positively correlated with slope angle and soil depth reflecting the fact that plots located high on the bluff feature were generally steeper and had somewhat deeper soils than sites on the terrace below. The strongest patterns of correlation in physical variables were observed in the soils traits within this minigrid sample. Specifically, soil moisture, percent carbon, and percent nitrogen were strongly positively correlated, and this set of variables was each negatively correlated with soil pH and soil temperature. This set of relationships reflects the fact that cold, highly organic soils tended to have very high water holding capacity (and thus moisture percentage) and to be more acidic (lower pH) due to the formation of weak organic acids with decomposition of organic matter. Soil temperature was positively correlated with slope angle, litter depth and organic horizon depth in this sample. This suggests that steeper slopes in this area may receive somewhat more radiation, and hence be warmer, or have some other factor that increases soil temperatures, such as increased drainage. The fact that soil depth was also positively correlated with slope angle suggests deeper active layers in the sloping sites.

Vegetation

Vegetation Types

We estimated that more than 58 % of the West Toklat minigrid was occupied by low shrub vegetation types, with 39 % having an open canopy, and almost 19 % having a closed canopy (Figure 5.13). An estimated 36 % of the area was classified as forested, with the primary type (24 %) being very open woodland spruce forest, and an estimated 8 % of the area being open spruce forest. Closed spruce forest accounted for only an

estimated 3.4 percent of this minigrid sample. Other minor vegetation types observed in the minigrid included open tall scrub (alder; 4 %), and ericaceous dwarf scrub (1 %). The distribution of the dominant vegetation types is shown overlaid on a Color IR spot satellite image of the study area in figure 5.14.

Vegetation Structure

The vegetation structure of the West Toklat minigrid was characterized by a deep and nearly unbroken moss mat that covered an estimated 84 % of the minigrid (SE = \pm 5%; Figs. 5.15 & 5.16a) and a high percentage of low to-medium-statured shrubs (45 % shrub cover \pm 7%; Figure 5.16b). Tree cover of the West Toklat minigrid averaged 4 % of the area (\pm 2.5%; Figure 5.17a) and trees were generally restricted to the slopes of the low bluff and particularly to the flat terrace surfaces below this feature. Dwarf shrub cover of the minigrid was an estimated 25 % (\pm 6 %; Figure 17a), and graminoid cover averaged almost 17% of the area (\pm 5%; Figure 5.18a). Forb species covered an estimated 4 % of the West Toklat minigrid, with a standard error of 2% (Figure 18b). Lichen cover of the West Toklat minigrid ranged between 0 % and over 40%, with a mean lichen cover for the sample of 14% (\pm 5%; Figure 5.19a). Lichen cover was much lower than bryophyte cover, in all landscape positions within the West Toklat minigrid sample.

On average, the plant cover in the West Toklat minigrid sample was quite low to the ground, with very little cover above 50 cm from ground level (Figure 5.15b). Tree cover above 2 m in height was negligible in the West Toklat minigrid. The low stature of the vegetation was not uniformly the case within the sample however, as there were nine plots in which plant cover above 50 cm exceeded 10 percent of the plot. These plots were all located on the bluff feature or the terrace surfaces below, in low elevation positions within the sample. Vegetation structure varied across this sample, with a more forested vegetation mosaic occurring in the low elevations and sloping areas, and open, very low dwarf birch scrub in the upper elevations of the sample on the bluff's upper surface. The most conspicuously atypical vegetation structure in the sample was observed in gully features on the bluff, where surface waters collected and resulted in localized areas of lush alder and forb vegetation. These areas likely receive additional moisture and intermittent surface disturbances that resulted in a deeper active layer and greater diversity of microhabitats for plant establishment. Incidentally, these areas also supported the highest mean vascular plant diversity, as will be discussed later.

Dominant Vascular Plant Species

The dominant vascular plant species observed in the West Toklat minigrid were dwarf birch (*Betula nana*; 17% cover) and several low ericaceous taxa including *Ledum decumbens* (16 %), *Vaccinium uliginosum* (15 %) and *Vaccinium vitis-idaea* (15 %; Figure 5.19b). Open areas of the landscape and wetter micro-sites had relatively high cover of the sedges *Carex bigelowii* (13 % cover) and *Eriophorum vaginatum* (2 % cover). In the West Toklat minigrid sample, the six species with the highest cover values were also the species that occurred with the highest frequency in the species composition measurements (Figure 5.20a). *Vaccinium vitis-idaea*, for example, was (remarkably)

observed in 99 of the 100 four m² quadrats read in this minigrid (frequency value of 0.99, or 99%). The other species that were observed in more than 80% of the quadrats were *Vaccinium uliginosum* (98 %), *Carex bigelowii* (95 %), *Ledum decumbens* (94 %), *Betula nana* (87 %), and *Empetrum nigrum* (81 %). These were all species that were also dominant in terms of biomass with this sample. This boreal sample was characterized by nearly ubiquitous cover of zonal dominant species—species common and widespread in their geographic distribution. The only species of more restricted range that was abundant in the sample was *Salix pulchra*, a willow that occurs only in Alaska and neighboring territories.

Vascular Plant Species Richness

Vascular plant species richness of the boreal vegetation in the West Toklat minigrid was very low. In fact, only 87 vascular plant species were recorded at the sample points in the West Toklat minigrid (Figure 5.20b). Mean vascular plant species richness observed in the 200 m² plots in the West Toklat minigrid sample was also low, with a mean of 20.3 species per plot and a range of observations spanning 12 to 40 species per plot (Figure 5.21a). There was a mean of 9.2 (\pm 0.6) vascular plant species per 1 m² quadrat and 11.4 (\pm 0.4) species per 4 m² quadrat (Figures 5.21b & 5.22a). These were also relatively low levels of mean species richness for these plot sizes.

Community composition

The first DCA axis from ordination of plot cover data (DCA-1) identified the gradient between low shrub vegetation at one end of the spectrum and forest and productive tall shrub vegetation at the other end of the spectrum. Plots receiving low scores on DCA-1 were uniformly low scrub vegetation dominated by *Betula nana*. Plots receiving high scores on DCA-1 were wooded plots and those with more productive willow or alder tall shrub vegetation. A selection of DCA-1 scores for common species within this sample are shown in table 5.2. Species with low scores on this axis were more abundant in areas dominated by low birch-ericaceous shrub vegetation.

Trees

White spruce (*Picea glauca*) and black spruce (*Picea mariana*) were the only two tree species observed in the West Toklat minigrid sample. The mean seedling densities in the West Toklat sample were 1800 stems/Ha for white spruce and 5150 stems/Ha for black spruce (Figure 5.22b). Tree densities across the entire sample were low overall, due to the absence of trees from the plots high in elevation within the sample (Figure 5.23a). Estimated mean density of live white spruce trees (individuals >12 cm dbh) in this sample was 44 stems/Ha (\pm 19), whereas there were no black spruce trees observed in this sample. Several plots in this sample had very high densities of live black spruce saplings (individuals <12 cm dbh). Mean density of black spruce saplings across the entire sample was 660 stems/Ha (Figure 5.23b). Mean density of live white spruce saplings in the West Toklat minigrid was 276 stems/Ha (\pm 72).

Dead trees and saplings were observed in very low densities in this minigrid (Figure 5.24a). There were an average of 22 dead white spruce trees (± 2), and 54 dead white spruce saplings (± 21) per Ha observed in this minigrid sample. There were no dead black spruce trees observed in the sample, and an average of 40 dead black spruce saplings per Ha (± 21 ; Figure 5.24b).

The size class distributions of the populations of white and black spruce observed in the West Toklat minigrid sample were strongly skewed toward the smallest size classes and there were very few large trees observed in this minigrid (Figure 5.25a). Because of the relatively small size of the trees in the West Toklat minigrid sample, the total basal area, (a measure of total biomass) of spruce in the sample was also relatively low. There was an estimated basal area of 0.81 m²/ha for live white spruce trees (Figure 5.25b) and an estimated basal area of 0.69 m²/ha of live black spruce trees in the West Toklat minigrid.

Relationships among Vegetation Variables

There were several noteworthy patterns of strong correlation among pairs of vegetation variables measured in the West Toklat minigrid sample (Table 5.3 presents a correlation matrix for a suite of vegetation variables). The four variables relating to the abundance of trees in the sample (tree density, tree basal area, seedling density, and % cover of tree species) were all strongly correlated within this sample. This group of tree variables was strongly negatively correlated with % shrub cover, possibly indicating the results of competitive interactions among woody taxa. Tree seedling density was particularly strongly negatively correlated with shrub cover, suggesting that seedling recruitment was limited in areas with high woody plant cover. Tree parameters were all positively correlated with the three measures of species richness included in this analysis, which means that treed areas within the sample tended to support a somewhat higher diversity of vascular plant species. The tree variables were also positively correlated with plot scores on the first DECORANA ordination axis (DCA-1).

A second cluster of correlated vegetation variables was the strong positive correlation coefficients among percent cover of forbs and each of the three measures of species richness, and plot score on DCA-1. In contrast, forb cover was negatively correlated with cover of graminoids and with percent lichen cover. Graminoid cover was negatively correlated with the measures of species richness observed in this sample. Similarly lichen cover of a plot was negatively correlated with species richness, and was also negatively correlated with plot score on DCA-1.

Taken together, these results suggest that one group of plots in the sample supported both trees and a relatively species-rich assemblage of vascular plants with high forb cover and relatively low shrub cover. These plots scored high on the first DECORANA axis. In contrast, plots that supported treeless, low-shrub dominated vegetation with relatively high graminoid and lichen cover received low plot scores in this ordination analysis. This ordering of plots appears to represent the gradient between relatively productive, forested sites in the sample and very open sites of low productivity dominated by low-statured vegetation of shrubs and graminoids (principally the sedge *Carex bigelowii*).

Examination of the species scores in this ordination support this interpretation. Taxa associated with more lush, meadow sites, such as *Salix reticulata*, *Carex podocarpa* and *Boykinia richardsonii* scored highly on DCA-1 and taxa that were common in open sites of low productivity such as *Pedicularis labradorica*, *Ledum decumbens* and *Eriophorum vaginatum* received low scores on this ordination axis.

We performed two further data analyses to assess the above observations. First, the plot score on DCA-1 was strongly correlated with the total amount of vascular plant cover above 50 cm in height ($r = 0.78$; Figure 5.26). Second, the mean score of all plots that were classified as 'low shrub' vegetation types by the field crew was 55 (± 9) whereas plots classified as forested vegetation types received a mean DCA-1 score of 146 (± 22). Both of these analyses confirm the interpretation that the primary gradient in the West Toklat minigrid was between relatively low-statured, open sites with low vascular plant diversity to wooded sites with higher diversity, and taller vegetation.

Relationships between Vegetation and Physical Attributes

We examined the relationships between the physical parameters and vegetation variables observed in the West Toklat minigrid sample to determine which physical factors most influence the structure and composition of the vegetation. There were four primary sets of vegetation attributes that we analyzed for purposes of this report, (although there are more metrics available for the long term monitoring program that is proposed): 1) measures of vegetation structure (abundance signatures of dominant species in relation to physical variables); 2) measures of tree abundance; 3) measures of species richness; and 4) measures of community composition as represented by plot scores on DCA-1 ordination.

We used two primary techniques to quantify relationships between vegetation parameters and physical factors within this minigrid study area – regression procedures (including simple linear regression and multiple regression, and stepwise model selection procedures) and direct gradient analyses. We used both simple stepwise regression to identify statistically significant relationships between sets of independent predictor variables (physical factors) and vegetation response variables. We used gradient analyses to graphically examine the response of vegetation variables to variation in particular predictor physical variables. Our goal was to quantify the primary underlying gradients controlling variation in measured vegetation attributes. We believe that understanding these gradients will allow us to more effectively detect changes in the vegetation over time, should they occur.

Vegetation Structure

We observed strong patterns of variation in the structure of the vegetation of the sample points within this minigrid as a function of elevation. There were three primary elevation zones discernable within the sample – toe slopes and terrace surfaces at low elevation (between 600 and 700 m elevation), areas on the upper surface of the large bluff (between

800 and 900 m elevation), and the slopes of the bluff feature at intermediate elevations within the sample (between 700 and 800 m elevation). These elevation zones each contained variation in vegetation structure within them, but there were also consistent, discernable differences among these three areas in vegetation attributes.

We pooled 25 sample points into three strata of elevation based upon the zonation described above and calculated the mean responses of vegetation parameters within these strata to examine observed differences quantitatively. The sample sizes within these strata were as follows:

- 1) 600-700 m (5 plots)
- 2) 700-800 m (14 plots)
- 3) 800-900 m (6 plots)

A analysis of vascular plant cover along this gradient showed that vascular plant cover above 50 cm in height above the ground and higher was virtually absent from areas in the upper elevation zone within this sample (Figure 5.27). Similarly, cover of tree taxa was entirely absent from these areas of the landscape (Figure 5.28). The vertical stature of the vegetation expressed on surfaces in these three zones was clearly different. This clear difference in vegetation was almost certainly due to differences in habitat for plants among these areas of the landscape (rather than, for example, successional differences). The physiological effects of abrading winter winds and the consequent redeposition of the snow pack on the exposed upper surface of the bluff has perhaps played a role in the formation of this pattern. In addition, the lack of fluvial disturbance of the upper surface of the bluff likely restricts variation in active layer depth and opportunities for establishment of trees and taxa unable to become established in the cold, wet moss layer that carpets this zone.

To examine *species-level* responses to this gradient, cover for each of the twelve most abundant species observed in the sample was averaged across all plots within each of these elevation strata. We then classified each species as responding positively, negatively, or neutrally to the elevation gradient. A species was considered to respond negatively to the gradient if cover was lower in the high elevation plots relative to the other elevation strata. A species was classified as responding positively to the gradient if cover was higher in the high elevation stratum than the two lower elevation strata, and a species was classified as neutral to the elevation gradient if cover remained essentially constant across these strata. A fourth category--"intermediate" responders--was composed of species that occurred in greatest abundance in the intermediate elevation category.

Gradient analyses of species cover values indicated that five of the dominant species responded negatively, to the elevation gradient (*Vaccinium vitis-idaea*, *Salix pulchra*, *Picea mariana*, *P. glauca*, and *Rubus chamaemorus*; see Figure 5.29a), whereas three species responded positively to the gradient (*Ledum decumbens*, *Carex bigelowii*, *Empetrum nigrum*; Figure 5.29b). Two species occurred in greater abundance in the intermediate elevation category (*Betula nana* and *Alnus viridis*; Figure 5.29c) and two

species were neutral, in terms of response of cover percent, across this gradient within the sample (*Vaccinium uliginosum* and *Eriophorum vaginatum*; Figure 5. 29d). The neutral species showed no discernable response to this physical variable – they occurred in more or less the same abundance across these three strata.

It seems likely that a factor or suite of physical factors related to the elevation of a plot on the landscape is responsible for the patterns in the abundance of the vegetation structure that we observed. Presumably, if the ecological factors underlying this gradient change in the future, the structure of the vegetation mosaic of the study area will respond to such changes. In that case, the species cover signatures described above should also exhibit changes. We submit that these changes would most likely occur differentially across this observed gradient. For example, if conditions that have precluded the establishment of trees and tall-statured vegetation on the upper surface of the bluff feature were to ameliorate, the cover signatures of the species that had negative responses to this gradient should show observable changes in the highest elevation stratum, as these taxa increase in abundance in this area. If changes in ecological conditions were to occur, it seems likely that they would not be limited to this one study area, and similar directional changes would be observed in other minigrid samples also.

Species Richness

Linear regression analyses of three species richness metrics (mean # species in 1 m² quadrats, mean # species in 4 m² quadrats and total # of species observed in each entire plot) all yielded significant positive relationships between the equivalent latitude of a plot and the species richness observed in the plot's vegetation within the West Toklat minigrid sample. Table 5.4 shows the ANOVA summaries from regression analyses of each of these measures of species richness on equivalent latitude. These analyses demonstrate that there was a significant positive relationship between equivalent latitude and species richness in this sample. In general, this result suggests that areas that receive less overall solar radiation supported somewhat higher levels of mean vascular plant diversity within this sample. Figure 5.30 shows the relationship between species richness and EQ observed in this sample.

Stepwise linear regression procedures added one additional physical variable, the depth of the living mat (covering the soil surface of a plot) to these predictive models. This physical variable significantly improved the predictive power of the regression model for each of the species richness parameters. Table 5.5 shows the regression coefficients, coefficient of determination (r^2), and p-value for these multiple-regression models. These models show that for this sample species richness at each of these plot sizes was significantly positively related to EQ values and a the depth of the mat of live plant material at the soil surface (live moss mat).

Community Composition

A series of simple linear regressions of plot scores on DCA-1 against the entire suite of physical variables measured during this study identified the equivalent latitude of a plot

as the physical variable that had significant predictive power for this value in the West Toklat minigrad sample (coefficient = 6.38, $r^2 = 0.21$, $p = 0.021$; see Figure 5.31). Stepwise regression procedures also added the depth of the living mat to this model. This result is nearly identical to those returned for species richness regression models, and confirms the observation that vascular plant community composition within the West Toklat minigrad sample is significantly influenced by these two physical variables. It is worth noting in this regard, the data that were used for the dependent vegetation parameters came from two separate data collection protocols – cover transects data were used for the ordination of plot data and species composition quadrats provided the species richness variables.

Trees

Trees were restricted to the lower elevations within the West Toklat minigrad, occurring in greatest abundance on the terrace surface below the bluff, and on the toe slopes of this topographic feature. However, there were also open areas with low-statured, shrub and graminoid-dominated vegetation that occurred in low elevation positions within the sample, so that forest was not uniformly established in these areas. Gradient analyses of tree and sapling density and basal area and seedling density clearly show the diminution of tree abundance with increasing elevation within the sample (Figure 5.32).

The establishment of populations of trees is a critical ecological boundary on the park landscape. There are major differences in both ecosystem processes and habitat attributes for both fauna and flora that ensue from the change in state from an open to a forested vegetation mosaic. The advent of trees in an area may lead to a variety of important ecological changes with significance for both the ecology of the park and its human visitors. One obvious ecological (and cultural) variable one could cite in this regard is fire. The advent of trees to a treeless area soon changes the dynamics, intensity and frequency for fires in the area. Thus the opportunity to monitor areas that have the potential for showing expansion of tree distribution at a landscape scale that exists in this data set is an important facet of this design. Each minigrad that was measured during the pilot study encompassed different facets of the ecotone between treeless and forested vegetation within the park. In the West Toklat minigrad, this ecotone was circumscribed by the gradient in elevation.

Summary

Our analyses of the data for the West Toklat minigrad have identified distinct gradients in physical and vegetation attributes within this sample. Vegetation structure, the distribution of trees, vascular plant community composition and species richness all responded to topographic variables within this boreal study area. Specifically, elevation and equivalent latitude were identified as two topographic attributes with significant influences on the character of the vegetation.

We believe that it was an important result that, even in this relatively homogeneous permafrosted boreal minigrid, we were able to identify significant relationships between the response of vegetation structure and composition to physical variables. Modeling the primary relationships between landscape and physical predictors of vegetation attributes is fundamental to our approach to monitoring. Developing more robust models will allow for predictions to be made concerning other areas of the park where sampling has not occurred. These models can be strengthened and improved as we continue to add to the baseline data set that is under construction with this project.

We anticipate completing further analyses of the data acquired in the West Toklat minigrid beyond these the exploratory set of analyses presented here. Causal modeling techniques such as path analysis will allow us to build more inclusive and refined models that will enhance our basic understanding of the relationships between vegetation and the landscape in this region of the park. Developing these causal models for each iteration of sampling in the long term monitoring program should provide powerful tools for detecting changes in the vegetation cover of the park over time. Furthermore, by detecting vegetation changes within this conceptual framework, we should be in a better position to understand the underlying ecological causes for any changes that are detected.

A Transitional Minigrid: Lower Stony Creek

Physical Attributes

Topography and General Character

The Lower Stony Creek minigrid sample was located in the northern slopes of the “outer range” on the eastern flanks of a low alpine plateau between Stony Creek and Mount Sheldon (see area map in Figure 5.33). This area is immediately northeast of where Boundary Creek enters lower Stony Creek. The minigrid included points on the floodplain terrace of the eastern tributary of lower Stony Creek, a variety of points on the east and north facing slopes of the ridge and alpine sites on the top of the broad, flat alpine plateau (see photographs of the area in Figure 5.34). This sample represented a wide spectrum of landscape positions and vegetation types, including steep, willow-filled gullies, spruce forest on the river terrace and alpine tundra vegetation on the ridges.

This minigrid was mostly subalpine in character, although there were both alpine and boreal vegetation types within the sample, as mentioned above. Elevations of the 25 sample points ranged between 810 m and 1086 m, with a mean plot elevation of 930 m (Figure 5.5a). Slope angles in the sample were evenly distributed between gently sloping plots in the upper and lower landscape positions, and moderately sloping plots on the flanks of the large plateau. The mean slope angle was 12°, with a range of observations spanning 2° to 30° (Figure 5.5b). The range of variation in slope angle was higher in the Lower stony minigrid than in the boreal minigrids, but less than in the alpine samples. The distribution of plot aspects observed within the minigrid were mostly northwest and northeast-facing, due to the large north-trending ridge dominating the landscape, there

were no points with southerly aspects within this sample (Figure 5.6a). The mean difference from due south aspect for the points in this minigrad was 115° and was the highest mean value observed for any of the minigrad samples (Figure 5.35).

Equivalent latitude (EQ) of the surfaces measured in this minigrad ranged between a low of 42.23° on point #24 high on the ridge, to 81.52° at point #2, on a north-facing bench near the northeast corner of the minigrad (Figure 5.6b). The mean equivalent latitude for the 25 points was 65.66° . Despite the relatively large range between the extreme high and low EQ observations, the majority of the points in this minigrad fell within a narrow range of EQ relative to the other transitional and alpine minigrad samples. This was due to the preponderance of northerly aspects in the Lower Stony Creek minigrad sample. EQ values for the Lower Stony Creek sample indicate that, on average, the topographic surfaces in this area receive less solar radiation than the norm for level surfaces at this latitude.

Soils

Mean soil depth measured at the points in the Lower Stony Creek minigrad averaged 34 cm (standard error = 6.5 cm), with a minimum average soil depth of 7 cm in a boulder field in point #7 and a maximum average soil depth for a point of 74 cm on the deep alluvial deposits of the creek underlying point #12 (Figure 5.7a). This broad range of soil depths reflects the relatively wide diversity of landscape surfaces in the sample, which included gently sloping and solidly frozen permafrost surfaces, rocky alpine areas on colluvium, and deep alluvial deposits on the valley floor.

A few points measured in this sample had high mineral surface cover of the ground surface (including rock, gravel and bare mineral soil), which was different from the boreal samples, in which this condition was never observed (Figure 5.7b). The mean mineral cover of the ground surface of the entire sample was less than 2% and high for an individual point of nearly 15 % exposed mineral surface (Figure 5.7b). In contrast, the surface of the Lower Stony Creek minigrad was heavily mantled with organic detritus (which included down wood, litter and standing dead material), accounting for an estimated 63 % cover ($\pm 6\%$) of the ground surface of the study area (Figure 5.8a). Mean litter depth for the Lower Stony Creek minigrad sample averaged 1 cm (± 0.8 cm), the depth of the living mat averaged 5 cm (± 2 cm; see Figure 5.8b), and organic soil horizon depths averaged 16 cm (± 3 cm; see Figure 5.9a).

Mean soil temperatures for the Lower Stony Creek minigrad sample points varied between 0.4°C and 9.5°C , with a mean soil temperature for the entire sample of 2.9°C (Figure 5.9b). We were unable to measure soil temperature in five points in the Lower Stony Creek minigrad due to equipment failure. The range of variation in soil temperatures observed in this sample was quite narrow, especially as compared to the Primrose Ridge alpine minigrad. This is likely due to the preponderance of north aspects in the Lower Stony Creek sample. The influence of permafrost is also an important influence on soil temperature in the Lower Stony Creek minigrad. The occurrence of

permafrost significantly dampens upward variation in soil temperatures in these areas because of the cooling effects of permanently frozen soil at very shallow depths.

We took soil samples at 16 of the points within this minigrid sample. Soil samples were not obtained from nine of the points because there was no mineral soil present at the soil sample points at these plots, only accumulated organic peat substrate over solidly-frozen permafrost. The soils from this grid were relatively fine textured, with a mean fine soil fraction (particles < 2mm) of 60 % of the sample, and a minimum observed value of 35 % fine fraction, and maximum value of 97 % fine fragment (Figure 5.10a).

Soil textural analyses for sand:silt:clay percentages were performed on only 9 soil samples from the Lower Stony Creek minigrid sample, because of the large number of highly organic samples (and consequent low mineral sample volume available for textural analysis testing). The average sand:silt:clay ratio for the lower Stony Creek soil samples was 55:34:12. The sand fraction of the soil observed in these samples was similar to the values observed for the alpine minigrids (Figure 5.10b). This is because the parent materials in this region are derived from alluvium and colluvium in a more active geomorphic context, as compared to the very high proportions of silt observed in the soils derived from glacial drift in the lowland boreal minigrid samples.

Mean moisture content of the Lower Stony Creek soil samples was relatively low at 27% water, with a minimum observed value of 17% water and a maximum water content of 38% (Figure 5.11a). The soils from this minigrid were relatively low in organic matter, although is partially because we did not take soil samples at the sites where there was only organic material. We have changed the protocol, and now take soil samples at each sample point regardless of whether there is mineral soil present. The mean percent soil carbon of these samples was 4.8% and the range of observed values was between 1.5 % and 8.8% C (Figure 5.11b). Nitrogen content ranged from 0.1 % to 0.4 %, with a mean nitrogen content of 0.3 % N (Figure 5.12a). The soils in this study area generally had markedly acidic reaction, and the mean soil pH in the Lower Stony Creek minigrid 4.48, the minimum observed value was pH 4.05 (Figure 5.12b). One plot in the sample was a conspicuous outlier – plot #11, located on the deep alluvium of the creek bed had pH of 7.01.

Relationships Among Physical Attributes

There are a few strong correlations among topographic parameters in this sample (see correlation matrix among physical variables in Table 5.6). Elevation, slope angle, and aspect off-180° are uncorrelated within the sample. This is because there were low-angle sample points both at the top of the ridge and on the lowest stream terrace. There was a diversity of plot aspects across the elevation gradient contained within the minigrid. Variation in equivalent latitude (EQ) is primarily a function of the plot aspect within this sample (the two are mathematically related), with a correlation coefficient between these two variables of 0.86.

The slope angle of a plot in the Lower Stony Creek minigrid sample was strongly correlated with several factor soil factors. We observed that increasing slope angle was correlated with increased soil depth, soil temperature and carbon and nitrogen content of the soil. Conversely, there were strong negative correlations between slope angle and organic horizon depth, the percent fine fraction of the soil and soil pH. These data suggest that soils in sloping areas of the landscape were warmer, had deeper active layers, a larger proportion of coarse mineral fraction, and were (unexpectedly) higher in carbon and nitrogen content. In contrast, soils of gently sloping sites tended to have a deeper accumulation of undecomposed organic horizon, and a somewhat more acidic soil reaction.

There were several other pairs of soils variables that were strongly correlated. Soil depth was strongly positively correlated with soil temperature, soil moisture percent and litter depth. This suggests a suite of variables that were related to the distribution of permafrost within the sample. Warmer soil temperatures would be expected in sites with deeper active layers. Organic horizon depth was negatively correlated with total soil depth, potentially indicating the accumulation of organic materials in level areas with less deep active layers, and slower rates of decomposition. In fact, soil temperature showed very strong negative correlation with organic horizon depth. Unsurprisingly, carbon and nitrogen content were positively correlated, and negatively correlated with soil reaction, indicating greater acidity in highly organic soils.

Vegetation

Vegetation Types

Nine different vegetation types were observed in the Lower Stony Creek minigrid (at Viereck level three; see Figure 5.36). The most abundant vegetation types were low scrub, mostly birch-ericaceous low scrub. An estimated 39 % of this study area was occupied by closed low scrub (including both dwarf birch and willow-dominated sites) and 35 % was occupied by open low scrub vegetation (predominantly dwarf birch). An estimated 8 % of the area was forested, with open spruce woodland occurring in the stream terrace and lower slopes of the ridge. Tall scrub vegetation types (both willow and alder) covered an estimated 10 % of the minigrid, with 6 % being closed tall scrub and the remaining 4% being open tall scrub vegetation. *Dryas* dwarf scrub tundra accounted for an estimated 5 % of the minigrid, and was restricted to sloping terrain with thin, rocky soils in the upper elevations of this area. Minor vegetation types recorded in the sample were mesic graminoid meadow, wet graminoid meadow and *felsenmeer* (boulder field). Figure 5.37 shows the location of the sample points overlain on a SPOT satellite image of this area.

Vegetation Structure

On average, the vegetation of the Lower Stony Creek minigrid sample was characterized by very high cover of moss and shrubs, although there was considerable variation in vegetation structure among plots. The entire Lower Stony Creek minigrid had a mean shrub cover of 55% ($\pm 7\%$) which was the highest mean shrub cover of any of the nine samples measured during the pilot study (Figure 5.38a & Figure 5.16b). Bryophyte cover of this minigrid averaged 75% ($\pm 4\%$; Figure 5.38a & Figure 5.16a). Lichen cover averaged 13% of this minigrid ($\pm 3\%$; Figure 5.38a & Figure 5.19a).

The Lower Stony Creek sample had the highest mean and median cover of graminoid taxa of any of the alpine and transitional minigrid samples (Figure 5.18a). This was mostly due to the relatively high cover of *Carex bigelowii* throughout the permafrost areas dominated by dwarf birch in this sample. Tree cover of the Lower Stony Creek minigrid was low, with mean cover of trees of 2% of the minigrid ($\pm 1.6\%$). Tree cover was generally restricted to the lower slopes, and alluvial terraces within this sample (Figure 5.17a).

The Lower Stony Creek minigrid had low mean cover of dwarf shrubs reflecting the relative scarcity of well-drained *Dryas* and other dwarf scrub tundra types within this area. Dwarf scrub vegetation types were more abundant in all of the other samples from mountainous regions performed during this study. The scarcity of these vegetation communities in this sample was likely due to the generally high cover of shrubs in the area in combination with impeded drainage on cold, low-angle north-facing sites that predominates in this area. Dwarf shrub cover averaged 14% ($\pm 3\%$) of this minigrid (Figure 5.17b).

In general, it is our experience that the subalpine zone is the area with the highest cover of forb taxa on the landscape of Denali Park. A deeper snowpack, higher moisture availability, increased frequency of geomorphic disturbance and a more open vegetation mosaic apparently result in a greater variety of habitats for forb species in this part of the landscape (over time, this observation will be testable with data acquired using this design). Several subalpine plots in this minigrid supported very high cover of forb taxa – primarily in well-watered, lush microsites within the landscape, including willow and alder-filled gullies and seep areas. In contrast, forb cover was negligible in dwarf-birch dominated ericaceous scrub vegetation. For the entire sample, forb cover averaged 9% of the minigrid ($\pm 2\%$), with a range of observations spanning 0% to 42% cover of the plots (Figure 5.18b).

The vertical distribution of plant cover within the Lower Stony Creek minigrid sample was strongly skewed towards the lower vertical strata, with very little plant cover above 50 cm above the ground (Figure 5.38b). Tree cover, as a mean of the entire sample was also negligible, although two open forested plots on the stream terrace had tree cover percentages greater than 20% (Figure 5.38b). Sample points in sloping, well-watered sites within this area supported patches of closed tall scrub vegetation (dominated by

alder and or willow). These areas were spatially-restricted in the sample, and the dominant vegetation was low-statured birch-ericaceous scrub.

Dominant Vascular Plant Species

Dwarf birch (*Betula nana*) was superabundant in the Lower Stony creek minigrid sample, with an estimated 30 % cover of the entire minigrid sample (Figure 5.39a). This was the highest mean cover of an individual species for any complete minigrid sample observed in this study (however, alder averaged nearly 29 % cover of the East Chitsia minigrid sample). The other dominant species observed within the Lower Stony Creek sample were *Salix pulchra* (11 %), *Carex bigelowii* (10 %), *Vaccinium uliginosum* (10 %), *Ledum decumbens* (7 %), *Calamagrostis canadensis* (7 %), *Empetrum nigrum* (6 %), and *Vaccinium vitis-idaea* (5%). This group of dominant species was the essentially same as was observed in the majority of the boreal minigrids. Clearly, although this sample represents a transitional area, it was substantially similar in important regards to adjacent boreal areas of the landscape.

Although these boreal dominant species had very high cover of the Lower Stony Creek minigrid sample, they species occurred in lower overall frequencies within the vegetation mosaic of this transitional minigrid as compared to the boreal samples (Figure 5.39b). For example, *Vaccinium vitis-idaea* occurred at a frequency of 99% in the West Toklat sample, but occurred in just 75 % of the 4 m² quadrats in this sample. Table 5.7 shows a comparison of frequency values for the seven most abundant species in the Lower Stony minigrid versus their abundance in the west Toklat sample. Whereas this set of boreal species occurs in relatively high abundance in the Lower Stony minigrid, it is apparent that these taxa are absent from the vegetation of many sites within this area as compared to the neighboring boreal minigrid, West Toklat.

In addition to differences in the overall frequency of the set of boreal dominants discussed above there were other differences between these samples revealed by the frequency data. Specifically, *Festuca altaica*, *Anemone narcissiflora*, and *Poa arctica*, three taxa that did not occur in high frequency in the West Toklat sample were observed in high frequency in the Lower Stony Creek sample. We remark upon these examples of differences between adjacent minigrid samples because they help to illustrate the utility of the area-based frequency data in examining more subtle changes in the composition of the vegetation not revealed through the point-based cover data.

Vascular Plant Species Richness

A total of 145 vascular plant species were recorded at the sample points in the Lower Stony Creek minigrid (Figure 5.20b). There was an average of 9.5 vascular plant species per 1 m² quadrat this sample, with a range of mean 1 m² richness of 6.25 to 14.5 species/m² (Figure 5.22a). There was an average of 12.6 species per 4 m² quadrat in the sample, ranging from a low of 8.0 to a maximum of 19.5 species per 4 m² quadrat (Figure 5.21b). The range in the number of vascular plant species per 200 m² plot was 13 to 46, with an overall mean of 27.6 species per plot (Figure 5.21b).

Vascular Plant Community composition

The first DECORANA axis from ordination of plot cover data (DCA-1) identified the gradient between low shrub birch-ericaceous vegetation at one end of the spectrum and woodland meadow and productive tall scrub vegetation at the other end of the spectrum. This ordering of plots was very similar to the ordering of plots in the West Toklat sample, although the eigen value for this ordination was much higher, reflecting the greater variation in the vegetation in this sample. Plots receiving low scores on DCA-1 were comprised of birch-ericaceous low scrub vegetation dominated by *Betula nana* and *Carex bigelowii*. Plots receiving high scores on DCA-1 were plots in open wooded situations with forb-rich understory and plots that supported sloping meadows and productive tall willow or alder scrub vegetation. A selection of DCA-1 scores for common species are shown in Table 5.8. Species with low scores on this axis were more abundant in areas dominated by low birch-ericaceous shrub vegetation, usually underlain by permafrost. Species with high scores occurred at higher abundance in more lush sloping meadows and floodplain areas.

Trees

White spruce (*Picea glauca*) was the only tree species observed in the Lower Stony Creek minigrid. White spruce occurred in 13 of the points in this minigrid, although individuals greater than breast height (1.37 m) were only observed in six of the points. This represents a potential for considerable future change in the vegetation structure of this sample, if this set of trees continues to grow and develop more forest within the area. The mean density of white spruce saplings in this sample was 102 stems/ha across the sample (Figure 5.23b), and the mean density of trees larger than 12 cm was 22 stems/ha (Figure 5.23a). The estimated means for these parameters are somewhat misleading, however because of the absence of the species from much of the higher elevations in this minigrid sample. The mean seedling density across the Lower Stony Creek sample was 200 stems/ha (Figure 5.22b). Mean basal area of white spruce (including all size classes) for the Lower Stony Creek minigrid was 0.97 m²/ha (Figure 5.25b).

The size class distribution of the trees observed in the Lower Stony Creek minigrid sample was strongly skewed toward the small size classes and there were very few large trees observed in this minigrid (Figure 5.40). There were very few dead trees observed in this minigrid (Figure 5.24b).

Relationships Among Vegetation Variables

A correlation matrix for a selection of the vegetation attributes measured in the 25 plots in the Lower Stony Creek minigrid sample is given in Table 5.9. The values for percent cover of trees, tree basal area, and tree density (for individuals >1.37 m tall) were all strongly positively inter-correlated in this sample. However, seedling density was not correlated with the other measures of tree abundance, because there were few seedlings in the forested plots, and only one plot (that supported no trees) had a high seedling density. The measures of tree abundance were positively correlated with scores on DCA-1 within

this sample, and they were negatively correlated with amount of shrub cover (which was also the case in the West Toklat sample).

Forb cover within this sample showed strong patterns of inter-correlation with other vegetation parameters. Specifically, forb cover was strongly negatively correlated with cover of nonvascular plants (both mosses and lichens), but positively correlated with measures of species richness and cover of graminoid taxa, as well as plot score on DCA-1. Cover of mosses, in turn, was negatively correlated with measures of species richness and score on DCA-1. The three measures of species richness were all positively correlated, and these variables were also positively correlated with plot score on DCA-1.

These relationships confirm the observation that the plots that scored highly on the first ordination axis supported relatively diverse vegetation, with high cover of trees and forbs, and relatively low cover of mosses. Plots scoring high on DCA-1 tended to support a fairly lush understory vegetation with meadow species such as *Valeriana capitata*, *Anemone parviflora*, *Polemonium acutiflorum*, *Mertensia paniculata*, and *Aconitum delphinifolium* receiving high positive species scores on DCA-1. At the other end of the spectrum were plots dominated by *Carex bigelowii*, *Eriophorum vaginatum*, *Ledum decumbens*, and *Oxycoccus microcarpus*. All of these species, which predominate in less-productive permafrosted and boggy sites, received low scores on DCA-1. Thus the gradient identified by the ordering of plots on DCA-1 represented the spectrum between more lush, meadow sites on deeper, warmer soils versus lower productivity sites on permafrosted surfaces with typical boreal zone dominant species. These low-scoring, low productivity sites also tended to support fewer vascular plant species than areas that scored high on DCA-1.

Relationships between Vegetation and Physical Attributes

Vegetation Structure

Relationships between physical parameters and vegetation structure were more complex within the Lower Stony Creek minigrid sample as compared with the West Toklat minigrid because there was more variation in both physical factors and vegetation in the Lower Stony Creek study area. Thus there were multiple axes of variation in this data set, which included the transition between boreal and alpine tundra vegetation, and also variation among differing boreal types, such as the transition from lush sites in thawed terrain, and areas with permanently frozen ground. An unambiguous elevation zonation of the Lower Stony Creek vegetation mosaic (as was observed in the West Toklat sample) was confounded due to the presence of complex, multi-faceted slopes and large ravines that bisected the slopes in this study area, resulting in a more variable vegetation mosaic. The complex topography likely interacts with prevailing wind patterns to create a more heterogeneous vegetation mosaic in this minigrid.

Elevation, slope angle and factors relating to permafrost (soil depth and soil temperature) all apparently exerted significant influences on patterns of variation in vegetation

structure among plots. We used arcsin-transformed percent growth form cover data in regression models to determine some of the underlying patterns in vegetation structure. The total amount of plant cover above 50 cm in height decreased significantly with elevation, as would be expected in a subalpine area (coefficient = -0.011, $r^2 = 0.30$, $p = 0.0045$). Shrub cover responded positively to increasing slope within the sample (coefficient = 0.029, $r^2 = 0.20$, $p = 0.025$). Forb cover was negatively correlated with increasing depth of moss mat (coefficient = -0.226, $r^2 = 0.30$, $p = 0.025$). Tree abundance within the sample declined significantly with increasing elevation, as will be discussed below. Further analyses of the complex set of relationships between physical variables and vegetation structural traits will need to be carried out to fully examine the other landscape-vegetation relationships within this minigrid.

Species Richness

We regressed three species richness metrics (1 m², 4 m² and 200 m² richness) individually on each of the physical variables to determine whether there were significant predictive relationships between the physical environment and mean species richness of the vegetation. This set of analyses identified numerous significant relationships between pairs of physical predictors and vegetation responses (Table 5.10).

Plot elevation, soil depth and soil temperature were all significantly positively influenced vascular plant species richness at each of the three plot sizes examined (1 m², 4 m², 200 m²). Elevation, in particular, was predictive of mean species richness at a high level of significance. In contrast, the depth of the living mat and depth of the organic soil horizon were both negatively related to species richness, in simple linear regression models (Table 5.10). These results strongly suggest reduced species richness in permafrost-influenced sites with low soil temperatures and thin active layers, and high species richness in alpine sites at high elevation within the sample, as well as areas free of permafrost.

These results showed that there were significant relationships between these metrics of *mean* species richness and this subset of the physical parameters. However, these analyses do not necessarily indicate whether *total* species richness increases if one considers data across numerous plots. To evaluate the relationship between total species richness and elevation, we prepared cumulative species area curves for two groups of plots – those below the median elevation observed in the Lower Stony Creek minigrid sample and the group of plots that fell above median plot elevation. By quantifying the number of *unique* species observed with each increment of area sampled within these two strata of elevation, across many plots (12 and 13 plots respectively) it is clear that total species richness also increased with elevation. More species were observed across 12 200 m² plots in the higher elevation stratum as compared to the same number of plots in the low elevation stratum (Figure 5.41). Thus we have observed an increase in species richness with elevation consistently across the spectrum of plot sizes ranging between 1m and 2400 m (12*200m).

Community Composition

We regressed plot scores on DCA-1 against environmental variables to determine significant relationships between plant community composition and physical variables in the Lower Stony Creek minigrid. The best model (using Cp criterion) contained three variables: elevation, slope angle and soil depth (see ANOVA table for model in Table 5.11). Plot scores on DCA-1, then, were correlated with increasing soil depth, decreasing elevation and decreasing slope angle within this sample. Plots that scored particularly high on DCA-1 were forb-rich areas located in the deeply-thawed ground along the stream terrace. Lush gully areas that received considerable surface runoff on the side slopes of the valley walls, (such as the lush forb meadow-alder vegetation recorded at point #23) also scored high on DCA-1. The lowest-scoring plots on this ordination axis supported low, dwarf birch-*Carex bigelowii*-dominated low shrub tundra with a deep moss mat over thin, cold active layer.

Trees

Due to the large proportion of zero values for tree parameters within this subalpine data set, valid statistical tests were not performed on these data. There were, however, very clear and interpretable patterns in the distribution of trees on the landscape of the Lower Stony Creek minigrid. Trees were abundant only in the lowest elevations of this minigrid. Open white spruce forest has developed in alluvial terraces along the creek, and in slope positions with better drained soils (Figure 4.42a). The predominant low-angle north facing slopes in this study area had strongly frozen soils and supported only very scattered trees. Interestingly, seedlings were not observed in greatest densities in these forested sites, but rather in a single plot located at almost 950 m elevation, well above forest habitats in this study area (Figure 4.42b).

Summary

Gradient analyses of species richness, vegetation structure, community composition and tree abundance identified elevation, soil depth and slope angle as significant variables determining the variation in important vegetation attributes within the Lower Stony Creek minigrid. The confluence of these results of data collected using several different protocols suggests that these physical factors represent the primary gradients along which the variation in vegetation attributes is arrayed in this region of the park. Furthermore, the nature of the variation along these gradients was substantially similar to the patterns observed in the boreal West Toklat minigrid. We have performed an initial set of analyses using the combined data set that includes both of these adjacent minigrid samples. This larger data set encompassed longer ecological gradients and allowed for an even more complete understanding of the factors controlling variation in vegetation attributes within this region of the park.

If substantial changes in the vegetation are going to occur in this region of the park, it stands to reason that such changes will not occur equally across these strong landscape gradients. Instead, we submit that changes will best be detected and understood in the context of these gradients. For example, deterioration of permafrost surfaces in the study area would likely have cascading effects across the different attributes of the vegetation there. These changes would thus change the slope and coefficients of the regression equations (or the shape of the gradient responses) that we have developed from this initial sampling. Analyzing responses of biological variables across the primary causal environmental gradients should be a sensitive method for detecting changes in resource attributes on the park landscape.

An Alpine Minigrid: Primrose Ridge

Physical Attributes

Topography and General Character

The Primrose Ridge minigrid sample was arrayed across the top of Primrose Ridge, with sample points extending down both the north and south flanks of this broad, moderately sloping alpine plateau just north of the Denali Park Road (see photographs of area in Figure 5.43). The crest of Primrose Ridge trends generally east to west within the study area (Figure 5.44). This minigrid was exclusively alpine in character, with tundra vegetation types predominating in all of the sample locations, and trees essentially absent.

Elevations of the 25 sample points in the Primrose Ridge minigrid ranged between 1002 m and 1454 m, with a mean plot elevation of 1277 m (Figure 5.5a). Slope angles measured in the plots were generally moderate with a mean of 17 degrees, and with values ranging from flat (0° slope) to very steep (37° ; see Figure 5.5b). The distribution of plot aspects observed within the sample was bimodal, reflecting the generally south to southeasterly aspects of plots lying on the south side of the ridge and north to northwesterly aspects of plots north of the ridge crest (Figure 5.6a).

Equivalent latitude of the surfaces measured in this minigrid ranged between a low of 42.76° on a steep, south-facing plot and high of 82.47° on a very steep north-facing plot, mean equivalent latitude for the 25 plot sample was 61.53° (Figure 5.6b). Thus the mean solar radiation receipts on surfaces in the Primrose Ridge minigrid sample was considerably higher than in the two minigrids that were discussed previously. This is because Primrose Ridge minigrid had several points lying on south-exposed slopes, and there were no sample points in these aspects in the West Toklat and Lower Stony Creek minigrids.

Soils

Mean soil depth measured at the plots in the Primrose Ridge minigrid averaged 38 cm, with a minimum average soil depth of 4 cm in a very rocky, steep plot, and maximum

average soil depth for a plot of 79 cm on site with deep, well-drained colluvium (Figure 5.7a). The mean percent mineral cover of the soil surface (including rock, gravel and bare mineral soil) for the Primrose Ridge sample was 30 % (± 8 %) reflecting an active geomorphic context in this alpine area (Figure 5.7b). Mineral cover of the ground surface was widely variable among plots within the Primrose Ridge minigrid, with a minimum value of 0 %, and a maximum of 83 % in a steep slide scarp. Cover of the ground surface by organic detritus averaged 42 % (± 8 %) in this minigrid, considerably less than both of the study areas discussed previously (Figure 5.8a).

The litter depth in the Primrose Ridge sample was thin, averaging less than a cm in thickness, and the living mat and organic horizon depths were similarly relatively thin, with mean thickness of 3.0 (± 0.4 cm) and 7 cm (± 1 cm) respectively (Figs 5.8b & 5.9a). Mean soil temperatures at 10 cm depth in the Primrose ridge sample varied between a minimum of 3° C and 16.8° C. Soil temperatures measured in this alpine minigrid was relatively high, with a mean soil temperature of 9.3° C for this minigrid sample (Figure 5.9b).

We obtained soil samples at 23 of the points within this minigrid sample. Two points were very rocky and did not have sufficient soils at the sample points for a sample to be taken. In general, the soils from this minigrid were coarse, with a mean fine (<2mm) fraction of 53 % of the sample, with a maximum value of 77 % fine fraction, and minimum value of 32 % fine fragment (Figure 5.10a). Soil textural analyses were performed on 13 soil samples from this minigrid, and the average sand:silt:clay ratio was 55:32:13, again reflecting relatively coarse, sandy alpine soils, especially as compared to values observed in the lowland minigrids (Figure 5.10b). The minimum amount of clay in the measured samples was eight percent and the maximum clay fraction was 18 percent. None of the soils were fine textured; the minimum sand content for any one sample was 49 % - nearly half sand by weight. Mean moisture content of the 23 soil samples taken was 29 %, with a minimum of 12 % water and maximum water content of 48 % (Figure 5.11a).

There was very low accumulation of organic matter in these alpine soils. Twenty-three samples were analyzed for carbon and nitrogen content. Percent carbon ranged from 0.48 percent to 6.63 percent, with a mean of 2.7 percent soil carbon (Figure 5.11b). Nitrogen content ranged from 0.05 percent to 0.47 percent, with mean nitrogen content of 0.2 percent (Figure 5.12a). The soils in this study area, which were derived from the schistose bedrock, were markedly acidic, with a minimum observed pH of 3.95 and a maximum observed value of 5.61. The mean soil pH for the Primrose Ridge minigrid sample was 4.82, indicating a markedly acidic soil environment (Figure 5.12b).

Relationships Among Physical Variables

Physical variables of the environment showed strong patterns of correlation across this grid sample (see correlation matrix for physical parameters in Table 5.12). Slope angle was negatively correlated with plot elevation. This is because Primrose Ridge is essentially a plateau, with a broad, relatively flat ridge top and much steeper slopes along

the flanks, as a result, the lower elevation points were generally lying on more steeply angled slopes. Equivalent latitude (EQ) was strongly positively correlated with elevation. The sample points on the south flanks of the ridge had low EQ values, and also did not reach as low an elevation as the high-EQ plots on the north side of the ridge.

Soil depth and slope angle were strongly negatively correlated. This is likely due to erosion and mass movement of materials down-slope in steep slope positions, which results in a thin soil mantle on steep surfaces. The consequent deposition of these eroded materials on flatter surfaces results, on average, in deeper colluvial soils accumulating in more gently sloping areas of the ridge.

There were several pairs of soils variables that were strongly correlated in this sample. Soil temperature was negatively correlated with litter, organic horizon and overall soil depth, and soil moisture percent. Soil pH was positively correlated with soil depth and organic horizon depth, but negatively correlated with equivalent latitude (EQ), indicating that more insolated landscape positions may have a more neutral soil reaction (possibly due to increased evaporation in these areas and consequent ion accumulation in upper soil horizon). Soil moisture was positively correlated with soil organic horizon depth, and strongly positively correlated with both % carbon and % nitrogen. As was the case in all minigrid samples, percent carbon and nitrogen content were tightly correlated in the Primrose Ridge minigrid soils.

The marked variation in topographic variables within the Primrose Ridge minigrid underlies the relatively strong patterns of inter-correlation among physical environmental variables that were observed in the sample. Topography strongly influences numerous physical and soil-forming processes. The influence of topography on these factors is particularly strong in the far north, due to the effects of the low solar angle on the distribution of solar energy. The topographic variation and active geomorphic context in the alpine zone clearly exert strong influences on the physical habitat for plants in these areas. As we will see, the physical factors were, in turn, highly predictive of variation in vegetation in this alpine minigrid.

Vegetation

Vegetation Types

We observed eight different Viereck level III vegetation types within the Primrose Ridge minigrid (Figure 5.45a). We estimated that more than two-thirds of this study area was occupied by dwarf scrub tundra vegetation types. An estimated 26 % of the area was classified as willow dwarf scrub, 24 % was *Dryas* dwarf scrub and another 17 % was classified as ericaceous dwarf scrub. Other vegetation types observed in the Primrose Ridge minigrid included mesic graminoid herbaceous meadows, closed tall and closed low scrub and lichen tundra. The distribution of these vegetation types is shown in Figure 5.45b, projected on a SPOT satellite image of the area.

Vegetation Structure

Overall, the vegetation in the Primrose Ridge study area was patchy, with a considerable amount of open, rocky area and a very low-statured tundra vegetation mosaic. There were isolated areas of tall scrub vegetation that have developed in mesic gullies at low elevation within this sample. Higher elevations support only barren fellfields, rocky dwarf shrub tundra and patches of forb-herbaceous meadow in areas of late-lying snow and gullies.

We estimated that bryophyte cover of this minigrid was 50 % (Figs. 5.46a & 5.16a). The vegetation mosaic of the sample was interrupted, particularly in steep areas and at high elevation, with nearly 30 % of the study area covered by rock and gravel and 20 % cover of lichens. Estimated abundance for the vascular plant cover classes were as follows: mean cover of dwarf scrub taxa was approximately 24 % of the minigrid, cover of shrubs averaged almost 9 % of the area, and was restricted to well-watered sites at lower elevation within the sample, graminoid cover averaged almost 12 % of the sample, and mean forb cover was 11 %.

Graminoid cover was relatively high in the Primrose Ridge minigrid sample, especially for an alpine minigrid (Figure 5.18a). The moist bench and swale areas on the southern side of the ridge supported high cover of several alpine *Carex* species, this graminoid-rich mesic tundra is not frequently encountered in the steeply sloping alpine landscapes in this area, and is fairly rare on the park landscape north of the crest of the Alaska Range in general. The high elevation of the Primrose Ridge minigrid also meant that the cover of shrub taxa was quite low overall. In fact, shrub cover of the Primrose Ridge minigrid was lower, on average, than in all of the other samples measured (Figure 5.16b).

An analysis of the vertical cover abundances of the different vascular plant growth form classes for the Primrose Ridge study area shows that cover was very low in all of the vertical strata above 10 cm above the ground surface (Figure 5.46b). The most abundant shrub species observed in this sample were *Salix pulchra*, *Vaccinium uliginosum*, and *Salix richardsonii* (Figure 5.47a). There was very little tall vegetation in the area, and cover above 1 m above the ground was strictly confined to the lowest elevations and protected sites, sheltered from winds.

Dominant Vascular Plant Species

The vegetation cover of this alpine minigrid was dominated by a diverse assemblage of dwarf shrub, forb and graminoid vascular plant taxa with low cover of tall shrub taxa and no tree cover (Figure 5.47a). The patterns in relative dominance of the vegetation by the most abundant species observed in this sample were considerably different from those observed in the boreal and transitional minigrids discussed earlier. Specifically, the absolute cover percentages of individual dominant taxa were much lower in this sample. For example, whereas *Betula nana* covered about 17 % of the West Toklat sample and 30 % of the Lower Stony Creek sample, *Dryas octopetala*, the most abundant vascular plant species in this sample, covered less than 8% of the area of the Primrose Ridge minigrid.

Furthermore, dominance of the vegetation mosaic by different groups of species was much more variable in the alpine minigrids, including Primrose Ridge. Whereas the dominant species were nearly ubiquitously dominant (with few exceptions) in the boreal minigrid samples, there was much more turnover in the dominant species among points in the alpine samples, including Primrose Ridge.

The seven most abundant taxa, by cover, observed within the Primrose Ridge minigrid were the following (Figure 5.47a): *Dryas octopetala* (8%), *Carex bigelowii* (6%), *Salix pulchra* (6%), *Cassiope tetragona* (4%), *Salix arctica* (4%), *S. polaris* (4%) and *S. reticulata* (3%). Five of the dominant species in this sample were dwarf shrubs, with only one shrub species (*S. pulchra*) and one graminoid species (*C. bigelowii*). *Salix pulchra* and *Carex bigelowii* were the only two dominant species in the Primrose Ridge minigrid that occurred in high abundance in the boreal or transitional minigrids.

There were a few conspicuous differences between the set of plants that were most abundant in the Primrose Ridge minigrid (as expressed by cover from the transect measurements) and the set of species that occurred at highest frequencies in the area-based species composition measurements. In fact, only four of the species that had the highest cover in the Primrose Ridge minigrid, also occurred on the list of species that occurred at the highest frequency for the minigrid (*Salix arctica*, *Dryas octopetala*, *Carex bigelowii*, and *Artemisia arctica*; see Figure 5.47). These differences between the set of plants that had high biomass and the set that had high *frequency* of occurrence in the sample presents a marked contrast to patterns observed in the boreal and transitional minigrids. Specifically, in the boreal minigrids there were few differences between the set of most abundant species and the set of species that occurred at highest frequency (see Figs. 5.19b & 5.20a; West Toklat), and Figure 5.39; Lower Stony).

There were nine species that occurred at high mean cover within the primrose Ridge minigrid sample, but did not occur at high *frequency* across the minigrid. In general, these species were patchy on the landscape of the study area, and were locally dominant in some sites, but entirely absent from others, thus they had a lower mean frequency of occurrence. The set of locally dominant taxa with lower overall frequency of occurrence includes the shrubs *Salix pulchra*, *Salix richardsonii*, and *Vaccinium uliginosum*. These species occurred in highest abundance in the lower elevations of this alpine study area. In sharp contrast to patterns observed in the boreal areas of the landscape, there was a set of plant species that occurred very frequently throughout the vegetation mosaic of Primrose Ridge, but only at very low abundance (biomass). This group of common, but low biomass, species included several small forb species including *Polygonum vivipara*, *Lloydia serotina*, and *Podistera macounii* (see Figure 5.47b).

Vascular Plant Species Richness

A total of 149 vascular plant species were observed in the sample points in the Primrose Ridge minigrid (Figure 5.20b). There were an average of 15.61 species per 1 m² quadrat (± 0.9), and 22.81 species per 4 m² quadrat (± 1.3) observed in this minigrid. These were the highest levels of mean species richness for these scales observed within this study

(Figs. 5.21b & 5.22a). There was an average of 43.8 vascular plant species per 200 m² plot in the Primrose Ridge minigrid (± 2.7 ; Figure 5.21a). Only the Gorge Creek sample supported a higher mean number of species per plot (44.4 ± 2.8), and the two samples are statistically indistinguishable. Thus whereas the Primrose Ridge minigrid sample contained apparently less *overall* species richness than the other alpine minigrids, the *mean* species richness of the vegetation was at least equally species rich. Therefore, there was apparently less turnover of species among plots in the moderately sloping terrain of the Primrose Ridge sample as compared to the very high relief terrain of other alpine minigrids sampled during the pilot study.

Species richness was variable at all of the measured spatial scales within the Primrose Ridge study area. For example, the lowest mean species richness per 1 m² quadrat observed in a plot was 8 species, and the highest mean species richness per 1 m² for a plot was 24.8 species. Mean species richness in the 4 m² quadrats was similarly variable and ranged between 9.3 and 34.3 species/4 m². The minimum number of species observed in an entire 200 m² plot was just 15 species, and the maximum number of vascular plant species observed in a single plot was 66. Clearly, species richness was extremely variable in the study area – the most diverse site contained, on average, more vascular plant species per square meter (15.6 species) than were observed in the entire 200 m² area of the least species rich plot (15 species).

The high species richness observed in the Primrose Ridge minigrid (and other alpine minigrids), stimulates questions regarding the components of vascular plant diversity. Our data acquisition and database design allow us a variety of options for examining different components of species diversity within the samples. For example, we can assess the contribution of species in different plant growth classes to the total diversity of a minigrid (or other spatial arrangement of sample points). We found that, on average forbs contribute the majority of the species to this sample, many more than any of the other growth form categories (Figure 5.48). The distribution of species richness among growth forms is also apparently variable among different areas of the park landscape. Thus one would expect that changes in major attributes of the vegetation cover over time would result in attendant changes in the contribution of different growth forms to the total species richness of a minigrid sample.

Similar species acquisition curves to the one depicted above may be developed using any of the species attributes stored in the “ref_taxon” table of the vegetation monitoring database, including geographic range, endemism, nativity, and life-cycle traits. These tools provide numerous avenues for understanding the patterns of variation in park plant communities and ecosystems, and for detecting how these patterns might change over time. For example, a loss of forb species relative to woody taxa would be expected over time with transformation from alpine tundra to shrubby vegetation in this minigrid.

Relationships Among Vegetation Variables

There were several very strong patterns of correlation among pairs of vegetation variables within the Primrose Ridge minigrid sample (see Table 5.13). Shrub cover of a plot was

strongly positively correlated with both graminoid and forb cover and score on DCA-1 for this sample. Shrub cover was negatively correlated with cover of lichens. Dwarf shrub cover was positively correlated with increasing species richness and amount of moss cover. This reflects the high vascular plant diversity observed in mesic dwarf shrub tundra types in the study area. Forb cover was also positively correlated with mean species richness measures, and strongly correlated with cover of graminoids. Forb cover was negatively correlated with cover of lichens. Lichen cover was negatively correlated with most of the other variables analyzed. However, this was at least in part due to the influence of a single outlier plot, which had very high lichen and rock cover, and little else, except scattered saxifrages. This multivariate outlier (plot #11) was removed from the DECORANA ordination, and the cover data from the remaining 24 plots were re-run to obtain the DCA-1 scores presented here. Plot score on DCA-1 was positively correlated with cover of shrub, forb and graminoid taxa, and negatively correlated with lichen cover.

The strong patterns of correlation among these vegetation variables indicate that the primary gradient identified in the ordination of the vegetation cover data was the transition between relatively lush, forb and graminoid rich areas with higher cover of shrub taxa (such as occurred in well-watered gullies lower in elevation within the sample) and well-developed alpine dwarf scrub tundra in exposed, well-rained landscape positions. Certain of the plots that scored highly on this ordination axis were also likely in areas of late-lying snow in gullies and more north-exposed positions. Species with high scores on DCA-1 included all of the shrub taxa observed in the sample, (among them *Alnus viridis*, *Salix alaxensis*, *Betula nana* and *Salix richardsonii*) as well as species of lush subalpine meadows in this area, including *Luzula parviflora*, *Claytonia sarmentosa*, *Carex podocarpa*, *Dodecatheon frigidum* and *Mertensia paniculata*. The plant species that received low scores on DCA-1 were the tundra dominants *Dryas octopetala*, *Minuartia arctica*, along with an assemblage of other common dry tundra taxa, including *Androsace chamaejasme*, *Hierochlœ alpina*, and *Senecio resedifolius*.

Relationships between Vegetation and Physical Attributes

Vegetation Types

There were differences in the distribution of discrete vegetation types within this minigrid sample as a function of landscape variables. We examined these differences by calculating the mean values for a variety of different physical factors for groups of plots that shared the same Viereck level III vegetation classification (Table 5.14). We only included vegetation types that occurred in three or more of the sample points in this group of analyses.

On average, *Dryas* dwarf scrub tundra occurred on sites with thin soil mantles, relatively high mean soil temperature, and low soil moisture, relative to the other three types investigated. In this sample this group of sites occurred at relatively high elevation, and low slope angle as compared to the other dwarf scrub types. In contrast, the willow

dwarf scrub and mesic graminoid herbaceous types occurred in areas of deep soils, with higher moisture percentages and lower average soil temperature. Willow dwarf scrub occurred on relatively steep slopes while the herbaceous tundra occurred in level sites on the south facing side of the ridge, relatively high in elevation.

The estimates of physical parameters for different vegetation types presented above are based on a limited amount of data from a single minigrid. As such, we must be cautious about inferring too much from these estimates. However, as we continue to add more plots to this data set, we can become increasingly confident in these kinds of estimates of soils traits based upon vegetation types. Once we have a spatially extensive set of data collected according to a consistent protocol, these kinds of data could then play a fundamental role in building models for various ecosystem processes at large spatial scales. Such models are normally constructed from data from a very small spatial data set (observations from one LTER station, for example). We believe this spatially extensive data set will allow for much more accurate characterization of variation in ecosystem processes than are possible from limited spatial data sets.

Vegetation Structure

Elevation had the strongest influence on vegetation structure within this minigrid. Vascular plant cover decreased substantially with increasing elevation, and the soil surface was covered by more mineral cover classes including rock, gravel and bare mineral soil. We performed a series of gradient analyses to quantify the response of elements of vegetative cover by separating plots into strata of elevation in increments of 100 m, as shown in Table 5.15, and calculating the mean response for vegetation variables within those strata.

These analyses showed that total plant cover decreased precipitously with increasing elevation within this minigrid (Figure 5.49). Mineral cover of the soil surface and lichen cover were the only two variables to show an absolute increase in cover over the gradient of elevation captured in this minigrid sample (Figure 5.50a). Cover of all of the growth form classes of vascular plants showed steep declines in abundance with increasing elevation (Figure 50b). However, because the cover of dwarf shrubs and graminoid taxa declined relatively less over this gradient than the other elements, these cover elements had a higher *relative* cover in the high elevation strata. That is, they represented a larger fraction of the total vegetation cover that occurred in the high elevations of the minigrid (Figure 5.51a).

Table 5.15. Elevation strata defined for gradient analyses of the relationship between vegetation variables and plot elevation in the Primrose Ridge minigrid sample.

Stratum	# plots in stratum
< 1200 m	3
1200- 1300 m	8
1300 – 1400 m	8
>1400 m	6

Species Richness

Regression analyses identified highly significant relationships between species richness attributes of the vegetation and physical environmental factors in the Primrose Ridge minigrid sample. We regressed the number of vascular plant species observed in a plot against each of the physical variables separately. This set of analyses returned significant relationships in simple linear regression models between plot species richness and three different predictor variables: elevation, slope angle, and soil pH (see Table 5.16 for regression coefficients).

Plot species richness was significantly positively correlated with slope angle and higher soil pH, but apparently declined with elevation in this sample. To further explore these putative relationships between species richness and physical variables, we performed stepwise regression to determine the best model predicting plot species richness. All physical variables were entered into this procedure, and the best model included elevation, slope angle, soil temperature, and soil pH in a multiple regression model that was very highly significant ($r^2 = 0.739$, $p = 0.00004$). An ANOVA table for this model is shown in Table 5.17. The same analysis for the mean species richness of the 4m quadrats returned a nearly identical result ($r^2 = 0.743$, $p = 0.00004$).

Community Composition

To determine the most important physical gradients controlling variation in plant community composition we regressed the plot scores on DCA-1 (data from 24 plots was used in ordination, after plot #11 was identified as a multivariate outlier, and removed from the sample). This set of analyses identified three variables with explanatory power for DCA-1: elevation, soil temperature, and depth of the soil organic horizon (Table 5.18 shows the regression coefficients from this set of analyses). Plot score on DCA-1 was negatively correlated with elevation and soil temperature, but positively correlated with increasing organic horizon depth in the plot.

We performed a stepwise regression procedure to determine the multiple regression model that best predicts vascular plant community composition, (as captured by variation in DCA-1). The model identified by this procedure included the following variables; elevation, plot equivalent latitude, soil temperature, and plot aspect off 180 degrees. The aspect-off-180 degrees term was removed from the model due to multicollinearity between equivalent latitude and this variable. An ANOVA table for this multiple regression model is shown in Table 5.19.

These regression analyses confirm the observation that the primary gradient identified by the ordination was the transition from more mesic and lush meadow vegetation in less-exposed, well-watered gullies low in elevation within the sample (lower soil temperature, lower equivalent latitude) to very exposed open tundra vegetation at high elevation with

higher soil temperatures. Soil temperature was negatively correlated with both soil depth and soil moisture within this sample (Table 5.12).

Summary

The data on vegetation and its relationship to physical factors collected in the Primrose Ridge minigrid clearly allow us to create useful predictive models that describe the variation of fundamental vegetation attributes within this study area. The highly significant relationships between elevation, slope angle, soil pH and organic horizon with vegetation composition, structure and species richness indicate that the methods that we have developed have some potential for detecting changes in these relationships on this section of the landscape over time. For example, should woody vegetation increase in abundance over time as we might expect, this should be reflected in the vegetation measurements made in the 25 point plot network. One primary prerequisite we had for this project was to assess our ability to quantify variation in some of the baseline vegetation and physical attributes, and identify significant relationships among them.

The reason that quantifying gradient responses of vegetation is important is that we submit that if substantial ecological change is to occur within the Primrose Ridge study area, it will likely occur differentially across the primary gradients controlling vegetation. Thus any such changes would best be detected by comparing models of the relationships between environmental factors and vegetation attributes from successive iterations of sampling performed in a systematic manner over time.

Discussion

In this chapter, we have presented a large number of data summaries and exploratory data analyses performed on the physical and vegetation attribute data acquired in three representative minigrid samples during the pilot study. In each case, we have found that the minigrid samples encompassed meaningful variation in resource attributes that could be modeled using data acquired on the physical environment. Each of these cases encompassed specific ecotones and transition areas on the park landscape. Examples of the ecological transitions apparent in these minigrids included the boundary between forested and treeless vegetation, the ecotone between shrub-dominated subalpine vegetation and alpine tundra, and the transition in vegetation that occurs between permafrosted and 'thawed' areas of the boreal landscape.

These important ecotones underlie much of the variation in habitat and ecosystem process extant on the landscape of the park. To monitor the distribution and abundance of any biotic resource attribute on the park landscape (vegetation or fauna) the location and character of these primary ecological transitions must be quantified and understood. It is within the meso-scale study areas represented by each minigrid that the specific nature of particular ecotones can be quantified. However, there is likely considerable variability in the nature of these particular ecological transitions on the larger landscape of the park. This variability is the reason that multiple sets of data regarding a particular primary

ecotone must be acquired to make more general statements about the location of an ecotone (and the physical factors that cause the transition) on the landscape as a whole. In the next chapter, we begin to consider some of this variability on the landscape, and examine the variation in physical and vegetation attributes *among* minigrid samples.

Chapter 6. Among Minigrids: Variation in Vegetation at the Regional Scale

In the previous chapters we discussed examples of the monitoring data from individual points and variation within minigrids. We now turn to examples of how this design allows scaling-up of observations from minigrids to make inferences about the variation in vegetation patterns at regional scales. We present two different sets of data summaries:

- 1) Comparisons of the ranges of variation *among* the nine minigrids measured during the pilot study; and
- 2) Data analyses that show the results of post-stratification of the entire data set to examine the relationships between specific environmental gradients and vegetation variables.

The conceptual basis for scaling-up observations from points to minigrids, and from minigrids to the region, is the randomization of site selection procedures used to define the sample population for this program. Combining data from minigrids must be done carefully, however, with the inference space appropriately limited each time such a combination of samples is made.

In the previous chapter, we presented results from three minigrids that represented the boreal-alpine gradient that typifies much of the Denali landscape. These minigrids contained the spectrum of vegetation from spruce forest on lowland permafrosted terraces through shrub-dominated subalpine slopes to diverse, forb-rich high alpine tundra, and scree slopes. These data were collected with a consistent plot design that allowed direct comparisons of information collected across a diversity of different landscape positions. We have seen that this design has allowed us to begin the process of developing statistical models that predict variation in fundamental attributes of the ecosystem. That is, within a minigrid- what are the important physical gradients that explain variation in the vegetation? In this section we consider a similar question at larger spatial scales. That is, how do data collected in this design inform our understanding of the variation in physical and vegetation attributes *among* minigrids?

As discussed previously, the nine minigrids that we have sampled thus far may be placed into one of three broad categories – boreal, transitional, and alpine. These categories form the basic context for our discussion of the results of this project among minigrids. As in previous chapters, we first discuss variation in physical attributes, vegetation attributes, then the relationships between vegetation and physical attributes.

Physical Attributes

By design, there was considerable diversity in both the ranges of variation and estimated mean values for physical factors represented by the nine pilot study minigrids. Elevation of the points in the boreal minigrids was considerably less variable as compared to the

transitional and alpine minigrids (Figure 5.5a). The boreal sample that did encompass substantial variability in elevation was the East Chitsia minigrid, which was located on a ridge at the northern end of the Kantishna Hills, and encompassed some steep, alder-covered slopes in this region. The West Toklat minigrid, being located close to the mountains on the lower apron of terrain flanking the northern slopes of the outer Alaska Range, had the highest mean elevation of the boreal minigrids. The sample with the highest average elevation was Primrose Ridge, and the minigrids that encompassed the greatest *range* of elevations were Rock Creek and Upper Savage River (Figure 5.5a). East Toklat minigrid showed the narrowest range of variation in elevation, being located in very low-relief terrain on the floor of the Toklat Basin.

Ranges of variation in slope angle showed a similar pattern to that of elevation, with relatively slight ranges of variation in slope angles evident in the boreal minigrids and very wide ranges of variation observed in the alpine and transitional minigrids (Figure 5.5b). The boreal minigrids that did encompass variability in slope angle were the Wigand Creek minigrid, and the East Chitsia minigrid, which was located in hilly terrain, as previously described. The alpine samples were similar in observed ranges of slope angle, although Gorge Creek encompassed both the greatest variability, and the highest mean slope angle.

Equivalent latitude characteristics of these minigrids differed considerably (Figure 5.6b). Specifically, the minigrids located in the Toklat Basin (Wigand Creek, East and West Toklat) and the nearby Lower Stony Creek minigrid all exhibited relatively high mean values of EQ, and very low variability in this parameter. Thus these sections of the landscape receive considerably less radiation, on average, than the other sites as a result of their generally north-trending aspect. Not coincidentally, these four minigrids were heavily affected by permafrost – more so than other minigrids we have measured. High variation in EQ was observed in all of the alpine minigrids because of a diversity of slope facies, and low values of this index were observed only in minigrids that encompassed terrain with steep south aspect – the Rock Creek, Upper Savage, Gorge Creek and Primrose Ridge minigrids.

Soils

The range of values for soil depth was quite similar among the three boreal minigrids situated within the Toklat Basin – Wigand Creek, East and West Toklat. There were few plots on thawed terrain that were observed in these grids, but these were distinct outliers within these minigrids (Figure 5.7a). In general, the boreal minigrids that have been sampled thus far all show a small range of variation in soil depths relative to the transitional and alpine minigrids. This is likely due to the fact that all of these minigrids are located in the Toklat Basin, an ecoregion of the park that is particularly influenced by continuous permafrost. The East Chitsia minigrid, the boreal minigrid located on sloping terrain underlain by bedrock showed a range of soil depths that was deeper than the other boreal minigrids, but with a narrower range of variation than the alpine minigrids. In the alpine minigrids, the limiting factor on soil depth was not permafrost, in general, but the presence of bedrock near the soil surface, and thin poorly developed alpine entisols. The

alpine minigrids showed median soil depths not conspicuously higher than the lowland grids, but with much more variation due to the presence of sample points in zones of accumulation of slide debris and alluvium.

The presence of plots with substantial mineral cover at the soil surface (including rock, gravel, and bare ground) is a defining difference between the boreal minigrids, which had essentially none, and the alpine minigrids, which had numerous plots with considerable mineral cover of the soil (Figure 5.7b). The active alpine and subalpine landscapes had both much more mineral cover exposed at the ground surface, and more overall variation in this metric than the heavily vegetated lowland minigrids. This fact has important impacts on the vegetation mosaic, as well as the opportunities for populations of plants to become established. The heavily moss-laden lowlands, which have little mineral soil exposed except in stream and river corridors, present many fewer micro-sites for the establishment of seedlings on the landscape, until a secondary disturbance (such as fire) occurs.

In contrast to mineral cover of the soil surface, the cover of organic detritus (predictably) was generally both higher and less variable in the boreal areas of the landscape as compared to the alpine minigrids (Figure 5.8a). This simply reflects the greater productivity and lower rates of removal (by gravity) of organic matter in these climatically less harsh areas of the landscape. This parameter would be an important monitoring metric were something similar to the spruce bark beetle outbreak to occur – a primary result of which is the conversion of living tree cover to “organic detritus”. Through this design, we should be able to quantify, at least in relative terms, the amount of reduction in live tree cover that results from such an episode within a minigrid.

The depth of the layers immediately above the surface of the mineral soil – the living mat and the organic soil horizon, also showed differences among the nine pilot study minigrids. Specifically, the depth of these horizons was apparently both deeper and more variable in the boreal minigrids as compared to alpine minigrids (Figs. 5.8b & 5.9a). The mean and median depth of the organic horizon in the West Toklat minigrid was the highest observed in any of the six minigrids where soil observations were performed. Gorge Creek, located in a very rocky alpine portion of the park, had the lowest depths and least variability for both of these strata (Figure 5.9a).

We have soil temperature data for four of the minigrids sampled thus far (Figure 5.9b). These data show that soil temperatures were both low, and relatively unvarying in the boreal minigrids. In comparison, soil temperatures observed in the Primrose Ridge minigrid were higher, on average, and considerably more variable. This is likely related to several factors, including the following: 1) greater shading of the ground surface in boreal vegetation; 2) Primrose Ridge had south-exposed terrain which received more total insolation; and 3) the presence of substantial areas of permanently frozen ground in the lowland minigrids. The occurrence of permafrost significantly dampens upward variation in soil temperatures in areas where it occurs because of the cooling effects of permanently frozen soil at very shallow depths.

Alpine soils, in general, contained a considerably larger fraction of younger, bedrock-derived colluvium (generally of larger particle sizes) than the very silty alluvial, eolian and glacial drift-derived lowland parent materials.

The relative contribution of fine fraction (< 2 mm particle size) and coarse fraction (>2mm particle size) of the soil was apparently variable among minigrids (Figure 5.10a). In general, alpine soils tended to be coarser, with higher mean and median percent coarse fractions as compared to soil samples taken in the lower elevations sites, which were generally very fine textured. Soils from the boreal minigrids in general, had higher percentages of fine particles than the soils from alpine sites, reflecting the differences in sedimentation regimes between these two areas of the landscape. The soils in the lowland sites were derived from glacial drift and outwash sediments high in silt-sized particles. In contrast alpine soils were derived primarily from bedrock colluvium, thus were less weathered and had considerably higher percent coarse fraction.

The soil textural analyses performed on the fine fraction of the soil samples show a similar pattern to that described above. That is, soil textures in the lowland minigrids were lower in coarse, sand sized particles and higher in silt-sized particles as compared to alpine minigrids (Figure 5.10b). Soil texture has important influences on nutrient status and water holding capacity of the soil column. Variations in this parameter will interact with other environmental influences to affect growth and development of the vegetation.

Soil moisture content varied in a similar way to many of the other soil factors described above among the minigrids sampled during the pilot study. Mean and median soil moisture was high in the boreal minigrids (East Toklat, West Toklat and East Chitsia) as compared to the alpine and transitional minigrids, which were lower in soil moisture (Figure 5.11a). There was a relatively large range of variation in soil moisture in the East Chitsia minigrid. This minigrid had highly organic soils on gentle slopes, as well as very steep slopes, the differences in drainage characteristics among these points likely cause this greater range of variation in soil moisture.

The carbon and nutrient content of all of the soil samples were closely related. None of the samples low in organic matter had appreciable nitrogen content. Soils of the boreal areas, in general had higher levels of organic matter than soils from transitional and alpine minigrids, as would be expected (Figs. 5.11b & 5.12a). In the highly organic soils of permafrost areas, a large fraction of the soil was organic material, due to slow rates of decomposition in cold, highly acidic situations.

Highly acidic soils were observed in almost all of the soil samples taken thus far, although samples from the boreal minigrids on silty glacial sediments had the lowest pH, on average (Figure 5.12b). The East Chitsia minigrid, and one sample from an alluvial terrace in the Lower Stony Creek minigrid were the only samples where soils of neutral reaction were observed, and neutral-reaction soils were certainly not the norm. The principal bedrock underlying most of the minigrids sampled thus far has been schist and related metamorphic geologic units, which form soils of acidic reaction. The formation of sphagnum-rich bogs and other vegetation processes in the boreal areas have also

certainly caused acidification of the landscape of much of the sampled area over time. Samples from areas of the landscape where the surficial geology is dominated by bedrock appeared to have modestly higher soil pH, on average (East Chitsia, Gorge Creek and Primrose Ridge minigrids).

Relationships Among Physical Attributes

We performed the same set of correlation calculations for the entire data set as were presented within each minigrid to explore whether correlations observed at the smaller spatial scale were the same or different when a much larger data set was considered. For some variables, including soils factors, data for some points were missing – in all cases we omitted those points for which there was missing data, but we used the most complete set of data available to calculate the correlation coefficient for each pair of variables (Table 6.1).

This set of analyses provides us with relatively powerful indications of how these sets of physical variables covary on the landscape in a general way. A lack of correlation in this data set between two variables that were strongly correlated within an individual minigrid does not necessarily suggest that the relationship observed at the smaller scale was spurious. It simply means that the correlation does not hold at the larger spatial scale. An example of this is the case of soil depth, which essentially equates to active layer depth in lowland areas on deep sediments, but is a function of depth to bedrock in the alpine zone. The absence of correlations of this parameter to other physical variables in this larger data set is a function of its varying in different ways within different segments of the landscape.

Elevation was strongly positive correlated with both slope angle and soil temperature at this spatial scale. Elevation was negatively correlated with the depth of both the living mat and organic soil horizon as well as with soil moisture and the fine fraction of the soil. Soils in the lowlands were thus generally wetter, more organic-rich and had a higher fraction of fine particles, according to this set of data. Slope angle was positively correlated with soil temperature (as was also observed in each of the individual samples), and negatively correlated with organic horizon depth. Figure 6.1 shows the response surface of soil temperature to slope and elevation across the pilot study dataset.

Equivalent latitude varied primarily as a function of aspect within this set of observations, and thus was strongly negatively correlated with aspect off-180°, and EQ was negatively correlated with slope angle. Organic horizon depth in the soil column was positively correlated with soil moisture, organic matter content (% c and % n) and negatively correlated with soil temperature. A deep organic horizon insulates the soil and reduces upward variation in summer soil temperatures. Soil moisture is very strongly correlated with the organic matter content of the soil, and the fine fraction thereof, both of which increase water-holding capacity in the soil column.

Vegetation Attributes

Vegetation Types

The basic vegetation type (Viereck level II) that was most prevalent in the nine pilot study minigrids was low scrub (primarily open low birch-ericaceous, but also including other types, including willow). Low scrub covered an estimated 35% of the area that was sampled in this study (Figure 6.2). Dwarf scrub types (including *Dryas*, ericaceous and willow subtypes) covered an estimated 22% of the area sampled. The most abundant forest type was needleleaf (spruce) forest, which occupied almost 20% of the area sampled. Mixed needle-leaf-broadleaf forest occupied another 4% of the sample. Tall scrub types, including primarily closed alder or willow scrub occupied an estimated 8% of the sample. Barren areas such as scree slopes and outcrops covered approximately 6% of the sample (all of this concentrated in alpine areas) and graminoid herbaceous vegetation (including mesic and wet graminoid meadows) occupied nearly 3% of the sample, forb herbaceous vegetation only accounted for 0.3% of the sample.

We believe that areal estimates of cover of different vegetation classes on the landscape will be an important tool for assessing broad changes on the landscape over time. This particular subset, however, is strongly influenced by the particular group of minigrids that have been sampled thus far. Once sampling has been completed of an entire region of the park (the northeastern quadrant, for example) we will be able to make unbiased estimates of the percent of the park landscape in different vegetation classes. In contrast to estimates derived from maps prepared from coarse scale remotely-sensed data, our estimates will not be affected by the thorny problems of minimum mapping units, and subjectively-determined polygon boundaries. These data will represent a direct sample of the landscape, and should provide an unbiased estimate of the percentage of the landscape in different vegetation types. Furthermore, these estimates are attended by specific quantitative information concerning variation in physical attributes, species composition and vegetation structure.

Vegetation Structure

We observed major and consistent differences in the vegetation structure among minigrids measured in this pilot study. The proportion of cover among the basic growth classes that comprise the vegetation was variable among minigrids. In addition, the stature and vertical arrangement of the vegetation differed strongly among minigrids.

The range of variation in total vascular plant cover was consistently similar among the boreal and transitional minigrids, which differed from the three alpine minigrids in this regard (Figure 6.3a). Vascular plant cover consistently ranged between 60% and 100% of the boreal and transitional plots, with much wider variation in this parameter among the alpine plots. Median vascular plot cover was consistently lower in the alpine

minigrids as compared to the boreal and transitional minigrids. However, the distribution of total vascular plant cover among different growth forms was considerably different within and among boreal, transitional, and alpine sets of minigrids, as we will discuss below.

Cover of bryophytes differed consistently among the boreal (and permafrost-influenced) minigrids and the minigrids located in transitional areas and in the alpine zones (Figure 5.16a). Specifically, the boreal plots exhibited generally higher median bryophyte cover, and exhibited somewhat less variability in the range of observations for this parameter due to an absence of any plots with low cover of bryophytes in these minigrids.

Bryophyte cover in the alpine minigrids was variable, and particularly low in the dry, rocky landscape of the Gorge Creek minigrid.

Mean lichen cover of the minigrids, on the other hand, was quite similar among all of the minigrids that were measured in the pilot study (Figure 5.19a). One difference worth noting was the occurrence of a handful of outliers in the transitional and alpine minigrids with very high cover percentages of lichen. The group of plots with very high cover of lichens generally occurred in north-facing ericaceous-lichen tundra in the mountains, usually in areas of late-lying snow.

Predictably, tree cover was limited to the boreal and transitional minigrids (Figure 5.17a). There were considerable differences among the boreal minigrids in this parameter, however. Well-developed forest with high cover of tree species was observed only rarely in this set of minigrids. This is primarily due to the fact that the lowland minigrids taken thus far have been mostly located in the Toklat Basin subsection of the park, a region that is unusually open and treeless, probably because of a combination of continuous permafrost and climatic factors, such as high winds. Closed forest vegetation types were encountered only in areas located on bedrock terrain or thawed alluvial terrace situations. These areas included the East Chitsia minigrid, the south-facing flanks of the low hill in the Wigand Creek minigrid, and the valley floor and south-facing slopes of the Rock Creek minigrid.

Cover of shrub taxa was high in all of the boreal and transitional minigrids, with remarkable consistency in median percent shrub cover among these minigrids (Figure 5.16b). Alpine minigrids contained few plots with high mean cover of shrub taxa. These shrubby alpine plots were located in low elevation positions and protected sites, such as gullies. Primrose Ridge, which had the highest mean elevation of all the minigrids was particularly low in shrub cover. The plots with the highest observed values of shrub cover were located in subalpine areas of the landscape. The Lower Stony minigrid, in particular, had very high values for shrub cover.

Cover of dwarf shrub taxa was similar among most of the minigrids, although alpine minigrids had a greater number of plots with high cover of dwarf shrubs (Figure 5.17b). The West Toklat minigrid was a conspicuous outlier in the regard, with much reduced level of cover of dwarf shrubs. High outliers with greater than 60% cover of dwarf shrubs

were observed in the transitional and alpine minigrids, but not in any of the boreal minigrids.

Graminoid cover was highest in the two minigrids that had relatively well-developed *Eriophorum vaginatum* and *Carex bigelowii* tussock fields – the Wigand Creek minigrid and the East Toklat minigrid (Figure 5.18a). Each of these minigrids contained plots with very high cover of graminoid taxa. The two other plots with strong permafrost influence – West Toklat and Lower Stony Creek, also showed relatively high median graminoid cover, again, mostly represented by *Carex bigelowii* and *Eriophorum vaginatum* in these areas. The Primrose Ridge minigrid contained a greater number of plots with relatively high graminoid cover than the other alpine minigrids measured during the pilot study. The relatively high cover of graminoids in the Primrose Ridge minigrid was due to the mesic sedge-dominated tundra that occurred on the broad, well-watered benches south of the crest of the ridge in this minigrid. This mesic, graminoid-rich alpine tundra is unusual in this region of the park due to the very steep and well-drained nature of the majority of the alpine landscape. It is these habitats that give the feature its name, because *Primula eximia* (a “primrose”) also occurs in unusually high frequency in these mesic alpine meadows.

Cover of forb taxa was lowest in the boreal minigrids measured in this study, and generally highest in the alpine minigrids (Figure 5.18b). Among the boreal minigrids, the East Chitsia minigrid, which was located in high relief terrain on bedrock, was considerably higher in forb cover than the low-relief boreal minigrids. Among the alpine minigrids, the Upper Savage River minigrid had the highest number of samples with relatively high forb cover. The Upper Savage River minigrid was the only minigrid in which well-developed lush forb subalpine meadows were observed. This area has a relatively transitional climate, with apparently more moisture crossing the Alaska Range from maritime zone to the south. Minigrids located in the lower alpine zone south of the Alaska Range crest will certainly show even higher percentages of cover of forbs.

The vertical distribution of vascular plant cover differed among minigrids. Cover above 200 cm was low in all of the minigrids, except for the East Chitsia and Rock Creek minigrids, as well as a few outliers with high cover in this vertical stratum within the West Toklat minigrid (Figure 6.3b). The amount of cover in the vertical stratum between 50 cm and 150 cm was conspicuously higher in the three minigrids that had high upland and subalpine terrain – the East Chitsia, Lower Stony Creek and Rock Creek minigrids (Figure 6.4a). Plots with particularly high cover in this vertical stratum were almost uniformly restricted to sections of the landscape dominated by alder (*Alnus viridis*). East Chitsia and Rock Creek were the two minigrids containing large areas dominated by closed tall alder shrub vegetation. The primary variation among minigrids in mean cover in the vertical stratum below 50 cm in height was the existence of plots with low overall cover values in alpine and transitional areas of the landscape (Figure 6.4b). Plots with low cover of vascular plants in this ground-level stratum were also observed in those areas of the landscape with dense tall alder scrub vegetation. The ground layer vegetation in tall alder scrub is often limited due to the low levels of light penetrating the dense alder canopy.

The most conspicuous difference in vegetation structure between the alpine areas and the boreal and transitional areas was the much diminished cover of shrub and tree taxa, and the lack of cover in the higher vertical strata above the ground. This is certainly not an unexpected finding. However, we anticipate that on a large spatial scale there will be considerable variability in the relationship between elevation and diminution of shrub cover. This relationship has myriad influences on other ecosystem variables, including habitat quantity and quality for wildlife and patterns of nutrient turnover, to name two.

Dominant Species

A valuable attribute of this study design is the ability to make unbiased estimates of absolute abundance, by species, across very large areas of the park. Thus we can begin to quantify the relative contribution to total primary productivity of different dominant species within the vegetation cover at a set of nested spatial scales. This provides a important set of metrics for monitoring changes in the character of the vegetation at large spatial scales over time. In addition, the ability to quantify these patterns should allow for more detailed modeling of habitat quantity and quality for a variety of different faunal species, from birds to large herbivores, which prefer different species for forage or nesting habitat.

The most abundant species, in terms of cover that were observed during the pilot study were *Betula nana*, *Vaccinium uliginosum* and *Ledum decumbens* (Figure 6.5). We estimated that *Betula nana* and *Vaccinium uliginosum* each cover over 11 % of the entire area encompassed by the pilot study minigrids. Note that the five most abundant species, in terms of cover were shrub taxa. Of the twelve most abundant species observed in this pilot study, only one of them, *Dryas octopetala*, is generally restricted to the alpine zone.

It is worth noting that there were remarkable similarities in the dominant species cover values observed among the three relatively level, lowest elevation boreal minigrids sampled (Wigand Creek, East Toklat and West Toklat; see Figures 6.6 through 6.8). The most abundant species within these boreal minigrids were *Betula nana*, *Ledum decumbens*, *Vaccinium uliginosum*, *Vaccinium vitis-idaea* and *Carex bigelowii*. The observed values for these taxa were remarkably similar among the three low-relief boreal study areas. This uniformity in the median value and range of variation of cover of individual species (!) among widely separated study areas reflects the substantially similar ecological contexts of these three study areas. These dominants were replaced by high cover of alder and spruce in the fourth boreal minigrid – East Chitsia (Figure 6.9).

The relative uniformity in the cover values of the suite of dominant species among the lowland boreal minigrids, and the sharp diminution of these species dominance in the alpine sites is unsurprising – these are widespread boreal species that occur only infrequently in alpine situations. However, we also observed conspicuous differences in the overall *patterns* of dominance within the vegetation between boreal and alpine zones during the pilot study. Specifically, boreal areas were always heavily dominated by a small suite of *hyper*-abundant species, whereas dominance was shared much more evenly

among a much larger group of taxa in the study areas located in the alpine zone. For instance, there was an average of almost five species with greater than 10 % cover in each of the four boreal minigrids, whereas there was an average of less than one species with greater than 10 % cover in the three alpine minigrids.

The dominant species across the three alpine minigrids (see Figure 6.10) included three shrub species (*Vaccinium uliginosum*, *Betula nana*, and *Salix pulchra*) six dwarf shrub species, two graminoid species (*Festuca altaica* and *Carex bigelowii*) and one species of forb (*Artemisia arctica*).

Frequency of Occurrence of Vascular Plant Species

The cover data provided estimates of abundance for dominant members of the vegetation, but are much less sensitive to turnover in species composition among less dominant, but potentially as important vascular plant species. These measurements identified *Vaccinium uliginosum*, *Vaccinium vitis-idaea* and *Empetrum nigrum* as the three species that occurred in highest frequency within the 9 minigrids sampled (Figure 6.11). Remarkably, *V. uliginosum* was found in 84 % of all of the plots measured during this study, which included a very large cross-section of landscape positions, edaphic situations and vegetation types. Several species that do not occur in high *abundance* anywhere on the landscape were among the species with the highest frequency of occurrence, including the small forbs *Polygonum bistorta*, *Stellaria longipes*, and *Anemone narcissiflora*. The faculty to detect species that occur in low abundance is crucial to the long term monitoring program. These measurements will allow us to better detect any invasions into native habitats by new (or exotic) plant species.

Species Richness

Patterns in the distribution of both mean and total vascular plant species richness were consistently strong across this dataset. The highest number of species observed in an individual minigrid was 192 in the Upper Savage River minigrid, and the lowest number of species in a minigrid was 43 in the East Toklat minigrid (Figure 5.20). In general, the alpine minigrids contained both many more total species and higher mean species richness at the 1 m², 4 m², and 200 m² plot sizes than the transitional or boreal minigrids (Figures 5.21 & 5.22). These differences among alpine and boreal areas apparently represent fundamental and general patterns in plant biodiversity on the park landscape. There was considerably higher range of variation in the observations within the alpine minigrids relative to the boreal minigrids, because species-poor plots were also observed in alpine areas, but highly species-rich plots were absent from the boreal minigrids.

There was also variation in the metrics of species richness *among* the grids within the broad landscape categories (alpine, transitional, boreal). For example, East Chitsia was the boreal minigrid with the highest observed mean and total species richness, with an average of 9.5 species per 1 m², 13.6 species per 4 m², and 28.9 species per 200 m². This was 30 % more species per 4 m² than were observed in the most species-poor East Toklat minigrid. Among the alpine minigrids, Primrose Ridge had the highest mean species

richness with 15.6 species per m², 22.8 species per 4 m², and 43.8 species per 200 m² plot. However total species richness was considerably higher in both the Gorge Creek and Upper Savage River minigrids. Species turnover *among* plots was thus higher in the very high-relief landscape of the Upper Savage and Gorge Creek minigrids.

Components of Vascular Plant Diversity

We observed considerable differences in the *overall* species richness attributes among the nine minigrids measuring during this pilot study. This general result may be further investigated by asking whether this pattern is due to an across-the-board reduction in species richness, or whether there are particular *sets* of species missing from areas of low species diversity (such as the lowland boreal minigrids). Using geographic range information for each species, we were able to examine differences in the richness of sets of species with differing geographic ranges on the park landscape.

We found that there were two particular groups of species that were generally “missing” from the vegetation of the boreal areas of the landscape:

- 1) Species endemic to Alaska and Yukon, and
- 2) Species with an amphiberian distribution (those that occur in Asia and North America, centered on the Bering Strait region).

These two groups were *differentially* absent from the low-diversity boreal areas of the landscape that we sampled. In other words, the diminution of species richness was uneven among different classes of species with divergent geographic distributions (Figures 6.12 & 6.13). For example, the total number of vascular plant species observed in the West Toklat minigrid was 45 % of the total number of species observed in the most species-rich Upper Savage River minigrid. In contrast, the number of Alaska-Yukon endemic species was only 30% of the number of such species observed in the Upper Savage minigrid. Similarly, the West Toklat minigrid contained only 28% of the number of amphiberian species that was observed in the Upper Savage River minigrid. The species accumulation curves for the Alaska-Yukon endemic and amphiberian species groups clearly indicate that the boreal, transitional and alpine minigrids cluster together (with distinct differences among these different areas of the landscape), with regard to these two specific components of vascular plant diversity.

Another element of total vascular plant diversity is the contribution of different growth form classes to the total species richness. We separated the nine minigrids into three groups of three minigrids each, and calculated separate species acquisition curves for each growth form class in the vegetation. We grouped East Chitsia with the two transitional minigrids for this set of analyses to even the sample sizes to three minigrids for each group. In addition, the East Chitsia minigrid did contain some subalpine terrain, and was similar to the transitional minigrids in that it encompassed more wide variation in terrain and elevation (in contrast to the relatively uniform low relief boreal minigrids). The minigrids were grouped as follows:

1. Strictly low-relief boreal minigrids – Wigand Creek, East and West Toklat;
2. High relief boreal and transitional minigrids – East Chitsia, Lower Stony Creek and Rock Creek;
3. Strictly alpine minigrids – Upper Savage River, Primrose Ridge and Gorge Creek.

We examined the species-area relationships in four growth form categories among the three elevation strata described above (Figures 6.14 thru 6.15). A larger number of shrub species were observed in the three transitional minigrids than in either the alpine or low-relief boreal minigrids, and overall dwarf shrub species richness was identical between the alpine and transitional groups. The two growth form types that primarily contributed the higher species richness to the alpine areas were herbaceous forb and graminoid taxa (Figure 6.15). In both cases, species richness was highest in the alpine group, and lowest in the low-relief boreal group of minigrids.

Trees

The species composition, density, basal area, and size class distribution of tree species were all highly variable among minigrids (see Figures 5.23 - 5.25). Areas of dense forest were rare in the 9 minigrids sampled, and essentially restricted to areas underlain by bedrock or unfrozen alluvial soils. Specifically, closed forest was observed in the lower elevations of the Rock Creek drainage, in the East Chitsia minigrid, and on the south-facing hill in the Wigand Creek minigrid. The sample size of densely forested sites that we have acquired thus far is small, but with a larger number of lowland sites, we will be able to generate unbiased estimates of the landscape positions and environmental conditions 'required' for the establishment of closed forest communities on the park landscape through this design.

Overall tree density for an entire minigrid was highest in the East Chitsia minigrid, whereas trees were essentially absent from the Upper Savage River, Gorge Creek and Primrose Ridge minigrids. Mean and median basal area for trees was also highest in the East Chitsia samples, followed by Wigand Creek and West Toklat (Figure 6.16).

White spruce and black spruce were the most abundant species observed during the pilot study. In terms of total basal area across the entire pilot study data set, white spruce was by far the most abundant tree species (Figure 6.17). White spruce also had the highest density of tree-sized individuals across the entire pilot study data set (Figure 6.18a). In the sapling size class, black spruce had the highest density (Figure 6.18b).

Paper birch (*Betula papyrifera*), larch (*Larix laricina*) and aspen (*Populus tremuloides*) were the only tree species that showed high ratios in the number of dead individuals relative to the number of live individuals (Figure 6.18). The causes of mortality were apparently quite different among these three tree species however. The dead individuals of birch were large, old trees observed in the Rock Creek forested plots, where they were

dying out of the mature spruce forest canopy. Most of the dead aspen individuals were suppressed saplings in the subcanopy or understory of forest where they presumably were being out competed for light.

The high mortality of larch individuals was apparently the result of the recent defoliation by the Larch sawfly. This mortality has apparently occurred in the past decade with the progress of the sawfly “outbreak” across the state. The high mortality of larch was a significant observation. Had this set of measurements been the *second* iteration of sampling, rather than the first, we would have been able to quantify this mortality of larch on the large scale. That is the ratio of dead to live sapling would have been different in sample iteration 1 vs. sample iteration 2. This is significant because larch occurred at sparse densities in only three minigrids. The ability to detect a change in such a sparsely distributed species would bode well for detecting changes in the more abundant tree taxa.

In general, deciduous species, including birch and aspen, occurred at much lower densities and basal area within the pilot study. This distribution of abundance of trees reflects, in part, the particular set of minigrids that have been measured thus far. Other segments of the park landscape, including low boreal hills in the Minchumina Basin and the lower slopes of the western Kantishna Hills would show much higher density and basal area for deciduous tree species, particularly birch. Continuation of this sampling regime should allow us to quantify the characteristics of those areas where deciduous forest communities have developed, and whether these differ from areas supporting conifer forests.

Relationships Among Vegetation Attributes

Some striking patterns of correlation among vegetation attributes were observed in this extremely variable and spatially extensive dataset (Table 6.2). As was the case at in most of the individual minigrids, shrub cover was negatively correlated with each of the species richness measures. Shrub cover was also negatively correlated with cover of dwarf shrubs, and to a lesser degree, with cover of nonvascular plants. Not surprisingly, all of the tree abundance and density measures were inter-correlated in this sample. Tree basal area was negatively correlated with graminoid cover, although the same was not true of measures of tree density. This is due to the low basal area of tree species in areas dominated by tussock forming graminoids such as *Eriophorum vaginatum* and *Carex bigelowii*. While these areas were low in overall basal area of trees, there were often high densities of small spruce saplings in these areas. Thus whereas basal area was negatively correlated with graminoid cover, tree density varied independently of it.

Cover of dwarf shrubs and forbs were both positively correlated with the measures of mean species richness. This is a result of the relatively higher cover of forbs and dwarf shrubs in alpine areas, which were also the most diverse sites. In addition, higher forb cover in the lowlands was also positively correlated with species richness metrics. Cover of bryophytes was negatively correlated with mean species richness at the 200 m² plot size.

Relationships Among Physical and Vegetation Attributes

One significant benefit of using the entire set of points for examining the relationships between vegetation and environment is that it provides a more complete representation of the landscape. For example, whereas a single minigrid may contain a large range of variation in plot elevation, the variation in other landscape attributes *within* each level of elevation may be relatively low. That is, most high elevation slopes could, by chance, have similar aspect and/or slope angle characteristics. This correlation of physical attributes within a minigrid can make it more difficult to completely parse the independent effects of different landscape variables at the smaller spatial scale. Once multiple minigrids are combined, however, each combination of landscape attributes is always more fully represented in the sample, and we can better elucidate response *surfaces* of vegetation parameters to two or more landscape variables simultaneously.

Along with the benefits, there is also danger inherent in combining samples from discrete minigrids into a larger dataset. This must always be done advisedly, with close attention paid to the specific inference space that results from such combinations of samples. For instance, if we were to lump four alpine minigrid samples from south of the Alaska Range crest, with two samples from the boreal lowlands north of the range, the conclusions resulting from such analyses would likely be unintelligible. However, if we were to ask a question about variation in vegetation structure within a certain ecoregion, and then combine all of the points that occur within that ecoregion, there would be much more clarity in the applicability and spatial frame of reference for the resulting sets of analyses. In short, combining data from multiple minigrids must be done with a specific set of a priori questions and assumptions in mind.

There is an array of analyses available to examine the response of vegetation to environment using the data from the pilot study, which encompassed a large cross section of the landscape of the northeastern quadrant of the park. For this report, we restricted our consideration to one class of analyses in which we used post-stratification of the entire data set to examine variation in vegetation across two important landscape gradients simultaneously – elevation and soil depth.

Numerous analyses of the data collected thus far have indicated that soil depth and elevation were consistently strong predictors of variation in several important vegetation attributes. In addition, these two factors often had interactive effects in analyses of vegetation attributes. This interaction between the two variables means that it is important to simultaneously consider the effects of both of these variables on the vegetation response variable in question. We present this set of analyses as an example for how the landscape-scale data can be analyzed, acknowledging that there are certainly other sets of predictor variables that will be used in further analyses.

Vegetation Structure and Tree Distribution

We used the plot pooling functions developed in StatServer® to separate the 213 plots sample thus far into nine “cells”, each of which was defined by a specific range of

elevation and soil depth (Table 6.3). In defining strata for this set of analyses, we created a matrix in which each cell had at least 5 plots, to be confident that the estimate for the cell was reasonably precise and unbiased. Another criterion was that each segment of both gradients encompassed the same span of observed values. For example, each cell along the gradient in soil depth spanned 27 cm, and each category of elevation spanned 340 m. The responses of vegetation variables for all plots were averaged within each cell to give a mean response (according to form of equations given in Chapter 3).

Table 6.3. Number of plots in each of nine cells that were defined by a combination of elevation and soil depth attributes.

Mean Soil Depth	Elevation Class		
	< 785 m	785 – 1124 m	> 1124 m
< 27 cm	36	17	19
28 – 54 cm	48	41	21
>54 cm	5	10	14

The results of these two-factor gradient analyses yield coarse, 9-cell response surfaces of the vegetation variables to the two-dimensional gradient represented by elevation and soil depth. Tree cover, density and basal area varied strongly in response to the two dimensional gradient described by these two variables (Figures 6.19 & 6.20). Each of these metrics of tree abundance declined monotonically with increasing elevation, and also increased with increasing soil depth, within these categories of elevation. The cell defined by low elevation and high soil depth, for example, had a mean tree basal area of 66.7 m²/ha (\pm 15.1 m²/ha) whereas the low elevation cell with low soil depth had a mean tree basal area of 2.9 m²/ha (\pm 3.2 m²/ha). High elevation cells all had 0 m/ha of trees.

The percent cover of different growth forms within the vegetation was also variable across this gradient. Shrub cover was highest in the intermediate stratum of elevation with the deepest soils, and was lowest in shallow soils in the high elevation category (Figure 6.20b). Mean shrub cover of the high soil depth, intermediate elevation category was 66% (\pm 26%) whereas the higher elevation, low soil depth category supported 5% shrub cover (\pm 9 %). The cover of shrubs in the high elevation, low soil depth cell was thus only 7 % of the mean cover in the mid-elevation, high soil depth cell. Forb cover was highest in the high elevation, high soil depth cell (21% \pm 7%), and lowest in the low elevation, medium soil depth cell (6% \pm 3.6%; Figure 6.21a). Graminoids occurred in highest abundance in the low elevation categories and were apparently less responsive to changes in soil depth (Figure 6.21b). Graminoid cover averaged 20 % (\pm 8%) in the low elevation, low soil depth cell, and 3 % (\pm 3.7%) in the high elevation, low soil depth cell. Dwarf shrub cover was highest in the cell described by high elevation and high soil depth (41% \pm 7%), and lowest in cell described by low elevation with high soil depth (4% \pm 6%; Figure 6.22).

Species Richness

The relationship between increasing elevation and increasing mean species richness is a general one in this data set (see Figure 6.23). High elevation minigrids consistently had, on average, higher species richness than low elevation areas of the landscape. This relationship was not restricted to measures of mean species richness, because cumulative species acquisition curves indicate that even with the addition of species composition data from numerous whole plots, the number of species acquired in alpine minigrids was higher than the same number of plots in the low elevation minigrids (Figure 5.20b).

We investigated this trend further by stratifying plots into four levels of elevation, regardless of minigrid, and calculating species acquisition curves for these four strata of elevation (Figure 6.24). This analysis suggests that while total species richness generally increases with elevation, it declines somewhat for the strata including plots above 1200 m in elevation. This stands to reason, because plant species richness declines to zero somewhere above 2200 m in elevation. With additional sampling, it should be possible to determine the mean elevation “tip-point” where vascular plant species richness reaches its maximum, and begins to decrease with elevation. In this sample, it appeared that the crest of Primrose Ridge was higher than this elevation, because plant species richness declined somewhat in the upper elevation of the sample.

A two-factor gradient analysis of mean 4 m² quadrat species richness in response to elevation and soil depth showed that vascular plant species richness responded positively to *both* increasing elevation and increasing soil depth (Figure 6.25). Mean species richness of the high elevation, high soil depth cell is 25 vascular plant species (± 3.8), whereas mean species richness in the low elevation, low soil depth cell was 11.1 (± 1.7). It stands to reason that if changes occur in permafrost distribution that affect the active layer depth, and/or changes occur in the structure of subalpine vegetation that alter the species richness attributes of the vegetation, the shape of this response surface for this set of plots would also change over time.

Discussion

We have learned a great deal concerning the pattern of variation in key vegetation attributes across a large segment of the park landscape during the course of this relatively brief pilot study. The patterns of species dominance among different segments of the landscape, the remarkable variation in species richness attributes in different landscape positions, as well as the particular gradients observed and quantified within each minigrid were all significant results. Taken together, these results represent a quantum step forward in our specific knowledge of how the landscape is put together from a vegetation perspective. In comparison, the data acquired during the first ten years of the vegetation monitoring program in the Rock Creek watershed fade into insignificance (Boudreau 2003).

The data we have acquired thus far using this design have allowed us to begin the important process of building more refined conceptual and quantitative models of the relationships between the principal environmental gradients and the variation in vegetation resources on the park landscape. These models are based on quantitative information collected according to a standardized set of measurements, performed across the landscape in a systematic fashion. Prior to the inception of this project, modeling of these attributes was, of necessity, made through extrapolation of measurements made in relatively confined areas to other areas where no sampling occurred.

It is possible to examine some of the results presented herein and think that they are essentially trivial – for instance, we have quantified the reduction of tall woody vegetation across the transition from the subalpine to the alpine zone. This is certainly not an unexpected finding, being apparent to even a casual observer of the park landscape. However, we submit that in order to effectively monitor the attributes of the park ecosystems at a landscape scale it is precisely such obvious (and fundamental) attributes that *need* to be quantified. It is very different to quantify and describe the precise nature of this type of gradient relationship, and how it is *specifically* expressed in different regions of the park than it is to generically state that woody vegetation is reduced in abundance in the alpine zone. A major goal of this effort has been to create a monitoring design that adequately captures such fundamental ecological transitions using a statistically rigorous design that will allow for inferences to be made concerning variation in vegetation at large spatial scales.

The set of two-factor gradient analyses showing the relationships among soil depth, elevation and a suite of vegetation characteristics that were presented in the final section of this report give one indication of the utility of this design for examining status and trend in vegetation along major gradients on the park landscape. Prior to the collection and analyses of these data, the nature of these relationships could not have been surmised.

There are differences in gradient responses of vegetation to physical environmental factors across the park landscape as a result of variation in current macroclimatic conditions and landscape age (to name two factors). Therefore we would anticipate that any changes in these gradient relationships that ensue from large-scale climate perturbations, would similarly occur differently in different climatic zones within the park. If for no other reason, the considerable differences in the taxonomic composition of the vegetation between the two sides of the Alaska Range would result in varying responses of the vegetation as a whole to climate change (or other major ecological perturbations) between these two large regions.

Any major changes in the conformation of the vegetation mosaic at the scale of a minigrid or larger, will have profound implications for the other biota resident there, and have numerous cascading influences through the ecosystem. Thus, while it may at first seem trivial to be able to say shrubs are less abundant in the alpine zone, as we have just done, quantifying the specific structural and taxonomic changes that exist across the major ecological boundaries is a fundamental activity for the monitoring program. This kind of basic baseline data do not exist for Denali, or any of the other of Central Alaska

Network parks. Without establishing the “baseline” relationships between landscape and vegetation through quantitative measurements carried out systematically, major changes in the ecosystem will be undetectable, except through purely descriptive means.

We have presented a variety of data summaries in the foregoing chapters of this report. We believe that each of the figures shown in this presentation represent a potential monitoring metric that can be assessed over time to detect changes occurring in the park ecosystem. For example, the figures showing the percent cover of the different growth forms within the vegetation at each spatial scale: within a sample point, for an entire minigrid, and among multiple minigrids are “signatures” of the current conformation of the vegetation. Changes in these cover signatures over time portend potentially major changes over the landscape of the park. Alternatively, the estimates for density of trees among different size classes and species were quite variable among the individual minigrids. We propose that it is of significance to the long term ecological monitoring program if these density estimates change in subsequent sample iterations.

Similarly, the regression equations describing the relationship between physical predictor variables and vegetation attributes are another tool for detecting change in the relationship between landscape and vegetation at a set of nested spatial scales. Changes in the slope of these lines, or significance level of the relationship would suggest that changes in underlying relationships might be occurring on the landscape

We have begun the process of creating statistical models that relate observed variation in vegetation to primary landscape gradients. Our initial assessment is that this design shows substantial promise for further progress in understanding how these physical and vegetation attributes interrelate, and thus for monitoring these relationships through time. We have amassed ample data to continue, and to further refine the process of model building beyond what we have presented herein. We submit that building more powerful causal models through a variety of other techniques, such as path analysis, will allow the monitoring program to provide high-quality information to park management, the scientific community and educational institutions concerning the question “what makes Denali Park tick?” This is the question that stands at the core of this program.

Causal models built from successive iterations of sampling that has occurred according to an identical protocol may be compared to determine whether change in the modeled relationships has occurred in the intervening period. Changes in the cover or frequency of a species on the park landscape, in the species-area relationships within the vegetation cover, or the density and basal area volume of trees each portends substantial other changes in the functioning of park ecosystems, as well as the fabric of the natural heritage we are charged with safeguarding.

This project is beginning to provide us with the component pieces for an emerging understanding of the patterns of natural variation on the park landscape. In a sense, each minigrid sample represents another piece in a jigsaw puzzle. Once we have completed an iteration of sampling, we believe that these pieces will eventually fit together to allow us to visualize a relatively complete and nuanced picture of the complex set of relationships

that exist on the landscape. At present, our ability to specifically model these relationships is fragmentary, because we have just a few pieces of the puzzle. However, the data collection protocols, storage database, and a powerful set of data reduction and analysis routines are in place to allow us to make progress toward the broader goal as each new piece of the landscape puzzle is added.

Chapter 7. Introducing the Songbird Data

In this chapter, we present an overview of our experiences and initial findings from bird surveys on the pilot study minigrids. Due to other work assignments for the Principal Investigator (CM) in 2002-2003, we have not fully analyzed the data and therefore only present preliminary findings about bird occurrences on the minigrids. Although these findings are preliminary, the bird data we present here help demonstrate the potential for using data collected in the minigrid design and are therefore important to the evaluation process. A report on initial findings on the bird pilot study is also found in McIntyre (2003).

The specific objectives for this pilot study for birds in 2001 and 2002 were:

1. Describe the distribution (spatial patterns) and develop indices of relative abundance (including species richness) of common songbirds;
2. Develop species lists for the minigrids and associated habitats and ecoregions, to describe distribution of all species of birds;
3. Assess point counts and the minigrid sampling design for collecting data on the distribution and abundance of songbirds; and
4. Use results of field work in 2001 and 2002 to make recommendations for future years.

In this chapter, we first overview field sampling and logistics. In keeping with the spatially nested character of the design, we then present examples of data from points, minigrids, and the landscape (all minigrids). Because one of the minigrids (Rock Creek) overlaid the two original point count routes established in the Rock Creek watershed by the Alaska Bird Observatory, we also compared our findings for the minigrid to findings from the point count routes. This comparison is informative to our evaluation of sampling approaches.

Overview of Field Sampling and Logistics

In 2001 and 2002, we conducted surveys on 10 minigrids. Table 7.1 summarizes basic information about the surveys. By design, the 10 pilot study minigrids encompassed broadly different habitat types (alpine, transitional, boreal) and access methods (helicopter, foot travel). We surveyed 200 out of 250 possible points (80%). We surveyed all 25 points at 5 minigrids, and from 9-20 points at the remaining 5 grids. Weather was a factor preventing completion of surveys at 3 minigrids, and topography was a factor at 3 minigrids. Injury to a crew member was a factor at one minigrid.

Songbird Occurrence on Pilot Study Minigrids

As noted earlier, we have not begun formal analysis of the bird data. A full analysis of the bird data will include use of the distance estimates we collected to calculate detection functions and densities, and use of the vegetation data to inform analysis of avian habitat patterns. Our purpose here is to give a sense of what the bird data—at their most basic level—look like.

To review, the basic unit of observation used in the variable point count survey methodology (described in Chapter 3 on methods) is the “detection.” A “detection” is an observation of an individual bird by sight or sound during the 8-minute count period. Here, we focus on two measures: (1) the total number of detections, and (2) frequency of occurrence, which is the total number of detections divided by the number of points surveyed. Two additional measures are the number of species at each point or minigrid (often called species richness), and the basic composition of the bird community at each point or minigrid (i.e., species list).

Point Data: Example of Songbird Data from an Individual Point

To build understanding of the bird data from the ground up, we will start by showing an example of data from an individual point. The example is from the East Chitsia minigrid, Point #1, surveyed on June 9, 2002, starting at 04:32 ADT (Table 7.2). During this 8-minute count, the observer detected a total of 10 individual birds of 5 different species. All the detections were of singing birds, ranging in distances from 30-90 m from the point. More data are collected than are shown in Table 7.2 (e.g., the observer, level of background noise, etc.), but the table demonstrates the “detection” as the basis of the bird data set.

Songbird Distribution and Vegetation Structure within a Minigrid

A preliminary examination of our dataset suggests that species composition at individual points was related to vegetation structure (forest, muskeg, etc.), as we would have predicted. For instance, the species composition within the Wigand Creek minigrid changed as we traveled from low shrub vegetation to the forested areas on the small ridge on the north end of the minigrid. Five species commonly associated with forested regions of the western North American taiga (Kessel 1998) were found only in the forested sections of Wigand Creek minigrid. These species were Alder Flycatcher, Boreal Chickadee, Yellow-rumped Warbler, and White-winged Crossbill. Conversely, three species commonly associated with low and medium shrub regions of the western North American taiga (Kessel 1998) were found primarily in the low shrub sections of the Wigand Creek minigrid. These included Savannah Sparrow, Lincoln’s Sparrow and White-crowned Sparrow.

Individual Minigrids: Variation in Songbird Occurrence at the Meso-Scale

Now we move to the next level of spatial analysis to see how data from the points are combined at the minigrid level. Here, we show the number of detections and frequency of occurrence for species observed on 3 of the 10 surveyed minigrids (Table 7.3). The examples are from alpine, transitional and boreal minigrids. These examples help demonstrate some of the differences one can see in bird occurrence related to broad differences in habitat (discussed below). (Similar tables for all minigrids sampled are found on the program web site.)

Among Minigrids: Variation in Songbird Occurrence at the Regional Scale

We now move to the regional level of analysis where we consider data from all points and minigrids. To begin, we consider some of our general findings, considering all the data. We then make some preliminary observation about variation among minigrids.

As mentioned earlier, our preliminary results are based on data collected at 10 minigrids in 2001 and 2002. We surveyed 200 out of 250 possible points (80%). During these surveys, we detected 1,937 individual birds of 45 species on the actual point counts (Table 7.4). Most birds were detected within the first five minutes of a count; 84.0% of all detections on 8-minute counts occurred during the first 5 minutes. The majority of detections involved single birds (97.7%). The majority of detections on 8-minute point counts were of singing (89.0%) or calling (4.2%) birds. We recorded distance for 1,861 birds detected on 8-minute counts. Of these, 60% were made within 100 m of the center of the point count.⁵

Overall during point counts, we detected:

- 1 species of waterbird,
- 5 species of shorebirds,
- 2 species of raptors,
- 31 species of songbirds,
- 2 species of corvids,
- 1 species of woodpecker,
- 2 species of ptarmigan, and
- 1 species of gull (Table 7.4).

Based on the behavior of these birds (singing, territorial displays, etc.), we expect that most of these species were breeders.

We also identified 14 species between sampling points that we did not detect during 8-minute counts (Table 7.5). These included:

- 4 species of waterbirds,
- 3 species of shorebirds,

⁵ These distance estimates will be used in data analysis to calculate detection probabilities and allow estimation of density.

- 2 species of raptors, and
- 5 species of songbirds.

Most of these were species that either occur at low densities or are not usually detected using point count methodology during mid-June. We did not encounter any unexpected species on the minigrids, and we did not record any new species for Denali.

The species that were detected with a frequency of occurrence (# detections / total number of points) of ≥ 0.10 were White-crowned Sparrow, Savannah Sparrow, American Tree Sparrow, Fox Sparrow, Wilson's Warbler, Dark-eyed Junco, Orange-crowned Warbler, Yellow-rumped Warbler, Redpoll sp., Swainson's Thrush, Lincoln's Sparrow, Varied Thrush, Gray-cheeked Thrush, Hermit Thrush, American Robin, Gray Jay, Ruby-crowned Kinglet, White-winged Crossbill, and Arctic Warbler (Table 7.4). These 16 species made up 93.3% of all detections on the 8-minute counts. The remaining 28 species made up 6.7% of all detections on the 8-minute counts.

Frequency of occurrence of species varied across minigrids (see Table 7.3 and the web site). For example, Arctic Warbler was only detected on three minigrids, but it was one of the more common species when combining results from all minigrids.

No species was observed on all 10 minigrids, but 4 species (Wilson's Warbler, White-crowned Sparrow, Fox Sparrow, and Redpoll sp.) were detected on 9 minigrids. Seventeen species including Gray Jay, Horned Lark, Gray-cheeked Thrush, Swainson's Thrush, Hermit Thrush, American Robin, Orange-crowned Warbler, Yellow-rumped Warbler, Wilson's Warbler, American Tree Sparrow, Savannah Sparrow, Fox Sparrow, Lincoln's Sparrow, White-crowned Sparrow, Golden-crowned Sparrow, Dark-eyed Junco, and Redpoll sp. were detected on at least half of the minigrids surveyed.

As expected, species occurrences varied between and among minigrids, and the variation was greatest between minigrids that varied by environmental attributes such as vegetation composition and elevation. An example of variation between minigrids is illustrated by examining the species composition between the E. Chitsia minigrid and the Gorge Creek minigrid. We detected 12 species on each of these minigrids, but only 3 species-- Wilson's Warbler, White-crowned Sparrow, and Redpoll--were found on both minigrids, Black spruce forest and alder-choked creeks dominated the East Chitsia minigrid, and elevations ranged from 457 to 884 meters. Dwarf alpine vegetation, talus slopes and rock outcroppings dominated the Gorge Creek minigrid, which had elevations ranging from 1036 to 1700 meters.

Minigrids that were more similar in environmental characteristics shared more species. For example, East Toklat, West Toklat and Wigand Creek lacked much topographical relief and, on a broad-scale, had similar vegetative characteristics (i.e., boreal). We detected 11 species on all three minigrids including Gray Jay, Gray-Cheeked Thrush, Orange-Crowned Warbler, Yellow-rumped Warbler, Wilson's Warbler, Savannah Sparrow, Fox Sparrow, Lincoln's Sparrow, White-crowned Sparrow, Dark-eyed Junco, and Redpoll sp.

Species Richness and Distribution

We can also examine the data in relation to species richness and distribution within and among minigrids where we sampled at all 25 points. We used analyses suggested by Gill et al. (2002) to calculate diversity indices. A direct comparison of the diversity of species detected on the minigrids can be made using the number of species recorded only during the 8-minute point counts (site diversity) (Table 7.6). According to this index, diversity per minigrid ranged from 15 to 25 species.

To examine variability in the distribution of birds, we first calculated the average number of species recorded per point within each minigrid (average point diversity). We then calculated an index of spatial homogeneity for each minigrid by calculating the average proportion of species recorded in the minigrid that were recorded at each point (average point diversity/site diversity). Point diversity ranged from 4.80 to 6.28 species per point (Table 7.6). Spatial homogeneity was highest on the West Toklat and East Toklat grids, suggesting that species were distributed more evenly on these grids.

Comparing Minigrids and Transects

An important aspect of the evaluation of the minigrid design is understanding the differences in what information is gained in comparison to the original design. The original approach used in the Denali LTEM program for landbirds employed off-road point counts, mainly in spruce forest along the park road, and the goal was to detect population changes of individual species. We found an opportunity to compare the two approaches in 2001. Because the two original point count routes established in the Rock Creek drainage overlapped the area sampled by the Rock Creek minigrid, and both were sampled in June 2001, we compared the results.

In June 2001, 8-minute point counts were conducted in Rock Creek on the 25 sample points on the minigrids by Crew A and on 24 points on two transects (12 points per transect) by the crew from the Alaska Bird Observatory. The surveys were conducted within three days of one another. Comparing the findings provides some insight into how the designs affected the results.

More species and more individual birds were detected on the minigrid than on the transects (Table 7.7). Twenty-five species were detected on the minigrid (92.6% of total) and 17 species were detected on transects (62.9% of the total).

The only two species detected more frequently on the transects than on the minigrid were Swainson's Thrush and Yellow-rumped Warbler. These results are not surprising given that the transects occurred exclusively in spruce forest where these species are more common. The Rock Creek minigrid includes spruce forest only at its southern end.

The Rock Creek minigrid traverses a number of environmental gradients including aspect, slope, elevation, and vegetation types. Point counts conducted on the minigrid

provided a more realistic description of the songbirds in the overall area, while also providing adequate sample sizes to estimate the relative abundance of the most common species.

Discussion

While these examples rely on preliminary examination of the data, they illustrate the potential for using data collected using 8-minute point counts on the minigrid system in conjunction with the vegetation monitoring data to assess and describe the relationships between bird community dynamics and landscape structure in Denali. Long-term monitoring of birds should include both the tracking of trends and the description of habitat associations and land-use effects (Hutto and Young 2002). Further, because these data were collected using a probabilistic sampling design and because our sampling universe is the entire park and preserve, these data can be used to describe bird distribution, abundance, and habitat associations at a park-wide scale. Finally, because these data were collected at co-located sampling sites with the vegetation data, we have a unique opportunity to test hypotheses about the relation between bird distribution and landscape structure. This is a unique opportunity because the vegetation data available for these points, minigrid, and eventually the landscape, is much more detailed than vegetation data collected elsewhere in the region during 8-minute point counts. Most other studies employ the bird surveyors to collect broad-based “habitat” data at each point or within a designated distance of each point. By co-locating our bird sampling points with the vegetation monitoring work, we eliminate the need to make these broad classifications and can rely on a much more detailed dataset for our analyses.

Because the success of the proposed design depends upon our ability to safely travel in difficult terrain, our experiences in the pilot study are crucial to future planning and decision-making about the program. Our ability to get to 80% of the points in 2001 and 2002, and 97% of the points (170 out of 175) in 2003, suggests that the program is logistically feasible. Learning from the experiences in the pilot study in 2001 and 2002, improved our success rate at getting to points and completing surveys on grids. For instance, weather problems were alleviated by allowing more time for completion of surveys at a given minigrid (i.e., waiting the weather out). However, the extremely compressed window for bird sampling (~ 8 June to 30 June) makes longer periods of inclement weather a difficult problem. Some topographic challenges can be dealt with, by again, allowing more time to complete surveys or by better route planning. Scouting of minigrids prior to deploying the survey crews can also allow better planning for the difficult ones. However, not all topographic challenges can be surmounted and some points simply cannot be reached due to the highly complex topography found in Denali. With respect to crew injuries, the single incident occurred on a grid with high relief and thick vegetation. The Yukon-Charley bird inventory project, which used methods similar to those in this study, also found crew injuries to be a factor that needed to be planned for (Swanson and Nigro 2003). One extra person was hired to be available if a crew member became injured. In the future, safety and fitness training would also help prevent injuries.

Even though only 10 minigrids were sampled during this portion of the pilot study, we can already begin to see the value of the unbiased dataset about bird distribution and abundance in Denali this design will help build. Our knowledge of the distribution of many common species of songbirds has been growing rapidly and the potential of this data set for examining species-habitat relationships is waiting to be tapped.

Chapter 8. Estimating Costs for Implementation

A clear understanding of the costs involved in long-term monitoring is critical to program success (Hinds 1984, Caughlan and Oakley 2001). Often, costs are underestimated which can lead to important aspects of program operations, such as data management and reporting, being neglected. Overestimation of costs is also a problem, if it leads to abandoning an otherwise useful approach. As mentioned earlier in this report, probabilistic sampling designs for large or difficult to access regions may not even be attempted because it is assumed that the costs are too high. From our pilot studies, we have been able to hone in on what the operational costs of implementing the proposed design in Denali will likely be. In this chapter, we explore these costs to provide a basis for developing a sustainable program.

Operational Costs

Currently, the minigrid design is in a developmental stage, and it is important to recognize that the costs to design and test long-term monitoring protocols are different from the costs to implement the program. The costs we discuss here are projected costs during implementation. We have restricted our current analysis to costs for the vegetation portion of the program.⁶ A spreadsheet was constructed to allow various scenarios to be explored. While we focus on the tangible costs of operating the program, we also consider the “costs” often overlooked because the general resource management program in the park pays for them. These costs are important to consider because if conditions change, and the “subsidy” is lost, the monitoring program could suffer.

Operational costs for any monitoring program include the following major categories:

- 1) scientific leadership,
- 2) data collection, including personnel, training, travel, supplies, and equipment,
- 3) data management, data analysis and reporting, and
- 4) administration.

We used these categories to explore what the annual operating expenses might be for implementing the minigrid design. Based on a preferred scenario, we estimate an annual budget of \$95,000 (Table 8.1). The preferred scenario includes deployment of two field crews and hiring of a GS-9 Biologist to cover some duties currently performed by the Principal Investigator. With this level of funding, 7 minigrids would be visited each year, and the Principal Investigator would be able to devote more time to data analysis and reporting.

⁶ CM was unavailable to discuss costs associated with the songbird work at the time of this writing. We will update this chapter to include the songbird costs later in the fall.

Table 8.1. Estimated annual operating costs of implementing the minigrid design in Denali National Park and Preserve.

Cost Category		Estimated Costs	Percentage of Total Costs
Data Collection			
	Personnel	\$63,266	66%
	Travel	\$13,250	14%
	Supplies	\$500	1%
	Equipment	\$2,000	2%
Data Management/Analysis			
	Personnel	\$6,660	7%
	Contracts	\$8,500	9%
Total Cost		\$95,176	

Below, we consider each category of expense, based on our pilot study experiences, focusing on the assumptions used to estimate costs.

Scientific Leadership

One important lesson learned from the early years of the 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, 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, in our opinion, at the GS-11 level or above.

For the vegetation aspects of the proposed minigrid design, the Principal Investigator is the Denali Botanist, a GS-12 Plant Ecologist position, currently held by Carl Roland. The salary costs of this position are currently supported from the park’s base budget for its natural resources division. For the purposes of this cost estimation exercise, we have assumed that the salary costs for work of the Principal Investigator related to the minigrid design are paid by the park. There are additional costs associated with support of the Principal Investigator, including training (aimed at professional improvement) and travel to professional meetings. We are assuming that the natural resources program also pays these costs. However, if the training or travel were specifically related to the monitoring program, the costs should be covered by the monitoring budget. We have not included anything for these types of expenses in our scenario budget, but they should be considered at some point.

During the developmental phase, the amount of time devoted by the Principal Investigator to work on the minigrid design has been substantial. In implementation, we

expect the time commitment to drop substantially, and for there to be a shift in the allocation of effort by the Principal Investigator. Under our preferred alternative scenario, a GS-9 biologist (seasonal) would be hired to carry out many of the duties currently being assumed by the Principal Investigator. These duties include getting ready for the field season, leading one of the field crews, and assuming responsibility for many of the operational details. This will free the Principal Investigator up to spend more time on data analysis, interpretation and writing.

Data Collection

Costs associated with data collection include personnel, training, travel, supplies and equipment. Under our preferred scenario, we estimate the annual costs associated with data collection to be almost \$80,000. With 7 minigrids visited per season, this results in a cost per point of \$451. Below, we explore each category of data collection expense in detail.

Personnel.—To carry out the sampling on a minigrid requires a crew of 3 people (see the Landscape Scale Vegetation Monitoring Handbook for details about each crew member’s responsibilities). The crew consists of a Crew Leader, and 2 Biological Technicians. The Crew Leader position can either be filled by the Principal Investigator, a GS-9 biologist or GS-7 Biological Technician. (For the purpose of this analysis, we have assumed that one crew is led by the GS-9 Biologist and the other crew is led by a GS-7 Biological Technician.) The technician positions can be filled either at the GS-5, GS-6 or GS-7 level, depending on experience and qualifications of the candidates.

The main variables affecting the personnel costs, and the assumptions we used in our analysis, are shown in Table 8.2.

Table 8.2. Variables influencing personnel costs for data collection in the minigrid design.

Cost Variable	Assumptions	Notes
Crew Size	3 (Leader, 2 Technicians)	See Landscape Scale Vegetation Monitoring Handbook.
Number of Crews	2	
Salary Costs per Pay Period	GS-9 1,810 GS-7 1,480 GS-6 1,350 GS-5 1,200	Alaska salaries include 25% Cost of Living Allowance
Number of Pay Periods	6.5 for all Technicians, 8 for GS-9 Biologist	Crews begin work in mid-May and work until mid-August. This includes time needed for required safety training and scientific training in the monitoring procedures.

Cost Variable	Assumptions	Notes
Amount of Overtime	Each crew member is paid overtime (1.5 base hourly wage) for 20 hours per field session.	A field session is the 7-10 days needed to complete sampling on 1 minigrid.

Using these assumptions, we estimated the personnel costs associated with data collection to be \$63,000 (Table 8.3).

Table 8.3. Estimated costs of personnel to support data collection during annual operation of the minigrid design in Denali National Park and Preserve. (Note: These do not include data management costs.)

Positions	Regular Time	Overtime
GS-9 Crew Leader (1)	\$14,480	\$1,787
GS-7 Crew Leader (1)	\$9,620	\$1,461
GS-5 Technicians (4)	\$31,200	\$4,718
Total	\$55,300	\$7,966
Percent of Personnel Costs	87%	13%

Training.—To simplify our analysis, we included the costs of training under personnel. For the vegetation part of the monitoring program, training costs primarily accrue as the salary costs of the employee during the time required for training, so this seems like a reasonable approach.

We estimated that about 1.25 pay periods (2.5 weeks) were required for each employee to cover all the needed training. There are two types of training:

- 1) Mandatory safety training, and
- 2) Scientific training needed to become competent in the monitoring procedures.

Required safety training includes bear safety training, gun training (needed for bear safety), helicopter training, CPR/wilderness first aid, and park road/backcountry travel training. These trainings easily take up most of a week. Safety trainings are mandated by NPS or Department of the Interior policies. Each type of safety training is valid for a different number of years (i.e., some are required annually, some every 2-3 years). The scientific training includes working with park plant collections, field excursions to gain familiarity with the park flora, instruction in data collection procedures, and testing in the procedures. This training requires about 1.5 weeks. We estimated that training costs represented almost 20% of total personnel costs associated with data collection (Table 8.4).

Table 8.4. Estimated costs for personnel training to support annual operation of the minigrid design in Denali National Park and Preserve.

Positions	Training	Regular Time Not in Training	Overtime
GS-9 Crew Leader (1)	\$2,715	\$11,765	\$1,787
GS-7 Crew Leader (1)	\$2,220	\$7,400	\$1,461
GS-5 Technicians (4)	\$7,200	\$24,000	\$4,718
Total	\$12,135	\$43,165	\$7,966
Percent of Personnel Costs	19%	68%	13%

Although the training costs represent a large portion of the personnel budget, these costs are necessary. The safety training is required, so this portion of the budget is non-negotiable. The scientific training is critical to data quality, so is also an important expenditure. To the extent that experienced personnel can be retained on the project, the annual costs of training should decline somewhat, as not all safety trainings are required each year. Similarly with the scientific training, retaining personnel should reduce the amount of time spent on teaching the procedures and gaining familiarity with the flora.

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 minigrids is provided by park vehicles and by helicopters. Use of the park vehicles has fit 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.

One of the driving forces leading us to explore the minigrid design was an assumption that we needed a design that was conservative in helicopter use. During the pilot study, we have relied on use of the FirePro helicopter stationed at Denali to support the interagency fire management program in Interior Alaska. From the perspective of the monitoring program, there are significant advantages to using the FirePro ship, including the fact that someone else is responsible for managing the helicopter contract and operations. For the relatively limited use made of the FirePro ship by the minigrid project, this is appropriate, but use of the FirePro ship needs to be included in our accounting of subsidized costs. The main disadvantage of using the FirePro ship is that its availability cannot be guaranteed, depending on the occurrence of fires. So far, availability has not been a problem, but it is conceivable that monitoring personnel could be grounded for long periods. This would require the monitoring program to charter its own helicopter, which would obviously cost more.

When using the FirePro ship, the costs to the monitoring program are charged on a per hour basis, typically \$500/hour of use. Of the 7 minigrids 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 minigrid, 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. This comports with usage during the pilot study. In 2003, helicopter costs were \$4,900, which covered transportation to two minigrids.

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 seem reasonable and allay one of our biggest concerns, 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 minigrid design have occurred during the pilot study. 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. The life cycle cost of each kind of equipment is likely different, and it will take some years of experience to determine what the actual equipment replacement costs are likely to be. An important aspect of equipment cost is adequate training and supervision of field personnel in care and use of equipment. Thus, equipment costs and personnel training costs are to some extent related.

Data Management, Analysis and Reporting

The costs of managing, analyzing, interpreting and reporting data are often the most overlooked and underestimated costs of monitoring. Realistic estimates are that all these activities, often lumped into the “data management” category, are on the order of 30% or more of total costs.

We found that these costs for minigrid design implementation were the most difficult to quantify. An important aspect is that much of the data management and analysis work effort is “subsidized.” The Principal Investigator is the key to data analysis, interpretation and reporting, so salary costs of the Principal Investigator are a large, but unquantified portion of these costs. The creation and maintenance of the entire data management structure for the Central Alaska Network monitoring program (of which the Denali LTEM program is a part) is also a subsidized aspect of the data management costs. The support of the network data management operations by the Alaska Regional GIS shop in Anchorage, as well as support by the national I&M data management staff in Fort Collins must also be noted. These subsidized aspects of data management must be

taken into account, but are difficult to impossible to quantify as annual costs of implementing the minigrid design at Denali.

In the same vein, the USGS has helped finance development of data analysis methods for the minigrid design. Funding from the USGS has supported the long-term involvement of Dr. Eric Rexstad and Research Analyst Ed Debevec from the University of Alaska Fairbanks, Institute of Arctic Biology. The creation of the StatServer web site, a vital part of the data management and analysis structure for the minigrid design (see Chapter 3 on Field and Analytical Methods), would not have been possible without their involvement. At this point, the costs for annual maintenance of StatServer, and for further development of support in the data analysis area, are difficult to estimate. Continued support by the USGS is still an important need for this aspect of data management, analysis and reporting.

The annual data management costs that we can predict include the costs for data entry, and for various contracts required to analysis of samples (Table 8.5). We have found that keeping one technician on for several pay periods after the field season is the most efficient way of entering data.⁷ Data entry costs can then be easily calculated as the salary costs times the number of pay periods needed to complete data entry. We estimate these costs as 4.5 pay periods of a GS-5 technician.

The contracts needed to complete analysis of samples collected in the field include a soils contract with the University of Alaska Fairbanks soils lab in Palmer, Alaska; a small contract for support of the University of Alaska Fairbanks Museum herbarium; and small contract for identification of vascular and nonvascular plant specimens that need be examined by experts. The soils contract costs will be fairly predictable, based on the number of samples taken in a given field season. The other contract costs are more flexible and can vary among years, depending on needs.

Realistically, we are not yet in a position to estimate the annual costs associated with data management, analysis, interpretation, and reporting. Thus, the estimated amount included in our scenario budget is an underestimate. As we continue to analyze the pilot study data and flesh out what is needed to maintain strong data management and reporting efforts, we will be able to provide a solid estimate.

⁷ During 2000 pilot studies, Dr. Dot Helm experimented with use of a portable field computer (similar to those used by the U.S. Forest Service in the Forest Health Monitoring Program) for data entry. While the field computer had some advantages, we prefer to record data on data sheets. Data sheets were easier to use in the Denali environment, weighed less, and did not require batteries. We also felt that these data sheets would provide a better archive of the original monitoring data, than electronic files or printouts from electronic files.

Table 8.5. Estimated annual costs for data management-related activities in implementing the minigrid design at Denali National Park and Preserve.

Personnel		Estimated Cost
	Data Entry	\$6,660
Contracts/Agreements		
	Soils Analysis Contract	\$6,000
	UAF Herbarium Support	\$2,500
	Specimen Identification	\$1,000
	Total-Data Management	16,160

Administration

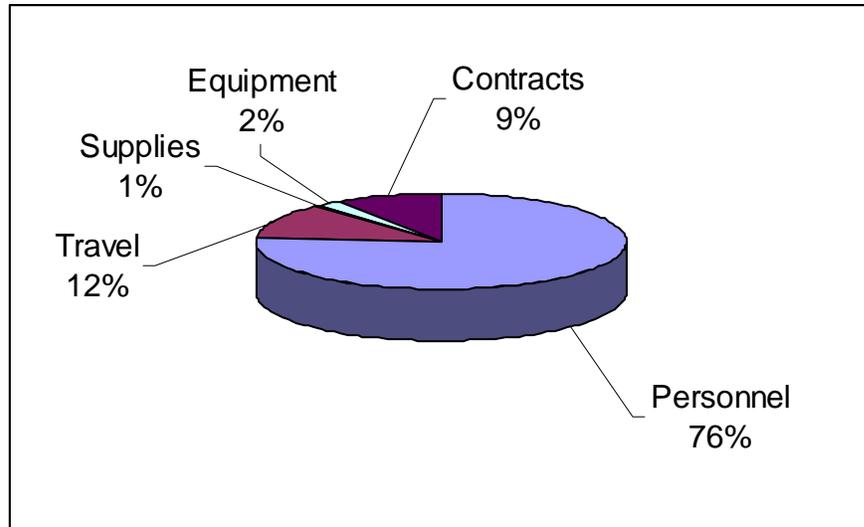
We have assumed that the natural resource program pays all administrative costs required to implement the minigrid design. These costs include managing the payroll of the personnel hired for the program, budget tracking, issuance of contracts and agreements, and supervision of the Principal Investigator.

Discussion

Swanson and Nigro (2003) reported operational costs for their recently completed bird inventory of Yukon-Charley National Preserve, Alaska, of \$120/point. This compares favorably to the costs we have estimated for the vegetation part of the minigrid design of \$451/point—given that the amount of time spent by bird crews at each point (~15 minutes) is much less than the amount of time spent by vegetation crews (4 hours). Swanson and Nigro (2003) found that personnel costs were the majority of costs (60%) even though they relied completely on helicopters for transportation. The information about costs and logistics provided by Swanson and Nigro (2003) provide useful comparisons, and will be especially helpful when we analyze the costs for the songbird portion of the program.

A key finding from this cost analysis is that the majority of the expense to implement the program is for personnel (Figure 8.1). Roughly 75% of the cost is for personnel, including training and overtime. Training represents 20% of personnel costs, emphasizing the importance of finding qualified employees and retaining them as employees. During the pilot studies, we have learned that hiring employees with familiarity with Alaskan flora is important, and that retaining employees with such familiarity, both with the flora and with the monitoring procedures, is critical. A key factor in the long-term success of the minigrid design monitoring program will be our ability to create a stable program that allows recruitment and retention of qualified employees.

Figure 8.1. Percentage of estimated annual operating costs allocated to personnel, travel, supplies, equipment and contracts for implementing the minigrid design in Denali National Park and Preserve.



Costs of transport to minigrids (helicopter) were a relatively minor portion of the overall budget. A basic premise of the design was to minimize helicopter use, so this finding is not surprising. Future helicopter costs are difficult to predict, although we can presume that costs will always rise (very hard to imagine the helicopter costs would ever decline). So anticipating future costs for getting to minigrids is an area of uncertainty for the budget. We can feel confident, however, that we have a design that minimizes helicopter use.

Another important finding relates to “subsidized” costs. These include salary of the Principal Investigator, administrative support, and some portion of data analysis and management support provided at the network, regional and national levels. Although the exact costs for these activities are difficult to pin down, simple recognition that these costs must also be supported is critical to the program’s long-term success.

We are confident that the budget we have described here is a good ballpark estimate. Although there are uncertainties, we have acknowledged them, and their potential impact on costs of the program through time can be assessed. This ballpark estimate should provide a solid basis for evaluating trade-offs as the process of refining a sustainable long-term monitoring program continues.

Chapter 9. Synthesis and Recommendations

We conclude the minigrid report with a brief chapter to summarize the progress that we have made thus far, and to discuss the proposed future of the program. First, we summarize what has been accomplished thus far, and then discuss our immediate plans—the tasks we plan to tackle in FY 2004. However, we believe that the most important activities relating to this project in the next six months will be the discussions and evaluations of this approach that we hope will ensue from our work in producing this document. We hope that this report represents a starting point for building a successful long-term, multiple-scale ecological monitoring program. For this to be true, we need review and comment from as wide an audience as possible.

We believe that the review of the ideas by our scientific and management peers is a critical step in the development of the proposed long-term program. For such an undertaking to succeed, it must undergo rigorous scrutiny and evolve according to concerns raised in this process. We encourage feedback and welcome the opportunity to engage with a wide variety of interested parties concerning the objectives, methods, or any other aspect of the proposed program.

Synopsis—FY 2001-2003

We began this pilot study essentially “from scratch”. The methods, statistical design and data structures of existing monitoring protocols in Denali offered very little in the way of guidance or useful field methods for the task we set for ourselves. Our intent was to embark upon the process of designing a practicable multi-scale, integrated ecological monitoring plan that would meet the scientific and management needs of the park. This intention was informed by what we had learned from the reviews of the existing program, the results of our modeling work on spatial scales for monitoring and our development of the conceptual approach to monitoring that occurred during 1999-2000.

In the last three years, we have progressed on two parallel tracks (1) actively testing field methods and logistics under a variety of conditions and in various biotic communities using crews of seasonal technicians, and (2) developing a foundation for analyzing and assessing multiple-scale monitoring data by creating a relational storage database and set of data analysis routines. We have also created a web site for communicating the scope, background and results of this work to a wider audience, which will hopefully continue to grow and develop with the program itself. In summary, we have accomplished the following steps toward making a viable multi-scale long-term ecological monitoring project:

1. Formalized a set of program goals, with specific measurable objectives organized within the spatial and temporal frameworks within which to meet these objectives;

2. Created a park-wide, two-stage systematic grid sample (set of points) based on a random starting point, which resides in the park GIS;
3. Created an original plot design for the program and set of field sampling procedures for measuring the fundamental aspects of the vegetation cover of the park necessary to meet the program objectives;
4. Designed a normalized relational database structure using Microsoft Access® software to store and effectively analyze vegetation data, including data from several iterations of sampling from a park-wide two stage systematic grid sample;
5. Field tested the set of sampling procedures to assess their logistical practicability;
6. Constructed a comprehensive set of data summary and analysis routines in StatServer® software, that operate independently from the data storage database and are served on the world wide web to allow for numerous users to access the data from a variety of locations;
7. Developed a prototype website to be used for the dissemination of information concerning the landscape scale monitoring program.

As a complement to the accomplishments listed above, we have been active in presenting the proposed design and preliminary results from this program in a variety of forums, including Network, Statewide and National level scientific meetings. The program has also resulted in the inception of cooperative studies with university scientists, and the beginning of collaborations that we believe will pay dividends to the monitoring program in the future. In addition, educational opportunities have been created through this pilot study, with graduate student projects ensuing from our efforts.

Immediate Plans—FY 2004

Our goal in writing this report was to solicit scientific and management feedback so the design we propose can be strengthened and modified to meet park needs. Now that the veil has been lifted—so to speak— from the “minigrid” project, we hope to engage in discussions with a wide variety of interested parties inside and outside of the NPS. Our first priority in FY 2004 will be these discussions, and reviewing, evaluating and responding to reviews of this report. Where these discussions and reviews will lead us is unknown at this point, but we hope that a strengthened plan will emerge.

During the 2003 field season, we sampled three minigrids, so another important activity in FY 2004 will be entering and summarizing the 2003 data. For the bird data, as noted in Chapter 5, we have not yet begun formal data analysis of the pilot study data. Thus,

we will use the 2001-2003 data in that effort. All 2003 data will be incorporated into our existing data management structures, including the StatServer and program web sites.

During the 2003 field season, the vegetation crew performed double sampling of six plots. We will analyze this dataset to help resolve questions about measurement error in the vegetation sampling protocol. Up to this point, we have assumed that observer effects were not significant, and we want to test that assumption. What we learn from this analysis will allow us to modify the measurement procedures, improve training, and/or hire appropriate technicians.

Now that we have data from 285 points in 12 minigrids, we will also examine questions about variances and allocation of sampling effort. Are we undersampling or oversampling at each level of the grid hierarchy? How does our precision differ among attributes? We know that the design cannot be optimized for all the attributes we are interested in, but we can now examine which attributes offer the greatest precision more closely. An important aspect of this will be to use the pilot study data to take a closer look at our ability to detect change. We have previously approached this question using simulations, but having actual data to use in evaluating this question will be a major improvement.

In 2003, Dr. Eric Rexstad of the Institute of Arctic Biology, University of Alaska Fairbanks, conducted feasibility trials for small mammal monitoring in the minigrid design on the Rock Creek minigrid. We await his results, and hope to move forward with integration of other monitoring components, such as small mammals, to the minigrid design.

In terms of field work for the 2004 field season, at minimum, we plan to do one more grid in the Toklat Basin region of the park. The purpose of this sampling will be to complete the aforementioned NRPP project for “North Side Access” baseline studies in the Toklat Basin. We also want to address the questions relating to observer difference more closely, by performing repeated sampling at numerous points.

Proposed objectives for the FY 2004 Work Plan related to the Minigrid design are:

1. Respond to peer and management reviews of the Minigrid report.
2. Follow standard operating procedures for data management with 2003 Field Season data.
3. Write analysis plan for 2001-2003 songbird minigrid data, analyze the data, and write a report. We intend to enter the world of “integration” by incorporating vegetation and physical data into our analyses of songbird occurrences.
4. Analyze vegetation data to address measurement error and other detection of change questions.

5. Write study plan for field season FY 2004 and beyond in keeping with review comments and results of other pilot study data analyses.

Postscript: “*Being Out There*”

During this past summer, vegetation field workers observed a conspicuous, and ecologically significant, phenomenon over a very large area of the Toklat Basin. Low-growing berry-producing plant species experienced dramatic die back during the winter of 2002-2003. We noted ubiquitous mortality in important components of the vegetation, including crowberry (*Empetrum nigrum*), low-bush cranberry (*Vaccinium vitis-idaea*), and bog cranberry (*Oxycoccus microcarpus*). This was evident in a part of the park where we saw no evidence of it during field work in the summer of 2002.

This dieback was almost certainly due to the extremely low snowfall and the short duration of the snowpack that occurred in the winter of 2002-2003. The lack of insulation apparently resulted in desiccation and frost-induced death of plant tissues among species adapted to occur under the snowpack. Because these species are all major berry-producing plants, the effects of this dieback may have cascading effects through the ecosystem in those areas where it occurred. Numerous organisms at the base of park food webs, including microtines, other rodents and some birds will likely be impacted, as well as the carnivores and omnivores that rely on them. Without a crew of trained botanists making systematic observations over a large area of the landscape, it is very likely that the scope and potential significance of this phenomenon would have gone unrecorded. We believe that this type of ancillary information is actually an important component of the monitoring effort, and that this instance will not prove to be unusual case.

Detecting change in fundamental vegetation attributes of the park over time is the primary reason we propose embarking on this monitoring program. Our ability to detect such changes rests on making direct, statistically valid comparisons of data derived from repeat observations performed according to identical protocols at a fixed network of permanent plots. For the landscape-scale level of inference that we are targeting with this program we will be able to detect changes in these properties only over relatively long periods of time. For example, we currently envision completing a single sampling of the entire park approximately every decade.

The long-time horizon envisioned for the program means that, for the formal analyses that we envision as part of this program, some patience will be required of park management to lay the groundwork for a truly successful long-term program. An investment of this sort requires that all of the stakeholders in the monitoring program “buy in” to this paradigm. However, there is a considerable amount of information that we will be able to provide in the interim, including an increasingly refined understanding of the distribution and abundance of important resources on the current landscape. In Chapters 5 & 6 of this report, we presented a variety of data and analyses that allow us to understand the distribution and abundance of primary vegetation attributes on the current landscape. These data represent the primary “interim” value of this program, prior to the ability to make direct inferential tests for change detection.

Another byproduct of this landscape-scale effort is that by simply “*being out there*” carefully observing the park across large areas each summer, we put ourselves in a position to observe important events on the park landscape—such as the berry plant dieback we observed this year--that may cause substantial changes in the ecosystem.

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