Long-Term Ecological Monitoring Program

Synthesis and Evolution of the Prototype for Monitoring Subarctic Parks: 1991 to 2002 Perspective

Denali National Park and Preserve
Denali, Alaska

United States Department of the Interior • National Park Service

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Executive Summary

The ability to detect and document resource changes, and to understand the forces driving those changes, are fundamental to accomplishing the National Park Service (NPS) mission of conserving parks unimpaired (National Park Service 1992). In 1991, the National Park Service selected several parks representing 10 major biogeographic areas, to serve as prototypes for the development of Long-term Ecological Monitoring (LTEM)[1] programs. Denali National Park and Preserve was one of the prototype parks selected to design and test methods for monitoring in subarctic ecosystems.

This report is a product of the past decade (1992 to 2002) of the LTEM program. The goal of this report is to present an overview of the LTEM program since the establishment. This monitoring overview and assessment provides the reader with the background on and the evolution of significant historic events at the programmatic and monitoring component level. Most importantly, this report discusses ecological highlights and reflects on the lessons learned. It is our sincerest hope that this report will not only serve as reference for managers but that it will also contribute to a stronger understanding of long-term ecological monitoring in subarctic parks. If it does so, then all our efforts for the past decade will have been worthwhile.

We divided this report into three chapters and appendices. All the Monitoring Site Location Maps and Chronological Tables are presented on a CD that can be found at the end of this report.

- ***Chapter 1: Overview of Programmatic History and Evolution***

  In Chapter 1 we describe how the monitoring program was conceived and established and how it was managed to the present day. This chapter provides the reader with historical documentation on overall program management and decision making, leadership and direction of the program, the funding component, and personnel involved. It also develops contexts within which significant changes have occurred during the evolution of Denali's first full-scale prototype Long-Term Ecological Monitoring Program.

This chapter is divided into five phases:

In the Beginning: 1991

Design Phase: 1992 to 1995

Development Phase: 1996 to 1998

Implementation Phase: 1999 to 2000

Transition Phase and Beyond: 2001

- ***Chapter 2: Overview of Monitoring Components***

Here, we describe the evolution of each monitoring component (e.g., glaciers). This chapter includes an overview of history that includes a discussion on project organization, a general approach to the project, start-up phase, and spatial expansion. This chapter also includes ecological highlights, a summary of products, and status.

- ***Chapter 3: Lessons Learned***

In Chapter 3 we discuss what has been learned about designing and implementing a monitoring program. Collectively, we have made mistakes, found creative solutions, and most importantly, learned from each other. In this chapter, we offer that experience.

- ***Appendices***

Finally, in two appendices, we provide:

- Acronyms and abbreviations
- List of authors, reviewers, editor, and support staff for this report.

Intended Audience

This report is targeted at individuals who are NPS monitoring program managers and Inventory and Monitoring Network coordinators within the subarctic ecosystems. This report may also serve anyone wishing to learn about establishing a monitoring program or interested in specific monitoring components (e.g., glaciers, weather, small mammals). Others who will benefit from this report include NPS superintendents, scientists, graduate students, and non-profit organizations.

The People Who Took Risks

This report represents more than a chronology of documentation; it chronicles those individuals who risked their careers and spoke out for what they believed—preservation and protection of natural resources. All those mentioned in this report have one thing in common—an overriding faith in and desire to see the monitoring program succeed. The people involved with LTEM quite literally brought their hearts and minds to the program. While many voiced different opinions, all united in the risk and effort to produce the first program of this kind in Alaska. Their creativity and hard work more than anything else have advanced our understanding of monitoring. Half the battle in making a program successful are those staff members who work through the difficult times and differences of opinions to achieve the ultimate mission of Denali National Park and Preserve – *to ensure the protection of wildlife, natural and cultural resources, and aesthetic and wilderness values along with the use and enjoyment of the park by present and future generations. It is the park's mission that visitors understand and appreciate the significance of natural systems. Recognizing the unique development and character of Alaska, we are also responsible for sustaining subsistence lifestyles and a setting conducive to scientific investigation.*

It is impossible to name all the people who have worked on the LTEM program and we apologize for those we have missed. In rough chronology: John Dalle-Molle, Jim Benedict, Dale Taylor, Joe Van Horn, Phil Brease, Joe Moore, Larry Edlin, Chien-Lu Ping, Eric Rexstad, Joseph Cook, Robert Ambrose, Mike Britten, Mike Kochert, Karen Steenhof, Alaska Bird Observatory, David F.

DeSante, Pamela Furtsch, Russ Berry, Jamie Roush, Gordon Olson, Steve Carwile, Mark Clark, Bob Stottlemyer, Larry Edin, Joe Moore, Paul Atkinson, Al Lovaas, Gary Koy, Dottie Kunz, Lyman Thorsteinson, Gary Williams, Ken Karle, Tom Ford, Larry Mayo, Keith Echelmeyer, Alex Carter, Matthew Sturm, Carl Benson, Gordon Nelson, Steve Martin, Karrin Alstad, Greg Probst, Pam Sousanes, Mike Tranel, Linda Toms, Kathy Wightman, Todd Eskelin, Andrea Blakesley, Jon Paynter, Roseann Densmore, Pam Edwards, Todd Eskelin, Lisa Popovic, Dave Hanneman, William W. Emmett, Bill Seitz, Barry Noon, Nancy Deschu, Milo Adkison, George Dickison, Paul F. Haertel, Ross Kavanagh, Tom Stohlgren, Tom Smith, Dot Helm, Layne Adams, Leslie Holland-Bartels, Jeff Keay, Carol McIntyre, Robert E. Ambrose, Ted Swem, Michael N. Kochert, Ann-Marie Benson, Karen Steenhof, Michael W. Collopy, Fredrick Dean, Mike Britten, Dana Hoad, Carl Roland, Penny Knuckles, Karen Oakley, Al Smith, Ed Debevec, Alexander M. Milner, Jerry Belant, Lynne Caughlan, Sarah Marshall, Meg Perdue, Glen Juday, Chad Hults, Andy Irvine, Simone Montayne, Maggie Arend, George Dickison, Paul Geissler, Bill Halvosron, Gail Irvine, Glenn Juday, Lyman McDonald, Trent McDonald, David Peterson, Scott Rupp, Page Spencer, Tony Starfield, Andrea Woodward, Michole Alhadeff, Adam Bucki, Laura Weaver, Tent Hubbard, Sharon Kim, Shan Burson, Austin Baldwin, Dana Hoag, Lyman McDonald, Steve Fancy, Susan L Boudreau, Guy Adema, Jan Timmons, Sioux-z Humphrey, Chester Zenone, Robert Krimmel, Sara Wesser, Maggie MacCluskie, Paul R Anderson, Olga Helmy, Jedediah Brodie, W.L. Cranor, Keith Echelmeyer, Jay Fleisher, J.N. Huckins, Trent Hubbard, Chad Hults, Adry Irvine, B.T. Johnson, Kyle Joly, E. Little, Dan Mulcahy, J.D. Petty, Gretchen Roffler, Leslie Viereck, James Walton, Larissa Yocum, and others.

Various people also contributed directly to the completion of this report. We gratefully acknowledge the assistance of reviewers and the refinements they offered: Karen Oakley, Sara Wesser, Ken Karle, Page Spencer, and Dave Schirokauer. In addition, we owe a special thanks to Jan Timmons for editorial and layout design. Her suggestions and gift of writing added to the flow and consistency of this report.

Endnote

[1] Throughout this report we refer to the Denali prototype Long-Term Ecological Monitoring Program as LTEM.

Chapter 1
Overview of Programmatic History and Evolution

Introduction

Significant changes have occurred during the evolution of Denali's first full-scale prototype Long-Term Ecological Monitoring Program (LTEM). Beginning in 1991 and extending through 2002, the LTEM saw extensive evolution within the administrative portion of the program, as well as changes to essential correspondence, reports, program reviews, and personnel. This chapter details the program's history by describing the conception, establishment, and management of the program to the present day. This history provides the reader with baseline documentation on overall program management and decision making, leadership and direction of the program, funding component, and personnel involved. In addition, the relationship between Denali National Park and Preserve and USGS-Biological Resource Division evolved into a closely working team uniting toward one goal—to develop a formal system to monitor the natural resources of Denali National Park and Preserve. This chapter documents that evolution and highlights administrative achievements.

In the beginning — 1991

Denali National Park and Preserve's Long-Term Ecological Monitoring (LTEM) Program began in 1991 when the National Park Service selected Denali as one of four prototype parks for the Servicewide Inventory and Monitoring (Servicewide I&M) Program. In August, Denali and Alaska Regional Office (ARO) staff prepared the proposal submitted for inclusion in the program ***"Long-term Ecological Monitoring in Denali National Park and Preserve,"*** (August 1991). The proposal covered two major supporting factors. The first involved the accessibility of Denali compared to other more remote Alaska National Parks. The second factor concerned the ready availability of research from the preceding 75 years. The proposal further explained how three watersheds (Kantishna River, Teklanika River, and Yentna River) would form the base for the monitoring. These three watersheds represent the major terrestrial habitats, aquatic systems, and climatic regimes within Denali. The watersheds would be divided by vegetation type and then sampled systematically for breeding birds, small mammals, vegetation, soils, and aquatic resources. The proposal also included a human use component to collect data following visitor use and consumptive uses (hunting and subsistence activities).

In October 1991, Denali received notification of its selection as a prototype park in the Servicewide I&M program. The project received a budget of $140,000 and allowed one full-time equivalency (FTE), out of $325,000 requested, for Fiscal Year (FY) 1992. The Servicewide I&M Program also selected as prototypes the Channel Islands National Park in California, Great Smokey Mountains National Park in Tennessee, and Shenandoah National Park in Virginia. A memo (dated November 25, 1991) from the Associate Director of Natural Resources, F. Eugene Hester, to the NPS Regional Directors, indicated that he hoped to fund the I&M program more fully in the following four fiscal years. Denali was scheduled to receive $275,000 and three FTEs if additional funding became available in subsequent years. Mr. Hester requested an updated proposal for FY 92 to reflect the amount of monitoring possible with the reduced budget.

The November 25 memo included a summary of the selecting committee's views on the proposal's strengths and weakness. The committee commended the presentation of information, the regional strategy for supporting long-term monitoring, the watershed approach, the ability to transfer methods and results to other Alaska NPS areas, and the high priority the program has in Denali's Resource Management Plan. However, the committee criticized assumptions underlying the invertebrate study plans, rationale for why a human-use component was included, the lack of in-park geographic information system (GIS) capability, the low level of staffing proposed, and the small percentage of park area slated for monitoring.

The Design Phase 1992 to 1995

In January 1992, the Servicewide I&M program held the first meeting involving the prototype parks and the Washington Office (WASO) staff. Jim Benedict, Resource Management Specialist, attended as Denali's representative, as did Dale Taylor, ARO.

Denali submitted to ARO and WASO the updated version of the proposal, "*Long-term Ecological Monitoring Proposal: Natural Resources Inventory and Monitoring Initiative,"* dated January 1992, that outlined a smaller monitoring program to meet the reduced budget for the 1992 field season. Reducing helicopter costs by $90,000 provided the largest proposed change. In addition, the updated version of the proposal identified study areas with the easiest road access as a way to reduce costs. The three originally proposed watersheds were subdivided into five sections and ranked in priority (McKinley River, Toklat River, Bearpaw River, Teklanika River, and Yenta River). The smaller program reduced supplies and material costs and combined two temporary positions. Additionally, the authors strengthened the sections that had received criticism by the selection committee. These modifications included adding a terrestrial invertebrate component, developing a stronger rationale for including a human use component, strengthening the in-park Geographical Information System, and soundly justifying an increase of funding and FTE needs.

A January 29, 1992 memo from Denali Superintendent Russ Berry to the ARO Regional Director indicated that the LTEM staff at Denali had selected the study watershed for the 1992 monitoring season. The LTEM staff would focus for the first year on the South Fork of Moose Creek, an undisturbed stream in the otherwise extensively mined Bearpaw River watershed.

By April 1992, Gordon Olson had become Chief of Research and Resource Preservation in Denali and would administer the LTEM Program at the park level. Joe Van Horn, Denali's Resource Specialist, had a position with 50 percent of his time dedicated to the LTEM Program management and logistical support at Denali.

A special workshop focused on research design and monitoring techniques used in long-term studies of subarctic terrestrial ecosystems convened in April 1992 at the University of Alaska-Fairbanks campus. The Alaska Inventory and Monitoring workshop was structured into disciplinary sessions that addressed the major ecosystem components for pilot research: glaciers, climate, soils characterization and chemistry, aquatic systems, vegetation, birds, and small mammals. Scientists from the Bonanza Creek Long-term Ecological Research Program attended and discussed site comparison possibilities. The workshop attendees also discussed integrating mechanisms that warranted considerable future attention. Some opinions among participants concerned inclusion of glaciers and exclusion of large mammals from the pilot research. Meeting notes from this workshop by Lyman Thorsteinson, ARO, and Dale Taylor, ARO are available in Park files.

The *"Study Plans for Long-Term Ecological Monitoring, Denali National Park and Preserve"* was completed in June 1992. Goals for the first year included reviewing all ongoing and past research, implementing monitoring activities and refining procedures, developing written protocols applicable to other watersheds, initiating the writing of a long-term plan, and evaluating activities for effective implementation of the program. Furthermore, significant changes had to be made regarding implementation of the monitoring program because the park did not receive full funding. One such change involved selecting the Rock Creek Watershed because it was smaller and more accessible. This watershed was not included in the list of five prioritized watersheds in the January 1992 proposal, but decreased funding required a more accessible watershed study area. However, the monitoring protocols based on Rock Creek would apply later to the initially selected watersheds.

A tour of Denali's LTEM sites for ARO and WASO staff occurred in July 1992. Lyman Thorsteinson, ARO Natural Resources I&M Coordinator; Gary Williams, Servicewide I&M Coordinator; and Denny Fenn, WASO Associate Director of Natural Resources, attended. The tour included the monitoring in Rock Creek and some mining reclamation in the Kantishna hills.

The future of the LTEM program took an upturn when, in a November 25, 1992 memo from Denny Fenn, WASO Associate Director of Natural Resources, Denali staff learned that the LTEM Program would be fully funded at $275,000 for FY 93. The memo also indicated that annual funding should continue at this level for at least three additional years. In addition, the NPS objective was to build a network of 10 prototype long-term monitoring parks over the next few years.

In 1993, a draft *"Five Year Strategic Implementation Plan: Natural Resource Inventory and Long-term Ecological Monitoring Plan"* for Denali was presented to WASO and ARO personnel. This plan specified the direction of the LTEM program on a year-by-year basis for the next five years, and included field activities, personnel management, data management, and facility needs.

Approximately one month later, a memo dated February 11 from Dale Taylor, ARO, to Gordon Olson, Denali Chief of Research and Resource Preservation, indicated concerns over portions of the plan. In February, Denali staff submitted a revised and final plan that addressed specific concerns.

Gordon Olson, Denali NPS; Joe Van Horn, Denali NPS; Lyman Thorsteinson, ARO; and Dale Taylor, ARO, met at Denali in February to plan the FY 93 LTEM Program and to discuss the Five-Year Strategic Plan Strategies[1] to maximize the usefulness of the LTEM studies approved for Denali predominated. The four discussed plans for future expansion beyond the Rock Creek Watershed. The discussion included plans for the other five watersheds [2] and addressed problems inherent when a staff cannot dedicate time solely to the LTEM.

In 1993, the National Biological Survey (NBS) was created. This significantly affected the Denali LTEM Program in two ways[3]. First, Lyman Thorsteinson and Dale Taylor were moved from ARO to NBS. Second, Denali's funding source would now come through NBS until the program had fully completed protocols and monitoring designs (*see Table 1, next page*). This created a more complicated accounting of funds transferred between two agencies. The arrangement would continue through FY 95, the year slated for completion of the "design phase." The NPS then would resume funding the program. Funding levels were to remain at the projected levels. The oversight of the program now became the responsibility of the NBS. Much of the responsibility of carrying out the research projects and facilitating cooperation with scientists continued to fall to Denali staff, with some NBS scientists involved.

The NBS organized a February 1994 meeting in Fairbanks to improve communication and cooperation between research scientists and program managers, reviewing past research, and discussing the future direction of the program. Participants included staff from Denali, ARO, and NBS. Minutes from the meeting indicated differences of opinion as to the optimum direction of the program[4]. Attendees did not reach consensus about whether funds were better spent on staff positions or in forming partnerships with outside researchers, nor did participants agree about the value of continued small scale sampling rather than scaling the project to the larger watershed as originally proposed.

Table 1. Funding History of the LTEM Program

	Design				*Development*			*Implementation/Transition*			
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
NPS I&M	140	275		60	35	35	20	266.5	485	485	485
Program						165	266.5				
DENA											
Base							345.5	345.5	506	493	493
Other							33.5	33.5	33.5	33.5	33.5
USGS			275	275	275	150	205	205	285		
ABSC Base							136	136	136	163	113
TOTAL	140	275	275	335	310	350	1006.5	986.5	1445.5	1174.5	1124.5

1994 — $275.0K transfer from the park to the National Biological Service, now the Alaska Biological Science Center. No other funds provided to the park.
1995 — $60.0K Service-wide Monitoring Program funding transfer to park base for GIS Coordinator.
1996 — $35.0K Service-wide Monitoring Program funding transfer to park

Not all activities involved controversy, however. NBS and ARO staff presented a poster in Palmer at the Alaska Conservation Foundation Conference *"The National Park Service's Inventory and Monitoring Program in Alaska: Pilot research in Denali National Park and Preserve"* on August 2, 1994. The poster outlined the LTEM Program in Denali, and indicated intent to expand the program to the larger watersheds named in the original proposal in 1995.

A report from the end of the 1994 field season, *"Prototype Long-term Ecological Monitoring Program, Denali National Park and Preserve, National Park Service Accomplishments Fiscal Year 1994,"* summarized the year's efforts. In 1994, 29 scientists and technicians worked on 18 studies. Although this season saw the oversight of the program transferred to the NBS, many responsibilities remained at the park level. These included field coordination, logistical support, protocol development, the reconnaissance of other watersheds for future expansion, and data management. Draft protocols for many of the studies were projected for 1995.

A July 1995 *"Long-term Ecological Monitoring Program, Strategy, Denali National Park and Preserve"* summarized the program to date and outlined future direction. A section titled "Issues" referred to some of the unresolved frustrations with the program. These included the limited immediate value of the Rock Creek drainage data, limited funding, uneven funding for different studies, data backlogs, lack of space to accommodate needed workers, inefficiencies of working with two agencies, and the lack of ability for management to make use of the data collected. The section titled "Specific Five-Year Goals and Proposed Actions" suggested ways to deal with these frustrations:

Goal 1: Refine the conceptual foundation of the program and develop a more robust model that can better incorporate an extensive, landscape level sampling as well as the current site-specific, intensive activities.

Goal 2: Complete field studies necessary to resolve protocol development for the current list of monitoring program components. Prepare peer-reviewed protocol documents.

Goal 3: Establish a sustainable level of monitoring from a financial, personnel, and resource-impact perspective in Rock Creek.

Goal 4: Continue to expand the spatial scope of the program and the ongoing efforts to characterize resources at a park-wide scale.

Goal 5: Improve integration of LTEM program monitoring components with other monitoring and research activities.

Goal 6: Initiate protocol development in important areas such as invertebrates, other small mammals (hares, ground squirrels, etc.) small carnivores, lake and pond systems, human use, natural soundscapes, etc. that have not been addressed in first years of the program.

Goal 7: Continue special focus on the establishment of good data management procedures in this phase of the program.

Goal 8: Increase GIS program.

Goal 9: Provide regular technical and popular reports on the program.

Goal 10: Resolve remaining personnel issues such as conversion of long-term seasonal positions to permanent positions and the need for some additional temporary positions.

Goal 11: Provide improvements to the infrastructure that are needed to support a program in the long term, particularly workspace and a bunk house for researchers.

In the summer of 1995, the prototype I&M parks underwent a national review. The review of Denali's Program took place August 1 through 4. The comments from the review team came in a memo, dated February 26, 1996, from the Assistant Director of I&M in the NBS, Doyle Frederick. The review team complimented the work done to date and the professionalism of the staff. However, they expressed concern about the relevance of the research to threats and issues and the focus on research questions rather than ecosystem monitoring in some studies. The review team made two recommendations. The first was to hold a workshop involving park management, NPS and NBS scientists, experts in various fields, and a neutral facilitator to work out differences and provide a unified direction. The second recommendation was to hire a full-time staff person at Denali dedicated to the park LTEM program. A memo from Gary Williams, Servicewide I&M Coordinator, on February 5, 1996, indicated that he would transfer funding to the park in support of the Denali LTEM position.

The Development Phase 1996-1998

The effort to improve the LTEM Program at Denali continued in 1996. The first full-time coordinator, Penny Knuckles, began work in May. The first of a series of workshops that focused on strengthening the conceptual design occurred in July, the second in October. Participants in the July workshop included Denali staff; Bill Seitz, Assistant Director of the Alaska Science Center (NBS); wildlife biologists; a statistician; an ecosystem modeler; and a remote sensing specialist from the NBS. Barry Noon, an ecologist with the U.S. Forest Service, and Tom Stohlgren, an ecologist with the NBS in Fort Collins, Colorado, attended. Both have experience with watershed scale studies. The workshop resulted in more clearly defined program goals, identified important attributes within Denali and stressors to those attributes, and attempted to predict future stressors.

In October 1996, at the beginning of FY 97, Congress moved the NBS from its own entity within the Department of the Interior to an agency of the USGS and renamed it the Biological Resources Division (USGS-BRD). With this reorganization, the past commitment to the LTEM prototype and cooperation between USGS-BRD and the NPS continued.

In October 1996, the second in the series of suggested workshops occurred in Anchorage. During most of the workshop, participants divided into six work groups, each focusing on an identified stressor (Table 2).

Monitoring specific known stressors involved collecting data relevant to ecosystem function. The ecosystem data would allow the study of unanticipated stressors and the ability to distinguish naturally occurring and anthropogenic stressors. Extensive notes from this workshop are available in Park files.

Table 2 – Working Groups

Roads, Facilities, and Development within the Park	Barry Noon, USFS
Regional and Global Development	Nancy Deschu, NPS Alaska Systems Support Office
Animal Harvest	Layne Adams, BRD Wildlife Biologist
Resource Extraction	Milo Adkison, BRD Fisheries Biologist and Ecosystem Modeler
Plant Harvest	Eric Rexstad, University of Alaska, Fairbanks wildlife biologist and statistician at UAF.
Visitor Use	Bill Seitz, Assistant Director of the Alaska Science Center (NBS)

In February 1997, 30 NPS managers and natural resource specialists associated with the LTEM programs met in Arizona. Their objectives were to review program progress since 1991 and to discuss a variety of administrative and managerial issues. Considerable discussion focused on the cooperative relationship between the NPS and the USGS-BRD regarding needed support for the LTEM programs. As a result of this meeting, Denali submitted a programmatic request to the Servicewide I&M Program revising the original funding and staffing requirements for the operational phase.

By 1997, the Denali LTEM program had reached a transition stage and moved from protocol development to routine and repeated implementation of standard procedures. The time had come to initiate a review of the draft protocols for air quality, meteorology, glaciers, land birds, avian productivity and survivorship, small mammals, stream hydrology and surface water chemistry, vegetation, aquatic macroinvertebrates, and data management. In March, Penny Knuckles, Denali LTEM Coordinator, sent a memo to Dale Taylor, USGS, that provided review comments on the draft protocols for Landbird Monitoring, Monitoring Avian Productivity and Survivorship, Small Mammal Sampling, Assessing Long Term River Ecosystem Change, and Vegetation Monitoring. Denali had four recommendations:

1. The protocols should be reformatted, either by the authors or by USGS, into a consistent layout;
2. Before final publications, USGS and NPS should assure that monitoring questions are clearly defined, objectives supporting those questions are stated for each method, site maps and other site specific information are provided, and data management is explained to the same high standard as sampling techniques;
3. Investigators should prepare a separate document, in a consistent format developed jointly by USGS and NPS, that provides discussions of attribute selection, experimental design and results;
4. Investigators also should provide data and data analyses of the results of the five years of completed field studies.

In anticipation of the final protocols in 1997/98, WASO provided $165,000 to the park to implement specific monitoring activities (Table 1). WASO added $35,000 to the park base to match another $35,000 in 1996 for the newly established Denali LTEM Coordinator position. USGS-BRD had contributed $150,000 in 1997 to finish program design work that began in 1996, improve data management, and complete development of the soils monitoring protocols. USGS-BRD transferred $35,000 to Denali to provide logistical support for the glacier monitoring protocol and for travel costs incurred to attend workshops early in the fiscal year.

In April, the park developed four science working groups to help integrate management and scientific approaches to monitor park resources. The groups included water resources, air quality, weather, and vegetation. This marked the first major effort to expand the scope of each monitoring effort beyond Rock Creek Watershed, and tied the work accomplished thus far into the monitoring program as a whole.

Lyman Thorsteinson, USGS-BRD, and Dale Taylor, USGS-BRD, published a paper entitled *"A Watershed Approach To Ecosystem Monitoring In Denali National Park and Preserve, Alaska"* (1997). In it, the authors describe portions of the pilot research in Denali during 1992-1995 and suggest further research. Thorsteinson and Taylor state that "monitoring in a single watershed addresses a limited, but linked, number of ecosystem parameters and attributes including a small portion of the tropic spectrum." They believed that the protocol research was aimed at the major physical controls on the aquatic, vegetation, landbird, and small mammal community systems. The authors also suggested that expanding the LTEM program to additional watersheds could target other valued resources (i.e., large mammals and various birds of prey).

Two significant documents were drafted in 1997 but never finalized. The first was the draft *"Denali Long- term Ecological Monitoring Conceptual Design"* compiled by NPS staff in April. This document spelled out the justification, objectives, working parameters, and theories that provided the underpinnings of the current monitoring program at Denali. The document outlined a strategic framework or process that park staff undergo to bring the monitoring program into operation and application. The Conceptual Design document also introduced the new "Stressor-based"[5] sampling approach (Noon 1997). This new approach would modify the watershed approach by incorporating relations between effects and stressors through the selection of monitoring indicators. The success of this modified approach depends on the validity of the assumed cause-effect relationships between the stressor(s), their ecological effects, and the selected indicators of stress. Finally, this document set the context for developing a Monitoring Implementation Plan and for requesting funding and personnel needed to assure implementation.

Tom Smith, USGS BRD, and Layne Adams, USGS BRD, submitted comments about the draft document. Both Smith and Adams agreed on the concern they had of using a "Stressor-based" approach to monitoring within pristine subarctic ecosystems. Smith expressed strong reservations whether the "Stressor-based" approach actually could delineate trigger-points and thresholds for monitoring, and identify linkages between indicators and stressors. His major concerns were:

1. How could the investigators define thresholds or trigger-points for components of subarctic ecosystems when lacking baseline data?
2. Was it appropriate to use "best guesses" in the absence of long-term data?
3. Was it possible to construct simplistic linkages between indicator variables and ecosystem stressors when our knowledge is so scant at this time?

Adams also expressed concerns about the "Stressor-based" approach and added that this approach would apply more to intensive management regimes rather than pristine ecosystems.

The second document was completed in October. The NPS and USGS-BRD drafted a *"Strategic Plan Long-term Ecological Monitoring Program"* for Denali to provide overall program direction for the next five years. This document described:

1. The guiding principles, purpose and objectives, fundamental elements, and monitoring priorities that would provide the framework for the LTEM Program;
2. The relationship of the program to the Division of Resource and Research Preservation, and its role as a national prototype;
3. A phased approach for development and implementation of the program over the next three years—1998 to 2000.

Program operations for the Denali LTEM prototype were fully integrated into the park Research and Resource Preservation Division with solid support from Steve Martin, Denali Superintendent. Ten base-funded permanent employees directed, supervised, and implemented monitoring activities. Two seasonal technicians, one full time and one part time, were hired to carry out specific monitoring activities. A third technician was on a short-term appointment to assist with data management and mapping.

However, it appeared to Denali participants that in 1997, USGS-BRD interests in supporting monitoring work had diminished. The role and responsibility of USGS-BRD in fulfilling the research and development phase so vital to the ultimate success of the LTEM program needed to be clearly defined and understood. In October, Dale Taylor retired from USGS-BRD and Leslie Holland-Bartels took a reassignment as the USGS-BRD LTEM project manager. In addition, Holland-Bartels reassigned Karen L. Oakley as LTEM project leader and promised to dedicate this position to continued involvement and development of protocols.

In February 1998, the principal investigators for the Denali LTEM program met in Anchorage. This was the first opportunity for Karen Oakley to meet with the Denali LTEM staff and outside investigators. The first day of the meeting focused on "lessons learned" and four questions:

1. What parts of the program work and make a difference?
2. What is not working that would make a difference if it were?
3. What is missing that would make a difference if it were provided?
4. What parts of the program work, yet make no difference?

The second day focused on the future of the research supporting the development of the LTEM Program.

In 1998, the USGS-BRD contracted with Western Ecosystems Technology, Inc. for a statistical review of the existing protocols. This marked the first statistical review since the program began in 1992. Two review papers, *"Denali National Park and Preserve, Long-term Monitoring Program,"* by Dana L. Hoag, and *"Review of the Denali National Park and Preserve Long-term Ecological Monitoring Program,"* by Lyman McDonald (et al.) were completed in September. McDonald (et al.) presented recommendations in four groups: realistic expectations, design considerations, operational considerations for acceptance and credibility, and linking LTEM to resource management decisionmaking. Hoag, in his paper, based his comments on the purpose of the LTEM program stated in the 1997 Annual Administrative Report. This purpose involved developing an information system about status and trends in the structure and function of the park's ecosystem that would:

1. Improve management decision-making on preservation concerns;
2. Increase understanding of ecological dynamics;
3. Enhance national and global monitoring networks.

Hoag's major recommendation suggested a four-stage plan to proceed toward success:

1. Conceptual plan
2. Implementation Plan
3. Implementation
4. Evaluation

In May, another significant personnel change occurred when Penny Knuckles accepted a new job and left Denali. Denali hired a full time coordinator, Susan Boudreau, in August 1999. In December 1998, USGS-BRD and Denali submitted a study plan for 1999. The study plan provided an overview of the ongoing research program and how USGS-BRD and Denali finalized the development phase and the strategy for moving into the implementation phase.

Implementation Phase 1999 to 2000

The National Park Service announced in 1999 the new *"The Natural Resource Challenge Program"* (NRC), a five-year program (2000 to 2005) focused on the natural resources of the national parks, building on key existing programs, and adding important, previously missing resource components. Moreover, for the first time, the Challenge program provided a coordinated, system-wide approach to natural resource management. In the first year (2000) of the Challenge, an increased base funding of $14,320,000 helped accelerate completion of natural resource inventories, target efforts to eradicate non-native species, and improve current management and expertise of biological and geological resources.

The Servicewide I&M program hired Steve Fancy as the new Monitoring Coordinator for NPS.

A memo dated September 13, 1999 from Steve Fancy, NPS, defined the key items to accomplish before fully implementing the Denali LTEM program. The following steps needed completion by Denali and USGS-BRD:

1. Develop an all-encompassing framework diagram that presented the comprehensive monitoring program at Denali, regardless of funding source.
2. Organize and clarify the links between indicators or "vital signs" that were monitored and their applicability to current or future management interests.
3. Develop a statistical sampling design that allowed park-wide inferences to be made regarding monitoring indicators.
4. Prioritize monitoring components further and decide which indicators to measure.
5. Develop an implementation plan after completing the Strategic Plan and Conceptual Design documents that detailed how the NPS staff would complete the developmental phase and make the transition to full implementation.

A new monitoring initiative entitled Servicewide I&M "Vital Signs" Network was unveiled at the National LTEM meeting in Fort Collins, Colorado, November 1999. The prototype park monitoring coordinator expressed a major concern: as the NPS shifted from a model of intensive and comprehensive monitoring at the park level to a more extensive effort at the network level, the role of the LTEM programs became unclear. To address this concern, the coordinators sent a memo to Gary Williams, Servicewide I&M Coordinatordefining the role of LTEM Parks in the Network Monitoring System. In the memo, they answered the question, "What role should the LTEM parks play in the new network model?" The coordinators believed that it was imperative that the prototypes take a leadership role to ensure the success of the Servicewide I&M effort. The coordinators defined three primary responsibilities of the LTEM programs within the network monitoring strategy:

1. LTEM parks could serve as centers of excellence, providing leadership, training, and assistance to networks in the design and implementation of long-term ecological monitoring. Collectively, the LTEM parks had made mistakes, found creative solutions, and most importantly, learned from each other.
2. The professional staff of the LTEM programs could contribute to conducting monitoring throughout their respective networks.
3. Maintaining the LTEM programs intact would allow NPS to retain a small system of intensive and comprehensive monitoring sites. This would enable testing to determine whether more extensive vital sign monitoring would provide sufficient data on which to base resource decisions.

A December memo from Gary Williams, Servicewide I&M Coordinator, summarized the meeting notes from the I&M steering committee. During the steering committee meeting, the group decided to set aside the funding that the seven current prototypes had received. The prior funding would not reflect upon the new Vital Signs monitoring funds. Thus, network-based monitoring would not jeopardize the integrity of the LTEM programs.

An email message from Gary Williams to Susan Boudreau, Denali LTEM Program Manager, restated what the program needed to phase into full implementation. Williams wrote that before he could consider providing additional funding for Denali beyond the current approved staffing and budget plan ($275,000), a revised conceptual framework and associated monitoring goals and objective would have to be finalized and then reviewed and approved by the I&M advisory committee.

Under the *Natural Resource Challenge Program* in 2000, monitoring ecological vital signs began in approximately 270 parks throughout the United States. Parks were organized into 32 monitoring networks, linked by geography and shared natural-resource characteristics. Parks in each monitoring network would share resources and professional expertise to implement a core program that focused on the most critical ecological parameters and stressors identified for the network. Denali joined Wrangell-St. Elias

National Park and Preserve and Yukon-Charley Rivers National Preserve to become the Central Alaska Monitoring Inventory and Monitoring Network (CAKN).

As part of the request from Steve Fancy[6], the staff of Denali and USGS-ABSC (formerly BRD, now the Alaska Biological Science Center)developed the *"Long-Term Ecological Monitoring Work Plan and Funding Request for FY2000 & Beyond"* jointly. The work plan described the goals that helped move the LTEM program toward a full operating program for FY2000 and following years. The plan explained the financial and human resource support necessary to implement park monitoring activities and updated the *"Long-term Ecological Monitoring 1992 Proposal: Natural Resources Inventory and Monitoring Initiative."* In addition, this work plan emphasized new program elements and working relationships with USGS-ABSC, principal investigators from academia, and other state and federal agencies.

Steve Martin, Denali NPS; Gordon Olson, Denali NPS; Susan Boudreau, Denali NPS; Gary Williams, Servicewide I&M Coordinator; and Steve Fancy participated in a conference call in February to discuss the 2000 Work Plan. Gary Williams agreed to increase the Denali LTEM funding from $266,500 to $485,000. However, this funding was contingent on the completion of the Denali Conceptual Design.

The final *"Conceptual Design of the Long-term Ecological Monitoring Program for Denali National Park and Preserve"* was completed and presented in May to the I&M Steering Committee in the Great Smokies National Park. This document identified and incorporated:

- The 1995 national panel recommendation that the park develop a stronger conceptual basis for the monitoring program, documented in a written conceptual plan (Frederick 1996);
- The draft *"Denali Long- term Ecological Monitoring Conceptual Design"* (April 1997);
- Lessons learned from the cumulative monitoring activities, ongoing since 1992;
- Past reviews of the Denali LTEM program.

- Two recent memos in the Servicewide I&M Program defining the expectations of Steve Fancy, Servicewide Monitoring Coordinator, and Gary Williams, Servicewide Inventory and Monitoring Coordinator.

The final document also clarified the type of monitoring and set a single goal to help park managers protect park resources by providing the ecological context for resource preservation decisions.

In November 2000, the Denali LTEM held a two-day conference in Fairbanks to celebrate eight years of monitoring and outreach that had helped Denali preserve the park's pristine subarctic ecosystem.[7] The monitoring program had, thus far, attracted a number of researchers, non-profit organizations, and students who worked with park staff. The conference provided a perspective and a forum to present current findings and future strategies.

Transition Phase 2001 and Beyond

In 2001, The Central Alaska Network (CAKN) received $150,000 start-up funds for the new network monitoring program. The network program saw completion of several major milestones in 2001, such as hiring the CAKN Coordinator, completion of work plans, establishing a Board of Directors and a Technical Committee, and summarizing data for vital signs scoping sessions.

Significant changes in the LTEM staff occurred in 2001. Susan L. Boudreau accepted a temporary reassignment to Acting Division Chief of Research and Resource Preservation.[8] Guy Adema became acting Denali LTEM Coordinator.

Simultaneously during the fall and winter of 2001, the Denali LTEM staff and Alaska regional advisors held a series of meetings to discuss the status of the LTEM program and its future direction. Staff and advisors generally recognized that a formal shift from a watershed approach (i.e., Rock Creek) to a landscape approach, including a probability_based sample design, would allow for large-scale understanding of ecological changes more representative of the park and more useful for park management. The shift had already begun with some of the monitoring components, including small mammals, weather, vegetation, and others; the decisions of the staff effectively approved the new approach.

The landscape approach to ecological monitoring would allow for a monitoring effort that would integrate more easily among physical and biological components. Use of a park-wide grid sample design[9]—the plan set forth by the vegetation program—epitomized the shift to a landscape scale. An integrated vegetation, birds, and small mammals reconnaissance pilot study also was planned for the 2001 field season.

Contemporaneously with the shift in Denali's approach to monitoring, the CAKN began holding technical committee meetings to develop its monitoring program, culminating in a successful scoping workshop in April 2002. It became evident that the direction of the Denali LTEM program and the CAKN monitoring program were heading in similar directions, and that maintaining the infrastructure for two distinct programs would have many redundancies. During discussions throughout the scoping workshop, a consensus emerged to integrate the Denali LTEM program more fully with the CAKN monitoring. Ensuing meetings with WASO and AKSO staff at Denali finalized this direction.

In conjunction with the CAKN Scoping Meeting, Steve Fancy visited Denali to discuss the park's preparations for a review of the program scheduled for later that year. During discussions throughout the week, a consensus emerged to integrate the LTEM program fully with the CAKN program. Steve Fancy requested that Denali and CAKN, with support from the parks management, develop a formal document that described the integration between the two programs. In June, Denali and CAKN submitted to the Servicewide I&M Coordinator a document titled, *"Integrating the Denali Long-term Ecological Monitoring Program (prototype) into the Central Alaska Network Vital Signs Monitoring Program."* This document provided background information on the Denali LTEM and CAKN programs, a summary of their status, the impetus for integration, overall integration strategy, and some of the implications. In addition, the document described several reports that will be completed in FY2002 and 2003. This report, *"Synthesis and Evaluation of the Prototype for Subarctic Parks,"* was one of the reports described in the integrated document.

A significant change to the Denali LTEM program was formalized at the fall 2002 meetings, when Denali LTEM staff, Susan Boudreau, Acting Division Chief of Resources, and Paul Anderson, Denali Superintendent, decided to adopt the landscape approach—already informally in practice—for ecological monitoring, rather than focus specifically on the Rock Creek Watershed. Some elements of this change to a landscape approach also had been proposed for the CAKN monitoring plan. Those at the fall meetings evaluated the consequences of the change thoroughly and determined that the quality long-term data sets that began in Rock Creek would continue.

For example, the four weather stations currently in the Rock Creek Watershed would be maintained to conserve the data set, but new stations would be placed across the landscape of Denali in an attempt to describe the suite of ecosystems encompassed by the park boundary (see Chapter 2). The vegetation-monitoring program had begun tests of a new approach during the 2001 field season. A grid-based approach was developed that involved sampling at the intersections of a 20-kilometer by 20-kilometer grid. Test sites showed that under certain assumptions, the accessible sites in the park could be sampled in an approximate seven-year period. Detailed sampling methods would then allow monitoring staff to resample and compare the sites to document ecological change. A terrestrial vertebrate monitoring approach based on the same grid system was tested during the 2002 field season.

Summary

In FY 2004, the Denali LTEM program will be fully integrated into the Central Alaska Network (CAKN). We feel that the LTEM program will contribute significantly to CAKN while maintaining the continuity and long-term ecological integrity of the existing LTEM efforts. For example, the LTEM program was established primarily in an attempt to learn how to design scientifically credible and cost-effective monitoring programs. Furthermore, the level of monitoring conducted in Denali is both more comprehensive and more intensive than what Wrangell-St. Elias National Park & Preserve and Yukon-Charley Rivers National Preserve will be able to undertake. For those reasons, a major function of LTEM is to take a leadership role and serve as a "center of excellence" being responsive to the needs of CAKN. What's more, the LTEM program possesses a wealth of experience and expertise relating to the development and implementation of a monitoring program. The LTEM staff will be available to assist CAKN staff on conceptual designs, modeling, administration issues, protocol design, monitoring methods, database management, data analyses, educational outreach and reporting. We view the LTEM program as serving all these functions as an integral part of CAKN.

Furthermore, LTEM will also have a significant role in the Denali Science and Learning Center (Center). This center is a collaborating effort with eight northern Alaska parks: Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, Noatak National Preserve, and Yukon-Charley Rivers National Preserve. The Center will facilitate the exploration of the science behind the conservation and protection of over 26 million acres of Alaska parklands, approximately one-third of the total National Park Service. When fully implemented, the Center will substantially augment our ability to advance the mission of the National Park Service by fostering the continued scientific exploration of the parks and enhancing the information interchange among parks, visitors, and the global scientific community.

Highlights of the Overview: 1991 to 2002

1991

- Denali submits proposal to the Washington Office *"Long-term Ecological Monitoring in Denali National Park and Preserve."*
- Denali is chosen as one of the four prototype Long-term Monitoring parks.

1992

- AK I&M Workshop held in Fairbanks.
- Denali completes the "*Long-term Ecological Monitoring Study Plan."*
- First field visit by the Servicewide I&M Coordinator.
- Gordon Olson becomes the Denali Division Chief of Research and Resource Preservation.
- Joe Van Horn's position in Denali is 50 percent dedicated to the LTEM program.
- Rock Creek watershed is chosen as the monitoring site.

1993

- Five-year *"Strategic Implementation Plan: Natural Resource Inventory and Long-term Ecological Monitoring Plan"* was provided to Servicewide I&M Program.
- National Biological Survey is created.
- Russ Berry, Denali Superintendent, leaves.

1994

- Steve Martin becomes Superintendent in Denali.
- Jon Paynter is hired as the LTEM GIS Coordinator.
- National Biological Survey sponsors a workshop to review the Denali LTEM program.

1995

- Servicewide I&M Program reviews the Denali LTEM program.

1996

- Penny Knuckles becomes the first full-time LTEM Program Manager.
- Denali LTEM Workshop held in Anchorage.
- National Biological Service moves to the USGS.

1997

- National I&M Monitoring Program Review.
- Review of the draft protocols.
- Funding proposal submitted to the Servicewide I&M Program.
- Draft *"Long-term Ecological Monitoring Program: Conceptual Design"* completed.
- Draft five-year *"Strategic Plan Long-term Ecological Monitoring Program"* completed.
- Dale Taylor retires.
- Dr. Leslie Holland-Bartels reassigned LTEM project manager.
- Karen Oakley is designated LTEM project leader for BRD.

1998

- Denali LTEM principal investigators' meeting.
- Penny Knuckles accepts new job and leaves Denali.

- Joint work plan by Denali and USGS-ABSC (formerly BRD).
- Study plan *"Development of a Prototype Long-term Ecological Monitoring Program at Denali National Park and Preserve, Alaska."*

1999
- The NPS five-year "Natural Resource Challenge Program" is launched and the creation of "Vital Signs" Monitoring Networks initiated.
- Joint NPS-ABSC funding request submitted to the Servicewide I&M Monitoring Program.
- Susan Boudreau is hired as the Denali LTEM Program Manager.
- Sharon Kim is hired as the Denali LTEM Data Manager.
- Steve Fancy is hired as the Servicewide Monitoring Coordinator.
- National LTEM meeting held in Fort Collins, Colorado.
- Evaluation of the Denali LTEM program: What will it take for Denali to phase into full implementation?

2000
- Denali LTEM program joins Wrangell St. Elias and Yukon Charley to become the Central Alaska Monitoring "Vital Signs" Network.
- Denali and USGS-ABSC submit the "Long-term Ecological Monitoring Work Plan and Funding Request for FY2000 and Beyond."
- The final "Conceptual Design of the Long-term Ecological Monitoring Program for Denali National Park and Preserve" completed and presented to the Servicewide I&M Steering Committee.
- The Denali Long-term Ecological Monitoring Program holds a two-day conference in Fairbanks.
- Guy Adema is hired LTEM Physical Scientist.

2001
- Pam Sousanes is hired LTEM Environmental Specialist: Weather.
- Janie Lasell is hired LTEM Budget Administrator and support to the CAKN.

- CAKN receives startup-up funds to initiate the program.
- The first phase of pilot studies to test a probability-based landscape monitoring design.
- Susan Boudreau accepts a four-month detail in 2001 as Acting Division Chief.
- Numerous meetings held with LTEM staff and Alaska regional advisors discussing the status of the LTEM program and its future direction.

2002

- Susan Boudreau becomes Acting Division Chief and Guy Adema accepts a detail as the LTEM Program Manager.
- Olga Helmy is hired as the LTEM Data Manager.
- Denali, with the support of management, decides to adopt a landscape approach to ecological monitoring.

Endnotes

[1] Memo dated February 23, 1993
[2] McKinley River, Toklat River, Bearpaw River, Teklanika River, and Yenta River
[3] Memo dated August 16, 1993
[4] Memo dated February 24, 1994 from Lyman Thorsteinson to Joe Van Horn
[5] The term "Stressor-based" refers to disturbance events that result in significant ecological effects.
[6] Memo dated September 13, 1999
[7] See PDF of conference presentations on the Denali National Park and Preserve website.
[8] Susan Boudreau was acting as Division Chief from August-November 2001 and from March 2002-April 2003.
[9] Denali Long-term Ecological Monitoring: Mini-grid Sampling Design (Carl Roland et al. October 2003)

Chapter Two
An Overview of the Monitoring Components

Overview of the Monitoring Components: 1992 to 2002

The LTEM program is organized into four major monitoring components[1], one to cover the physical science components, and three to cover biological science components (Table 3). Oakley and Boudreau (2001) define the rationale for this approach as major building blocks and "*that an ecological monitoring program must include both physical science and biological science components because an ecosystem is comprised of the interacting parts of the physical and biological world. If the program includes one but not the other, we will not be able to build our ecological understanding.*" Each monitoring component represents an essential building block in LTEM.

Table 3. Denali Monitoring Components

Physical	Flora	Aquatic	Fauna
Glacier	Vegetation	Aquatic Systems	Wolf/Prey Interactions
Snow		Aquatic Invertebrates	Small Mammals
Weather			Eagles/Gyrfalcons
Air Quality			Passerines
Soils			

The Physical Component is the most important abiotic factor in the Denali Ecosystem. Within the Physical Component, we describe *Glaciers, Snow, Weather, and Air Quality*. We include a section covering abiotic as well as biotic factors in *Soils*. The Flora Component describes *Vegetation* and factors that affect vegetation. In the Aquatic Component, we include *Stream Channel Morphometry and Water Chemistry and Aquatic Invertebrates*. Within the Fauna Component, we describe the *Wolf/Prey Interactions, Small Mammals, Eagles and Gyrfalcons, and Passerine monitoring*.

In this chapter, we wish to do more than just summarize 10 years of monitoring. First we will provide the reader with an understanding of the evolution of each monitoring component – an overview of history, a general approach to the project, and a discussion about the start-up phase. The authors conclude with a discussion on "What have we found out?" and "Where are we going in the future?" We asked the authors to conclude each monitoring component discussion with a summary of personnel involved in the program, publications, reports, brochures, presentations, and a bibliography.

Endnote

[1] 2002 Conceptual Design of the Long-Term Ecological Monitoring Program.

Physical Environment

Glacier Monitoring

Guy W. Adema,
Denali National Park and Preserve

Introduction

Glaciers are a major feature in Denali National Park and Preserve, currently covering about 17 percent or 1 million acres of the park. Unlike other major features such as lakes, mountains, and rivers, glaciers advance and retreat as climate fluctuates. Glacier behavior in Denali varies from apparent steady flow glaciers to erratic surge-type glaciers. This variety offers opportunities to study glacier movements dominated by climate as well as those movements influenced by other factors.

The objective of the glacier-monitoring program in Denali is to establish the baseline conditions of selected glaciers and to detect and understand glacial processes. Pursuing this objective will allow detection of the effects of climate fluctuations as they happen and to better understand the natural evolution of the Denali landscape, much of which has been shaped by glacial processes. The data obtained can be used to test dynamic models of climate and glacier flow and emerging hypotheses regarding the effects of climate change. The data also may help us estimate the effects of these changes on other related systems, such as the discharge of glacier-fed rivers.

General Approach to the Project

In May 1990, the National Park Service proposed global climate change research on Alaska-region glaciers within Park Service lands. During the winter and spring of 1990, Dale Taylor and Phil Brease, NPS, initiated contact with Larry Mayo, U.S. Geological Survey (USGS), and Keith Echelmeyer, University of Alaska-Fairbanks (UAF). Larry Mayo quickly expressed interest in monitoring glaciers in park service units and began a formal dialog with Taylor and Brease, suggesting various monitoring opportunities and potential observations and research (Mayo 1990).

On February 5 through 7, 1991, the National Park Service held a glacier research workshop in Alaska to develop recommendations about glacier monitoring (Sturm 1991). Seventy people : representing universities, federal and state agencies, along with interested individuals : attended a three-day workshop on glacier research and monitoring. The goal of the workshop was to promote cooperation and coordination between groups. Those in the workshop recommended a NPS glacier monitoring system and examined the nature of this system and how it would fit in with ongoing or planned research programs. Additionally, a steering committee was formed to develop an inter-disciplinary group of interested parties to pursue five goals for the newly conceived permanent coordinating group for North American Glacier Observations. The steering committee consisted of Dr. Dale Taylor, NPS; Dr. Matthew Sturm, Cold Regions Research and Engineering Laboratory (CRREL); Dr. Carl Benson, UAF; and Mr. Gordon Nelson, USGS. As of this writing, the steering committee no longer exists, but the glacier monitoring ideas suggested for the NPS evolved into the glacier monitoring program at Denali National Park and Preserve, a direct result of the workshop recommendations.

In March of 1991, Larry Mayo (USGS) and Keith Echelmeyer (UAF) submitted a proposal to Phil Brease to begin monitoring three glaciers in Denali National Park and Preserve, Traleika, Kahiltna, and Kichatna[1], using a single point measurement method, referred to as the *index method*. This method adopts established USGS glacier monitoring standards and involves visiting an *index site* twice per year to measure mass balance, volume change, and rate of ice flow. An index site is a single 2.5 centimeters in diameter, 6- to 12-meter-long pole that is melted into the ice near the equilibrium line of the proposed glaciers. The proposed glaciers had straightforward geometry, spanned a large elevation range, each was in a distinct climatic region, and they were generally representative of other glaciers in the area.

Site selection and installation of survey monuments were done during the spring of 1991. Index site monitoring began in June 1991. It continued as a cooperative program with the USGS : specifically, Larry Mayo : from 1991 to 1997. Keith Echelmeyer has also been an instrumental cooperator with the program since its inception, helping with program development, technical assistance, field advisement, and informal review.

As mentioned in the introduction, the initially conceived objectives of the index site monitoring program, and the forthcoming entire glacier monitoring program, will establish the baseline conditions of selected glaciers, allowing us to better detect and understand glacial processes. Pursuing this objective also will help detect the effects of climate fluctuations as they happen. Using the data obtained, we can test dynamic models of climate and glacier flow and emerging hypotheses regarding the effects of climate change. The data also can help us estimate the effects of these changes on other related systems, such as the discharge of glacier-fed rivers.

The formulation of the complete glacier monitoring program also began in 1991. Phil Brease, Denali National Park and Preserve, proposed a glacial monitoring program (Brease 1991a) that included:

1) establishing the aforementioned index site monitoring,
2) establishing photo points for monitoring glacial surface and termini changes,
3) investigating sites for automated weather stations near each index site, and
4) performing longitudinal surveys to monitor ice volume changes and surge-type glaciers.

At the same time in 1991, Denali submitted a proposal to the national Inventory and Monitoring Program to become a prototype LTEM program. In January 1992, Van Horn (1992) outlined the proposed program, which included a glacier monitoring component. LTEM program development continued in April 1992 when an inventory and monitoring workshop was convened at the University of Alaska – Fairbanks campus. The workshop goal was to describe, through research and development, a core monitoring program which would be transferable to other parks and implementable by resource managers and technicians. The meeting was structured into disciplinary sessions addressing major ecosystem components to be examined in pilot research (glaciers, climate, soils, aquatic systems, vegetation, birds, and small mammals). Some arguments concerned inclusion of glaciers and exclusion of large mammals from pilot research. A glacier monitoring element was incorporated into the conceptual watershed model because of glacial presence in many headwaters in Alaska's ecosystems, role in shaping the physical environment, and importance as early indicators of global climate change. From this meeting forward, glacier monitoring has been included as a component in the Denali LTEM program.

Fieldwork continued in ensuing years under the general direction of the draft monitoring plan described earlier (Brease 1991). The fieldwork consisted of index measurements (including geoid refinement), termini mapping, longitudinal surveys, and movement surveying. Larry Mayo agreed to a formal volunteer position in 1993, with a detailed description of duties to support the index site monitoring portion of the glacier monitoring program. By June of 1994, the direction of the Denali LTEM program required monitoring components to establish formal protocols, including methodologies, field procedures, data reduction protocols, and publication goals. Phil Brease completed a draft glacier monitoring protocol in December 1994 (Brease, 1994). It included the index method of mass balance, weather stations near the index sites, elevation surveys, flow rate stations, terminus monitoring and photo points, and water outflow monitoring. Early in 1995, Denali LTEM contacted Larry Mayo about developing a protocol and field procedure manual specifically for the index site monitoring. A formal contract was announced in 1996 and awarded to Larry Mayo in 1997.

Also in 1996, the National Inventory and Monitoring program sent an interdisciplinary review team to Denali to review the LTEM program. Reviewers had two chief concerns: (1) monitoring in Rock Creek seemed poorly linked to resource management goals, issues and threats, and (2) current efforts seemed more focused on answering research questions than on ecosystem monitoring. Reviewers noted major differences in opinion among researchers and park staff on program goals. The review team recommended holding a workshop in spring 1996 to solidify program goals and objectives. The review team also noted the need to move from intensive monitoring in Rock Creek to more extensive monitoring throughout the park. Pursuant to the review, a workshop to "establish the conceptual framework for implementing Denali's Long-term Ecological Monitoring Program" occurred in July 1996. The development of the glacier monitoring program did not change significantly as a result of the review or workshop.

The glacier monitoring protocol draft, prepared by Phil Brease and Jamie Roush (hired as a NPS physical science technician for glacier monitoring in 1996), was submitted to the Alaska Science Center for review. William Seitz (of the Alaska Science Center) returned the reviewers comments to Steve Martin, Denali Superintendent. Phil Brease and Jamie Roush responded to comments and made appropriate changes to the protocols. The revised protocols were considered complete after the revisions. The glacier monitoring protocol (Roush and Brease, 1997) included design considerations, sampling methods for index measurements, aerial reconnaissance and photography, remote sensing (SAR-synthetic aperture radar), stake net surveys, topographic surveys, and data management.

The stake network included in the protocol by Roush and Brease (1997) included a stake net on a *benchmark* glacier, the East Fork Toklat Glacier. Formal protocols and standard operating procedures were not produced, but with the technical assistance of Keith Echelmeyer, a network of monitoring stakes was installed on the East Fork Toklat Glacier in 1997 and measured twice annually. Longitudinal surveys, terminus surveys, photo documentation of conditions, and index measurements continued after the protocol acceptance in 1997. Roush and Brease (1998) provide a data summary and analysis for 1991 through 1997, primarily of the index site data that Larry Mayo prepared. Larry Mayo transferred responsibility of index site measurements to Denali in 1998, providing comments and technical assistance briefly thereafter.

In 2000, Jamie Roush's four-year position ended as a physical science technician for glacier monitoring. A new physical scientist position to oversee glaciers, air quality, weather, and snow, developed by the LTEM program and announced in 2000, became the responsibility of Guy Adema, who began work in January 2001. No glacier monitoring fieldwork occurred in 2000.

In April of 2001, Larry Mayo presented the park with the "Manual for Monitoring Glacier Responses to Climate at Denali National Park, Alaska, Using the Index Site Method" (Mayo 2001). Developed after the contract award in 1997, the manual had periodic reviews by James Roush between 1998 and 2000. The manual went to two USGS staff for review in 2002, Chester Zenone and Robert Krimmel. They submitted their comments to Denali later that year.

During the fall and winter of 2001, an internal review of the Denali LTEM program occurred. Many components had formally shifted in design from a watershed approach to a landscape approach, though no changes affected the glacier monitoring program.

Glacier monitoring continued in 2001 and 2002, with index site measurements, a GIS-derived glacier inventory, terminus surveys, longitudinal surveys, radar depth measurements, Muldrow glacier outflow monitoring, photo-point documentation, glacier movement surveys, glacial landform mapping, surging glacier monitoring, and a reconnaissance glacial invertebrate survey. In 2001, temperature loggers were installed on the index sites and a few other locations near the equilibrium line altitude (ELA) of the monitored glaciers.

Surveys prior to 2001 were completed with conventional techniques. In 2001 a survey-grade differential GPS system was acquired through the Denali Fee Demo program. Using this equipment, LTEM staff could perform surveys in significantly less time with a much smaller field party, and in inclement conditions. However, the equipment also introduced complications in integrating data from both techniques. LTEM staff spent the winter of 2002 overhauling the database that was formally maintained by Larry Mayo for use with data acquired through GPS. Data acquired from 1991 through 2002 from other areas of the protocol are being compiled and reduced during 2003.

Data Summary and Highlights

Summary of Monitoring Data

Table 4 (*next page*). Data acquired in the glacier monitoring program at Denali has been compiled in the table on the following page. It identifies which data were collected in each year since the glacier monitoring program began in 1991.

Table 4

	Traleika Index[1]	Kahiltna Index[2]	East Fork Toklat [3]	Terminus Monitoring[4]	Longitudinal Surveys[5]	Movement Surveys[6]	Surge Monitoring[7]	Photo documentation[8]	Other[9]
1991	spring, fall	spring, fall							
1992	spring, fall	spring, fall		Middle and West Toklat, Foraker				Muldrow	
1992	spring, fall	spring, fall		Middle and West Polychrome, Cantw ell		Muldrow			
	spring, fall	spring, fall			Muldrow	Muldrow			
1994	spring, fall	spring, fall			Muldrow	Muldrow			
1995	spring, fall	spring, fall				Muldrow			
1996	spring, fall	spring, fall				Muldrow	Slippery	Park flight	
1997	spring, fall	spring, fall	Installation, fall						
1998	spring, fall	spring, fall	spring, fall						
1999	spring, fall	spring, fall	spring, fall						
2000	none	none	none						
2001	spring, fall	spring, fall	spring, fall	Heron, Sunrise, Sunset, Muldrow , Kahiltna, Polychrome	Muldrow	Muldrow , Tokositna	Lacuna, Tokositna	Upper Muldrow	Glacier landform mapping on 11 glaciers, glacier invertebrate survey, temperature loggers installed at index sites.
2002	spring, fall	spring, fall	spring, fall	Cantw ell, Middle Fork Toklat	SE Kahiltna, Middle Fork Toklat, Polychrome	Ruth, Muldrow , Brooks		Middle Muldrow	Radar depth measurements on EFToklat, SE Kahiltna, Muldrow . Water level meter installed on Muldrow outflow .

[1] Surveying of index site on the Traleika Glacier.

[2] Surveying of index site of the Kahiltna Glacier.

[3] Surveying of stake net on the East Fork Toklat Glacier.

[4] Terminus surveys involve a detailed survey of the terminal position of the glacier.

[5] Longitudinal surveys involve a detailed survey of the centerline of the glacier, allow ing for general volume change calculations.

[6] Movement surveys involve a precise survey of movement targets over a know n time period in order to determine flow characteristics of a glacier.

[7] Surge monitoring includes surveying, photo-documentation, stream monitoring, and any other related characteristics that can be recorded before, during, or after a glacier surge.

[8] Photo documentation may be at surveyed photo-points, through oblique aerial photography, or re-occupying approximate locations of historical photos.

[9] Other glacier monitoring efforts are pursued opportunistically, w hen personnel w ith special skills and interests are available, or w hen logistics and conditions allow .

Index Site Data Highlights

Preliminary mass balance data from the Traleika and Kahiltna glacier index sites appears in Figures 1 and 2. Casual observation of these data suggests some interesting findings. With regard to mass balance, there does not appear to be a strong trend for the Kahiltna Glacier (Figure 1), though Traleika Glacier (Figure 2) has been consistently negative throughout the study. Flow rates for Kahiltna Glacier have been steady at approximately 200 meters per year and the glacier has thinned by about 3 meters since 1991.

The Traleika Glacier, however, has exhibited much more interesting behavior. The surface height of Traleika Glacier has increased some 25 meters since 1991 despite the negative annual mass balances and the rate of flow has nearly doubled. Because flow rate is partly a function of the ice thickness (under normal flow conditions), the increase in speed is consistent with the thickening of the ice. The cause of the glacier's thickening, however, is less clear. A strong possibility is that Traleika Glacier is storing ice in advance of the next major surge of the Muldrow Glacier, of which the Traleika is a tributary ice stream. Surging glaciers are known to increase their thickness and speed near their equilibrium line prior to a surge. The Muldrow Glacier has surged approximately every 50 years. The last surge of the Muldrow occurred in 1956; the next should occur near 2006.

Another interesting finding appears in the anti-correlation between the annual mass balances of Kahiltna and Traleika Glaciers. Comparison of the equilibrium line altitudes shows that in years in which the balance of Kahiltna Glacier is positive, that of Traleika Glacier is negative, and vice versa (with the exception 1992). The high ELA on Kahiltna Glacier in 1992 was the result of a coating of volcanic ash from the eruption of Mt. Spurr (south of Denali NP&P on the Alaska Peninsula), which increased melting by heat absorption. This condition was observed in the field. In all other years, the anti-correlation is obvious. Further analysis would determine the cause of the anti-correlation. Possible explanations are that the orographic effect of Mt. McKinley causes snow fall and cloud cover to concentrate on only one side of the mountain in a given year, or that an annual variation in climate exists between the two sides of the Alaska Range.

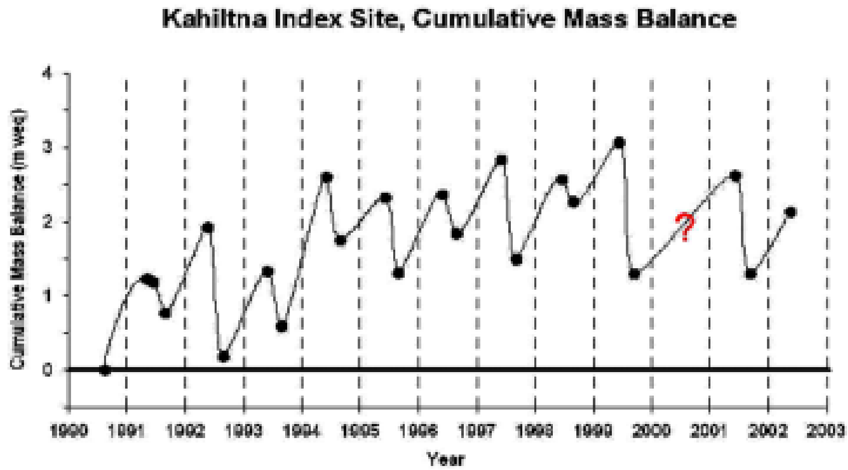

Figure 1. Cumulative local mass balance at the Kahiltna (K17) index site. Data is missing for spring and fall 2000 and is marked with a “?”. Solid line indicates the zero mass balance level. Data is in reference to Fall of 1991.

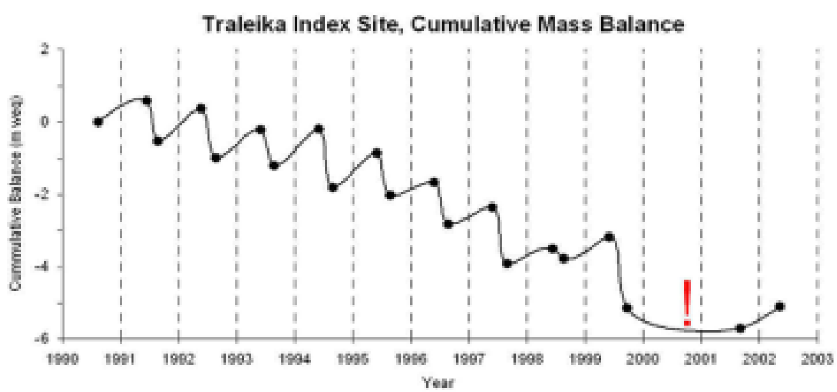

Figure 2. Traleika Index Site. Local cumulative balance measured at the Traleika (T02) index site. Data is incomplete in 2000 and is marked with a “!”.

Terminus Monitoring

Two of the processed terminus surveys are provided as examples for this report, the Cantwell Glacier and the Middle Fork Toklat Glaciers. The Cantwell Glacier terminus is retreating at a rate of approximately 10 meters per year (Figure 3). The Middle Fork Toklat Glacier terminus is retreating at an average rate of retreat is 24 meters per year (Figure 4).

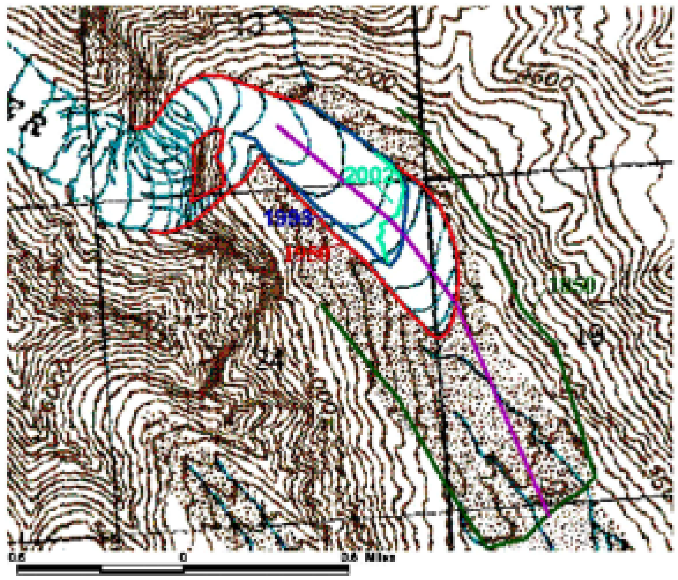

Figure 3. Map showing the locations of the Cantwell Glacier terminus.

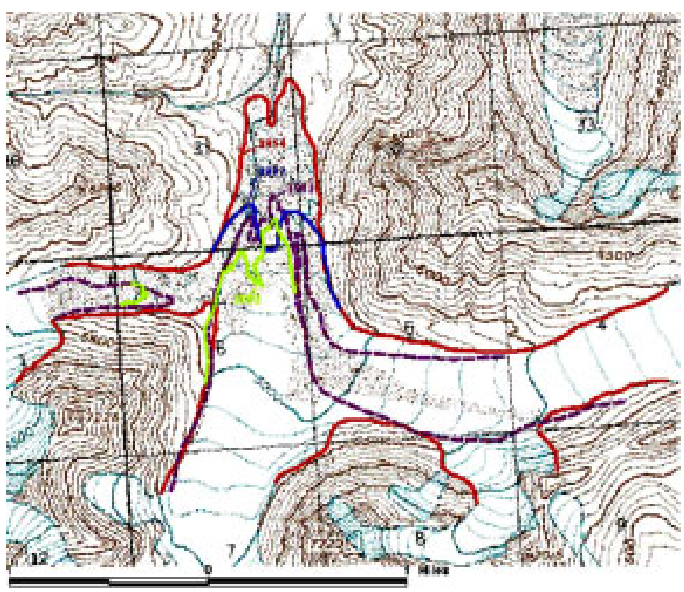

Figure 4. Map of the terminus locations of the Middle Fork Toklat Glacier.

Longitudinal Monitoring

Volume loss estimates of the Middle Fork Toklat glacier were made using ArcView, the centerline elevation data and the USGS Healy B6 quadrangle. The centerline data was taken in the field August 2002 and from the USGS Healy B6 quadrangle, which is based on 1954 aerial photography. The area of the glacier surface was taken from the terminus study measured in the field August 2002 and from the USGS Healy B6 quadrangle. The total volume change from 1954 to 2002 is -3.30×10^8 m^3. The rate of volume change is -6.88×10^6 m^3/yr.

Longitudinal surveys on the East Fork Toklat glacier also indicate a loss of more than 3 meters per year of water equivalency. Further analysis of longitudinal surveys is expected to reveal similar results on other lower elevation glaciers. The data from LTEM longitudinal monitoring is consistent of that performed by laser altimetry by Keith Echelmeyer, Anthony Arendt and others, who published their results from Denali and other Alaskan glaciers in Arendt and others (2002).

Surge monitoring

During the surge of the Tokositna Glacier in 2001 maximum ice velocities of more than 2 meters per day were measured, the surge front was surveyed, and the outflow was sampled. The data gathered will yield valuable insight to the mechanisms of surging glaciers. The events were discussed in Echelmeyer and others (2002) and were published in multiple newspaper and television articles in 2001.

Personnel

Guy Adema, Physical Scientist, Denali National Park and Preserve. Began work on Denali glacier monitoring program in January 2001.

Phil Brease, Geologist, Denali National Park and Preserve. Initiated Denali glacier monitoring effort in 1990, worked closely with the glacier monitoring program through 2000, still involved in program advisement and development

Keith Echelmeyer, University of Alaska - Fairbanks. Helped initiate Denali glacier monitoring in 1990, instrumental in index and benchmark monitoring site installations, continual technical advisement.

Larry Mayo, USGS – Water Resources Division, retired. Helped initiate Denali glacier monitoring program in 1990, acted as a formal volunteer performing index surveys and data analysis from 1991 to 1997, authored a manual for index site measurements in 2001.

Jamie Roush, Physical Science Technician, Denali National Park and Preserve. Worked on glacier and climate monitoring programs from 1996 to 2000, developed glacier monitoring protocol, established benchmark monitoring sites on East Fork Toklat Glacier, liaison to index site manual authored by Larry Mayo.

Pam Sousanes, Environmental Protection Specialist, Denali National Park and Preserve. Field assistant for glacier program since 1996.

Seasonal Assistants. All work completed for the glacier monitoring program could not have been done without the hard work of seasonal assistants and Geological Society of America GeoCorps volunteers: Paul Atkinson, Meg Perdue, Gregg Probst, Chad Hults, Andy Irvine, Simone Montayne, Nichole Alhadeff, Adam Bucki, Trent Hubbard, and Austin Baldwin.

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Endnote

[1] Kichatna is a region found in the southwest of Denali; a specific glacier was not identified.

Snow Monitoring

Pam J. Sousanes,
Denali National Park and Preserve

Introduction

Denali National Park and Preserve (Denali) consists of six million acres. The highest peaks of the Alaska Range arc east to west, creating two major climate regimes within park boundaries: a transitional maritime climate to the south and a continental interior climate to the north. In the winter months most of the precipitation falls as snow on the south side of the Alaska Range, true to the transitional maritime climate. The north side of the range receives snow, but usually not as much and usually less dense. Snow surveys provide a good indicator of variation in winter precipitation from the northern to the southern extents of the park.

In cooperation with the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), snow data are collected on a monthly basis at Denali from November through April yearly at 13 sites in and around the park. Six of these sites are snow courses, requiring ground measurements, and seven are aerial markers. The information collected for the snow surveys includes snow depth, length of snow core, and sample weight. Snow density and snow water equivalent (SWE) are calculated from the collected data. Aerial surveys are conducted for sites that have no appropriate fixed wing landing area nearby. For the aerial surveys, we record the snow depth and calculate density using data from the nearest site.

The six snow courses are located on the north side of the Alaska Range at Kantishna, Minchumina, Purkeypile, Stampede, Lower Rock Creek Ridge, and Upper Rock Creek Ridge (Figure 5). The seven aerial snow markers are located on the south side of the range at Eldridge Glacier, Tokositna River, Dutch Hills, Ramsdyke Creek, Nugget Bench, Chelatna Lake, and Yentna. Snow courses are permanently marked locations where Denali Long-term Ecological Monitoring (LTEM) staff measure snow depth and snow water equivalent. Most snow courses consist of five to ten sample points. The snow courses in Denali all have five sample points. Individual measurements are averaged to derive one value of snow depth and SWE for each course. Aerial markers are 10- to 12-foot posts with horizontal slats affixed every foot. By flying in a fixed-wing aircraft past the markers at low altitude and reading the height of the snow on the marker, LTEM staff can obtain snow depth.

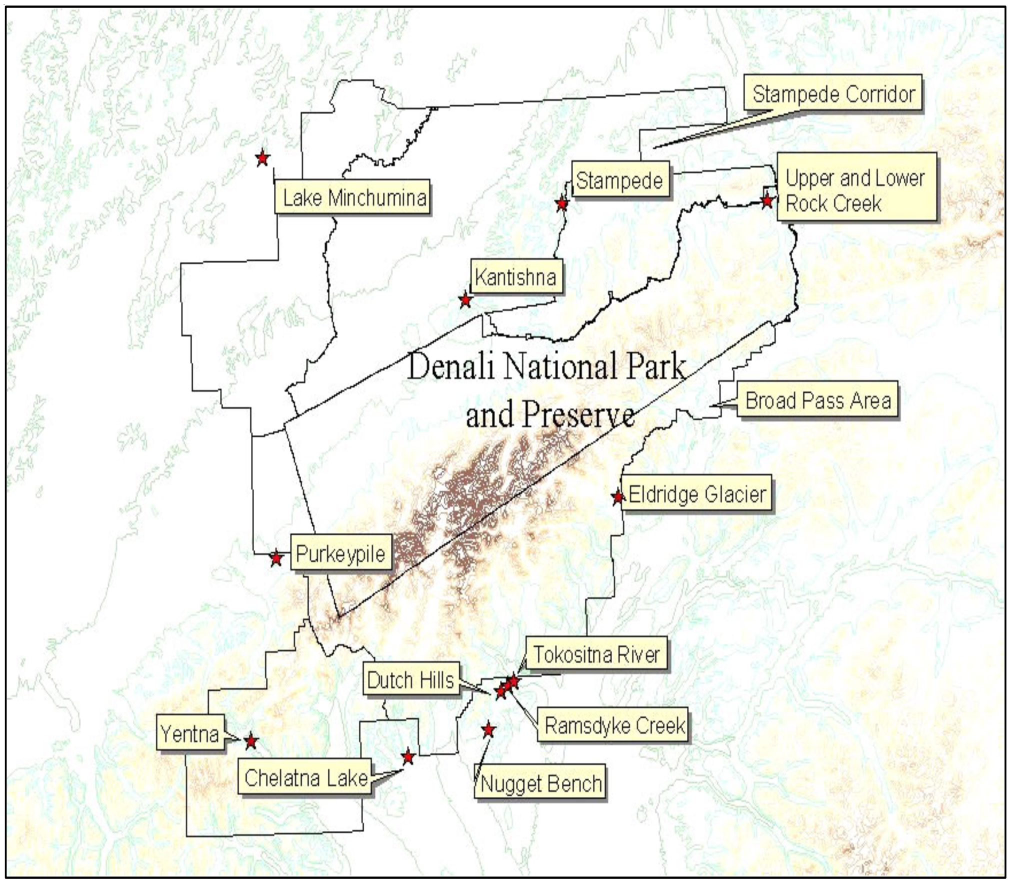

Figure 5. Map of snow course and snow marker locations in Denali

Once gathered at the park, we send the data to the NRCS for compilation and dissemination on a statewide basis. All data are archived with NRCS. The NRCS has operated the Federal-State-Private Cooperative Snow Surveys in the western United States since 1935. Initially more than 2,000 snow courses were established in Denali to collect information on mountain snowpack, which provides over 75 percent of Denali's west-side water supply. The current network consists of approximately 800 active snow courses.

Overview of Project History

General Approach to the Project

The objectives of the snow survey are to obtain, manage, and disseminate high-quality information on snow, water, climate, and hydrologic conditions.

The original specific park objectives were:

- To continue to provide snow data to the NRCS statewide network.
- To continue to provide data to park scientists and management and to outside researchers for numerous projects spanning from maintenance to research.
- To determine, through the addition of data points, the spatial and temporal variation of snow cover park-wide.
- To understand the key relationships between snow cover patterns and the physical and ecological ecosystems within the park.

In 1999, an additional objective was added to the program corresponding with the completion of the *Conceptual Design of the Long-term Ecological Monitoring Program for Denali National Park and Preserve* (Oakley and Boudreau 2000) that highlighted a management focus objective as well as an ecological focus objective. The methods of snow monitoring were adopted for a particular area of the park of concern to management, and within the scope of long-term monitoring.

The objective of the adequate snow study is to characterize the snowpack of areas within Denali frequently used by snowmobiles and to determine whether a definition of adequate snow cover could be developed for Denali that would help park managers decide when an area should be opened or closed for snowmobiling.

Snowpack information provides additional understanding of a large number of natural resource processes within the park. This includes wildlife research such as population density, birth survival rates, herd movements, and vegetation succession, as well as hydrologic information regarding surface water supply.

Project Organization

Start–up Phase

In 1992, the original Denali Long-Term Ecological Monitoring (LTEM) proposal recommended installing snow courses in cooperation with the Soil Conservation Service (SCS). Before 1992, the daily snowfall amount at the National Weather Service Cooperative Weather Station at Denali Park Headquarters provided the only information on snow depth recorded at the park. In 1993, the SCS assisted with the installation of a snow pillow at the Air Quality site near Denali National Park and Preserve headquarters. Gordon Olson, Chief of the Division of Research and Resource Management, recommended that additional snow survey sites should be co-located with other ongoing winter park functions to reduce costs.

In 1993, Denali entered into an agreement with the SCS to conduct snow surveys at two new snow courses established in the Rock Creek drainage and one existing snow course at Lake Minchumina. In 1995, the area expanded to include other existing aerial snow survey markers on the south side of the Alaska Range along the park's boundary. These existing sites had been in operation under the SCS program, but because of funding issues could not continue without the support of the National Park Service (NPS). In 1995, two new snow courses were established at Kantishna and Purkeypile. A Memorandum of Agreement between the National Park Service and the Natural Resources Conservation Service (NRCS –formerly the SCS) on Snow Surveys was signed in February 1995.

In 1994, Phil Brease suggested adding snow temperature sensors to the micrometeorology sites in Rock Creek. Additional data loggers were purchased that would record surface temperatures and snow temperatures at varying depths. Phil Brease, Paul Atkinson, and Jan Richter originally installed the sites in 1994 and 1995. The sites needed to be reestablished each year due to damage sustained by wildlife, snowpack, and frost heaving. The site at Permafrost was badly damaged by moose and tower failures, and was not reestablished after 1998.

Spatial Expansion

In 1999, park management decided to obtain snow depth information from specific areas of the park popular with snowmobile users. Since no snow courses or aerial markers existed near these areas, Jamie Roush, Phil Brease, and Pam Sousanes developed a sample design that incorporated the snow survey protocols within the study area. Five sites were established and snow monitoring took place at these locations periodically throughout the winter. LTEM staff now use this information to determine when the snowpack becomes adequate for snowmobile use without damaging the underlying soils and vegetation. The adequate snow study sampling interval does not follow NRCS protocol; therefore, the data are not forwarded to the NRCS data officer. The data are archived at the park and reports that document the data collected have been produced for 1999 to 2000, 2000 to 2001, and 2001 to 2002.

In 2002, the number of snow markers and snow courses was increased to cover variable terrain more effectively and to integrate data with other long-term monitoring programs. One additional snow course was installed in the summer of fiscal year 2002 at Stampede Mine Airstrip, a site co-located with new weather stations. Co-location makes data collection and maintenance of the two monitoring components more efficient and affordable. Additional aerial markers were established at sites on the south side of the range near Eldridge Glacier and the Upper West Fork Yentna. LTEM staff will collect data from these additional stations in fiscal year 2003 and report the data in the same manner as that collect in 2002.

The addition of snow courses and aerial snow markers will provide park managers with additional information on snow cover around the park while providing scientists with data that is useful for research projects including population dynamics, subsistence issues, vegetation changes, and glacier mass-balance. This strategy of adaptive monitoring will fill data voids and provide useful information for elected grid sites used by other LTEM components. Snow monitoring, similar to climate monitoring, is not efficiently sampled at the mini-grid level (Roland et.al. Minigrid Report, 2003); instead, representative sites are chosen that can provide information for a particular region.

A cooperative study at Denali NP&P between the National Park Service and the U.S. Geological Survey (USGS) took place in 2001through 2002 to determine the occurrence and distribution of polyaromatic hydrocarbons (PAH) in park aquatic environments. Snowmobile emissions may affect such park aquatic environments. LTEM funding in 2002 was used to deploy semi-permeable membrane devices (SPMD) designed by USGS scientists at the Columbia Environmental Research Center (CERC) to mimic the bioconcentration of hydrophobic organic contaminants such as PAHs. The SPMDs were deployed in Camp Creek in the Dunkle Hills, an area identified by the NPS as heavily traveled by snowmobiles. LTEM staff had attempted the year before to sample larger stream systems, but high spring flood events and ice jams in the selected rivers prevented recover of the the SPMDs. During 2001, a reference watershed also was selected to measure any background PAH contamination (i.e., non-snowmobile related) in park surface water. The stream flow on the watershed chosen this year is lower, but the concentrations of snowmobiles in the drainage area are high. In 2002, the samples were left in the stream for more than 90 days and recovered at the end of the summer season. These samples were shipped to the USGS Columbia Environmental Research Lab (CERL) for analysis, along with the reference sample.

Status

Snow surveys will continue indefinitely at all of the sites listed in Table 5. There may, however, be changes in schedules as budgets permit, reducing the surveys to one or two times each winter rather than monthly.

The snow surveys occur every month from November through April and the data are sent to the Data Collection Officer at NRCS for processing, dissemination, and archiving. The data also is archived in files at the park, and the data is summarized on an annual basis for park and LTEM reports at the end of the season.

Table 5. Current Snow Survey Sites—Dates of Operation

Site	Year of Installation	First LTEM survey
Rock Creek Bottom	1993	1993
Rock Creek Ridge	1993	1993
Kantishna	1995	1995
Purkeypile	1980	1995
Lake Minchumina	1967	1993
Stampede	2002	2002
Eldridge Glacier	2002	2002
Tokositna Valley	1980	1995
Ramsdyke Creek	1980	1995
Dutch Hills	1980	1995
Nugget Bench	1968	1995
Chelatna Lake	1964	1995
Upper W. Fork Yentna	2002	2002

The Adequate Snow Study, which assesses the snow conditions in areas popular with recreational snowmobilers, focuses on the physical aspects of the snowpack that may allow adequate support of snowmobile travel without adversely affecting vegetation and soils. In 2003, established sites were visited monthly to determine the depth and density of the snowpack in the Broad Pass area south of Cantwell. The study began in mid-November with the first significant snowfall. LTEM staff compiled data for park managers to determine snowmobile access within the park. Reports, photos, and data were archived within the snowmobile files; these files were established at the park as part of the administrative record for snowmobile use.

After 1995, records for the snow pillow at headquarters are minimal. The entire site (Air Quality area) was reconstructed in 1998, and monitoring equipment was damaged. We attempted to restore the snow pillow in 1999, but were unsuccessful. There is no discussion in the existing documentation regarding the reasons for installing the snow pillow at this location, where a plethora of other precipitation measurements already exists. If program managers decide not to restore the snow pillow operation, the instrument will be removed and the site rehabilitated. If the data are deemed valuable then the snow pillow will be restored and operated in the winter, since the infrastructure for the measurement is already in place. More discussions will ensue regarding the necessity of a snow pillow at this site.

Summary of Products

The snow survey data is summarized in annual reports either as a stand-alone report or as part of the annual climate summary. NRCS also publishes Monthly Basin Outlooks for the state of Alaska that includes data from the 13 sites in and around Denali1. Reports are on file for the Adequate Snow Study for all years of the project, and the final report from the USGS/NPS cooperative study of assessing PAH contaminants is on file at the park.

Protocols and Reviews

Snow temperatures in Rock Creek – Protocols included in peer reviewed final draft of Weather Monitoring Handbook, 1997.

Snow Course Surveys – NRCS Snow Sampling Guide (Handbook No. 169)

Adequate Snow Study – Methods of Study 1999. Jamie Roush

See list of reports and documents at end of this section.

What Have We Found out about Snow?

Because of the availability of a 30-year data record from some of the snow survey sites, we can calculate average snow depths and snow water equivalencies (see Table 5). The averages are estimated if the sites are less than 30 years old. Table 6 shows the monthly snow-depth averages since 1961.

Table 6. Monthly snow depth averages 1961 to 1990 – NRCS Snow Surveys

Snow Course	Elevation (ft)	February (in.)	March (in.)	April (in.)	May (in.)
Chelatna Lake	1650	33	40	42	37
Dutch Hills	3100	62	77	76	74
Nugget Bench	2010	44	52	57	51
Ramsdyke Creek	2220	56	66	70	60
Tokositna Valley	850	44	53	56	46

The Adequate Snow Survey has taken place at Denali for four winter seasons and we have seen much variability in the snowpack over the first four years (1999 to 2002). During 2000 to 2001 and 2001 to 2002, the recorded snow depths were much lower than the previous two years, with an adequate base, defined as 24 inches of snow, not occurring until late in the season (late January to early February). During March of the first season, the average snow depth was 54.9 inches; for 2002 to 2003, the March average depth was 36.8 inches. During the first two seasons, LTEM staff collected data from the north side of the Alaska Range, but there was not enough snow for access to these north side sites in the most recent years. Figure 6 shows the difference in snow depths during 2000 to 2001 between Headquarters and Broad Pass.

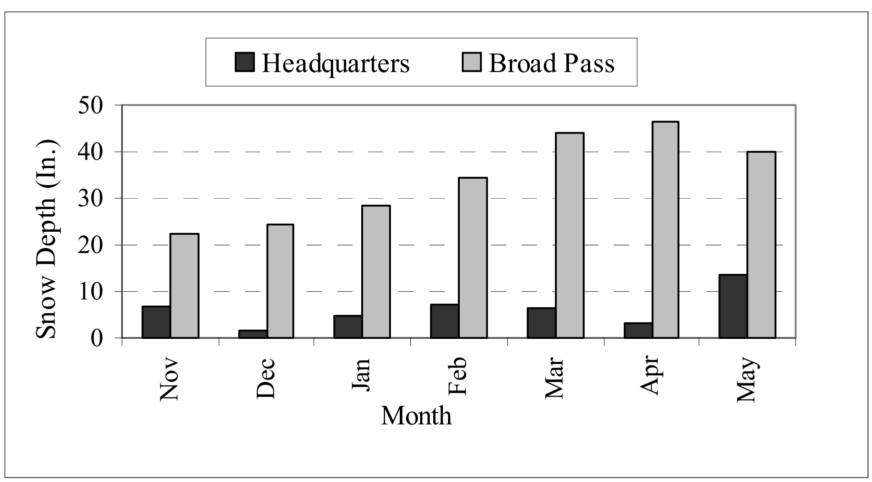

Figure 6. Snow depths at Headquarters and Broad Pass 2000-2001

The wide variability found within just a few seasons of this study supports the necessity of conducting long-term monitoring to assess trends in ecosystems. This is also obvious in the dataset for the Rock Creek snow survey sites. In 1992 we had record-setting snowfall in the fall that tended to skew the average over a five-year period. Such an occurrence also emphasizes the value of the 78-year record for the National Weather Service (NWS) Park Headquarters site, which provides a unique and invaluable data base for analyzing trends and patterns (see Figure 3).

Interestingly, the 2002 through 2003 season marks the lowest annual snowfall on record at the headquarters site with 30 inches total snowfall for the year. The record held before this winter was set in 1985 through 1986 with 33.7 inches. The "snow on" date for this winter was December 15, 2002 and the "snow off" date was April 13, 2003, the shortest season on record. The year with the greatest amount of total snowfall on record occurred during 1970 through 1971 with 173.6 inches.
A report from the USGS/NPS PAH project, summarizing analytical results and the potential biological implications of any detected PAH residues, was submitted to Denali National Park and Preserve in February 2003. No quantifiable PAH residues were found in the sample extracts from either the control site or the study site. However, a limited number of pesticide residues were found to be present in the deployed sample extracts above background levels.

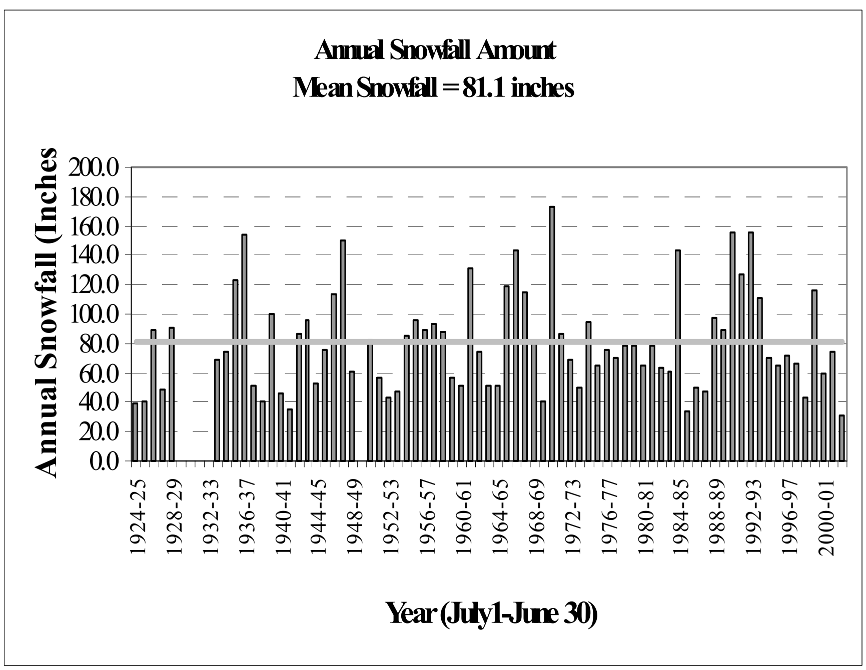

Figure 7. Snowfall Chart – NWS Headquarters Station

No evidence of any significant contamination was found from the analysis of these integrative samples. The 2004 plan for this project will depend on the interpretation of the results from this report.

Personnel changes for the LTEM Snow Monitoring Program

Major changes in personnel - The personnel changes for the weather monitoring program are the same as for the snow monitoring program.

1993 to 1996: Principal Investigator Phil Brease -Geologist (GS-12), Paul Atkinson –Technician (GS-5) (1993 to 1995)

1996 to 1998: Principal Investigator Jamie Roush - Physical Science Technician (GS-6/7)

1998 to 2000: Principal Investigator Jamie Roush - Physical Science Technician (GS-7), Technician –Pam Sousanes (GS-6/7) 1998 to 2000

2001: Principal Investigator Pam Sousanes-Physical Science Technician (GS-7)

2002: Principal Investigator Pam Sousanes - Environmental Protection Specialist (GS-9)

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Sousanes, P.J., G. Adema, and P. Brease. 2001. Assessing Adequate Snowcover and Snow Conditions for Snowmobiling. Winter Season 2000-2001. 19 pp.

Sousanes, P.J. 2002. DRAFT Assessing Adequate Snowcover and Snow Conditions for Snowmobiling. Winter Season 2001-2002. 11 pp.

Monthly Publications (February to May) available for all years of LTEM snow monitoring:

Natural Resources Conservation Service. Alaska Basin Outlook Report. (Month, Year)

National Oceanic and Atmospheric Administration. Climatological Data. Alaska (Month, Year)

Endnote

1 Website for NRCS:
http://www.ak.nrcs.usda.gov/Snow/snowsites.html

Weather Monitoring

Pam J. Sousanes,
Denali National Park and Preserve

Introduction

Climate has a dominant influence on the ecology of Denali National Park and Preserve, and understanding the key relationships affecting climate patterns plays a critical role in understanding and predicting physical and ecological changes within the park. The most direct and profound effects are likely to include changes in temperature and precipitation. Latitude, altitude, and continentality are the primary determinants of climate in the mountainous region of Denali.

The climate of Denali is characterized by great spatial variability, and includes both transitional maritime (influenced by the ocean) and continental (influenced by the Alaska Range) climate subtypes. The maritime climate on the south side of the Alaska Range is influenced by the prevailing weather patterns of the Gulf of Alaska, with milder air temperatures and less seasonal variation and more precipitation. On the north side of the range where the park headquarters is located, temperatures are typical of a continental climate with strong seasonal variations. There is also less precipitation on the north side because of its location on the windward side of a major mountain range. See Figure 8 for the generalized climate model for Denali.

Continentality

Denali lies approximately 140 miles north of the Gulf of Alaska, but the prevailing weather patterns generated by the Aleutian Low significantly affect Denali's climate, bringing considerable precipitation in the form of rain and snow to the windward side of the Alaska Range and moderating the air temperatures. On the north side of the range however, the continental interior climate conditions generated by the Arctic High prevail. Temperature variations from summer to winter are high, and precipitation is low.

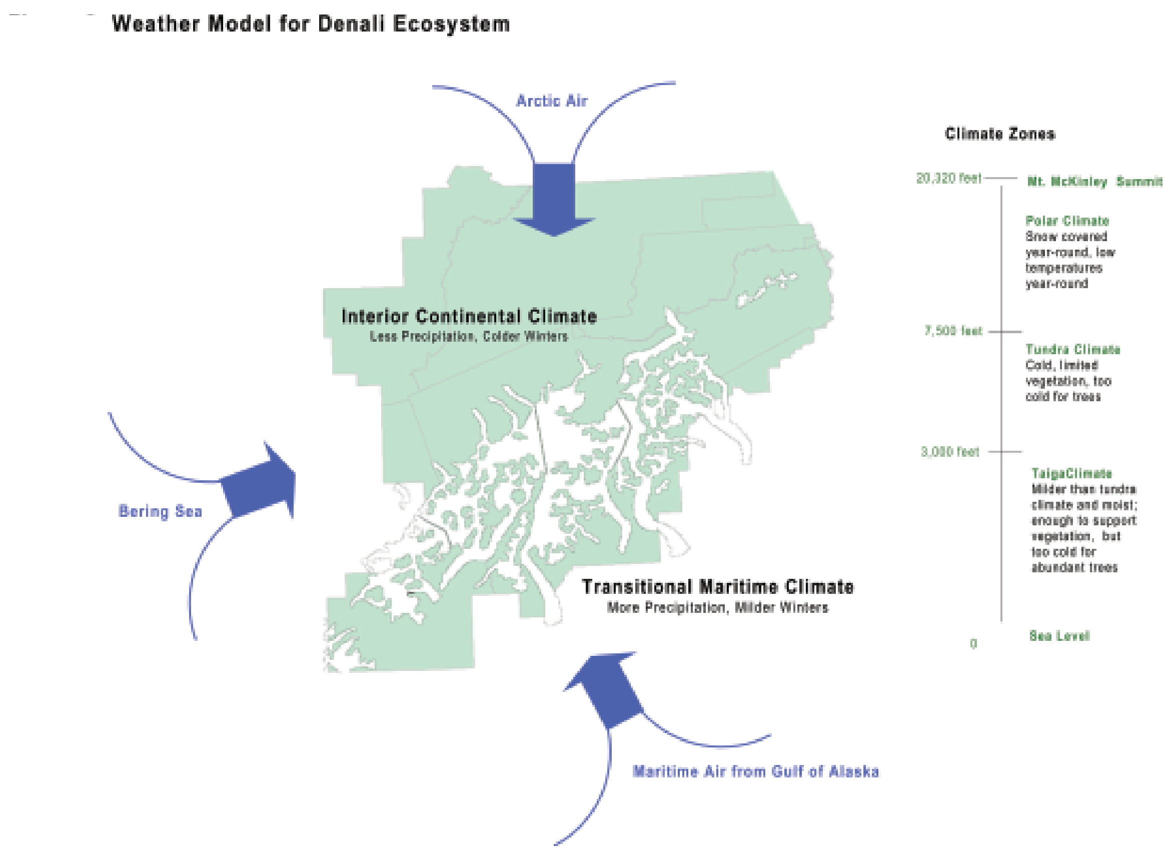

Figure 8. Generalized Climate Model for Denali National Park and Preserve

Latitude

One constant about Denali weather is that the extreme solar radiation conditions of high latitudes affect the climate in all subarctic areas. Denali is located between 62 degrees and 64 degrees north latitude and experiences strong seasonal fluctuations in incoming solar radiation with nearly 21 hours of daylight on the summer solstice and only about four hours of daylight on the winter solstice. The low sun angle at these latitudes means that even minor topographic features, such as low hills, can cause major differences in climate at the local level by shading. The heat gained during the long summer days is relatively small and highly dependent on surface properties such as topography and albedo. For instance, wet tundra and bare ground (with low albedo) absorb more solar radiation than do high-albedo glaciers. Similarly, wet snow absorbs more radiation than dry snow. Solar radiation during the winter months is minimal, and some areas are without direct sun for months.

The latitude of Denali affects its climate because not only latitude determines the angle of solar radiation and the length of day, but also because it determines Denali's exposure to latitudinal belts of surface high and low pressure. The belt of polar high pressure, known as the Arctic High, and Sub Polar low pressure, known as the Aleutian Low, affects Alaska. These pressure belts shift north in the summer and south in the winter, causing significant seasonal changes in weather and climate. Most of the precipitation that falls on the north side of the range falls as rain during June, July, and August.

Altitude

The elevational profile of Denali is impressive, with nearly a 20,000-foot difference from a low point of around 400 feet to Mt. McKinley, the highest peak in North America, at 20,320 feet. Temperature, atmospheric moisture, precipitation, winds, incoming solar radiation, and air density all vary with altitude. At the surface of the earth, temperature generally decreases with altitude. The rate of decrease is typically 65 degrees Celsius per kilometer. An exception to this rule is the formation of temperature inversions. In the winter, subarctic weather is dominated by the frequent occurrence of inversions (when warm air lies above a colder air layer near the surface). In summer, inversions are less frequent and weaker.

Overall, we monitor and record weather conditions at representative locations in Denali to identify long and short-term trends, to provide reliable climate data to other researchers, and to participate in larger-scale climate monitoring and modeling efforts.

Overview of Project History

A number of climate stations exist within Denali; the locations of the stations were determined by the original Long-Term Ecological Monitoring (LTEM) watershed approach and by fire management data requirements. This report summarizes the history, as it is known, of the climate and meteorology component of the LTEM program at Denali.

General Approach to Project

Programmatic objectives for the Weather/Climate Monitoring component of the LTEM program shifted somewhat as the program progressed. The reason behind the slight shift in objectives is unclear from the documentation, but we assume different personnel and management had an influence over the specific objectives of the period. The objectives described below originated from a series of LTEM annual reports.

Initial Objectives 1994 to 1996

Objectives for the Weather/Climate Monitoring component from 1994 to 1996 stated the following: To develop and test standardized meteorological measurements (including snow) for long-term ecological monitoring sites include

(a) establish baseline meteorological conditions for site characterization,

(b) document cyclic and long-term changes in the physical environment, and

(c) provide a record of the physical environment for describing ecological relationships and assisting the development of environmental models.

Objectives 1996 to 2001

Objectives for the Weather/Climate Monitoring component from 1996 to 2001 stated: The overall purpose of weather monitoring in Denali is to gather data in support of the numerous research and monitoring projects such as air quality data or vegetation data.

Other specific documented objectives taken from annual reports and from comments made by the Chief of Resources (Gordon Olson) in 1999 include:

- Provide meteorology data for real time applications in park operations, including fire management, mountain safety, aviation safety, and road maintenance.

- Collect data to determine how average climatic conditions vary throughout the park.
- Provide a system of instruments to characterize general climatic conditions across the entire park.

Objectives 2001

Objectives for the Weather/Climate Monitoring component in 2001 stated: The overall purpose of weather monitoring in Denali is to monitor and record weather conditions at representative locations in order to identify long and short-term trends, to provide reliable climate data to other researchers, and to participate in larger scale climate monitoring and modeling efforts.

Project Organization

Major Changes in Personnel

The weather monitoring program was run, for the most part, by technicians. As noted by project personnel, the weather monitoring program would have been stronger if there had been some direction from a specialist or coordinator overseeing the monitoring from the start. Seasonal technicians often did not have a clear concept of the overall objectives of the LTEM program, and spent most of their time on maintenance of the stations, not program development. Most of the success and credit for the stations that do exist go to the two GS-5 technicians who installed the initial stations in Rock Creek. See appendix 1 for personnel changes.

Start–up Phase

Rock Creek Watershed

In 1992, the majority of the various components in the LTEM program focused on the Rock Creek watershed. In the summer of 1992, Lyman Thorsteinson and Greg Probst installed two 10-meter meteorology towers, provided by the U.S. Fish and

Wildlife Service, in the Rock Creek drainage at an intermediate location along the ridge (Lower Ridge) and at an upper elevation (Tundra). These sites, referred to as mesoscale, or regional monitoring sites, were intended to give a broad view of weather integrated along the watershed's elevation gradient. By summer of 1993, the original two meso-scale stations had failed, the upper tower had bent over, and the sensors were destroyed.

In 1993, Paul Atkinson and Greg Probst replaced the two towers with new sturdier towers, which were anchored in concrete and properly guyed. The data loggers were upgraded and the sensors were replaced. Also in 1993, four 3-meter towers, complete with an array of meteorological sensors, were installed as part of the soils monitoring component. These were referred to as micrometeorology stations. The soil monitoring sites were selected in 1993 based on the USDA-Natural Resources Conservation Service Soil Inventory Report (Moore 1992) and the Denali vegetation inventory. The stations in the Rock Creek watershed range in elevation from 659 to 1338 meters

The stations measure air temperature, relative humidity, wind speed, wind direction, and solar radiation. One also measures summer precipitation and another measures barometric pressure. Instruments installed for the soils program measured soil temperature at multiple depths and soil moisture content at the four-micrometeorology stations. Data are recorded hourly and downloaded monthly.

Beyond the Rock Creek Watershed

These soil monitoring sites were established as part of the original core LTEM weather monitoring program. Other stations, which had been collecting weather data prior to 1992, were incorporated into the LTEM program along the way. Additionally, other stations established in the park after 1992 as components of other networks were incorporated into the LTEM program. These additional stations belong to networks not run by the LTEM program. This means that network-specific protocols or handbooks dictate many nuances of these stations and operations.

A National Weather Service (NWS) station has operated at park headquarters since 1925. Park Rangers have recorded daily weather observations at this site 365 days a year for the past 80 years (there are missing data however, especially in the early years). Both Eielson Visitor Center and Wonder Lake Ranger Station have similar stations where data are collected daily from early June to mid September. These stations run manually are part of the National Weather Service Cooperative Observer Program. The stations collect daily minimum and maximum temperatures and precipitation records.

In support of Air Quality Monitoring, a meteorology station has operated near park headquarters since 1980. Air Resource Specialists (ARS) is the data contractor for this meteorology station, with a protocol in place for data quality and control. Air temperature, relative humidity, wind speed, wind direction, solar radiation, and precipitation are measured at this station.

Phil Brease installed a manual air temperature station at an intermediate location on Rock Creek Ridge in December 1990. This station consists of a minimum/maximum thermometer in an NWS cotton shield. The temperatures are recorded in a logbook by sporadic recorders/skiers who pass by the station. The logbook is brought down periodically and the data are entered into an Excel spreadsheet.

Four Remote Automated Weather Stations (RAWS) exist in Denali ranging in elevation from 225 meters to 1006 meters. Three of the four are located on the north side of the Alaska Range: Wonder Lake (installed 1995), McKinley River (installed 1992), and Lake Minchumina (installed 1992). The other RAWS is located on the south side adjacent to the terminus of the Ruth Glacier (originally installed in 1996 at Ramsdyke Creek, and relocated in 1998). Air temperature, relative humidity, wind speed/direction, precipitation and fuel temperature are measured at all of these sites. Additionally, solar radiation and fuel moisture are measured at two of the sites. These RAWS stations are part of a contingent of more than 1150 stations within Alaska and the western U.S. managed by the National Interagency Fire Center (NIFC) in Boise. The Bureau of Land Management (BLM) Alaska Fire Service maintains the stations in Denali with the support of the National Park Service's Alaska Support Office Radio Shop and Denali Park staff. The data are recorded hourly and sent via satellite to NIFC every one to three hours.

An Automated Weather Observation Station (AWOS) operates at the McKinley National Park Airstrip as part of the network of

Federal Aviation Administration (FAA) sites located adjacent to almost all active airstrips and airports. These stations provide critical weather information to pilots. The real-time data are available via radio or telephone. The parameters measured are air temperature, wind speed and direction, dew point, visibility, cloud height and coverage, lightning data, altimeter, rain accumulation and fog/mist data.

There is a station at 5900 meters on Mt. McKinley that was installed by the International Arctic Research Center. There has been a station at this location since 1990. In June 2002, a new station was installed with satellite telemetry capabilities, making the data accessible via the web. This station records temperature and wind speed and direction.

Weather Stations for Specific Research Projects

A station existed that operated from 1995 to 2000 in support of various resource management projects along the road. This station was located between the Sanctuary and Teklanika Rivers in the area known as the Teklanika Flats. Data from the years it functioned are archived in the park's weather database. The measurements are the same as the Rock Creek stations, including summer precipitation. This site was removed in 2000 for a number of reasons: 1) the project it supported ended in 1999; 2) the station was located within view of park shuttle bus passengers; and 3) the station was located within the wilderness area of the park.

In1998, Jamie Roush built two stations to withstand conditions on Mt. McKinley. They operated for the summer only, and were pulled from the mountain at the end of the summer. The measurements from these were the same as those on the Rock Creek stations.

Middle Years of LTEM Weather Monitoring 1994 to 1998

There is inconsistency within the documentation as to when the Remote Automated Weather Stations (RAWS) were included under the LTEM umbrella. As early as 1992, the original proposal cited incorporating these stations within the LTEM program. The Annual Administrative Report for 1994 states that, in an effort to broaden the Denali study area, two existing weather stations were brought into the I&M network that year; these stations include McKinley River RAWS and Lake Minchumina RAWS. Many field notes from Paul Atkinson refer to numerous trips to the stations for repairs from 1993 to 1995.

In 1998, Jamie Roush worked on station installations for Mt. McKinley. The lower elevation station (2133 meters) operated during the summer of 1998, but the upper elevation site (known as the Edge of the World station at 4267 meters) ran only intermittently. It was difficult to troubleshoot the problems with these stations from headquarters by relaying suggestions to the climbing rangers. The stations were removed from the mountain at the end of the 1998 season. This was not solely an LTEM project, and other funding sources were used to operate these stations.

Spatial Expansion

Beyond the Rock Creek watershed and aside from areas of concern for fire management, Denali lacked strategically placed stations to characterize climatic conditions. In 2001, the direction of the LTEM program started shifting from watershed level studies. Discussions ensued about having weather stations in different climate regimes around the park that could tie in with the new mini-grid locations (Roland et al. 2003). It was not efficient or feasible to install complete weather stations at each of the proposed grid sites; instead, the physical science team members chose representative sites in different climatic regions that were not yet covered by current monitoring efforts. These sites were proposed to the LTEM staff at a meeting in October of 2001, and the sites were accepted as good regional locations for additional weather stations.

An important consideration when installing new stations is the access and expense of the location. Sites that are only accessible by helicopter are particularly expensive to operate. Two sites near remote airstrips were chosen for the initial expansion phase in 2002: Stampede Mine in the Toklat Basin north of the Outer Range and Dunkle Hills on the south side of the Alaska Range. The Stampede site was equipped with satellite telemetry for real-time data transmissions similar to the RAWS sites. The Dunkle Hills site was installed but needs to have the satellite transmitter and data logger added. This station is scheduled to be online in summer of 2003. See Figure 9 for weather station locations in Denali.

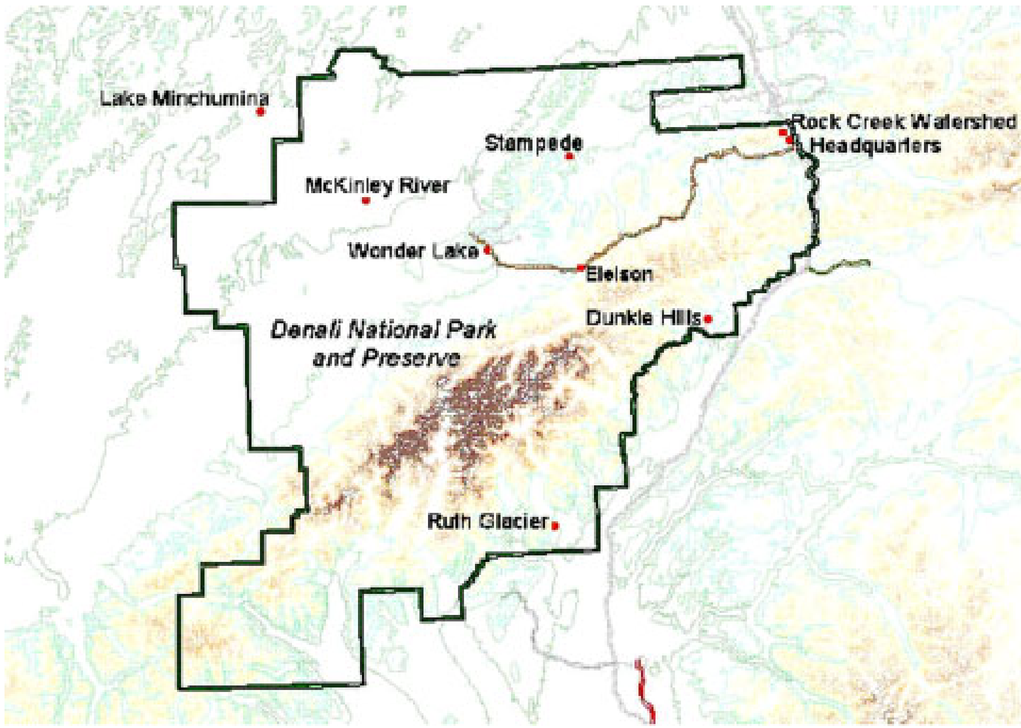

Figure 9. Locations of weather stations in Denali National Park and Preserve

Within the context of the Ecoregions of Alaska map, most of the park falls within either the Alaska Range ecoregion or the Tanana-Kuskokwim Lowlands ecoregion, with small fingers of the Cook Inlet Basin ecoregion extending into the broader valleys on the south side of the Alaska Range. Although both of the new stations fall within the Alaska Range ecoregion, the Stampede site will have some characteristics of the Tanana-Kuskokwim Lowlands and the Dunkle Hills site will have some of the Cook Inlet Region attributes. The stations were established in the fall of 2002, and are undergoing testing or "burn in" time. Because the Central Alaska Network's (CAKN) physical science component is moving forward, these two new stations will operate under the methods developed for the new CAKN stations for consistency. The data acquisition and data archiving methods will improve, along with improved data quality and control procedures.

Currently, Denali LTEM staff has begun the testing phase for physical science climate monitoring for the CAKN. Ten stations equipped with Campbell Scientific data loggers and sensors were purchased in the fall of 2002. The LTEM staff has begun assembling and testing at Denali headquarters in 2003, and may be placed in the field around the park to field test the power systems and satellite capabilities. Most of these new stations will be placed in Wrangell-St. Elias National Park and Preserve and Yukon-Charley Rivers National Preserve, and a few might be placed permanently in Denali.

See list of stations and years of record at end of this section.

Data Management and Reporting

Rock Creek Weather Stations

Campbell Scientific 21X data loggers are used for data collection at each of the six stations established in Rock Creek in 1993. Measurements are taken at 60-second intervals and recorded every hour. This data then are stored on an external storage module. These storage modules are swapped out monthly, and the data are downloaded into a computer. The meteorological sensors on these stations have been running since 1993, but the soils instrumentation and data quality are dubious after 1995.

The data from the early years (1993 to 1995) were stored in files on a dedicated Inventory and Monitoring computer that was backed up regularly. After 1996, this data was transferred to Jamie Roush's computer where the data was stored in raw data format and then compiled using MS Excel. In 2000, Pam Sousanes created an MS Access database for the weather data in Rock Creek, and updated the existing database for the NWS McKinley Park weather data (discussed below). Work on this database continues to evolve. In July 2000, after Jamie Roush vacated the position as PI for weather monitoring, Pam Sousanes received the data from Roush and entered it into the Access database. The annual summaries since 2000 have been done through queries built into this database.

As part of the CAKN, the LTEM team is working toward streamlining data transfer between weather stations and a user interface available on the web that would be available to the public. We are also working on archiving procedures and researching robust data quality and assurance techniques. New concepts and designs that may be developed for CAKN will include the existing stations at Denali (as well as the existing stations at the other two parks in the network).

National Weather Station Cooperative

This station has been operating since 1923 but is considered to have poor data quality because of the number of times the station has been moved during the past 80 years. The station originally was located at the confluence of Hines and Riley creek, and was moved to park headquarters in 1925. The station resides at the Denali dog kennels where instruments record observations each morning. Even though the data quality is considered poor, records remain valuable because of the longevity of the dataset and because it is the only record available for climate data prior to 1980.

In 1997, Jamie Roush acquired and validated the electronic database of daily records from the NWS manual station at the kennels for the period from 1988 to 1997. In 1998, Al Smith worked as a technician during the winter to validate the long-term record from this station. Smith spent the winter retrieving old paper and electronic records from the National Climatic Data Center and validating all the years of record (Smith 1998). Since 1998, Pam Sousanes has archived the weather data according to the LTEM Data Management Protocols.

This station often receives separate mention because of the long record of data collection and the type of data recorded. We can observe annual and seasonal temperature and precipitation trends over an 80-year period. The average air temperature is obtained from this station by averaging the maximum and minimum temperatures over a 24-hour period. Because we observe and record the data at 0800 for the previous 24-hours, the data actually accounts for the 24-hour period between 0800 the previous day to 0800 of the current day, but recorded under the current day's date. Direct daily comparisons with stations that collect hourly data, such as the RAWS and Rock Creek would produce inconsistent results. The temperatures that have been summarized over the past few years from the headquarters site have been taken from the uncorrected 80-year record, without the adjustment suggested by Juday (2000) to correct an anomaly that occurred in 1967 when the station was moved. The National Weather Service (NWS), the Western Regional Climate Center (WRCC) and the National Climatic Data Center (NCDC) use the uncorrected temperatures when distributing historical summaries. Research is needed to determine how the correction Juday has suggested can be applied universally to all archives of this dataset.

The annual summaries include the recorded temperatures, with no adjustments. The 80-year average air temperature from this station is –2.8°Celsius, with temperature extremes ranging from 32.8°C to –47.7°Celsius. The 80-year precipitation average for the site is 38 centimeters (15.2 inches) per year, including snowfall. The average annual snowfall is 202.8 centimeters (81.1 inches). See Figure 10 for summary.

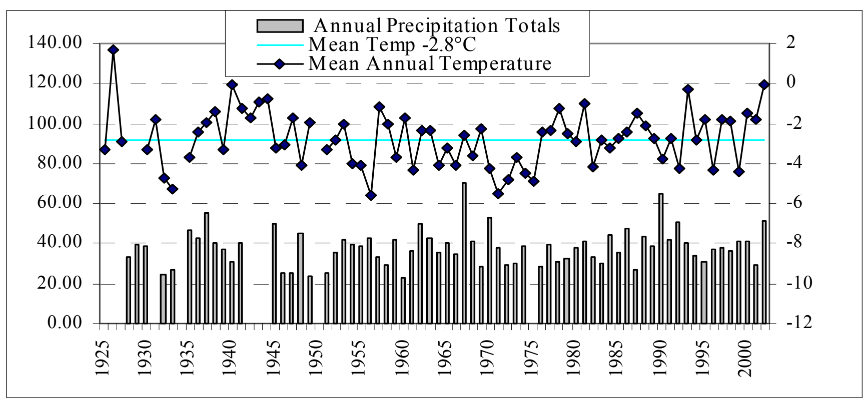

Figure 10. NWS Headquarters site annual precipitation temperatures.

Remote Automated Weather Stations (RAWS)

In 2001, Sousanes designed another table within the database for the RAWS data, and has worked to obtain and enter that data. Until 2001, the data from these stations were not summarized in annual reports. Reference in the reports was made to the web sites where the data were available. In 2001, summaries similar to those compiled for Rock Creek were done for three of the RAWS stations. The Ruth Glacier RAWS had many missing data values for 2001; as a result, the information was not summarized. The data are archived by the U.S. Forest Service Weather Information System (WIMS) and the Western Regional Climate Center.

Fire management officers at Denali use the fire index data from RAWS stations on a daily basis during fire season to assess climatic conditions for fire weather monitoring. These stations are on an annual maintenance schedule; sensors are swapped for calibration in June before the beginning of the fire season.

What Have We Found out about Weather?

Rock Creek Weather Stations

The data show an increase in average temperatures with an increase elevation for November through February. For example, the average monthly mean was 4.9 degrees warmer in January at Upper Ridge compared to Forest. Conversely, the monthly mean July temperature was 4.6 degrees warmer at Forest compared with the monthly mean at Upper Ridge (data taken from annual reports 1994, 1996, and 1998 to 2001).

July has the warmest monthly mean temperature (10.8°C) at all sites, and December has the coldest monthly mean temperature (-13.6°C). The winds increase from an average of about 1.3 meters per second at lower elevation sites to 4.3 meters per second at upper elevation sites. The proximity to the crest of the Alaska Range affects precipitation amounts, Headquarters receives slightly more rainfall than Lake Minchumina, and Eielson Visitor Center receives more summer precipitation than Headquarters, Wonder Lake, and Lake Minchumina.

We believe the most valuable contribution of weather data to the-long term monitoring program has been the use of weather data to support other research findings. For example, the latest correlation of weather data with another LTEM component related the variability in the aquatic macroinvertebrate community with winter temperature and snowfall data. In that respect, a few specific parameters became the key to the success, or in this case, failure of a community because of local climatic conditions. Tying in local climate events to specific phenomena will give us a better understanding about the complex interactions within the park's ecosystem.

What follows are just a few examples of requests for weather data used in correlation with other projects/research:

• Snowfall data for population dynamics modeling for caribou and wolves – Layne Adams, USGS-BRD

• Weather anomalies affecting Grizzly bear cub production in spring of 2000 – Pat Owen, NPS

• Small mammal abundance based on derived climate indices – Ed Debevec, Eric Rextad, UAF

• Watershed data for vegetation simulation modeling in forest and tundra of Denali – Chris Potter, NASA; Carl Roland, NPS

• Precipitation and maximum temperatures for sediment discharge of Yukon River – Kaz Chakita, Hokkaido University

• Precipitation data to calibrate a numerical model that simulates surface runoff response of Rock Creek Basin – Kenneth Karle, NPS

• Relating tree growth to tree location and microclimate – Martin Wilmking, UAF

Another vitally important aspect of weather data is the public's interest in the information. Weather data has been used in a variety of different educational and public outreach opportunities.

• Using the 75-year headquarters' weather database in 7th grade science class – TriValley School, Healy, AK

• Visitor/Public Information- Weather Summaries for visitors, contractors, etc. – Camp Denali Newsletter, Denali Park Resorts, Southeast Contractors, NWS.

Summary of Products

Annual summaries were compiled for climate monitoring in 1994, 1996, 1998, 1999, 2000, and 2001, with a report in progress for 2002. For most of these years, we compiled the data from the Rock Creek network including the NWS headquarters station and presented summary charts and graphs indicating monthly means. Reports for the Rock Creek stations include annual summaries, but there has never been a complete analysis of all the data for all years of record. The 2001 annual report is the first summary to include a narrative presentation of the data as well as summary charts and graphs. Though this data has helped support a multitude of other research projects in the park, meaningful climatic trend analysis will require a substantially longer period of record.

We have given presentations of the LTEM weather monitoring program has been given for a variety of conferences, informal presentations, and school groups.

See list of relevant reports and documents at end of this section.

Protocols and Reviews

LTEM

Rock Creek Watershed – Micro and meso-scale weather stations including Forest, Permafrost, Treeline, Lower Ridge, Upper Ridge, and Tundra.

Weather Monitoring Handbook. Denali National Park and Preserve 1997

Peer Review May1997, Final Draft– June 25, 1997

RAWS

BLM-NIFC Network protocols

McKinley Park, Wonder Lake, and Eielson Visitor Center

NWS Cooperative Observer Program standard operating procedures

Recommendations

In order for a long-term monitoring plan to be effective, the procedures have to be simple, robust, and repeatable. The micrometeorology focus within a small watershed seems well suited for a research application, but is too complex to continue for decades. The programming and intensive sensor array at each of the micro sites has resulted in difficult and time-consuming maintenance requirements. Additional problems occurred when the principle investigator for the soils project no longer participated in the program, resulting in unreliable data.

We recommend keeping the two 10-meter towers at the intermediate location and upper elevation in Rock Creek. However, the micrometeorology sites, which catered to an intensive soils monitoring research project, should be removed or the sites should be pared down to include only the basic suite of meteorology sensors. We also recommend that, in the future, meteorology towers should not be encumbered with many extraneous sensors for temporary or non-programmatic purposes. Such unplanned or extraneous installation of additional sensors requires additional time and money, and jeopardizes the basic concept of collecting good climate data. This is not to say that such information may not be of value to individual investigators, but such installations should remain separate from the core weather stations. A representative array of climate stations around the park complete with the basic suite of measurements will provide the most useful and most usable information for long-term monitoring.

Staffing for LTEM Weather Monitoring

1993 to 1996: PI: Paul Atkinson –Technician (GS-5) (1993-1996), Greg Probst –Technician (GS-5) (1992-1993)

1996 to 1998: PI: Jamie Roush - Physical Science Technician (GS 6/7)

1998 to 2000: PI: Jamie Roush - Physical Science Technician (GS 7), Technician –Pam Sousanes (GS 6/7) 1998-2000

2001: PI: Pamela Sousanes-Physical Science Technician GS-7

2002: PI: Pamela Sousanes - Environmental Protection Specialist - GS-9

List of Stations and Years of Record

Meteorological

Type	Station	Years of Record	Frequency	AT	RH	WS	WD	Precip	SR	BP
Manual	HQ Weather (Doggie)	1922- Present	Daily	X				X		
	Eielson Visitor Center	1993-Present**	Daily (Jun-Sep)	X				X		
	Wonder Lake	1993-Present	Daily (Jun-Sep)	X				X		
RAWS²	Wonder Lake	1995 - Present	Hourly	X	X	X	X	X		
	McKinley River	1992 - Present	Hourly	X	X	X	X	X	X	
	Minchumina	1992 - Present	Hourly	X	X	X	X	X	X	
	Tokositna	1997 - 1998	Hourly	X	X	X	X	X		
	Ruth Glacier*	1998 - Present	Hourly	X	X	X	X	X		
LTEM ³	Air Quality Station	1980 - Present	Hourly	X	X	X	X	X	X	
	Tundra	1993 - 1998	Hourly	X	X	X	X	X	X	
	Upper ridge	1993 - Present	Hourly	X	X	X	X	X	X	
	Lower Ridge	1993 - Present	Hourly	X	X	X	X	X	X	X
	Treeline	1993-Present	Hourly	X	X	X	X	X	X	
	Permafrost	1993-Present	Hourly	X	X	X	X	X	X	
	Forest	1993-Present	Hourly	X	X	X	X	X	X	
	Stampede	New Station 2003	Hourly	X	X	X	X	X	X	
	Dunkle Hills	New Station 2003	Hourly	X	X	X	X	X	X	
Others	Teklanika Flats	1995 - 2000	Hourly	X	X	X	X	X	X	
	Mt. McKinley 19,200'	1990-	Hourly	X		X	X			
	Rock Creek (Phil's	1990-Present	Random	X						
	McKinley Park AWOS		Hourly	X	X	X	X	X		X

[1]Manual – National Weather Service Cooperative station – Manual readings daily.
[2]RAWS – Remote Automated Weather Station – Used primarily by the Fire Mgmt officer for fire weather observations
[3]LTEM – Automated Weather stations.
*Station moved August, 26, 1998 from Ramsdyke Creek in the Tokositna Valley to current location.
** Intermittent data before 1993

AT=Air temperature, RH=Relative Humidity, WS=Wind Speed, WD=Wind Direction, Precip.= Precipitation, SR=Solar Radiation, BP=barometric Pressure

Relevant Documents and Reports

AMAP, 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 859 pp.

Juday, G.P. 2000. Recent climate and forest history of the Denali National Park and Preserve Headquarters area, based on tree ring analysis. Agricultural and Forestry Experiment Station. University of Alaska Fairbanks. Report to U.S. Geological Survey Biological Research Division. 26 pp. + figures.

Moore, J.P., 1993. Soil Survey Investigation: Rock Creek Watershed, Denali National Park, Alaska. USDA Soil Conservation Service, Anchorage, Alaska. 45 pp.

Searby, H.W.1970. Mount McKinley National Park Alaska – Climatic Summaries of Resort Areas. National Oceanic and Atmospheric Administration-National Weather Service. No. 21-49-1. 5 pp.

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Weller, G. 1979. Alaska's Weather and Climate – A collection of articles written for the educated layman by staff members of the Geophysical Institute and the National Weather Service in Alaska. Geophysical Institute, University of Alaska Fairbanks. 24 pp.

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Probst, Greg. 1992. Denali Inventory and Monitoring Program 1992. Soils: End of Season Report. On file at Denali National Park and Preserve. 6 pp.

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Roland, C., K. Oakley, and C. McIntyre. 2003. Denali Long-term Ecological Monitoring: Minigrid Report. Final Report to National Inventory and Monitoring Program. October 2003. On file in Denali.

Roush, J. and P. Brease. 1998. 1996 Weather Data Summary Denali National Park and Preserve. 27 pp.

Sousanes, P.J. 1999. 1998 Climate Data Summary. Long Term Ecological Monitoring. Denali National Park and Preserve. 42 pp.

Sousanes, P.J. 2000. 1999 Long Term Ecological Monitoring. Climate Data Summary. Denali National Park and Preserve. 34 pp.

Sousanes, P.J. 2001. 2000 Long term Ecological Monitoring. Climate Data Summary. Denali National Park and Preserve. 85 pp.

Sousanes, P.J. 2002. 2001 Long term Ecological Monitoring. Climate Data Summary. Denali National Park and Preserve. 120 pp.

Monthly Publications (February – May) available for all years of LTEM snow monitoring:

Natural Resources Conservation Service. Alaska Basin Outlook Report. (Month, Year)

National Oceanic and Atmospheric Administration. Climatological Data. Alaska (Month, Year).

Air Quality

Andrea Blakesley,
Denali National Park and Preserve

Introduction

Air quality was included in the first suite of parameters measured by the Denali Long-Term Ecological Monitoring Program partly because air quality monitoring was already being conducted, and partly because it was connected with a larger nationwide monitoring program tracking long-term anthropogenic changes. The first Denali annual administrative report (December 1992) stated that when the first year budget shortfall necessitated paring down the original multi-watershed sample design, "Rock Creek was selected for pilot research because (1) it is the site of a National Atmospheric Deposition Program monitoring station, (2) of the availability of existing information, and (3) the watershed is readily accessible to park investigators."

Overview of Project History

It is clear that airborne contaminant monitoring has played an integral part of the Denali LTEM program design from the beginning. Unlike other parameters measured at a scale the size of a watershed or a park, the air quality monitoring program is fully integrated into a continental-scale sample design. The first permanent air quality monitoring instruments in Denali were installed near park headquarters in June 1980 through the National Atmospheric Deposition Program (NADP). In August 1986, a stacked filter unit was installed near the NADP sampler as a precursor to aerosol sampling conducted by the IMPROVE network (Interagency Monitoring of Protected Visual Environments). In July 1987 continuous ozone and meteorological monitoring began through the NPS nationwide gaseous pollutant monitoring network, and the stacked filter unit was replaced by a full set of IMPROVE modules the following March. The EPA Clean Air Status and Trends Network (CASTNet), formerly named the National Dry Deposition Network, began sampling in July 1998. Spatial coverage for airborne contaminant monitoring was expanded in September 2001 when the interagency IM-

PROVE steering committee supported installation of a second Denali station south of the Alaska Range in Trapper Creek.

Table 7. Air Quality Monitoring networks represented in Denali

Network	Acronym	Parameters	Startup Date	Sampling Interval
National Atmospheric Deposition Program	NADP	*Wet Deposition of:* Sulfate Nitrate Ammonium Sodium Magnesium Potassium Chlorine Calcium pH specific conductance	June 1980	Weekly bulk sample in precipitation
Interagency Monitoring of Protected Visual Environments	IMPROVE	*Aerosols:* Aluminum Arsenic Carbon Absorption Bromine Calcium Chlorine Chloride Ion Chromium Copper Elemental Carbon Organic Carbon Iron Hydrogen Potassium Fine Mass Magnesium Manganese Molybdenum PM10 Sodium	August 1986	24-hour samples collected on filters, 2 to 3 times per week

Table 7 continued

Network	Acronym	Parameters	Startup Date	Sampling Interval
		Nickel Nitrite Ion Nitrate Ion Phosphorous Lead Rubidium Sulfur Selenium Silicon Sulfur Dioxide Sulfate Ion Strontium Titanium Vanadium Zinc Zirconium		
NPS ozone monitoring	N/A	Ozone gas	July 1987	Continuous analysis
Clean Air Status and Trends Network	CASTNet	*Aerosols:* Sulfate Sulfur Dioxide Nitrate Nitric Acid Ammonium	July 1998	Weekly bulk sample collected on filters

In the nationwide airborne contaminant monitoring networks, the permanent monitoring stations have fairly inflexible infrastructure requirements such as year-round accessibility and availability of line power. The NPS stations generally are located in areas designated Class I under the Clean Air Act. With a mandate to meet regulatory as well as long-term ecological monitoring objectives, the sample design of the national NPS air quality monitoring program is well suited to detect temporal changes in airborne contaminant concentrations. However, the sample design is less robust for spatial analyses in regions such as Alaska where few Class I areas exist. As a result, it can be difficult to determine whether observed seasonal and long-term trends in air quality are primarily due to local, regional, or global influences.

Participation in established nationwide air quality monitoring networks has advantages regarding data integrity and continuity. Sampling and analytical methods are peer reviewed during the development of the networks, and scientists from all participating agencies scrutinize subsequent method changes, generally through formal steering committee participation. Data collection continuity is achieved with the assistance of contracted technical support staff, and data management and reporting are designed into network operations. Central network staff or data management contractors validate, archive, and make the date available to the public.

Nationwide monitoring network involvement is not without its challenges, however. When monitoring network objectives do not completely match park and regional objectives, it is a long, slow process to adjust the national network sample design to accommodate park and regional needs. Most Denali LTEM components have undergone various changes in scale, methods, and objectives over the past decade through straightforward sample design adjustments. The air quality monitoring program, however, has developed primarily as a result of monitoring network changes prioritized at the national level. Only recently have the nationwide network sample design changes incorporated park and regional input. For example, when plans were being made for the NPS monitoring network to expand through Natural Resource Challenge funding, park staff and other Alaska resource managers gained support for adding a permanent air quality monitoring station near the Western Arctic National Parklands. In fall 2003, a station will be installed in Ambler, 560 kilometers northwest of Denali. This addition will significantly enhance the current spatial sample design in Alaska.

The specific objectives of each NPS and interagency air quality monitoring network differ somewhat, but the overall objective of each is the same: *to track the spatial and temporal trends of airborne contaminant concentrations through a nationwide array of monitoring stations.* In addition, the Denali program is working toward integrating biological and contaminant monitoring through support of regional and network protocol development efforts, such as the Arctic I&M Network lichen monitoring protocol designed to measure contaminant concentrations and effects.

What Have We Found out about Airborne Contaminants?

The most important findings of the air quality monitoring component to date are:

1. The air is exceptionally clean in Denali, and the airborne contaminant concentrations are often the lowest of any site in the nationwide monitoring networks.
2. Seasonal patterns of aerosol concentrations demonstrate that international transport brings low levels of agricultural and industrial contaminants into Denali, especially during the winter and spring.
3. Ozone concentrations show an increasing trend during the spring peak-ozone season.
4. Visibility has improved and sulfate and nitrate deposition have decreased in the past ten years.

Summary of Products

Data summaries and reports from each nationwide monitoring network are available at the web sites listed below. All networks summarize data for each site separately, and the IMPROVE network also reports interpreted results on a regional basis. In 2002, the NPS Air Resources Division published *Air Quality in the National Parks*, a comprehensive overview of nationwide air quality, incorporating data from each monitoring network.

NADP
http://nadp.sws.uiuc.edu/

IMPROVE
http://vista.cira.colostate.edu/improve/

NPS ozone monitoring
http://www2.nature.nps.gov/ard/gas/

CASTNet
http://www.epa.gov/castnet/

Air Quality in the National Parks
http://www2.nature.nps.gov/ard/pubs/aqnps.htm

Status

The NPS Air Resources Division continues to support airborne contaminant monitoring, and long-term trend measurements will likely continue. The spatial sample design of permanent monitoring stations in the Alaska Region will be strengthened in fall 2003 when an NPS air quality monitoring site is installed in proximity to the Western Arctic National Parklands.

Work is underway to assess the status of toxic airborne contaminants in various biotic and abiotic media as part of a multi-park program funded by the Air Resources Division. Preliminary and final results of this study may provide insights into integration of airborne contaminant monitoring with other components of the Central Alaska Network Inventory and Monitoring Program.

Soils Monitoring

Kenneth F. Karle, P.E.,
Hydraulic Mapping and Modeling

Introduction

Soil properties result from interactions among atmosphere, biosphere, and lithosphere. Soils function not only as water-nutrient life media but also as redistributors and regulators of most of the important fluxes of matter and energy. Soil properties also are sensitive to environmental changes over time. Therefore, soil environmental changes affect the immediate carrying capacity of the land, through their influence on the vegetation and land-use types, run-off, evaporation, and groundwater quality (Ping 1993).

Within the Denali watershed-based approach of long-term monitoring, a soils component was proposed for implementation on a landscape-mapping level. This approach integrated the fields of geology, soils, hydrology, and vegetation to identify areas with similar characteristics, referred to as landscape units. As described in the original Denali proposal, landscape units would be identified in each of five major watersheds1 in the park (Van Horn et al. 1992).

As with other components of the program, severe and immediate programmatic budget constraints led to significant reductions in study scope from the original proposal to project implementation. As such, soil studies were initiated in just one watershed near Park Headquarters. Rock Creek was selected as the initial study watershed for several reasons.2 Soil inventories were eventually expanded into other areas of the park, though intensive soil monitoring was constrained to the Rock Creek watershed.

Overview of Project History

Project Organization

NPS personnel, along with assistance and input from others, directed and oversaw implementation of the initial soils monitoring program, and participated in much of the early field work. In 1992, Phil Brease, Denali's Physical Science branch manager, proposed a cooperative effort between the Soil Conservation Service (now Natural Resources Conservation Service), University of Alaska Fairbanks, U.S. Geological Survey, and NPS to monitor soils (Brease 1992). In addition to Phil Brease, Dale Taylor, ARO, and Lyman Thorsteinson, ARO, participated in arranging a cooperative agreement between NPS and the University of Alaska for additional work. Later in the program, Phil Brease and Gordon Olson, Denali's Division Chief of Research and Resource Preservation, arranged an interagency agreement with the NRCS to conduct a park-wide soils inventory.

In most summer months, one or two seasonal technicians assisted various principal investigators with field work and data collection. Seasonal science technicians at Denali usually are involved in a number of projects and work for several supervisors throughout the summer months. The soils monitoring component of this program was considered an element of the park physical science program, and fell under the purview of Phil Brease, NPS.

Researchers from other agencies and universities assisted with program development and data collection. Joe Moore of the Soil Conservation Service (SCS) developed soil profiles at four primary study sites in the Rock Creek watershed. Mark Clark and others at the Natural Resources Conservation Service (NRCS-formerly SCS) conducted a multi-year park-wide inventory of soils. Dr. Chien-lu Ping, a research professor at the University of Alaska Fairbanks (UAF), established long-term soils monitoring sites within the Rock Creek watershed.

Graduate students were involved in several aspects of the soils monitoring program. Greg Probst began thesis work in 1993 for Dr. Ping of UAF. Probst conducted some of the early instrumentation of the initial Rock Creek soils sites during that summer, but left the program before completing his thesis work. Lisa Popovics, a graduate student at UAF, conducted work to quantify nutrient dynamics in the soil-water-plant system (Popovics 1999).

General Approach to the Project

The approach to the soils monitoring component of the LTEM program was guided by the recognition of the importance of soils and soil functions in a subarctic ecosystem.

A series of phased studies began; in the Rock Creek watershed. Results from the initial studies would be used to direct and focus the objective of the subsequent studies. This three-phased plan occurred in the following order:

(1) identify landscape units within the Rock Creek watershed,

(2) establish long-term monitoring sites based on these landscape units, and

(3) install instrumentation and operate these sites to measure a variety of soil and micro-climatic conditions (Brease 1992).

Protocol development also was recognized as an important goal for the soils component of the LTEM program. For the studies conducted by NRCS, established protocols, such as the Wet Soil Monitoring Project protocol, were implemented into the program with little or no modification. However, for the intense instrumented monitoring component, protocols were developed as part of the overall program.

Start-up Phase

The initial soils study in the Rock Creek watershed was conducted by the SCS. This study consisted of two components. The first component was a baseline geographic inventory of existing soils and accessory properties across the Rock Creek watershed. Eight landform/vegetation areas were identified as discrete soil units (Figure 1). The second component focused on detailed soil descriptions and characterizations of soil at four individual sites. These four sites were chosen due to their sensitivity and value as indicators of ecological change (Moore 1993). An Interagency Agreement transferred $10,000 from NPS to SCS to conduct the study.

The second component of the soil-monitoring plan involved establishment of long-term monitoring sites. Dr. Chien-Lu Ping, UAF, conducted this work, also started in 1992. Four sites were selected for long-term soils monitoring in the Rock Creek watershed. These sites, labeled Permafrost, Forest, Treeline, and Alpine Tundra, were located in different landscape units identified in the SCS mapping efforts, and each were adjacent to a permanent vegetation monitoring plot. Primary objectives at each site were to: 1) quantify micro-climatic conditions, 2) compare environmental conditions between sites, and 3) identify and monitor indicators of environmental change (Ping 1993). Each site had an assortment of soil and meteorological sensors. The soil parameters collected included soil temperatures (generally at depths of 2.5, 5, 10, 20, 50 and 100 centimeters), soil matrix potential (at depths of 20, 50, 75, and 100 centimeters), soil redox potential, depth to permafrost (only at the Permafrost Site), and carbon dioxide and methane emissions (Probst 1995).

Spatial Expansion

In an early effort to begin the integration of several LTEM monitoring components, program managers asked University of Alaska researchers to study the relationship of soil water quality to stream water quality and primary productivity. The objectives of the 1995 pilot study were to:

(1) collect baseline data of the dissolved organic carbon (DOC) and nutrient concentrations in soil solutions of different soil mapping units/vegetation communities;

(2) document the density and types of vegetation in close vicinity to the pizeometers;

(3) measure the flow rate of soil water (ground water) of each mapping unit and discharge rate into the stream during the growing season;

(4) relate the stream water chemistry to the nutrient levels of soil water and ground water discharge rate; and

(5) determine the controlling factor of stream primary productivity. In this manner, Ping and Popovics investigated the ecological linkages between terrestrial and aquatic ecosystems in several soil map units of the Rock Creek watershed (Popovics undated).

Additional expansion of the soil survey work followed this pilot study. Based on the success and usefulness of the Rock Creek watershed soil survey, park managers arranged an Interagency Agreement with the NRCS to conduct a parkwide soils inventory. As envisioned, this inventory, covering the 6-million acre park and preserve, would provide essential data for expanding the size and scope of several of the LTEM components, including vegetation and wildlife. This order for soil survey began by conducting soil delineations using stereoscopic photo-interpretation of color infrared aerial photography (dated July 1980 through 1982; nominal scale 1:60,000). We based polygon boundaries on observed patterns and relationships of landforms, soils, and vegetation. Collecting field data within selected study sites throughout the park validated these delineations. Study sites were selected to represent typical landscape patterns and conditions within broader geographic and physiographic units. Data collected at each transect stop included landform and site properties, soil profile characteristics, and plant community data. LTEM staff conducted field work between May 1997 and September 2001. Published results of this study are due in late 2003.

What Have We Found out about Soils?

The SCS surveys in the Rock Creek watershed delineated eight soil map units. The eight map units and their sizes are listed in Table 8. Of those eight, we determined that three units, with characteristics similar to other areas in Denali, could provide indications of ecological change. Map Unit 3 (Alpine Mountainsides-Vegetated) has a thin, fragile organic surface; any climate change will result in changes to both the vegetative community and the physical and chemical soil properties. Map Unit 6 (Stream Terrace) contains soils that have variations in hydrology; those variations result in variations of the associated plant communities. Alterations to the existing soil hydrology from natural changes should be reflected in changes in the plant communities.

Table 8. Soil map units in Rock Creek watershed

Unit	Name	Size (hectares)
1	Subalpine (Forested) Mountainsides	102
2	Steep White Spruce Valley Sides	41
3	Alpine Mountainsides (Vegetated)	260
4	Steep Mountain Drainages	76
5	Glaciated Uplands with Permafrost	29
6	Stream Terrace	9
7	Alpine Mountainsides	290
8	Flood Plain	18

Perhaps most notable is the Map Unit 5 (Glaciated Uplands with Permafrost), an area that is extremely sensitive to climate or other environmental change. The soils within this map unit are in a warm permafrost state, with an average temperature near 0 degrees Celcius. A thick moss organic surface serves as insulation to preserve the thermal properties in this map unit and acts as a sink for available carbon. The impermeable permafrost acts to create a perched water table and saturated active layer. Changes to climate, especially increases in temperature, will result in quick alterations to soil thermal regimes, active layer thickness, hydrology, physical and chemical soil properties, and the associated vegetative community (Moore 1993).

Figure 11. Soil unit delineation map of Rock Creek watershed, from Moore (1993).

Intensive soils monitoring at four map units provided additional detailed information about soils and soil properties of four different map units within the Rock Creek watershed. For example, soil redox probes were used to measure the state of the soil with respect to oxidation to oxygen and reduction to hydrogen at four soil depths. Soils under reduced conditions have a high redox potential value and oxidized soils have a low redox potential value. Reduced conditions often occur in waterlogged soils while aerated soils are under oxidizing conditions.

Findings show the redox potentials in alpine tundra soils vary with soil depth. Measurements at a depth of 15 centimeters show soils with more organic matter, which hold more water than at other depths. At a 40-centimeter depth, soils have less organic matter; saturation from spring thaw results in a reduced state. As soils thaw and water percolates through, the oxidation level increases. In the treeline-shrub unit, soils are thin and well drained, and redox potentials remain high for most of the summer. In the permafrost unit, saturation above the permafrost line creates a reducing environment. As a result, hydrophilic species dominate the vegetation types. While near-surface soils maintain high redox potentials for most of the summer, measurements at greater depths show a direct relationship between redox potential and the progression of the active layer depth as soils warm throughout the summer. Measurements from two monitoring sites (permafrost unit and treeline-shrub) at varying depths from the surface are shown in Figure 12.

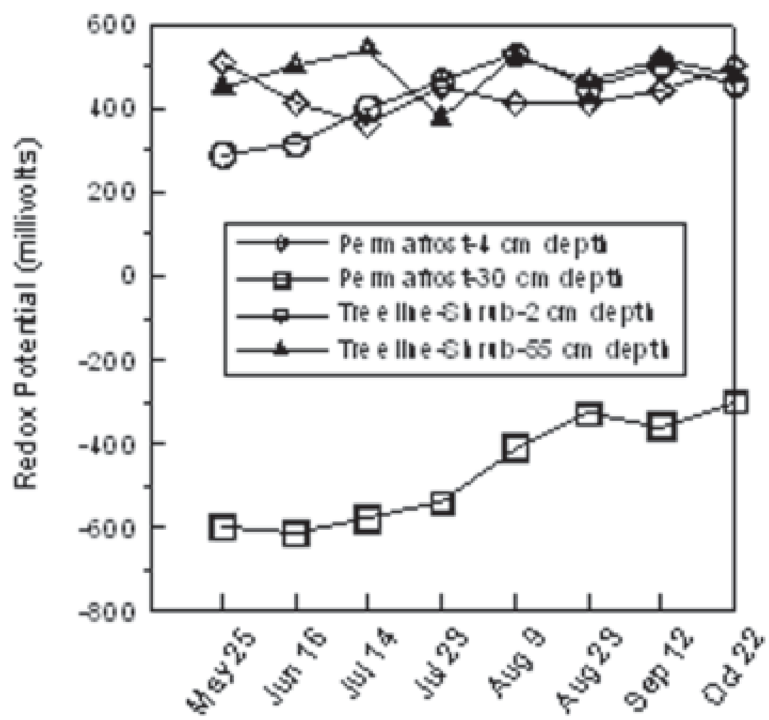

Figure 12. Reduction-oxidation potential records from two Rock Creek monitoring sites.

Temperature probes at varying soil depths provided additional information on soil properties and related ecosystem functions. Soil temperature responses to air temperature showed significant differences between soil unit types. For example, significant differences between the treeline-shrub site and permafrost site appear in a comparison of warming air temperatures to soil temperatures in spring (Figures 13 and 14). Ecosystem attributes such as solar radiation effects, soil thermal properties, and others may be analyzed using such data.

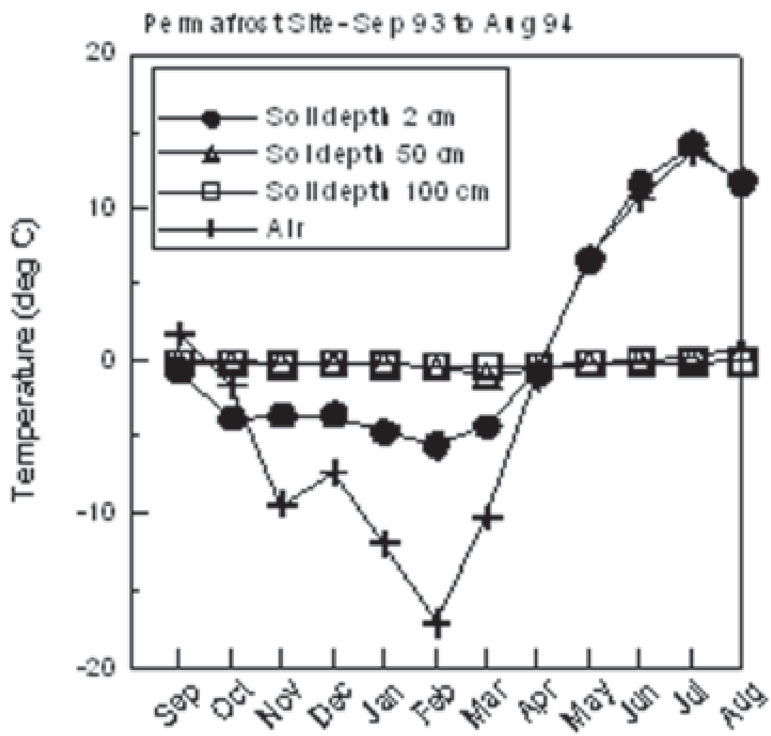

Figure 13. Mean monthly air and soil temperatures at the Permafrost soil unit.

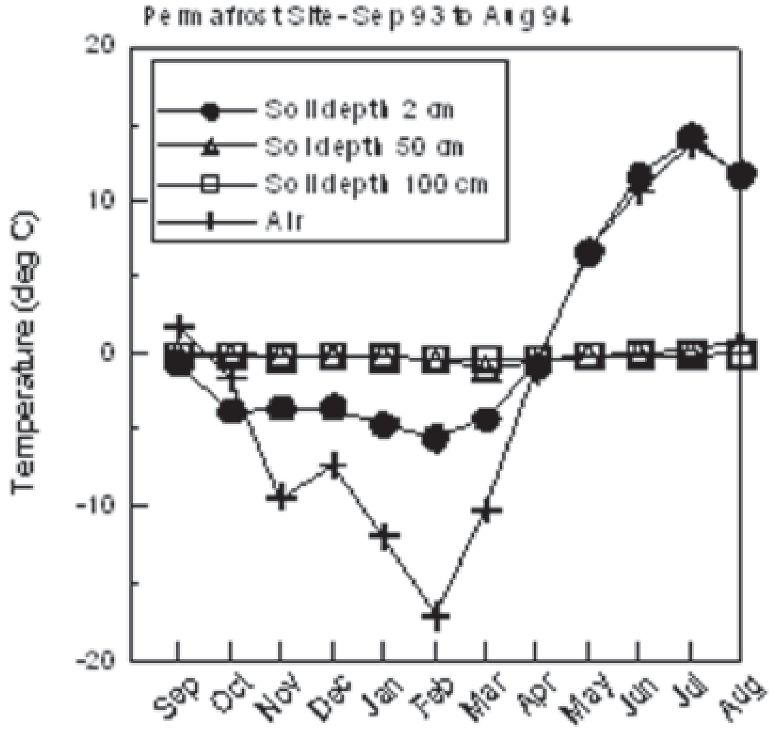

Figure 14. Mean monthly air and soil temperatures at the Treeline-shrub soil unit.

The soil water quality study measured the nutrient dynamics of the soil-plant-water system in the Rock Creek drainage by documenting soil-water flow rates and soil nutrient concentrations in different soil mapping units. The units selected as monitoring sites included the permafrost subalpine tundra, wet shrubland on moderate slope, moist steep slope with alder shrubs, and poorly drained riparian zone along the stream banks. Results from the monitoring indicated that nutrient species and quantities of soil and water reflect the characteristics of each map unit. Also noted was the fact that primary productivity did not correlate with soil and water quality; investigators theorized that this might be due to the flushing effects of the second order creek. Other results indicated that phosphorus is the limiting nutrient in the Rock Creek system. Additionally, physical factors such as limited organic matter retention, increased stream discharge, and unstable channel morphology characteristics are more significant in acting to limit the productivity of Rock Creek (Popovics 1999).

Summary of Products

A number of reports and papers have been published as a result of the soils monitoring program. The SCS published a report describing in detail the results of the Rock Creek watershed soils investigation (Moore 1993). This report provides complete descriptions of the representative soil profiles, their classification, and a discussion of their formation. Also included is a detailed color soil map of the watershed at a scale of 1:250000.

In addition to the SCS Rock Creek report, results from the park-wide NRCS soil survey are due to be published in late 2003.

The intensive soils monitoring study produced annual reports for the first several years of the program. A soils monitoring protocol was drafted by Chien-Lu Ping and Lisa Popovics between 1994 and 1997 (Ping et al. undated). This protocol describes the methodology used in conducting soil studies in the Rock Creek monitoring program, including 1) soil sampling, analysis, and classification; 2) soil temperature monitoring; 3) soil water measurements; and 4) soil redox potential. The protocol also devotes several sections to the methodology used in Popovics' study. To date, the protocol has been neither peer-reviewed nor finalized.

In addition to the draft protocol, Popovics produced a master's of science thesis on her Denali study (Popovics 1999).

Status

Soil data collected at the four Ping monitoring sites in the Rock Creek watershed subsequent to 1994 have not yet been compiled or analyzed, and a report on findings or trends has not been produced. None of the soil sensors have been maintained since 1996. Though all generated data continued to be logged and stored, most soil sensors have gradually ceased to function over the intervening years, and are not being replaced or repaired as they fail. The meteorological sensors, however, are still maintained at all but the Alpine Tundra site and these continue to gather good data.

We have completed fieldwork for the parkwide soils inventory, and a final report is due in late 2003. At this time, no other sampling of either soils or groundwater chemistry is being conducted in conjunction with the LTEM program.

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Endnotes

1 McKinley River, Toklat River, Bearpaw River, Teklanika River, and Yenta River.
2 Described in Chapter 1 of this report.

Flora

Vegetation Monitoring

Carl A. Roland,
Denali National Park and Preserve

Introduction

Vegetation monitoring has been a component of the Long Term Ecological Monitoring Program since 1992, when a set of permanent vegetation monitoring plots was established along a gradient of elevation in the Rock Creek drainage near park headquarters (*see map on CD with this report*). Permanent vegetation monitoring plots were installed in the following areas within the watershed: closed spruce-birch forest in the valley bottom, open white spruce woodland at treeline on the southwest ridge of the drainage, and in alpine tundra near the upper end of the drainage. The overall goal of this program was aimed at monitoring the vegetation dynamics associated with treeline in the park in response to potential changes in the climate. A detailed history showing the major events, relevant documents, and field work performed during each year of the monitoring program for vegetation are shown in Appendix table on the CD with this report. The document that describes the protocols for the original design was completed in 1997 (Densmore et al. 1998). A summary and analysis of the data collected for this initial program design may be found in a document prepared in 1999 (Roland 1999) as well as annual reports for this component for the years 1998 to 2001.

The original rationale and design for the vegetation monitoring program has been specifically reviewed on three occasions and found to be inadequate in several important respects (see Seitz memo, Roland 1999, and Helm and Roland 2000). As a consequence of these reviews, and a lengthy process of reevaluation and objective-setting for vegetation monitoring, a major departure from the initial design for vegetation monitoring began in 2000, and significantly expanded in 2001 to 2002. A pilot project aimed at developing an integrated, landscape-scale monitoring design for the park based on a systematic grid began in 2001 and continued in 2002. The results of this pilot study will appear in a separate document that is currently in preparation (Roland, Oakley, and McIntyre 2003).

Overview of Project History

Project Organization

The vegetation monitoring program has primarily been carried out by park-based personnel from its inception. Roseann Densmore, plant ecologist for the park until 1994, supervised the initial installation of the permanent monitoring plots in the Rock Creek drainage, and a seasonal technician was hired by the park for the project each year in order to accomplish the annual measurements in these plots. Although the requisite data were collected each year of the study, the project suffered from a lack of review, analysis, and interpretation of the results of this data collection effort. In short, the absence of a principal investigator who was substantively involved in the project was a key shortcoming in the early years. Page Spencer, ecologist for the Alaska Support Office, helped begin a new phase for the program in 1997, by consulting with park staff about potential new avenues for vegetation monitoring. Carl Roland was hired to fill the plant ecologist position in 2000, and took on the role of principal investigator for vegetation at that time. In addition, the USGS-BRD contracted Dr. Dot Helm of UAF to assist Denali with the development of a protocol for landscape-scale vegetation monitoring during the period 1998 to 2001. This move resulted in a review of the existing protocol and in a set of recommendations for the future design of the program (Helm and Roland 2000, Helm 2000, Helm 2001, and Helm 2001).

The vegetation monitoring component received approximately $30,000 in FY 2000; and FY 2001 from the park's LTEM annual budget. These funds were used to pay for two seasonal technician positions and to acquire supplies and equipment for the acquisition of field data. In FY 2002, LTEM program underwent a major change, and re-organized into four monitoring "spheres," based on the model established by the Central Alaska Network technical committee. The vegetation "sphere" of the newly reorganized LTEM program received $94,950 during FY 2002, which was used to accomplish work on the park-wide systematic grid pilot project as well as to complete the field activities based on the original monitoring design in the Rock Creek watershed. This allocation funded five seasonal positions, equipment purchases, and considerable logistical support for remote field work.

General Approach to Vegetation Monitoring

The initial design of the vegetation monitoring program was carried out at three sites (forest, treeline, and tundra), each of which had three identical replicates. Measurements that were recorded at these sites included the following elements:

1) Estimates of percent cover, by species, determined by ocular estimate in a set of quadrants located within permanent plots (performed twice in 1992 to 1993 and 2000). This was done in order to monitor any changes in the composition of the vegetation of the permanent plots over time.
2) Measurements of tree diameter, position, and condition within a 25 meter by 25 meter plot. We mapped and measured all trees within these plots.
3) A set of six seed traps in each of the forest and treeline replicates (a total of 36 traps that were collected and sorted annually to provide an estimate of seed fall and viability).
4) Dendrometers installed on a sample of 23 white spruce trees (five in each forest replicate and a total of eight bands in the treeline replicates, where trees are few and far between). These were read annually to provide an estimate of bole growth for white spruce on an annual basis.
5) Cone counts on the 23 spruce trees to which dendrometers bands were affixed in 1992, in order to obtain an estimate of the number of cones produced per year by white spruce.
6) Annual counts of number of berries produced by shrubs in two subplots of each of the permanent plots. This data acquisition was discontinued in 2000 following a review of the first six years of data.
7) Phenology of a group of plant species tracked weekly each year, to determine inter-annual variation in the timing of key events in the development of the vegetation over a summer (such as bud break, flowering and seed set). This protocol also was discontinued in 2000 after a review of the data.

Problems inherent in the original design of the vegetation monitoring component of LTEM are described in detail elsewhere (McDonald et al. 1998, Roland 1999, Helm and Roland 2000). Few conclusions regarding treeline dynamics outside of the individual plots themselves are warranted by the data that have been collected during this period. However, we have assembled a useful data set that tracks the inter-annual patterns in the relative reproductive output of white spruce (cones, seeds, and seed viability) and annual rates of bole growth in a small sample of trees at two elevation stations: the treeline and forest sites within the Rock Creek watershed. Because these spruce reproductive parameters vary over very large spatial scales, the problems inherent in the design of the initial program are less problematic than for other measured parameters. This set of measurements will be continued into the future.

The primary lessons learned from the experience of the vegetation monitoring component of the LTEM program are fourfold:

1) The program should have a clearly defined set of monitoring objectives that are explicitly tied to the spatial scale at which we seek to make inferences concerning changes in vegetation parameters.

2) The program must be founded on a rigorous underlying statistical design that allows design-based inferences to be made concerning changes in measured parameters.

3) Vegetation monitoring program for the park should have a landscape-scale spatial dimension in order to be of the greatest value to monitor the ecosystem and to provide useful data to scientists and managers.

4) And finally, it is clear that in order for the program to succeed, it must have a principal investigator in the park who is engaged with the program; and who has the responsibility for analyzing and presenting the data on a regular basis.

Future Design of Vegetation Monitoring: Spatial Expansion

The focus of vegetation monitoring in the park has shifted from the watershed-based approach represented by the original design to a nested, landscape-scale approach based on a systematic grid design with random start. The new direction for the program is aimed at quantifying the variation in plant community structure and species composition with the underlying ecological gradients that cause that variation on the park landscape at a broad scale, and at determining whether these relationships between physical and vegetation variables change over time. The rationale and design of this approach, and the preliminary data acquired to address this shift in focus are presented in the Minigrid Report (Roland et al. 2003). The results of the pilot project for this landscape-scale approach will help to determine the eventual course of vegetation monitoring in Denali National Park and Preserve. Meanwhile, the annual data collection on the long-standing plots in the Rock Creek drainage will continue.

What Have We Found out about Vegetation in the Rock Creek Drainage during the Years 1992 to 2000?

White Spruce Cone Production

Cone production and maturation in white spruce occurs over a two-year cycle. During the first year, cones grow on the tree and remain small and inconspicuous. In the second year of the cycle, the spruce cones mature to produce pollen and ovules, and female cones are fertilized and produce seed, which (in interior Alaska) reach maturity in August. In our area, white spruce cones open and release seed in late August and September. The production of a large number of cones by white spruce trees occurs only sporadically in interior and northern Alaska, with banner cone crops apparently occurring once every 12 to 16 years.

The overall mean number of white spruce cones produced per tree in the forest study site during this period was 95.5 cones per tree per year, as compared to a mean of 42.2 cones per tree per year in the treeline study site. Mean annual cone production by spruce trees varied during the study period. Mean cone production in the forest site ranged from a low of one cone per tree in 1995 to a high of 390 cones per tree in 1998 (see Figure 15: figures appear at the end of this section). Similarly, mean cone production in the treeline site ranged from a low of 0.33 cones per tree in 2001 to a high of 162 cones per tree in 1998 (Figure 15). Clearly, 1998 was a conspicuous banner cone production year for white spruce trees in both landscape positions within the study area. In fact, the mean number of cones produced by trees in the forest site in 1998 was more than four times the overall mean for annual cone production per tree. In addition, each alternate year since 1998 has seen relatively high spruce cone productivity in the study plots, with annual means of 267 and 115 cones per tree in the forest site in 2000 and 2002 respectively, which represent the second and third highest cone production years during the course of this study. This period of relative abundance contrasts sharply with the relatively low spruce cone production observed during the first six years of the study period in both treeline and forest study sites.

The initiation of large cone crops in white spruce is thought to be triggered by climatic factors, particularly early season warmth during the year cones are initiated. The observations made during this study confirm that, generally speaking, accumulation of high numbers of thawing degree days in June have resulted in initiation of relatively higher numbers of white spruce cones in the study trees (figure 16). The three largest years for cone initiation in the study area (1997, 1999, 2001) were also the years with the highest accumulation of thawing degree days in June (Figure 17).

White Spruce Seed Production and Viability

We measured seed rain in the study plots with an array of six seed traps per replicate. These traps were collected each May and spruce seeds were sorted from litter and counted. Germination trials then were performed on the spruce seed in order to determine the number of viable seeds. Unsurprisingly, the patterns that emerged from this set of observations of seed rain in the study generally paralleled those of cone production. That is, 1998 stands out as the year with the highest seed rain, by far, of any year in the study period (Figure 18). During the study period the overall mean in seed rain in the forest site was 300 seeds per square meter, whereas at treeline the seed rain averaged about 13 seeds per square meter. In 1998, however, we counted an average of 1884 seeds per square meter in the forest site and 63.4 seeds per square meter in the treeline sites. The highest number of viable spruce seeds was produced during the years 1997, 1998, and 2000 (Figure 19).

White Spruce Bole Growth

Bole growth was measured with band dendrometers bands that were affixed to a subset of white spruce trees that occur in the study plots (the identical set of trees on which annual spruce cone counts are performed). The overall mean annual diameter increase for the study population measured 0.33 centimeters per tree per year. In the treeline site, the mean diameter increase averaged 0.32 centimeters per tree per year over the period, although this parameter also showed considerable inter-annual variation in both landscape positions (Figure 20).

The highest annual rates of bole growth in the treeline site were observed during the years 1999, 2000, and 2002, with a conspicuously low annual rate of growth observed in 1998 (Figure 20). Similarly, the highest annual rates of bole growth in the forest site were observed during the years 1999, 2000, and 2002. The reason that 1998 was an outlier for low bole growth in both landscape positions likely reflects the allocation of resources to the very large cone crop that came to maturity during this year in the study population.

Products

The protocol document for the original vegetation monitoring design was prepared by Roseann Densmore, USGS-BRD, and is on file at the park (Densmore 1998). Two reports that evaluated the original design for vegetation monitoring were prepared during 1999 to 2000 (Roland 1999, Helm and Roland 2000). Annual reports summarizing the complete data sets for all of the vegetation monitoring program for 1998 to 2001 are also on file (Roland 1998, Roland 1999, Roland 2000, Roland 2001). Please refer to CD at end of this report.

Status

The primary focus of the vegetation monitoring program is on the development of the landscape-scale approach represented by the “mini-grid” two-stage systematic grid design. However, the annual monitoring activities in the permanent vegetation monitoring plots in the Rock Creek watershed are ongoing. There is no plan to alter the basic set of annual monitoring activities in the Rock Creek drainage plots at this time because they require little additional staff time, and contribute to a decade-plus record of spruce growth and reproduction across treeline in Denali.

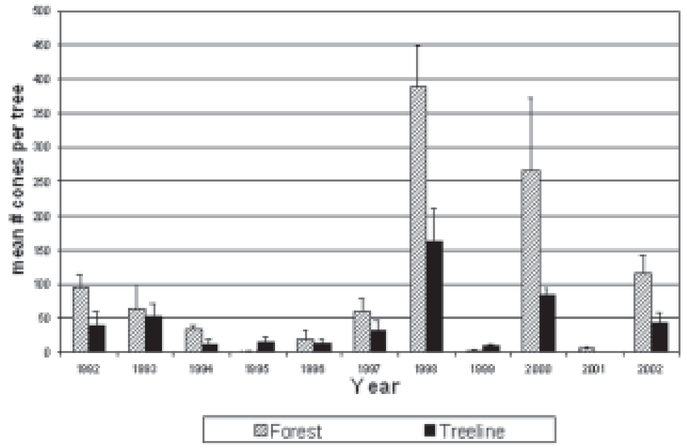

Figure 15. Mean number of cones per tree observed on white spruce in forest and treeline plots in the Long Term Ecological Monitoring (LTEM) program permanent vegetation plots in the Rock Creek drainage of Denali National Park, Alaska during the period 1992-2002.

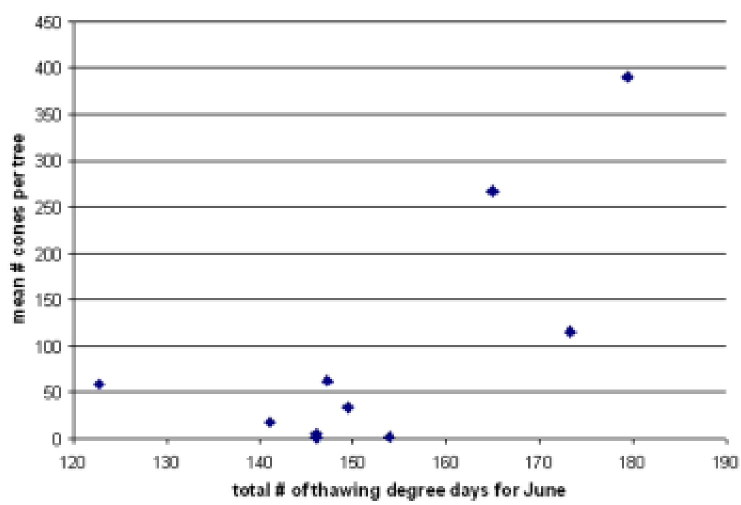

Figure 16. Scatterplot showing the mean annual number of cones per tree in the forest site of the LTEM program in the Rock Creek drainage as a function of accumulated thawing degree days for June during the period 1993-2002.

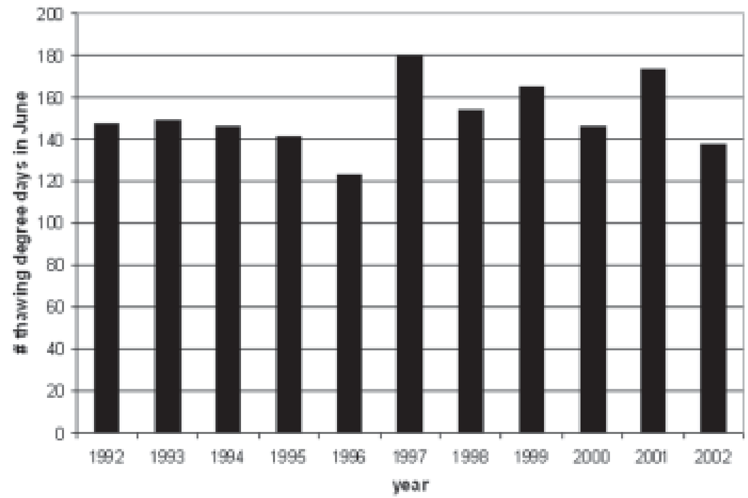

Figure 17. The number of thawing degree days accumulated during the month of June, calculated from weather data recorded at the dog kennels weather station at the headquarters of Denali National Park and Preserve, Alaska during the period 1992-2002.

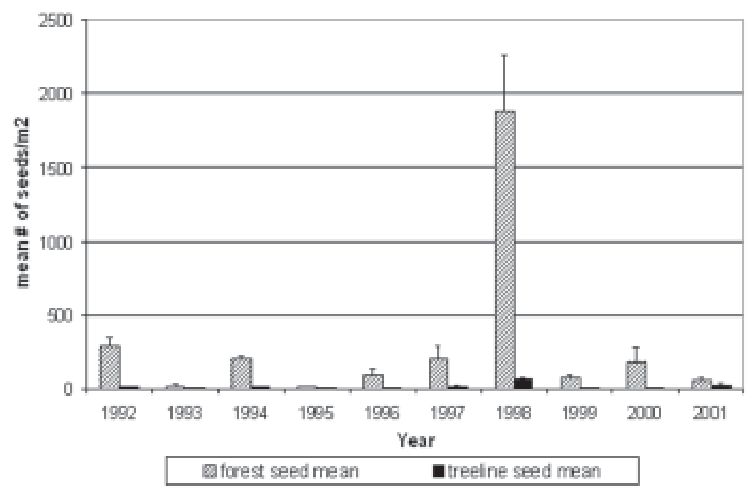

Figure 18. Mean number of seeds produced per square meter at Rock Creek Drainage permanent vegetation monitoring sites, Denali National Park, Alaska (error bars represent standard error).

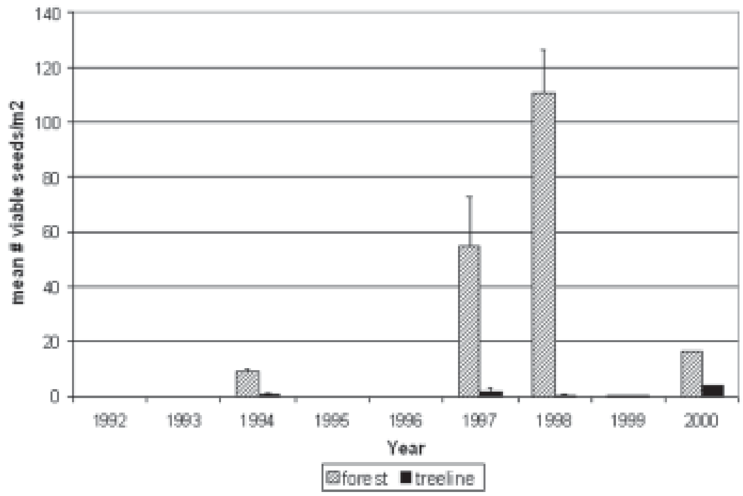

Figure 19. Mean number of viable seeds per square meter in Rock Creek Drainage permanent vegetation monitoring sites, Denali National Park, Alaska (error bars represent standard error).

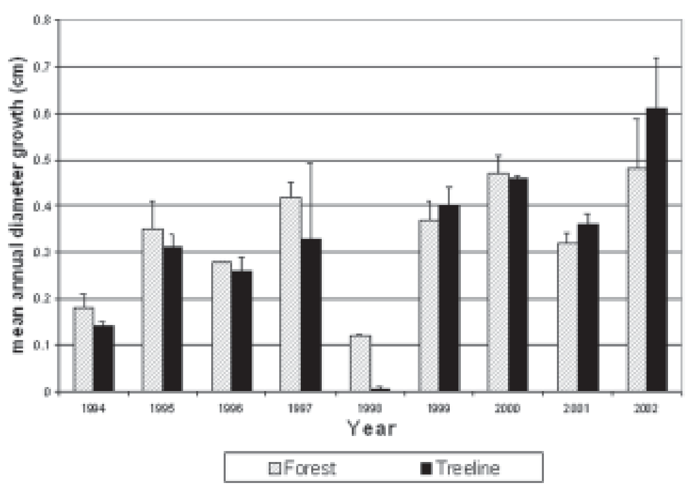

Figure 20. Mean annual diameter growth (cm) of trees in Rock Creek Drainage permanent vegetation monitoring plots, Denali National Park, Alaska (error bars represent standard error).

Aquatic Systems

Stream Channel Morphology

Kenneth F. Karle, P.E. ,
Hydraulic Mapping and Modeling

Introduction

A key feature of the original Denali Long-Term Environmental Monitoring (LTEM) proposal was the adoption of a watershed-based approach for integrated monitoring. A watershed-based approach establishes a connection between terrestrial and aquatic ecosystems by the common integrator—water—as it moves through the air, land, and watershed components of the environment. Watersheds are appealing as monitoring units because of their easily defined boundaries, such as soil, vegetation, topography, and hydrology (Hermann and Stottlemyer 1991). Early program managers also recognized the limits of a watershed-based approach; for example, attributes such as climate, migratory wildlife populations, and other low-density species would be difficult to monitor.

As a watershed-based program, aquatic studies of water chemistry and other components were a key part of the Denali LTEM proposal. A systematic program to monitor aquatic-based parameters in five 'representative watersheds' was described in the proposal. However, severe and immediate programmatic budget constraints led to significant reductions in study scope from the original proposal to project implementation. As such, water chemistry and stream channel morphometry studies were initiated in just one watershed near Park Headquarters. Rock Creek was selected as the initial study watershed because of several reasons:

(1) availability of long-term meteorological data;

(2) previous stream chemistry studies (Stottlemyer 1992);

(3) representation of Denali's environmental-elevational gradient;

(4) existing monitoring infrastructure; and

(5) accessibility and other logistic and cost factors (Thornsteinson and Taylor 1997).

Overview of Project History

Project Organization

NPS personnel have managed the stream channel and water chemistry component of the LTEM program since inception. Ken Karle, the park's hydraulic engineer, directed most of the activities for this component. Karle had extensive pre-existing duties at the park, including managing a water and land reclamation program for mined areas of the Kantishna Hills, and was unable to devote full-time attention to the LTEM program. In most summer months, one or two seasonal technicians assisted Karle part-time with fieldwork. Seasonal science technicians at Denali are commonly involved in a number of projects, and work for several supervisors throughout the summer months. The water component of this program was considered an element of the park physical science program, and fell under the purview of the Physical Science Branch Manager, Phil Brease.

Additionally, many others were involved in setting up original program goals and objectives. Tom Ford, an Environmental Specialist at the park until 1992, participated in many of the original meetings and discussions concerning hydrologic objectives and management. Nancy Deschu, the hydrologist for the NPS Alaska Regional Office, also participated in many of the early discussions.

Graduate students were involved in several aspects of the water chemistry program. Lisa Popovics, a graduate student at the University of Alaska Fairbanks, conducted work to quantify nutrient dynamics in the soil-water-plant system (Popovics 1996). Dave Hanneman investigated the presence of surface water heavy metals in the Rock Creek watershed (Hanneman 1993).

Researchers from other agencies were employed to assist with program development and data collection. William W. Emmett, a research hydrologist with the USGS, assisted with the development and preliminary fieldwork of the stream channel monitoring program. Pamela Edwards, a research hydrologist with the US Forest Service, conducted a study from 1994 through 1996. That study originally was proposed to investigate changes in water quality due to placer mining, but was subsequently expanded to provide guidance for the process of spatially extending the water chemistry program to other representative watersheds throughout the park.

Program funding was limited in most years, and paid for approximately one month of Principal Investigator Karle's salary, some seasonal technician time, and analytical laboratory costs. Annual budgets were estimated not to exceed $15,000 for any year during operation, and were substantially less than that for most years.

General Approach to the Project

The approach to this project was guided by the original program goal, which was to develop and test prototype monitoring designs for application in national park units throughout Alaska. The purpose of developing the protocols was to be able to establish practical methods for obtaining an initial characterization of existing hydrology and water chemistry in the study area. Additionally, the protocols were designed to provide for the identification of long-term temporal variations and trends for selected parameters.

To accomplish this goal, Karle decided to focus on two aspects of aquatic systems monitoring: water chemistry and stream channel morphometry. Water quality monitoring is often utilized as a method of ecosystem trend detection for wilderness areas. Characterizing surface water composition provides links to local geology, morphology, nutrient status, and biological productivity. However, though water quality routinely is recognized as an important component in monitoring programs, the significance of geomorphic and hydrologic landscape characteristics often is ignored or minimized when deciding which variables to monitor in a long-term ecological study. Some earth scientists believe that changes in basin characteristics may provide preliminary and direct indications of alteration in climate or land use, especially in areas that respond quickly to such alterations. As such, the program was developed to monitor for such geomorphic changes using measurements of channel geometry.

Many agencies have developed protocols and methods for sampling water chemistry, including the U.S. Forest Service, USGS, EPA, and others. Rather than create entirely new protocols, Karle attempted to test and modify existing protocols to fit the program requirements. Similarly, Karle adapted and modified existing stream channel geometry methods for application in the Rock Creek watershed. Adaptations of existing protocols were focused on identifying those parameters that would best meet overall program goals, given existing budget constraints. Analytical laboratory costs for water chemistry are expensive; thus, it was crucial to determine both: 1) which parameters would most precisely provide meaningful data to meet project objectives, and 2) the frequency of the sampling periods that would best represent field conditions.

Start-up Phase

During the summer of 1992, Karle established two permanent stream channel reference sites in Rock Creek that were used for most subsequent aquatic systems monitoring. A recording stream gaging station was installed immediately downstream of the lower site. Hydrologic measurements, including stream discharge, suspended sediment, bedload, and channel morphometry, were collected at these two sites on a monthly basis from May through September. This sampling frequency was selected to capture the vast majority of annual water and mineral budget output from the watershed, including the spring break-up discharge, typically the peak flow of the season. Water chemistry sampling included major ions, selected nutrients, alkalinity, pH, and total organic carbon.

In addition to water chemistry, early attempts were made to establish protocols for the monitoring of micro-biological components. Protocols for sampling Giardia lamblia and coliform bacteria were developed and tested for two years. These two parameters were selected because of their potential for impacts to human health. However, a critical review of the draft protocols led to calls for the deletion of such sampling, and these components were dropped.

Another critical part of the start-up phase involved determining the most efficient and reliable method of analyzing water chemistry samples. During the five-year development phase of the protocols, data were collected and analyzed using a variety of methods. For example, during the first several years of project development, water quality samples collected by NPS field technicians were not filtered during collection, and samples were preserved using acid, due to long holding times before processing. Administration and procurement requirements at the time forced the use of an analytical laboratory, which was located out of state.

In subsequent years, water quality samples were collected during a two-year period (1995 to 96) by a graduate student, who was conducting research involving the effect of soil and stream water quality on primary productivity in Rock Creek by examining the relationship between soil water chemistry and nutrient levels (Popovics 1996). Though water sampling techniques were similar, analytical work was conducted at University of Alaska laboratories, and analytical methods may have differed from currently used methods for some parameters. Following that study, samples were processed in Alaska using justified procurement procedures.

The first draft of protocols for the sampling and analyses of riverine aquatic systems was completed in 1995 (Karle 1995). These protocols included detailed instructions and guidelines for the three components of riverine aquatic systems (physical, chemical, and biological), as well as for data management and data analysis.

Spatial Expansion

Following extensive peer reviews, the protocols for stream channel morphometry and water chemistry monitoring were finalized in 1997 (Karle 1997). A substantial portion of the protocols was taken from procedures originally developed by the U.S. Forest Service, and incorporated either unchanged or with minor modifications into the LTEM protocols (Harrelson et al. 1994).

During development of the larger program, some concern was expressed that the water chemistry and channel morphometry measurements conducted in Rock Creek were not satisfying overall LTEM program goals[1]. On several occasions, Karle noted the limitations of conducting a long-term aquatic monitoring study exclusively within one small watershed (Karle 1998, Karle 1999). One of the early goals of the program was to determine the relationships between patterns and trends in atmospheric deposition and trends in surface water chemistry for defined subpopulations of aquatic resources. However, the chemistry of the Rock Creek basin is such that atmospheric deposition, specifically acidic deposition, is extremely difficult to detect through water chemistry sampling, due to the well-buffered nature of the system.

Because of this limitation, Karle suggested several options to expand and improve the aquatic systems component of the LTEM program. For example, instead of monitoring major ions in streamwater to detect acid deposition, one might place emphasis on detecting long-term change through nutrient cycling, as indicated by nitrification and nitrogen mineralization. In lieu of changing program goals, Karle suggested that a move out of Rock Creek and into a more pertinent watershed should be considered. For example, mean pH and alkalinity values were significantly different for streams on the north side of the Alaska Range versus the south side, which probably reflects differences in geology between the north and south sides (Edwards and Tranel 1999). Karle proposed that a south-side stream with lower pH and alkalinity values might have been a better choice for attempting trend detection of long-term acid depositional changes.

In addition, Karle proposed that initiating studies on three lakes and/or tundra ponds in the park as a lacustrine component of the aquatic systems LTEM program (NPS 1999). He observed that lakes and the more closed-system tundra ponds are an integral part of the larger watershed they occupy, and may be better indicators of anthropogenic stress than glacial and non-glacial rivers.

Another water quality study was conducted during the summers of 1994 to 1996 by Pam Edwards (U.S. Forest Service) and Mike Tranel (NPS). Though originally designed to detect water chemistry changes in mined streams of the Kantishna Hills, the study was expanded to characterize baseline water chemistry conditions in 72 streams and rivers (both glacier fed and clear water) across the park. With such data and analysis, it was proposed that additional representative watersheds could be identified and selected for additional monitoring. Edwards and Tranel noted important differences in water chemistry between the north and south sides of the Alaska Range, which they attributed to geologic differences (Edwards and Tranel 1999, Edwards et al. 2000). Based on their findings, they recommended that additional streams and rivers be added to the park's LTEM program, including one or more on the south side of the Alaska Range and one or more within the park's designated wilderness area (as a measure of background change that might also affect other sites). They also recommended monitoring Long Creek in Denali State Park and Moose Creek in the Kantishna Hills due to proposed development in these areas.

Other changes suggested by Karle included the utilization of scientists and graduate students to conduct future water chemistry work in order to gather higher quality data at lower cost to the NPS.

As program funding and priorities shifted away from process-based watershed studies to biological components, interest in the water chemistry component faded, and the program changes and expansions suggested by Karle and Edwards and Tranel were never implemented. All monitoring ceased following the 1999 season.

What Have We Found out about Stream Channel Morphometry and Water Chemistry?

Data were collected at the two stream channel reference sites during the summers of 1992 to 1999. Though long-term trend analysis based on only eight seasons of data is unreliable, an initial characterization of the Rock Creek watershed was made (Karle 1998, Karle and Sousanes 2000). Analyses show that Rock Creek is a highly buffered system, with basic pH values (pH greater than 8.0) and a high ability to neutralize acid. With the exception of chloride and total organic carbon, all ion concentrations show a strong negative correlation to instantaneous discharge. Sodium, calcium, and potassium show the strongest correlation to discharge. Magnesium, calcium, and sulfate have the highest ion concentrations, indicating that magnesium sulfate and calcium sulfate are the dominant ion pairs in the system.

Nutrient levels in Rock Creek are low; most samples of total nitrogen, total Kjeldahl nitrogen, nitrite, ammonia, total phosphate, and ortho phosphate fell below detection limits. Low primary productivity in Rock Creek has been attributed to low nutrient levels (Ping et al. 1994). Chlorophyll *a* is used as an algal biomass indicator. Sampling showed low levels of chlorophyll *a*. In 1997, chlorophyll *a* (biomass) was below detection limits during late spring and early fall sampling, but rose to a high of 226 milligrams per cubic meter in late July. Carbon input into Rock Creek also is low; most measurements also fell below detection limits for total organic carbon.

Permanent channel cross-sections show some erosion and deposition and movement of the thalweg within the channel. The energy gradient in Rock Creek is steep (5.2 to 6.3 percent for the two stream channel reference sites); the creek is classified as a Rosgen Type A3 stream, with high energy, high sediment supply, and very high bedload rates. Peak discharge commonly occurs between early May and mid June, and represents melt of snowpack storage during a period when soils are still frozen, before trees and shrubs begin to transpire, and when incoming solar radiation is near maximum. However, large precipitation events later in the summer can also induce large streamflow peaks (Figure 21).

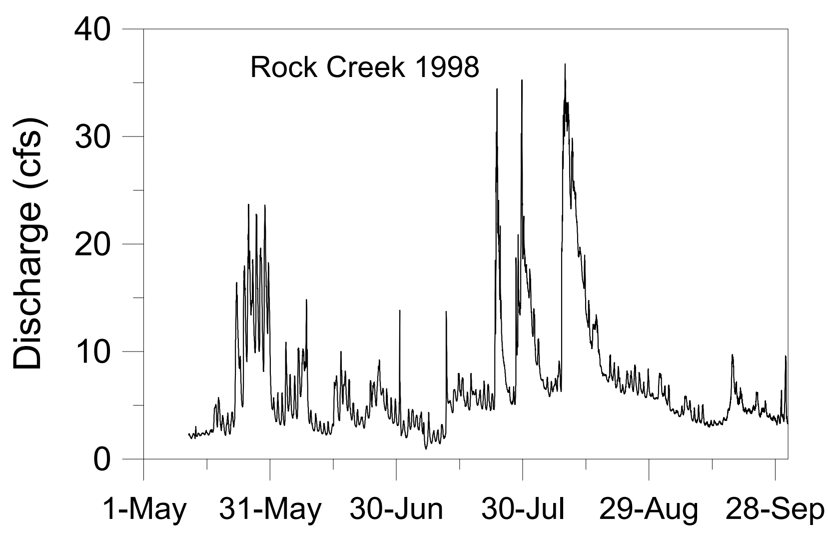

Figure 21. Hydrograph for Rock Creek, 1998.

Precipitation is the dominant hydrologic influence throughout the relatively cool summer, with precipitation amounts commonly exceeding pan evaporation (Figure 22). This contrasts to small arctic watersheds, where studies have shown that the potential for evapo-transpiration far exceeds summer rainfall, especially during June and early July. In Rock Creek, precipitation and evapo-transpiration (as pan evaporation) combine to account for virtually all runoff, signifying the lack of importance that soil recharge plays in the hydrologic ecology of the Rock Creek watershed.

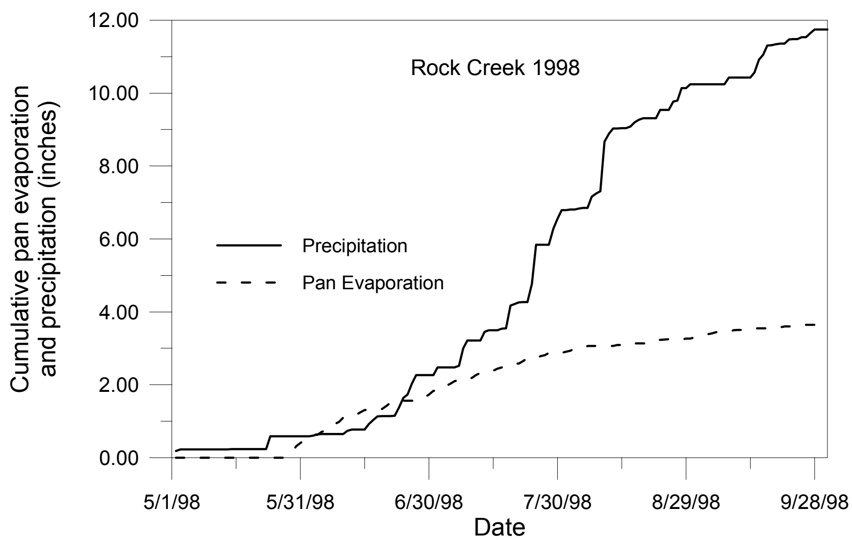

Figure 22. Cumulative precipitation and pan evaporation for Rock Creek, 1998.

Summary of Products

The water chemistry and stream channel morphometry produced annual reports for every year of the study, until 2000. The required *Investigators' Annual Reports* were filed for most years. In terms of documenting methods, an initial protocol was written and subjected to extensive review. Review comments were incorporated, and a final report was completed in 1997. While working for the National Park Service, Karle regularly presented results in numerous forums, including scientific meetings such as the American Water Resources Association (Karle and Sousanes 2000) and presentations for the general public. Work related to this project has resulted in two master's degree theses (Popovics 2000; Hanneman 1993).

The stream water chemistry and channel morphometry program has an excellent record in the area of data management. All project data was initially stored in a DBase III file, and was subsequently checked for quality and moved to the program's Access database in 1998, following the program's Data Management Protocol.

Status

At this time, no sampling of either water chemistry or stream channel geometry components is being conducted in conjunction with the LTEM program. The park's hydraulic engineer left the NPS in spring 2002, and a replacement hydrologist has not yet been hired.

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Endnotes

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Aquatic Invertebrates

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Introduction

The original Denali LTEM proposal advocated a comprehensive, integrated approach to monitoring of aquatic systems (Van Horn et al. 1992). Physical, chemical and biological data from streams and lakes in the five representative watersheds selected for monitoring would be collected. Although the proposed biological parameters for streams included aquatic invertebrates and fish, the aquatic effort has thus far focused solely on aquatic invertebrates.

Aquatic macroinvertebrates resident in northern river and stream habitats are mainly juvenile stages of insects, with the adults being terrestrial. Macroinvertebrates can be collected from the streambed by a number of methods involving nets, some quantitative, some qualitative. Samples then are sorted and identified in the laboratory to quantify the organisms present. Macroinvertebrate communities in a given stream indicate natural stream processes such as gradient, discharge, chemistry, geology, and riparian zone characteristics. However, aquatic macroinvertebrates also exhibit a range of tolerances to anthropogenic disturbances, such as chemical and thermal pollution, sedimentation, and organic loading. Hence aquatic invertebrate communities are widely used throughout the world as indicators of overall stream health.

The detailed history of Denali LTEM aquatic macroinvertebrate studies from 1991 to 2003 is provided in Table 9. This synopsis provides a succinct overview of the aquatic macroinvertebrate project, highlighting the initial investigations in Rock Creek, spatial expansion—primarily along the park road, and subsequent methodological experiments and investigations. We also briefly review key findings about aquatic invertebrates in the Denali ecosystem from this project, summarize products, and describe the current status of aquatic macroinvertebrate monitoring at Denali.

Overview of Project History

Project Organization

Alexander (Sandy) M. Milner has been the Principal Investigator for the Aquatic Macroinvertebrate project for its entirety. A number of agreements with the University of Alaska have funded this project. Milner has extensive experience with aquatic macroinvertebrates in high latitude streams, mainly in Alaska, but also Greenland, Svalbard, and New Zealand. He has contributed significantly to our understanding of biotic processes in glacier-fed streams and the colonization of new streams following glacial recession. When the LTEM program commenced, Milner was on the faculty of the University of Alaska Anchorage (UAA), and thus initial funding agreements were arranged with UAA. In 1995, Milner accepted a position with the University of Birmingham (U.K.), but maintained a faculty appointment with the University of Alaska Fairbanks (UAF) as Research Associate Professor of Aquatic Biology. All subsequent agreements with Milner were then run through the Alaska Fish and Wildlife Cooperative Research Unit or the Institute of Arctic Biology at UAF.

In addition to Milner, personnel involved in the aquatic invertebrate project have included several of his graduate students, including Elaine Major (nee Gabrielson) (1992 to 1993); Lisa Popovics and Sarah Conn (nee Roberts) (1994 to 2000); and James Ray (2001 to 2002). Jackie Harbok became the primary technician on the project after Sarah Conn left in 2000.

In the early years of the project, the NPS and the U.S. Environmental Protection Agency funded the aquatic invertebrate studies. In later years, the National Biological Survey and U.S. Geological Survey provided funding.

General Approach to the Project

The Denali LTEM proposal provided only general guidance as to how to administer comprehensive aquatic systems monitoring. The proposal suggested that sampling of all parameters (including aquatic invertebrates) would occur twice at each stream site in early and late summer to represent high and low flow conditions. The only other guideline was that the macroinvertebrate sampling sites would be co-located with the other aquatic sampling sites, which would be spread throughout the park according to the watershed design.

In general, the project has consisted of determining estimates of aquatic invertebrate abundance at various locations and times during the open water season, together with measuring environmental variables. A number of methods are available for sampling aquatic macroinvertebrates in Denali streams and rivers. Some methods provide qualitative results; others provide quantitative results. The method selected for the Denali aquatic invertebrate studies involved using a net known as a Surber sampler in which a known area of stream bed is disturbed, thereby resulting in a quantitative measure of abundance for each taxa (i.e., number per square meter).

Surber samplers are used chiefly in stream habitats known as riffles, where the water breaks as it moves over the substrate. Riffles provide productive habitats for aquatic invertebrates because they are well oxygenated and provide gravel and cobble substrate. The main reason for sampling in riffles is that riffles are the dominant habitat in Denali streams and rivers. Sampling in riffles also allows comparison among similar habitats so that LTEM staff can compare “oranges” with “oranges.” While other stream habitats (e.g., pools) that support aquatic invertebrates also may be present in a reach, sampling of these habitats is more difficult to perform consistently and can influence the fauna found. Thus, the basic method chosen at the outset for the Denali program was a quantitative method using similar habitats proved to provide comparability between sites and comparability to other monitoring studies. At each sampling site, typically five (minimum three) replicate samples were collected within riffle habitats using a Surber sampler with 343 micrometer mesh net. Samples were not pooled and no sub-sampling occurred in the laboratory – samples were counted in their entirety. The rationale for the selection of this method was the importance of repeatability for long-term monitoring.

Except for 1995 when helicopter access was available, LTEM staff reached all study sites using the park road, with the sampling locations generally within a short distance of the road crossing. A total of 57 river and stream sites have been sampled during the project. Some sites were sampled in only one year (1995), while others have been sampled eight to nine times over the 11-year period of the study. The majority of the sampling has occurred along the park road in 14 streams representing six stream types. The annual allocation of sampling effort throughout the project is summarized in Table 9.

A major emphasis of the aquatic macroinvertebrate study has focused on the development of a stream classification system to characterize the full diversity of stream types within the park. The important environmental variables driving this classification also were determined. LTEM staff viewed having an indication of the stream types as critical to knowledgeable deployment of monitoring effort. Stream classification was undertaken by using macroinvertebrate community distributions at the stream sites and the multivariate program Two-Way Indicator SPecies ANalysis (TWINSPAN). Additional data on the physical, chemical, and riparian zone characteristics at each sampling site then were used to help explain the groupings (using another multivariate analysis program, DECORANA (Detrended Correspondence Analysis and Basic Reciprocal Averaging).

The aquatic invertebrate study has progressed in three phases. Similar to other LTEM projects, at the beginning there was a start-up phase (1992 to 1993), followed by a spatial expansion phase (1994 to 1996). The third phase (1997 to 2003) has focused on three aspects:

(1) repeated sampling of selected sites to determine intra- and interannual variability in aquatic invertebrate communities in representative stream types,

(2) experiments to refine monitoring methods, including testing of additional attributes related to stream productivity, and

(3) examination of chironomid samples collected in earlier phases of the project to learn more about the invertebrate group that dominates Denali stream communities.

Start-up Phase

Aquatic macroinvertebrate studies began in Rock Creek to determine the abundance and composition of the aquatic invertebrate community at two study sites: Upper Rock Creek and Lower Rock Creek. In 1992, invertebrate densities and diversity in Rock Creek were so low that meaningful metrics could not be calculated. This finding of low productivity sparked efforts in 1993 to measure primary productivity and leaf retention, along with experiments in 1994 to determine what nutrients were limiting primary productivity (i.e., the clay pot study). This finding also led to the funding of master's degree student Lisa Popovics, co-supervised by UAF Soil Scientist Chen-Lu Ping and Sandy Milner (Popovics, 1998). In any case, for the aquatic invertebrate study, the start-up in Rock Creek ended quickly. Clearly, if you wanted to know about stream invertebrates in Denali streams, scaling up was necessary and other streams would have to be studied to see how well Rock Creek represented other stream types.

Spatial Expansion

In 1994, the aquatic invertebrate study expanded to study stream sites along the park road. Samples of invertebrates and physical and chemical data were collected from 26 different streams that crossed this road. These data were used in TWINSPAN and DECORANA analyses to determine if distinct stream groups were evident, based on their macroinvertebrate community assemblages. Five stream groups were identified:

(1) large, stable, non-glacial streams;

(2) narrow, spring-fed systems with stable channels and overhanging vegetation;

(3) smaller streams near the west end of the park road;

(4) glacial-fed rivers and other unstable channels with clear water; and

(5) Rock Creek.

Rock Creek was revealed as a unique system, most likely related to its steep gradient, low channel stability, and geology. The work in 1993 and 1994 was the subject of the master's thesis by Sarah Roberts (Roberts 1995).

In 1995, the aquatic invertebrate study was provided an important opportunity to expand the geographic extent of sampling further and obtain data on a wider array of environmental variables, particularly chemical variables. This opportunity came in the form of a planned water quality inventory (Edwards and

Tranel 1998), which had the facility of helicopter access for visiting sites off the road. A total of 53 rivers and streams, including streams on the south side of the Alaska Range, were sampled at different times during the summer field season during this joint effort. Sites along the road corridor sampled in 1994 also were included in this study to provide information about intra and inter-annual variation. The 1995 data also were subject to classification analysis producing a classification similar to the one prepared with 1994 data, with six groups:

- ***Group 1***: Clearwater rivers with a stable channel, and riparian zones with abundant growth of alder and willow (e.g., East Fork Tributary).
- ***Group 2***: Small (1 to 5 meters wide), spring-fed creeks with a high degree of channel stability and a close border of riparian vegetation (e.g., Hogan Creek).
- ***Group 3***: Kantishna area rivers and creeks that support the greatest diversity of benthic macroinvertebrates within Denali and possess a well-developed riparian zone (e.g., Moose Creek).
- ***Group 4***: Larger river systems, some partially fed by glacier melt-water (e.g., Sanctuary River).
- ***Group 5***: Small, unstable creeks of low order, high gradient, and actively migrating channel (e.g., Highway Pass Creek).
- ***Group 6***: Glacier-fed rivers and Rock Creek. Sites in this group had a low abundance and diversity of benthic macroinvertebrates (e.g., Toklat River).

The focus of effort in 1996 was to determine longitudinal variation in community composition along a given stream, as compared to the amount of variation between streams. This study was important to evaluate if one sampling site per stream would be sufficiently representative. Eleven rivers and streams along the park road were sampled at multiple locations and at different periods throughout the summer. More variation between streams of different types was found than within streams, supporting the concept that sampling at one site per stream would suffice to characterize most river sectors.

The work conducted in the spatial expansion phase was the subject of the doctoral thesis of Sarah Conn (Conn 1998).

Further Investigations into Community Trends and Monitoring Methods

The third phase of the aquatic invertebrate study began in 1998 with commencement of a three-year study funded by the USGS-BRD National Park Monitoring Project. During this phase, 14 long-term monitoring sites were established in streams along the park road, including representative streams in each of the six stream groups identified in the 1995 classification. LTEM staff conducted experiments to refine monitoring methods, and began a detailed examination of the chironomids (non-biting midges) collected in Denali streams.

The third phase of work also included experiments to resolve questions raised during reviews in the earlier phases about the overall monitoring approach and specific methods. Some reviewers criticized the approach as not in line with the most common macroinvertebrate monitoring methods used in the United States nor with the method being developed by the Alaska Department of Environmental Conservation, called the *Alaska Stream Condition Index*. These other methods—often referred to as the multimetric approach—generally rely on qualitative samples collected with a different type of net (the D-net), and enumeration of only a portion of the total number of organisms collected in sample (usually the first 300 counted). The data from these samples are analyzed using various metrics intended to provide indices of overall diversity and of the proportion of indicator taxa present. LTEM staff conducted experiments to compare the results of data collected and analyzed by the multimetric approach embodied in the *Alaska Stream Condition Index* and the quantitative approach used in Denali LTEM. Part of this work also involved looking at the number of replicate samples needed to describe the community present at a given time.

Experiments also were conducted to determine whether periphyton or some other measure of primary productivity could be monitored. Another investigation concerned whether biovolume—a measure of overall volume of aquatic invertebrates in a sample—could be used as a surrogate for biomass, as it is easier to estimate. To better understand the ecological relationships between streams and the surrounding landscape, the amount of coarse benthic organic material (referred to as CBOM) in the streams of different types was examined in relation to their macroinvertebrate communities. CBOM, derived generally from overhanging riparian vegetation, is an important source of food for some macroinvertebrates, and its availability depends on stream channel dynamics (structure and composition of riparian vegetation) and hydrologic cycle (flooding; erosion).

The last major focus of this phase of the work involved examining the chironomids collected in previous years and identifying them to genus and species, where possible. Identification of chironomids is difficult and time-consuming because the head of each organism must be mounted on a slide and examined under a microscope. Chironomids are the dominant macroinvertebrate group in Denali streams and by not identifying further than family, much information about the true taxonomic richness of Denali stream communities was being lost. To determine how the monitoring protocol should deal with this difficult, but important, taxonomic group, the chironomids collected in spring and fall of 1995 (the year of the intensive study with the environmental data) were identified with more than 22,000 head capsules mounted. Further classification analyses were undertaken using TWINSPAN. The chironomid study was the subject of the master's thesis of James Ray (Ray 2002).

What Have We Found out about Denali Aquatic Invertebrates and Stream Types?

Prior to this study, we had negligible information on the biotic communities of Denali streams. This study has advanced our knowledge of the diversity of taxa present in the streams, their distributional and abundance patterns, and the environmental variables driving community structure.

As discussed earlier, the dipteran family Chironomidae (non-biting midges) dominated the stream benthic communities of Denali—to an amazing degree. In the streams on the north side of the Alaska Range, this group averaged 67 percent of the individuals present in the samples collected. Other dipterans, as well as Ephemeropterans (mayflies), Plecopterans (stoneflies), and Trichopterans (caddis flies), were found. The presence of the latter three types of organisms, referred to as the EPT taxa, is often used to indicate high water quality, and their absence, to indicate degraded water quality. The low abundance of EPT taxa and high abundance of chironomids in pristine Denali streams, however, did not indicate degraded water quality, but rather normal conditions for this particular environment.

This study encompasses the first comprehensive investigation of the benthic communities of a wide range of streams in interior Alaska. For the first time we have an in-depth understanding of the types of streams found in this region of Alaska and the benthic macroinvertebrate communities that these streams support. We now know the major driving environmental variables determining macroinvertebrate community composition of these streams. For the EPT groups these variables are principally channel stability, turbidity, alkalinity, and altitude. The principal environmental variables driving five stream groups identified based only on the distribution of the chironomid fauna were altitude, conductivity, alkalinity, and sodium and magnesium ion concentrations.

We have opened the “black box” of the Chironomidae, which hitherto have typically not been identified past family, even though this group represents up to 70 percent by abundance of the fauna. In total, five subfamilies, 30 genera, and 65 species of Chironomidae were separated within Denali, increasing the total number of described macroinvertebrate taxa in rivers from 25 to 90. The occurrence of natural deformities of chironomid head capsules was relatively low.

Natural variation in the structure of stream macroinvertebrate communities over the eight-year period of study has been found to be extensive, even in the stable streams. Although we do not know the reasons for this high variability, winter ice regimes and depth of freezing and the severity of spring floods could be major contributing factors. By influencing overwinter survival of larvae, the winter and spring conditions influence the community composition in the following summer. These data have implications for the biological monitoring of streams using ratio metrics. Certain taxa are present one year and then absent in another year. Persistence was found to be higher in the more stable streams but overall was relatively variable.

Due to the natural variability we believe that stream monitoring based solely on multimetric approaches that use ratio metrics (e.g, the *Alaska Stream Condition Index*) are inappropriate for Denali streams. We recommend consideration of a predictive model that has built-in probabilities of occurrence and thus allows for the temporal variation from year-to-year that exists in Denali streams. The predictive model should be field-tested in other areas of interior Alaska where known anthropogenic impacts occur. The Chironomidae should be identified to at least genera to provide greater resolution in the number of taxa found. The use of chironomid deformities may be a valuable tool for evaluating long-term accumulative chronic (sub-lethal) effects on stream communities. Collection of macroinvertebrates should follow the field and laboratory protocols of the BLM National Aquatic Monitoring Center so that they are comparable to other areas of the United States.

Summary of Products

The Aquatic Invertebrate project has produced annual and summary reports covering all years of the study (see Appendix Table 9). The Final Report, currently in preparation, includes a review of all the work conducted since 1992. Two master's theses (Roberts, 1994; Ray, 2002) and one doctoral thesis (Conn, 1998) have been generated by the project. The scientific journal *Hydrobiologia* accepted a manuscript covering the stream classification work subject to revision; that manuscript is currently undergoing revision for resubmission. Draft manuscripts have been prepared for submission relating to the year-to-year variation in community structure and its implications for biotic monitoring and secondly using the 1995 data and General Additive Models to identify environmental variables important in the distribution at the taxon level. Milner has incorporated Denali findings into review articles, such as Running Waters of the Alaskan Taiga Forest (Oswood et al. in press).

Milner and Conn have presented findings at various scientific meetings including the British Ecological Society, North American Benthological Society, Alaska Science Conference, and the American Society of Limnology and Oceanography. Milner has also presented findings for Denali visitors and developed a flyer on Denali streams for park visitors.

In 2001, Milner conducted a two-day workshop at Denali for NPS personnel to introduce concepts of stream biomonitoring and provide field experience with collecting and examining stream invertebrates.

Data for the project are currently stored in Microsoft Excel.

Because of the methods employed, the aquatic invertebrate study has resulted in a substantial collection of invertebrates from Denali streams. All collected organisms are identified (at least to the family level), counted, then preserved for long-term storage. The specimens will be deposited in the Aquatic Collection of the Museum at the University of Alaska Fairbanks.

The work to date has focused on developing information needed to make recommendations for an aquatic invertebrate monitoring protocol for Denali. Improving understanding of Denali stream ecosystems and the driving variables that determine the structure and function of their biotic communities has been a critical step. Successful monitoring requires us to comprehend how stream ecosystems work. Thus, the work to date provides the foundation for recommendations and decisions about objectives and appropriate methods for monitoring of aquatic invertebrates at Denali and in similar areas in interior Alaska. The work does not provide a "protocol" per se, although the work includes recommendations about what such a protocol should contain.

Status

Milner is currently in the process of incorporating internal review comments and production of the final report for the most recent agreement. Aquatic invertebrate sampling at Denali is currently on hold pending decisions about the Denali LTEM program and integration with the Central Alaska Network.

Acknowledgments

This account is based on the written record of the aquatic invertebrate project as documented in Appendix Table x, and on my own experiences as USGS-Project Leader for Cooperative Agreement #98WRAG1015. Sandy Milner kindly reviewed and provided many helpful suggestions, improving the depth and accuracy of this account.

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Table 9. Aquatic Invertebrate monitoring studies as part of the Denali Long-term Ecological Monitoring program, 1992-2002.
Location of sampling sites and number of sampling sessions at each site in each year.
Sites in Bold are the 14 sites selected for long-term monitoring.

Stream Name	Stream Group	Park Road Mile	1992	1993	Synoptic Survey Park Road Streams 1994	Wide Water Quality Study 1995	Longitudinal Study 1996	1997	1998	1999	2000	2001	2002
Park Road Sites													
Lower Rock Creek			**1**	**3**	**1**	**3**			**1**	**2**	**x**	**2**	**1**
E. Fork Toklat Glacial		**44**			**1**	**3**			**1**	**2**	**x**	**2**	**1**
Sanctuary River		**23**			**1**	**3**			**1**	**2**	**x**	**2**	**1**
Savage River		**13**			**1**	**3**			**1**	**2**	**x**	**2**	**1**
E. Fork Toklat Clear		**44**			**1**	**3**			**1**	**2**	**x**	**2**	**1**
Igloo @ Ranger Station		**34**			**1**	**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
Little Stony Creek East		**65**			**1**	**3**			**1**	**2**	**x**	**2**	**1**
Tattler Creek		**34**			**1**	**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
Braided Channel (Highway Pass Creek)		**56**			**1**	**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
S1		**17**			**1**	**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
N4		**36**			**1**	**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
Hogan Creek						**3**	**3 (x 4 sites)**		**1**	**2**	**x**	**2**	**1**
East Arm Main Toklat						**3**	**3 (x 6 sites)**		**1**	**2**	**x**	**2**	**1**
North Fork Moose Creek						**3**	**3 (x 5 sites)**		**1**	**2**	**x**	**2**	**1**
Upper Rock Creek			1	3	1	3							
Sunset Creek (Thorofare)		66			1	3							
Sunrise Creek		66			1	3							
Main Toklat Glacial		53			1								
Teklanika Glacial		29			1	3							
Main Toklat Clear		53			1								
Igloo @ Teklanika R		29			1	3							
Gorge Creek		66			1	3							
Stoney Creek		65			1	3							
Little Stony Creek West		65			1	3							
S2		19			1	3							
S4		43			1	3							
S5		57			1	3							
S6		59			1								
N1		21			1								
N3		26			1	3							
West Arm Main Toklat						3							
Upper Glen Creek						3							
South Fork Moose Creek						3							
Jumbo Creek						3	3 (x 2 sites)?						
Rainy Creek						3							
4th of July Creek						3							
Cascade Creek						3							
Hidden Creek						3							
Snow slide Creek						3							
Cripple Creek						3							
Alder Creek above the Ruth Glacier						3	3 (x 4 sites)						
Alder Creek at mouth						3							
Slide Creek & Alder Creek at Slide Confluence						1							
Wildhorse Creek						3							
Cloud Creek						2							
Crystal Creek						2							
Bear Creek						2							
Somber						2							
Barren						2							
Slipper Creek East						2							
Slipper Creek West						2							
East Fork Upper Birch Creek						2							
Middle Fork Upper Birch Creek						2							
West Fork Upper Birch Creek						2							
Upper Stampede						2							
Clearwater at Stampede						2							
Thorofare River							3 (x 5 sites)						

Fauna

Wolf/Prey Interactions

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Introduction

Since 1998, the Long-Term Ecological Monitoring program has contributed $37,000 per year to an ongoing research and monitoring of the population dynamics of wolves and their primary ungulate prey, caribou and moose, in Denali National Park and Preserve. This research, directed by the U.S. Geological Survey-Alaska Science Center (ASC), in close cooperation with LTEM staff, had an annual budget (not including permanent salaries) of approximately $285,000 with roughly equal contributions from USGS and NPS through 2002. This research effort has produced a broad array of products including 18 scientific publications, one book, and two graduate theses (see attached list).

Overview of Project History

The Denali wolf/prey research program grew out of two separate studies initiated in the mid-1980s. In 1984, Francis Singer, the NPS regional research biologist, initiated a three-year Natural Resource Preservation Program (NRPP)-funded study to evaluate the causes of a major decline in the Denali Caribou Herd during the 1960s and early 1970s and to investigate neonatal calf mortality in the herd. Layne Adams, the second regional wildlife biologist, took over that study in 1986, following Singer's departure to Yellowstone National Park. Adams extended the caribou study and continued the investigations of caribou calf mortality while broadening the study to include regular population assessments and examinations of productivity and survival of adult female caribou. The wolf component of the study began in 1986 as another NRPP study slated to continue for three years and aimed at assessing the status and trends of the park's wolf population. The wolf research was directed by Dr. L. David Mech, then a U.S. Fish and Wildlife Service wolf researcher, Layne Adams, and John Dalle-Molle, Denali's resource management specialist. During the initial years of the concurrent wolf and caribou research it became apparent that Denali offered a unique opportunity to investigate the natural dynamics of wolves and their ungulate prey where both were largely unaffected by human harvest or other human effects. Further, the synergistic effect of working on wolves and their prey simultaneously were recognized. Largely through the efforts of Allan L. Lovaas, the NPS Regional Chief Scientist, the wolf and caribou project continued to be funded via the NRPP program through 1993. By 1993, the wolf and caribou projects were largely intertwined and Layne Adams took over as principal investigator for the entire program. During 1994 to 1997, the work continued via a combination of funding from the NPS Alaska Region and the new National Biological Survey and its successors. In 1998, the ASC entered into a cooperative arrangement with Denali to continue the wolf and caribou monitoring and to begin a five-year study of moose population dynamics in the park, with the two agencies roughly splitting the costs of the wolf/prey research program.

Since its inception in 1986, the goal of the wolf/prey research at Denali has been to monitor population characteristics of wolves and caribou in sufficient detail to determine the status and trends of these species. In addition, we seek to understand the factors affecting these populations in the context of the interrelationships that comprise the Denali wolf/prey system. In 1998, the goal of conducting similar research on moose was added to the overall program. This research strives to gain understanding of the roles that winter severity, differential landscape use, and relative vulnerability of prey species play in wolf/prey relationships in Denali, and ultimately in determining the abundance and trends of all three species. Through the conduct of this research and monitoring program, Denali National Park is provided with an annual assessment of the status and trends of wolves, caribou, and moose populations in the park and a thorough understanding of the natural and human-caused factors that influence those population trends. Specific objectives are as follows:

1. Monitor population trends, pup production, survival, distribution, and harvest of wolves in and adjacent to Denali north of the Alaska Range;
2. Determine population trends, calf production and survival, and adult survival in the Denali Caribou Herd;

3. Investigate nutritional condition, calf production and survival, and adult survival of moose in Denali north of the Alaska Range; and

4. Evaluate factors influencing the relationships among wolves and their ungulate prey.

We monitor wolves in Denali using standard radiotelemetry techniques that provide population estimates, as well as information on physical condition, distribution, productivity, survival, and dispersal. Radiotelemetry is also an important component of the caribou and moose research. Annual estimates of caribou herd size are derived from helicopter counts of adult cows on the calving ground in late May, helicopter composition surveys in late September, and survival estimates and distribution of caribou during surveys provided by radiotelemetry. As with the wolves, the handling and radiotelemetric monitoring of caribou provides additional information on physical condition, population age structure, productivity, and survival within the Denali Caribou Herd. We attempt moose population assessments every year via standard aerial survey methods, although snow conditions are not always adequate. The capture and radiotelemetry of moose also provide similar information to that gathered for caribou.

What Have We Found out about Predator/Prey Interactions?

Since 1986, wolf and caribou populations have varied in response to variation in winter snowfall. During 1986 to 1988, winter snowfalls were well below average. In 1986, the Denali Caribou Herd numbered about 2,600 animals and increased at about 7 percent per year. Wolf numbers were lower than we expected based on the abundance of ungulates, numbering about 60 wolves in March 1986. Further, pup production was poor and dispersal of young wolves was high. With the above-average winter snowfalls in 1988 to 94 and near record snowfalls in 1990 to 91 and 1992 to 93 winters, wolf numbers increased rapidly, reaching 135 wolves by late winter 1991, and stayed high through the 1992 to 1993 winter. Pup production was high and dispersal of young wolves substantially decreased during this period. The caribou herd reached 3,200 caribou in fall 1989, but declined to about 2,000 by fall 1993. Recruitment of calves was poor, averaging only 12 calves out of 100 cows in September 1990 to 93, compared to 35 out of 100 during 1984 to 1989. Further, mortality rates of cows increased from about 4 percent per year to 20 percent per year. Mortality of bulls also increased dramatically in that the adult sex ratio plummeted from an average of 56 bulls out of 100 cows during 1984 to 1990 to 30 out of 100 by 1995.

Winter snowfalls returned to average levels during the 1994 to 1995 winter and the following years. Wolf numbers have declined, with decreased abundance and vulnerability of their primary prey, to an average of about 94 wolves during March 1994 to 2002. Declines have occurred as a result of lower pup recruitment, higher dispersal of young wolves, and higher mortality of adults. The caribou population leveled off at about 2,000 to 2,100 caribou during 1993 to 1997, then declined to about 1,800 by fall 2002. Recruitment of calves has remained low, averaging only 13 calves out of 100 cows during 1990 to 2002.

With the low calf recruitment for more than a decade, the cow segment of the caribou herd has skewed toward the older age classes. We have noted higher mortality of adult cows in the last few years, compared to years of similar snowfall in the late 1980s. We suspect this results from a preponderance of old cows in the herd and their increased vulnerability to predation. Over the next few years, we expect the caribou herd to decline noticeably regardless of weather conditions as these old females die.

During the five years of moose research, we have determined that the moose population in Denali is relatively stable at a low density (less than or equal to 0.2 moose per square kilometers), comparable to many areas of interior Alaska. Because of their low population density, these moose are in superior physical condition and calf production is high, with 35 percent of two-year-old females producing calves and 44 percent of cows greater than or equal to three-year-old females producing twins. However, on average only about 15 percent of the calves produced survive to one year and that recruitment rate just balances natural mortality of adult females.

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Small Mammals Monitoring

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USGS-Alaska Science Center

Introduction

The terrestrial wildlife component of the original Denali LTEM program was proposed to include only two—relatively unknown—groups in the animal community: small mammals and songbirds (Van Horn et al. 1992). Key, but not explicitly stated, assumptions were that existing monitoring efforts at Denali targeted charismatic megafauna (i.e., wolves, caribou, bears and moose) and that park funding would likely always be available to support this work. The LTEM program therefore offered a unique opportunity to expand wildlife monitoring to a broader suite of Denali's biodiversity and ecological processes, and the small mammal component of the Denali LTEM program was born.

Denali supports about 20 small mammal species, including shrews, voles, mice, pikas, marmots, hares, and tree and ground squirrels. These species play critical intermediary roles in food chains because of what they eat, and what eats them. Like birds, they can also act as dispersers of plant and fungal reproductive parts thereby influencing vegetation dynamics. The extreme population fluctuations of some small mammals, mainly voles, also are believed to play an important role in overall ecosystem processes. Having a monitoring component to target voles, and other members of the small mammal community, would significantly broaden the diversity of organisms and ecological processes about which the park had information.

The detailed history of Denali LTEM small mammal studies from 1991 to 2003 is provided in Appendix Table x. This synopsis provides a succinct overview of the small mammal project, highlighting the initial phase of methods development and subsequent experiments with spatial expansion. We also briefly review key findings about small mammals in the Denali ecosystem from this project, summarize products, and describe the status of small mammal monitoring.

Overview of Project History

Project Organization

From the beginning, the park decided to contract for small mammal monitoring work with the University of Alaska Fairbanks. Eric Rexstad, Associate Professor of Quantitative Wildlife Biology, has been the Principal Investigator for the small mammal project through its entirety. From 1992 to 1997, this was arranged via an agreement directly between the National Park Service (NPS) and the university. Starting in 1998, the USGS-Alaska Science Center set up an agreement with Rexstad (Research Work Order No. 81), combining funding from both agencies. Under this new agreement, Rexstad was asked to continue the small mammal monitoring and also explore methods for integrating LTEM data sets.

In addition to Rexstad, personnel involved in the small mammal project have included the former curator of mammals at the University of Alaska Museum, Joseph Cook (1992 to 1993); graduate student Pamela Furtsch (1993 to 1994); and Research Analyst Ed Debevec (1999 to the present). For the field work, the project has typically relied on one crew, generally composed of two technicians, supplemented by volunteers.

Generally, between $25,000 and $35,000 was allocated each year to the small mammal project. In 1996, however, the National Biological Survey did not fully fund the agreement supporting the small mammal project, and funding was not available for a field crew. Eric Rexstad, using volunteers, conducted the field work that occurred that year. Throughout the study, Denali has provided some logistic support, including crew housing, bear resistant food containers and radio communications. Funds have primarily paid for field crew salaries and field camp costs, small mammal marking supplies, and transportation (which increased as the project attempted to look at more sites). The funds also generally covered about one month per year of Principal Investigator Rexstad's salary. Overhead costs were 10 percent. USGS funds provided to Research Work Order No. 81 helped support Research Analyst Ed Debevec, who has played a fundamental role in analyzing data and writing annual reports since 1998.

General Approach to the Project

The Denali LTEM proposal provided only general guidance to the small mammal monitoring project. The first guideline was that the methods should not adversely affect the study sites so as to support long-term usage of the sites. Thus, the project began with the assumption that live-trapping methods would be used. The only other guideline was that small mammal monitoring sites would be co-located with vegetation monitoring sites, which would be spread throughout the park according to the watershed design.

Using live-trapping methods opened an opportunity to observe the dynamics of small mammal populations, in addition to measuring yearly abundances. Using mark-recapture methods also allowed the project to produce estimates of abundance with confidence limits, rather than just indices of abundance. The project used state-of-the-art methods for marking animals. Animals were injected with microelectronic chips (called passive integrated transponders or PIT tags), which greatly simplified the process of identifying them when recaptured. Data were analyzed using the Program CAPTURE (Rexstad and Burnham 1991).

In general, the small mammal project has consisted of producing estimates of small mammal abundance at various locations and times during the snow-free season. At most sites, traps were deployed in a grid configuration consisting of 100 Sherman Traps, set out in 10 rows of 10 traps each, spaced at 10-meter intervals. At three sites, a configuration of six rows of 16 traps each was used due to topographic constraints. In Rock Creek, three sites were set up to test trapping web designs (166 traps) in 1994 to 1996. Two of the webs were converted to the standard grid design for 1997 to 2002. Locations of all sites were chosen based on judgment in areas thought to support voles. A total of 34 sites accessible from the park road have been sampled; some sites were only sampled once, and only two sites have been sampled every year. Each sampling occasion involved opening traps for four to five days to provide an estimate of abundance on a grid for that period. The annual allocation of sampling effort throughout the project is summarized in Table 1.

Ideally, sampling occasions would occur frequently throughout the snow-free season to provide estimates of survivorship and reproductive rates, in addition to end of the summer peak abundances. Knowing these would provide much more information about the status of the populations than just knowing the absolute number of animals present. However, such in-depth sampling within the summer season was frequently sacrificed to allow sampling at more locations. This is the classic problem faced by all monitoring projects (how to sample over both space and time with limited budgets), which forces difficult decisions about objectives.

The small mammal project has gone through two phases between 1992 and 2002. In the start-up phase, basic questions of logistic feasibility and methodology were determined. In the second phase, the question of spatial expansion was addressed.

Start-up Phase

In the first year (1992), six sampling grids were chosen in the Rock Creek watershed, including two replicates in three habitats: alpine, forest, and riparian. Using these grids, the basic logistical questions were addressed. These questions included such things as how often to check traps, how long should a trapping session be, and when should trapping occur throughout the season.

After the first year, the alpine sites in Rock Creek were dropped, based on several factors. In 1992, helicopter support was provided to get the crew and traps to the alpine site. When assurance of continued helicopter support was not forthcoming, returning to the alpine sites became infeasible. There was also a crowding problem, because the alpine vegetation plots occupied most of the quasi-flat territory in upper Rock Creek. In addition, without the helicopter, there was no source of drinking water for the four to five day stays required for small mammal sampling. Dropping the alpine sites shifted the project focus to small mammal populations in forested habitats. This adjustment in objectives, and therefore sampling effort, was a typical response to logistical realities, and would be replayed throughout the project.

In the start-up phase, an initial focus was to determine if trapping webs could be used to allow density, rather than absolute abundance, to be estimated. Density is the preferred measure because densities can be compared among sites and times, even if different plot sizes have been used. In a web formation, traps are laid in lines radiating from a central point. The web versus grid question was one of the topics addressed by master's degree student, Pamela Furtsch. She found that the density estimates based on trapping webs were not sufficiently precise for use as the basis for long-term monitoring (Furtsch 1995). This finding solidified the basic approach of using grids. This start-up phase and the eventual settling down into sampling with consistent methods on four grids in Rock Creek occurred over a five-year period, from 1992 to 1996.

Spatial Expansion

In the next phase, the small mammal project experimented with spatial expansion: how to expand the sampling out of Rock Creek to understand patterns of small mammal populations across the Denali landscape? This was a familiar question asked by all LTEM projects.

In 1994, Rexstad made a reconnaissance trip to the Wonder Lake end of the park road to look for additional areas for small mammal sampling. In August 1995, one grid was established in black spruce forest-muskeg off the McKinley Bar trail, south of Wonder Lake. Two more grids were added in 1997 and sampled at least once each year in late summer in subsequent years. The McKinley Bar grids, located roughly 100 kilometers west of Rock Creek, are within a different ecoregion, and data from these sites, although limited, provided much needed perspective on the findings from Rock Creek.

The spatial extent of sampling was broadened further in 1997 to 1999. During this period—which might be called the frontcountry period—grids were established in three watersheds near Rock Creek. This effort was to answer the question of how representative the Rock Creek results were to what occurred with small mammal populations in the rest of Denali. Did small mammal populations in areas near Rock Creek act in the same manner? In each new watershed, two riparian and two forest grids were established. To allow this additional sampling to occur, the sampling effort in Rock Creek was reduced in both space and time. After three years of sampling, during which vole populations experienced both a high and lows, the answer to the question was "yes": populations in nearby drainages appeared to act in a similar manner to populations in Rock Creek. However, McKinley Bar populations did not always track with Rock Creek populations, illustrating that LTEM staff should investigate an intermediate spacing of sampling sites.

Thus, for the next three years (2000 to 2002), the spatial expansion experiment took a new tact. Newly established grids at about 20 kilometer intervals along the park road took the place of the frontcountry grids. The new grids were established at Teklanika, Polychrome Pass, and Stony River, courtesy of expert opinion on siting provided by NPS Wildlife Biologist Carol McIntyre. These new grids occurred at higher elevations than either Rock Creek or McKinley Bar and sampled more non-forested habitat. The species composition on the new grids therefore differed, with *Microtus* voles being generally more abundant. With these new grids, the small mammal project could finally sample a broader array of the small mammal populations in the Denali landscape.

What Have We Found out about Small Mammal Populations?

The species that were caught often enough to allow LTEM staff to make abundance estimates were the red-backed vole (*Cleithrionomys rutilus*), the root vole (also called the tundra vole) (*Microtus oeconomus*), the singing vole (*M. miurus*), and shrews (*Sorex* sp.). Because most of the trapping occurred in forested habitats, the majority of animals trapped were red-backed voles. As noted earlier, when the study expanded out of Rock Creek to include alpine areas, more information was obtained about the two *Microtus* voles, especially the singing vole.

In general, small mammal populations exhibited the following basic pattern in the snow-free season: low numbers at the beginning of the summer, increasing over the summer and reaching a peak in late August or early September. Early season population estimates were consistently low—just a few voles per hectare. End of the season estimates ranged widely among years. For example, late August/early September point estimates (voles per hectare) in Rock Creek ranged from 2 to 82 for red-backed voles, 0 to 50 for root voles, and 0 to 16 for singing voles. When end of the summer populations were high, this was due in part to those animals born early in the summer who then reproduced.

Throughout the study, a variety of environmental conditions has occurred, allowing an opportunity to consider how these variations influenced vole populations. The predominant factors likely to influence small mammal populations include winter severity (snow depth, length of snow cover), characteristics of the spring (timing, temperature, wetness), berry production, and predator populations. On the riparian plots, aufeis—buildups of ice overflowing from the creek bed typically during winters with low snow—were discovered to delay plant growth. This effect on the habitat appeared to depress root vole populations in these riparian habitats.

As part of the effort to explore methods for integrating data sets, Rexstad and Debevec experimented with developing a "vole model." Could the end-of-summer abundance of voles be predicted based on weather conditions in the preceding winter and spring? The model employed three weather indices: a *winter severity index*, a *spring onset index*, and a *spring rainfall index*. Using current data from Rock Creek (1992 to 2002), the model performed well for red-backed voles (84.8 percent of variation explained), but less well for root voles (36.9 percent), singing voles (29.3 percent), and shrews (32.9 percent). Ideally, the model also would have been able to use annual data on berry, seed, and fungi production because these are important food sources for voles. The model ideally would have provided other types of data as well. Factors that best describe red-backed vole abundance may well differ from those that describe *Microtus* and shrew abundance. However, the only consistent data set available for examining correlations with small mammal abundance was weather. The "vole model" experience demonstrated the importance of designing the monitoring studies together, rather than in isolation.

Another part of the data integration effort involved the development of a metric termed the *probability of conformance*. The idea of this metric was to ask the question: do the data for this year conform to data from past years? That is, are the observations in any given year in line with past years, given the observed patterns of interannual variation? The metric is nicknamed *sigma,* which is the term used to describe process variation, or the amount of population variation due to natural ecological processes (as opposed to sampling variation). *Sigma* provides an alternative to trend analysis as a method of change detection. It also provides a tool for examining how all data sets are behaving in a given year (was everybody up or down?) and might therefore help with data integration.

Sigma has potential as a valuable analysis tool to evaluate the status of vole populations, because vole populations have such high interannual variability. Standard monitoring dogma suggests that one should not monitor highly variable things, but for the Denali ecosystems, high variability is a defining characteristic. *Sigma* provides a method for teasing apart process variation and sampling variation, thus allowing us to detect traditional changes in an attribute as well as changes in the underlying process variation itself. *Sigma* has been applied to the small mammal data sets since 2000, and is suitable for other Denali data sets where a measure of precision is generated along with a point estimate.

As with any long-term investigation, some observations were made during the small mammal studies that were not expected. Serendipitous findings from this project included:

- In 1993 and other years of generally high populations, a number of red-backed voles with dark pelage (fur) were captured in Rock Creek. Observers noted the dark color phase of the red-backed vole in Siberia and the Yukon Territory, but never before in Alaska. Dark morph individuals apparently are only found during population highs.
- In the frontcountry study, a juvenile male root vole captured and marked in Rock Creek was recaptured six days later on a grid 3 kilometers away in the watershed west of Rock Creek. This observation added to our understanding of population dispersal mechanisms by showing the distance and speed that young voles can travel.
- Twice during the study, several animals marked in one summer were recaptured the following summer. The recaptures of animals that survived the winter occurred following the relatively mild winters of 1994 to 1995 and 1999 to 2000.
- Shrews were not a target organism for this study, but often were caught in the traps. Generally, the number of shrews caught was few to none. However, during 2001, the traps caught a great number of shrews. Shrew population dynamics

have been little studied, and this observation suggests that shrew populations can grow rapidly under certain conditions.

- In 2000, two yellow-cheeked voles (*Microtus xanthagnathus*), a species never before caught at any other grids, were captured at McKinley Bar. Yellow-cheeked voles are a colonial species associated with taiga forest that has recently burned. A few yellow-cheeked voles also were found in 2001 and 2002. These findings provided insight into dispersal mechanisms in this species that occupies ephemeral habitats.

Summary of Products

The small mammal study produced annual reports for every year of the study, except 1994 to 1996. However, required *Investigators' Annual Reports* were filed for all years, and the 1994 to 1996 data were reported by other means (i.e., Furtsch's thesis, subsequent annual reports). In terms of documenting methods, an initial protocol was written and later revised by Rexstad to provide more detail to conform to NPS protocol guidance (Rexstad 1997 and Rexstad 2000 draft). Rexstad has regularly presented results in numerous forums, including scientific meetings and presentations for the general public. The small mammal project has thus far resulted in one master's degree thesis (Furtsch 1995) and two publications (Rexstad 1994, Oakley et al. 1999).

The small mammal project has an excellent record in the area of data management and experimenting with methods to improve the speed of data analysis and delivery. Since 2000, data from the small mammal project have been available on the Denali StatServer web site. Because the project has used palmtop computers in the field, and has transmitted data from the field to the office weekly and programmed basic analysis routines, results from each trapping session are now available almost instantly. These data management functions have supported the timely production of annual reports soon after the field season.

Some removal trapping was conducted in the early years of the project, and incidental mortalities have occurred in all years. All small mammal mortalities have been preserved as specimens for archival in the University of Alaska Museum mammal collection. These specimens are important by-products of this monitoring study. They provide material for future morphological, genetic, stable isotope, and contaminant studies, and for answering potential future questions. The specimens will allow comparison of data from Denali small mammals to data from small mammals in other locations, thereby allowing Denali data to contribute to our understanding of environmental change over broader scales of space and time.

Status

The small mammal monitoring project is currently on partial hold while the overall LTEM program is being evaluated. In 2002, a preliminary effort was made to see how the presence and abundance of small mammals could be assessed in the minigrid design. (Study of the minigrid design currently underway may help to understand changes in various attributes over the Denali landscape; initial efforts have focused on vegetation and landbirds.) During one week of the 2002 field season, an attempt was made to trap on the Rock Creek minigrid, but a number of logistical hurdles were encountered. In 2003, plans call for a slightly larger effort to figure out how to sample in the minigrid design. The approach that will be tested employs a new method for density estimation. This new method involves a passive approach to detection of animals (Lukacs et al. in press.). In addition, traditional sampling is planned to occur at least once on the two Rock Creek grids that have been sampled continuously since 1992 (RF1 and RR2). The McKinley Bar grids, which have been sampled continuously since 1997, will not be sampled in 2003.

Acknowledgments

This account is based on the written record of the small mammal project as documented in Table 10, and on my own experiences as USGS-Project Leader for Research Work Order #81. Eric Rexstad and Ed Debevec reviewed this account of the small mammal's project history, and I thank them for kindly filling in some of the blanks, correcting my mistakes, and for finding the account generally agreeable.

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See Table 10, next page.

Table 10. Small mammal monitoring studies as part of the Denali Long-term Ecological Monitoring program, 1992-2002. Location of sampling grids and number of trapping sessions on each grid in each year.

Grid Name/Location	Grid Code	HABITAT	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Rock Creek													
Forest Upper	FU	forest	3	6									
Forest 1	RF1	forest	3	6	6	6	3	4	5	5	3	3	3
Forest 2	RF2	forest						4	5	5	3	3	3
Riparian 1	RR1	riparian	3	6				4	5	5	3	3	3
Riparian 2	RR2	riparian	3	6	6	6	3	4	5	5	3	3	3
Forest Web East	FWE	forest			6	6	3						
Forest Web West	FWW	forest			6	6	3						
Riparian Web	RW	riparian			6	6	3						
Wonder Lake (McKinley Bar)													
Wonder Lake	WL	forest/muskeg				1							
Wonder Lake 1	WL1	forest/muskeg						1	1	1	2	2	2
Wonder Lake 2	WL2	forest/muskeg						1	1	1	2	2	2
Wonder Lake 3	WL3	forest/muskeg						1	1	1	2	2	2
Frontcountry Study Sites (1997-1999)													
"Clark" Creek (1st Creek West of Rock Creek)													
Forest 1	CF1	forest						1	2	2			
Forest 2	CF2	forest						1	2				
New Forest 2	NCF2	forest								2			
Riparian 1	CR1	riparian						1	2	2			
Riparian 2	CR2	riparian						1	2	2			
Hines Creek													
Hines Forest 1	HF1	forest						1	1	1			
Hines Forest 2	HF2	forest						1	1	1			
Hines Riparian 1	HR1	riparian						1	1	1			
Hines Riparian 2	HR2	riparian						1	1	1			
"Kiki" Creek (2nd Creek West of Rock Creek)													
Kiki Forest 1	KF1	forest						1	1	1			
Kiki Forest 2	KF2	forest						1	1	1			
Kiki Riparian 1	KR1	riparian						1	1	1			
Kiki Forest 2	KR2	riparian						1	1	1			
Park Road Study Sites (2000-2002)													
Teklanika													
Teklanika 1	TK1	forest/meadow									2	2	2
Teklanika 2	TK2	forest/meadow									2	2	2
Teklanika 3	TK3	river bar									2	2	2
Polychrome Pass													
Polychrome 1	PC1	alpine tundra									2	2	2
Polychrome 2	PC2	alpine tundra									2	2	2
Polychrome 3	PC3	wet meadow									2	2	2
Stony Creek													
Stony Creek 1	SC1	alpine tundra									1	2	2
Stony Creek 2	SC2	alpine tundra									1	2	2
Stony Creek 3	SC3	alpine tundra									1	2	2

Eagles/Gyrfalcons

Carol L. McIntyre,
Denali National Park and Preserve

Introduction

Birds of prey, or raptors, are top trophic level predators. The 11 species of diurnal raptors that breed in Denali National Park and Preserve, Alaska (hereafter referred to as Denali) include the smallest raptor, the American Kestrel (*Falco sparverius*); two of the largest raptors in North America, the Bald Eagle (*Haliaeetus leucocephalus*) and the Golden Eagle (*Aquila chrysaetos*); and the largest falcon in the world, the Gyrfalcon (*Falco rusticolus*). The five species of nocturnal raptors (owls) that breed in Denali include one of the smallest northern breeding owls, the Boreal Owl (*Aegolius funereus*), and one of the largest owls in North America, the Great Gray Owl (*Strix nebulosa*). The diversity of raptors breeding in Denali include:

1) the Osprey (*Pandion halieaetus*), a large raptor that preys primarily on fish;
2) the American kestrel, a small raptor that preys on voles, mice, insects, and small birds;
3) the Golden Eagle, a large raptor that preys primarily on medium-sized mammals and birds, but also preys on caribou calves and Dall sheep lambs;
4) and the Gyrfalcon that preys on medium sized birds and mammals.

This diversity of breeding raptors suggests that Denali contains not only a variety of habitats, but also a diversity of prey species. The conspicuousness of raptors in the Denali landscape poses questions about why this area supports a diverse guild of breeding raptors. In contrast, areas that do not support diverse raptor populations pose questions about their absence.

The population ecology of raptors is a fascinating field of research. Raptors are sensitive to changes in their environment and often respond quickly, and sometimes predictably, to such change. Such responses often appear in the reproductive ecology of raptors. For instance, many raptors do not produce young in years when prey is sparse. Additionally, other environmental factors such as weather can influence raptor reproductive ecology. Some raptors are also good indicators of severe changes in our environment, such as the presence of dichlorodiphenyltrichloroethane (DDT) and other environmental contaminants. Identifying factors that affect the reproductive ecology of raptors often leads to a better understanding of ecological relationships and interactions in the environment.

Unfortunately, monitoring the populations of many species of raptors is difficult due to their low densities, the remoteness of the breeding grounds, or the difficulty in finding nesting pairs. This is not the case with Gyrfalcons or Golden Eagles. The body size of both species is large and their nest sites are relatively conspicuous to the trained eye. Further, the high breeding densities of both species in Denali provide a unique opportunity for monitoring the reproductive ecology of both species over time.

In relation to other areas in interior Alaska, Denali supports a relatively high density of Golden Eagles and Gyrfalcons. As late as the mid-1980s, the reproductive ecology, nesting phenology, non-breeding season movements, and population dynamics of both species were not well described in interior and northern Alaska. Murie (1944) provided the most recent quantitative information on Golden Eagles nesting in Denali and Cade (1987) provided the most recent estimate on the size of the breeding population of Gyrfalcons in Denali. Both Murie (1944) and Cade (1987) limited their studies to areas within a day's walking distance of the Denali park road. Murie (1944) estimated that there were at least 25 breeding pairs of Golden Eagles and Cade (1987) estimated that there were at least five breeding pairs of Gyrfalcons in the north-eastern portion of Denali.

This monitoring program started in 1988, four years before the initiation of the Denali Long-Term Ecological Monitoring Program (LTEM). The initial goal in 1988 was to determine the abundance and distribution and describe the population ecology of both species. This summary provides a succinct overview of the Golden Eagle and Gyrfalcon monitoring program in Denali. A detailed history of this monitoring program from 1987 to 2003 appears in Appendix A. This synopsis highlights the initiation of the program, subsequent projects that stemmed from the monitoring program, key findings, products, and the program's status.

Although the Denali LTEM did not fund this project from 1991 to 1999, park managers in Denali considered many of the long-term monitoring programs:including the wolf-predator/prey studies and this project:part of the Denali LTEM. Gordon Olson, Denali Chief of Resources, attempted to include all monitoring occurring in Denali into the LTEM program, regardless of financial support.

Project History

Project Organization

In addition to Carol McIntyre, wildlife biologist and principal investigator for the Golden Eagle and Gyrfalcon monitoring program through its entirety, several biologists have served as technical advisors. These include Robert E. Ambrose, endangered species biologist, U.S. Fish and Wildlife Service (FWS) and National Park Service (NPS); Ted Swem, endangered species biologist, FWS; Michael N. Kochert, research wildlife biologist, U.S. Geological Survey (USGS), Biological Resources Division (BRD), Snake River Field Station (SRFS); Karen Steenhof, research wildlife biologist, USGS, BRD, SRFS; Michael W. Collopy, department chair, University of Nevada, Reno; and Fredrick Dean, professor emeritus, University of Alaska, Fairbanks.

Initiation of the Program

In 1987, the Denali resource program supported studies to locate nesting territories of Golden Eagles and Gyrfalcons in the northeastern portion of Denali and to summarize information on nest site locations collected by volunteers from 1979 to 1987 (Britten and McIntyre 1988, McIntyre et al. 1988). Joe Van Horn, NPS, and John Dalle-Molle, NPS, both former resource managers at Denali, were instrumental in starting this program. The purpose of these studies was to increase the knowledge base on the distribution and abundance of Golden Eagles and Gyrfalcons in Denali. Results of these studies showed that significantly more pairs of breeding Golden Eagles and Gyrfalcons were present in Denali than suggested by Murie (1944) and Cade

(1987). This increase resulted not from an increase in the size of the populations, but as a result of searching a much larger area for evidence of nesting pairs. In 1987, we located 52 occupied Golden Eagle nesting territories and at least 27 Gyrfalcon nesting territories in the northeastern portion of Denali (Britten and McIntyre 1988, McIntyre et al. 1988). The discovery of these large breeding populations increased National Park Service (NPS) awareness of these aerial predators in the ecosystems of Denali.

General Approach to the Project

In 1988, following a literature review on monitoring raptor populations, the team of Carol McIntyre (NPS), Robert Ambrose (FWS), Mike Britten (NPS), Mike Kochert (USGS/BRD/SRFS), and Karen Steenhof (USGS/BRD/SRFS) worked to develop a long-term monitoring program for Golden Eagles in Denali (McIntyre 1995). The consensus of Denali park managers and those just mentioned was that the Denali study should focus on locating nesting territories and collecting data on reproductive activities, including occupancy of nesting territories, production of clutches, production of nestlings, nest site characteristics, food habits, and movements during the non-breeding season. The Golden Eagle and Gyrfalcon monitoring program in Denali began officially in 1988 (McIntyre 1995, McIntyre and Adams 1999) using methods similar to those used for collecting data on the occupancy of nesting territories and reproductive activities of raptors in the Snake River Birds of Prey National Conservation Area (NCA) (Steenhof 1987, Steenhof et al. 1997). Because Gyrfalcons nest in the same habitat as Golden Eagles, we also collected information on their nesting ecology simultaneously with the Golden Eagle fieldwork without additional costs. This provided a unique opportunity to study the reproductive characteristics of two large raptors sharing similar breeding grounds, but with very different life history characteristics. The Golden Eagles breeding in Denali are migratory, spending nearly half their lives away from the breeding grounds. The Gyrfalcon, on the other hand, are residents and usually remain at northern latitudes throughout the year.

Monitoring Reproductive Success

We monitored the reproductive activities of Golden Eagles at an average of 70 nesting territories and of Gyrfalcons at an average of 17 nesting territories in the study area each year. We observed nesting territories using standardized aerial surveys two times during the breeding season (McIntyre and Adams 1999) and visited nesting territories to collect prey, band nestlings, collect blood samples and collect shed feathers. During all field activities, we also searched for new or previously undiscovered nest sites and nesting territories of all species of raptors. This last has particular importance, as relying on historic nesting territories alone can bias efforts of monitoring population trends (Steenhof 1987).

During the last week of April or the first week of May, we observed as many nesting territories as possible using standardized aerial surveys conducted from a small helicopter. We observed nesting territories located along the George Parks Highway from vantage points along the highway and categorized those that showed signs of territorial activity, courtship, brood-rearing activities, eggs, young, or any other conspicuous field signs (e.g., newly constructed or decorated nests) as "occupied". For both species, we defined a pair that occupied a nesting territory as a "territorial pair." If we could not find evidence of occupation during the aerial survey, we landed the helicopter and made observations from a vantage point on the ground.

From late June to mid-July, we visited a sample of nesting territories to collect prey remains, band nestlings with U.S. Fish and Wildlife Service aluminum leg bands, collect blood samples from nestlings, and collect shed feathers. We traveled to remote nesting territories via helicopter and to nesting territories within 5 kilometers of the Denali park road or the George Parks Highway via foot travel.

During the middle to later part of July, we observed all nesting territories and observed eggs or chicks using standardized aerial surveys, conducted from a small helicopter or from a vantage point on the Denali park road, to count fledglings. For Golden Eagles, we categorized a territorial pair that produced a clutch of eggs as a "laying pair" and a "successful" territory as one that produced greater than or equal to one young that reached 51 days of age (80 percent of normal fledging age; Steenhof 1987), unless the young did not survive until fledging. For Gyrfalcons, we categorized a "successful" territory as one that produced greater than or equal to one young that reached 30 days of age. For both species, we defined "productivity" as the number of young produced per territorial pair and mean brood size as the number of young produced per successful pair (Steenhof et al. 1997). Because Gyrfalcons often lay eggs before Golden Eagles in Denali and our surveys are timed to correspond to egg-laying dates for the former, we could not count the number of Gyrfalcons pairs that produced eggs. Because Gyrfalcons usually fledge before Golden Eagles, we based our estimates of Gyrfalcon productivity on counts of nestlings and fledglings. Appendix B contains the equations for calculating the reproductive activity of Golden Eagles and Gyrfalcons.

Calculating Nesting Phenology

Estimating the major events of the breeding season, including laying dates, hatching dates, and fledging dates, is necessary to protect nesting territories during the breeding season and to detect and assess changes in nesting phenology over time. Since 1988, we estimated dates of egg laying, hatching, and fledging at a sample of Golden Eagle and Gyrfalcon nests in the study area. We assigned hatching dates to all nestlings for which we could make reliable estimates of their age before fledging. By back- and front dating from the hatch date, we also estimated laying and fledging dates. From 1988 to 1994, we used a photographic ageing key (Hoechlin 1976) to age Golden Eagle nestlings. We also made repeated observations at a sample of nesting territories to estimate nesting phenology. After 1994, we used characteristic stages of feather development to estimate the age of Golden Eagle nestlings. In many years, we also made repeated observations at Golden Eagle nests to document actual dates of fledging. In all years, we used characteristic stages of feather development and size to estimate the age of Gyrfalcon nestlings.

All estimates of phenology are based on the estimated age of nestlings during our observations. We cannot determine the nesting phenology at nests that fail during incubation or very early in the nestling period. This limitation biases estimates of nesting phenology to successful nests.

Calculating Survivorship of the Breeding Population and Assessing the Fidelity of Golden Eagles to Nesting Territories

Golden Eagles frequently pluck or molt feathers at their nest sites. These feathers are easy to find and collect. We collect shed feathers at or near occupied nest sites simultaneously with visiting nests for banding the nestlings and collecting prey remains. After extraction and analyses, we transfer all feathers to the National Eagle and Wildlife Property Repository at the Rocky Mountain Arsenal in Commerce City, Colorado. The blood samples are archived at the USGS Alaska Science Center genetics lab for future use. Our preliminary results indicate that we can identify individual breeders using DNA extracted from the shed feathers. With an adequate sample size, we can use these data to assess fidelity to nesting territories and adult survival.

Developing Indices of Spring Prey Abundance

From April until late July, we recorded the number of adult Snowshoe Hare and Willow Ptarmigan observed each field day between 0800 and 1800 Alaska Standard Time. We constructed an index of the annual abundance for each species by summing the total number of animals detected each year and dividing the sum by the number of field days (McIntyre and Adams 1999). We developed these indices because raptors respond strongly to changes in the prey supply, particularly early in the breeding season. No other data are collected on Golden Eagle and Gyrfalcon prey in Denali.

Cost

The annual operating costs for this program are relatively low and have remained relatively flat for 15-years (Appendix B). We monitored the reproductive success of both species using field-tested methodology for operational costs of approximately $18,000 to $24,000 per year (Appendix C).[1] Actual costs per year varied depending on the number of remote nesting territories that we visited for banding nestlings, and collecting blood samples and feathers.

The annual cost to monitor each nesting territory has decreased over the years, despite the significant increase in the cost of aviation fuel. The decrease results from efficient survey techniques, the principal investigator's intimate knowledge of the study area, and the use of a fuel-efficient Robinson R-44 helicopter for the survey work from 2000 to 2002. We expect that the cost to continue this monitoring program will increase as the price of aviation fuel increases.

Significance of this Program

This is one of the longest running studies on Golden Eagles and Gyrfalcons in Alaska and our results provide critical information for conservation of these species in North America. Both species are of conservation concern: Golden Eagles because of habitat changes on their wintering grounds in western North America, and Gyrfalcons because the only place that they breed in the United States is in Alaska. There are very few contemporary monitoring programs for breeding either species in North America and even fewer long-term monitoring programs for these species across their range (Clum and Cade 1994, Watson 1997, Steenhof and Kochert 2002). The Denali study is one of three long-term Golden Eagle monitoring studies in Alaska and the only contemporary study with a large sample size of territorial Golden Eagles (greater than 50 territorial pairs). The other monitoring studies occur:

1) in the Yukon Delta National Wildlife Refuge
2) along the Porcupine River, Arctic National Wildlife Refuge

The other monitoring studies occur:

1) in the Yukon Delta National Wildlife Refuge
2) on the Colville River
3) on the Seward Peninsula (just now gearing up to study Gryfalcons)

In a recent review of the status and trends of Golden Eagle populations in North America, Kochert and Steenhof (2002) identified the need for monitoring populations consistently across the species' range, using well-designed monitoring programs. Further, Kochert and Steenhof (2002) recommended the continuation of long-term nesting surveys including our current efforts in Denali. The methodology used to monitor the reproductive activities of Golden Eagles in Denali is nearly identical to those used in the Snake River Birds of Prey NCA (Steenhof et al. 1997). Therefore, we can make comparisons between the reproductive success and population trends of Golden Eagles in Denali and the Snake River Birds of Prey NCA (McIntyre and Adams 1999). Such comparisons provide valuable insights about the responses of eagles to different environmental stressors in different geographic locations (Kochert and Steenhof 2002).

Results from our long-term monitoring of the reproductive characteristics of Golden Eagles in Denali provided the foundation for the development of several other studies of the ecology of northern breeding Golden Eagles including:

1. 1996 to present: cooperative research project with the USGS, BRD, Forest and Rangeland Ecosystem Science Center, USGS, BRD, Alaska Science Center, Department of Fisheries and Wildlife, Oregon State University, and ABR Inc., Environmental Services. Objectives of the research project are: (a) describe the landscape features of nesting territories of Golden Eagles in Denali, (b) examine the effects of landscape characteristics on the reproductive success and survival of Golden Eagles in Denali, (c) describe the fledgling dependence period and estimate survival of juvenile Golden Eagles during this period, (d) estimate survival of juvenile Golden Eagles during their first year of independence, (e) describe the migratory routes and migratory strategies of juvenile Golden Eagles, and, (f) identify and describe the winter and non-breeding summer ranges of juvenile Golden Eagles. The data analyses and manuscripts associated with this comprehensive study ended in December 2003.

2. 2001 to present: cooperative study with the USGS, BRD, Alaska Science Center to identify individual Golden Eagles using DNA from extracted from feathers shed at or near their nest sites and exploring methods for using these data to estimate adult survivorship (Pearce et al. 1997). This technique is non-invasive, inexpensive, and sustainable over many years.

3. 2001 to present: cooperative project with the Alaska Department of Fish and Game (ADF&G) in the Wood River/Dry Creek area (hereafter referred to as Wood River) approximately 70 kilometers east of the Denali study area to study the effects of Golden Eagles on survival of Dall Sheep (*Ovus dalli dalli*) lambs. The primary goal of this project is to understand the ecological relationship between Dall Sheep and their primary predators and to describe how these relationships change in relation to the Snowshoe Hare cycle. Results from this cooperative project may provide further insight into the ecological relationships of Golden Eagles and their prey in the central Alaska Range (Arthur and McIntyre 2002).

In addition to providing the foundation for these studies, information generated by this monitoring program has contributed to the knowledge of the ecology of Gyrfalcons in Alaska (Swem et al. 1994) and Golden Eagles in North America (McIntyre 1995, McIntyre and Adams 1999, McIntyre 2002, Steenhof and Kochert 2002, Kochert et al. 2002).

What Have We Found out about Golden Eagles and Gyrfalcon Populations in Denali?

This program has spanned nearly two complete population cycles of Snowshoe Hare. Our results, while circumstantial, suggest a strong relationship between the population cycles of Snowshoe Hare and Willow Ptarmigan. Our results also suggest a close relationship between the abundance of these prey species and the reproductive success of both Golden Eagles and Gyrfalcons in Denali. The numbers of territorial pairs present in the study area, however, are unrelated to prey abundance. These findings are consistent with Steenhof et al. (1997), Watson (1997), and Brown and Watson (1964) who reported stable numbers of Golden Eagle pairs in Idaho and Scotland regardless of prey abundance. The density of territorial pairs of Golden Eagles in some large areas may vary by no more that 15 percent of either side of the mean level for decades (Newton 1979).

The number of pairs of Golden Eagles producing eggs relates closely to spring prey abundance and far fewer pairs raise fledglings in years when prey supplies are low (Steenhof et al. 1997, McIntyre and Adams 1999). This seems to be the case with Gyrfalcons as well. Productivity, measured as the number of fledglings produced per territorial pair, varies greatly for both species in Denali. Steenhof et al. (1997), Watson (1997), and Kochert et al.

(2002) reported similar variation in the reproductive success of Golden Eagles. Newton (1979), Clum and Cade (1994), and Nielsen (1999) reported similar variation in the reproductive success of Gyrfalcons. In general, when conditions for breeding are good (high prey abundance and fair weather), both species successfully produce large broods (one to three fledglings for Golden Eagles, one to four fledglings for Gyrfalcons). But when conditions for breeding are poor (low prey abundance, and/or low prey abundance and poor weather), both species rarely produce broods. The difference between a high and low production year for Golden Eagles is dramatic; 71 fledglings in a high production year versus four fledglings in a low production year.

Golden Eagles in Denali reproduce at lower rates than Golden Eagle breeding at lower latitudes (McIntyre and Adams 1999). Decreased productivity could result from higher energetic demands needed for migration immediately before the breeding season, higher energetic demand, or from lower prey diversity on the breeding grounds. Gyrfalcons in Denali reproduce at rates similar to the species elsewhere in Alaska.

The Denali data set for both Golden Eagles and Gyrfalcons is one of the longest running and largest in the northern latitudes of North America. The strength of long-term data sets provides opportunities for detecting trends in populations that would be impossible with a short-term data set. A large data set means that we have statistical power to detect trends. The degree of variability in this population should increase with time, but this variability can be detected only by long-terms studies (Newton 1998). For Golden Eagles, our preliminary results suggest that less than 30 percent of all territories are responsible for producing greater than 60 percent of all fledglings. These findings initiated our ongoing studies on landscape characteristics and productivity.

The Alaska Audubon "Watchlist" considers the Golden Eagle a species of conservation concern in Alaska because of the vulnerability of the winter range and the relatively small population size in Alaska. Further, populations in the western United States have declined, apparently in response to decreased jackrabbit populations, loss of native vegetation, and increased urbanization (Steenhof and Kochert 2002). Because Denali's Golden Eagles are migratory and spend a portion of their year in western Canada, the western United States, and northern Mexico, there is concern that these factors may negatively affect migratory

Golden Eagles as well. The Gyrfalcon is considered a species of conservation concern by the Boreal Partners in Flight working group because Alaska is the only place in the United States where this species breeds. This species breeds in relatively remote regions and little is known about its population status in Alaska.

Both species are long-lived and their reproductive activities vary in response to changes in the environment. Thus, monitoring the reproductive activities and occupancy of nesting territories of both species, provides indices to changes in Denali ecosystems.

Activities associated with this project also have provided important data on the location of Peregrine Falcon (*Falco peregrinus*) and other raptor nesting sites, and the breeding activities of other raptors in Denali.

Summary of Products

The Golden Eagle and Gyrfalcon monitoring program produced annual reports for every year from 1987 to 2002. Additionally, Investigator's Annual Reports were filed from 1987 to 2002, and Denali Long-Term Ecological summaries were submitted from 1992 to 2002. In terms of documenting methodology, peer-reviewed papers were published (McIntyre and Adams 1999, McIntyre 2002a) and a master's degree thesis was completed in 1995. Additionally, a doctoral dissertation nears completion. The monitoring protocol for this program, however, has not been completed.

The results of this program were presented as numerous forums, including at least 15 scientific meetings (Appendix D) and more than 50 presentations for the public. The Golden Eagle and Gyrfalcon monitoring programs have thus far resulted in one master's degree thesis (McIntyre 1995) and five publications (Swem et al. 1994, McIntyre and Adams 1999, McIntyre 2002a, McIntyre 2002b, and, Kochert et al. 2002). This program also directly contributed to the development and publication of one paper (Britten et al. 1995), a book (McIntyre et al. 2002), two web sites (NPS ParkWise and Birds of Denali), an interactive science education program (Project Migration Station), several popular press articles, a PBS documentary and several public radio documentaries; and indirectly to one scientific paper (Young et al. 1995) and one book (West 2002).

The Golden Eagle and Gyrfalcon project is deficient in the area of data management and is experimenting with methods to improve the speed of data analysis and delivery. Our data are not available on the Denali StatServer. These deficiencies should be eliminated by the end of 2004.

Status

In 2003, we monitored the occupancy of nesting areas and reproductive success of Golden Eagles and Gyrfalcons, searching for new nesting territories for both species within the traditional and comparison study area, and monitoring the broad-scale trends in abundance of Snowshoe Hare and Willow Ptarmigan. We also assessed the feasibility of identifying individual Golden Eagles using DNA extracted from shed feathers and continued work with the Alaska Department of Fish and Game in the Wood River study area.

In 2004, we will:

(1) develop a weather index to examine reproduction and nesting phenology of Golden Eagles and Gyrfalcons in relation to spring and summer weather,

(2) work with Doug Wilder, Database Manager, Central Alaska Network, to improve our database and develop a relational database for the reproductive activities, nesting phenology, and nest site characteristic databases,

(3) initiate new analyses of historic data set to examine trends in occupancy rates and reproductive success of Golden Eagles and Gyrfalcons within individual nesting territories using route regression methods outlined by Geissler et al. (1990),

(4) continue working on the monitoring protocol and standard operating procedure documents for monitoring the occupancy of nesting territories and reproductive activities of Golden Eagles and Gyrfalcons and obtain peer review for these documents, and

(5) investigate the potential impact of West Nile Virus on Golden Eagles in Denali.

Conclusions

Continuation of the monitoring program for Golden Eagles and Gyrfalcons in Denali is essential for monitoring population trends and conserving populations of both species, and identifying and assessing changes in Denali's ecosystems. This monitoring program becomes more important as time passes, as Golden Eagle habitat declines in western North America, as the effects of global climate change increase, and as more humans visit Denali. This program also has many value-added components such as the science-based education projects such as ParkWise, the many public outreach presentations, and the additional aerial surveys that have documented the presence of breeding Peregrine Falcons in Denali. These value-added programs have increased the awareness of the NPS and the public on the conservation issues surrounding birds in Denali.

Acknowledgments

The 17 years of research and fieldwork described in this summary result from team effort, which includes Mike Britten, NPS; Skip Ambrose, NPS; Gary Koy, NPS; and Dottie Kunz, and the support of Al Lovaas (retired NPS); Layne Adams, USGS; the late John Dalle-Molle; Joe Van Horn (NPS); and Alex Carter (NPS) during the early years of this study, and Mike Kochert and Karen Steenhof, USGS, BRD, Snake River Field Station, for providing technical advise. Karen Oakley, USGS, BRD, and Laura Weaver, NPS, reviewed the 2002 annual report, from which most of this summary was extracted.

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Appendices

Appendix A. Chronological Events of Funding for Monitoring Program for Golden Eagles and Gyrfalcons in Denali.

Year	Event/Activity	Funding Source
1987	Aerial and foot surveys in new study area	Denali base
1988	Begin standardized aerial surveys to document occupancy and breeding activities at nesting territories.	Denali base funds and user-fee program
1989	Continue monitoring efforts in established study area; expand survey effort to Kantishna Hills	Denali base and NPS Alaska Regional Office
1990	Continue monitoring efforts in established study areas; continue survey effort in Kantishna Hills	Denali base and NPS Alaska Regional Office
1991	Continue monitoring efforts in established study areas; continue survey effort in Kantishna Hills	NPS Alaska Regional Office
1992	Continue monitoring efforts in established study areas; continue survey effort in Kantishna Hills	NPS Alaska Regional Office
1993	Continue monitoring efforts in established study areas; continue survey effort in Kantishna Hills	NPS Alaska Regional Office
1994	Continue monitoring efforts in established study areas; continue survey effort in Kantishna Hills	NPS Alaska Regional Office
1995	Continue monitoring efforts in established study areas; complete survey effort in Kantishna Hills	NPS Alaska Regional Office
1996	Continue monitoring efforts in established study area; begin habitat and migration studies	NRPP
1997	Continue monitoring efforts in established study area ; continue habitat and migration studies	NRPP, partial support by Denali LTEM?
1998	Continue monitoring efforts in established study area; continue habitat and migration studies	NRPP, partial support by Denali LTEM?
1999	Continue monitoring efforts in established study area; continue habitat and migration studies	NRPP, partial support by Denali LTEM, NPS fee demo
2000	Continue monitoring efforts in established study area; start survey work on the south side of Denali; continue habitat and migration studies	Denali LTEM, NPS fee demo
2001	Continue monitoring efforts in established study area; start survey work in the Wood River/Dry Creek study area with ADFG; initiate genetics study with USGS Alaska Science Center; continue habitat and migration studies.	Denali LTEM, NPS fee demo, ADFG (Wood River)
2002	Continue monitoring efforts in established study area; continue survey work in the Wood River/Dry Creek study area with ADFG; completed habitat and migration studies.	Denali LTEM, NPS fee demo, ADFG (Wood River)
2003	Continue monitoring efforts in established study area; continue survey work in Wood River/Dry Creek study area with ADFG; continue genetics study with USGS Alaska Science Center	Denali LTEM through the Central Alaska Monitoring Network, ADFG (Wood River)

Appendix B. Calculating Occupancy of Nesting Territories and Reproductive Success Parameters for Golden Eagles and Gyrfalcons

1. Occupancy Rate = the number of nesting areas occupied

the number of nesting areas surveyed

2. Laying Rate = the number of pairs with eggs

the number of occupied nesting areas

3. Success Rate = the number of pairs with fledglings

the number of pairs with eggs

4. Mean Brood Size = the number of fledglings

the number of successful pairs

5. Productivity = the number of fledglings

the number of occupied nesting areas

Assumptions

1. The number of occupied nesting areas is equivalent to the number of territorial pairs.
2. An incubating bird has eggs.
3. Laying is confirmed if an occupied nesting area contained an incubating bird, eggs, young, or any other indication that eggs were laid (e.g. fresh eggshell fragments in fresh nesting materials).
4. A pair is successful if it produced ^{3} one young that reached 80 percentof normal fledgling age (i.e., 51 days for Golden Eagles and 30 days for Gyrfalcons).

Appendix C. Estimated Operating Costs for Monitoring Program for Golden Eagles and Gyrfalcons in Denali, 1988 – 2002.

Operating costs include two aerial surveys per year plus travel, supplies, and equipment. They do not cover salary of principal investigator. The majority of operating costs, approximately 80 – 85 percent are for aviation costs.

Year	Estimated Operating Costs	% change	Eagle territories monitored	Gyrfalcon territories monitored	Total number of territories	Cost per nesting territory	% change
1988	16,000		56	16	72	222.22	
1989	18,000	0.11	66	18	84	214.29	-0.04
1990	18,000	0	66	17	83	216.87	0.01
1991	19,000	0.05	66	17	83	228.92	0.05
1992	19,000	0	70	14	84	226.19	-0.01
1993	20,000	0.05	68	16	84	238.1	0.05
1994	20,000	0	68	17	85	235.29	-0.01
1995	20,000	0	68	15	83	240.96	0.02
1996	21,000	0.05	72	16	88	238.64	-0.01
1997	21,000	0	72	16	88	238.64	0
1998	22,000	0.05	70	16	86	255.81	0.07
1999	21,000	-0.05	76	18	94	223.4	-0.15
2000	20,000	-0.05	80	17	97	206.19	-0.08
2001	21,000	0.05	80	17	97	216.49	0.05
2002	20,000	-0.05	80	21	101	198.02	-0.09
mean	19,733		71	17	87	227	
SD	1533.75		6.52	1.58	7.32	15.06	
CV	7.77		9.25	9.44	8.39	6.64	

Appendix D. Summary of presentations at Scientific Conferences and Meetings

Forum	Place	Year
Alaska Bird Conference	Fairbanks, AK	1989
Annual Meetings of the Raptor Research Foundation	Allentown, PA	1991
Alaska Bird Conference	Anchorage, AK	1991
Royal Society for the Protection of Birds	Edinburg, Scotland	1992
World Conference on Birds of Prey and Owls	Berlin, Germany	1992
Annual Meetings of the Raptor Research Foundation	Tulsa, OK	1993
Alaska Bird Conference	Cordova, AK	1994
Annual Meetings of the Raptor Research Foundation	Flagstaff, AZ	1994
114th stated meeting of the American Ornithologists' Union and 1996 annual meeting of the Raptor Research Foundation	Boise, ID	1996
Bi-annual Meeting of the Society for Research on Golden Eagles in Japan	Nagano, Japan	1999
Annual Meeting of the Raptor Research Foundation	La Paz, Mexico	1999
Alaska Bird Conference	Sitka, AK	2000
Association of the Advancement of Science	Denali Park, AK	2000
Annual Meetings of the Raptor Research Foundation	Jonesboro, AR	2000
North American Ornithological Conference	New Orleans, LA	2002

Endnote

[1] Current costs include the salary of a permanent GS-12 Wildlife Biologist to act as Principal Investigator and a part-time seasonal biological technician. These costs are covered by Denali base funding.

Landbird Monitoring: On- and Off-Road Point Counts

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Introduction

The terrestrial wildlife component of the original Denali Long-term Ecological Monitoring program (LTEM) was proposed to include only two groups in the animal community, small mammals and songbirds (Van Horn et al. 1991). This report summarizes the history of the on-road and off-road point counts program (hereafter referred to as the "point count study") that the Alaska Bird Observatory, Fairbanks, Alaska (ABO) conducted in Denali from 1993 until 2002.

Overview of project history[1]

Project Organization

From the beginning of the project to 2001, the National Park Service (NPS) contracted the point count project with the ABO. Over the years, the project had several principal investigators: 1993 to 1995, Thomas Pogson, executive director, ABO; 1996 to 1997, Dr. Peter Payton, senior scientist, ABO, and Dept. of Natural Resources Science, University of Rhode Island; and 1998 to 2001, Anna-Marie Benson, senior scientist, ABO.

In addition to the principal investigators, personnel involved in the point count study included many field interns and season scientists working with ABO. Dr. Eric Rexstad, University of Alaska, Fairbanks (UAF), also was involved with the point count study during the early years of the project. For the field work, the project typically relied on one crew, generally composed of the principal investigator and one seasonal technician or intern.

Generally, between $10,000 and $20,000 was allocated each year for the point count study. Funds have paid primarily for field crew salaries and data analyses and reporting. Overhead costs for this project were less than 10 percent in the early years of the study, but expanded to approximately 20 percent by the end of the project period.

Throughout much of the study, Pat Owen, wildlife technician, Denali, was park liaison for the point count study. She assisted with contracting, arranged for logistic support, provided training, and was the in-park contact for the field crews. Over the years, the various Denali LTEM program managers provided additional assistance. In 2000, Carol McIntyre became the park liaison for avian project and assumed responsibilities of overseeing this project for the park.

General Approach to the Project

The primary objectives of the point count study in Denali conducted by the ABO were:

(1) Develop a protocol to monitor population trends of common landbirds in Denali. This objective was spatially limited to the spruce forest habitats that could be easily accessed by the Denali road corridor. The development and testing of the protocol occurred from 1993 to 1997 (Paton 1997).

(2) Continue monitoring passerine population trends using on-road and off-road point-count surveys. This was ABO's primary objective from 1997 to 2001.

From 1993 to 1997 ABO examined facets of each of the biases identified by Verner (1985):

(1) Effects of multiple observers on detection rates

(2) Detection threshold distances of several species

(3) Number of routes needed to detect long-term trends in relative abundance of common species

(4) Seasonal variation in detection rates of common species

Sampling tool

ABO used point-count surveys for the avian monitoring protocol for several reasons. Unlimited-distance point-count surveys were the preferred method to monitor annual population trends in roadless tracts of land (Butcher et al. 1992, Ralph 1993). Additionally, point-count surveys have been the primary tool used to detect declining trends in Nearctic-Neotropical migrants (Rappole and McDonald 1994) and have been the primary method adopted by the Boreal Partners in Flight working for surveying birds in roadless areas in Alaska (Handel 1993).

Point-count surveys have advantages over other bird-survey methods for several reasons:

(1) They allow surveyors to control the time period for each count, in contrast to spot-mapping or transect methods.

(2) A large number of independent sampling units can be surveyed, thereby increasing sample size and power of statistical tests compared with other methods.

(3) Sampling units can be placed in relatively small, homogeneous patches.

(4) Observers are permitted to concentrate solely on identifying birds while counting, as opposed to transect methods that require observers also to pay attention to the path being surveyed (Verner 1985, Verner and Ritter 1986).

(5) The surveys are the most cost-effective method for estimating the abundance of birds in large tracts of land (Ralph et al. 1993).

The major disadvantage of systematic samples is that they may give biased estimates for irruptive populations (Ratti and Garton 1994), e.g., White-winged Crossbills and redpoll species.

Sampling Route Selection

Thirteen survey routes were chosen that were accessible by vehicle, were cost effective, and allowed for the daily start of surveys by 3:30 am Alaska Daylight Savings time (ADT) Two surveys were conducted along the park corridor in accordance with Breeding Bird Survey (BBS) protocols (Droege 1990). On-road Route 1 spans the eastern end of the road, while on-road Route 4 spans the western end. Routes 2 and 3 were surveyed from 1993 to 1997 only. The off-road routes were located between the eastern end of the corridor (four), midway (three), and the western end (four). The two off-road surveys added in 1998 increased the diversity of habitats covered; in addition to the mostly spruce-dominated routes, one riparian area along Moose Creek and one ridgeline alpine tundra were surveyed.

Starting points and exact locations of off-road point-count surveys were randomly selected within identified forest stands, 100 meters from the edge of forest stands (Pogson and Rexstad 1994). The direction of travel for each transect was randomly selected from 45 to 135 meters from the edge of forest stands (Pogson and Rexstad 1994).

Measure of Avian Abundance

Population trends detected using frequency data and total count data indicate the two measures are highly correlated (Bart and Klosiewski 1989, Paton and Pogson 1995). The variance structure of the actual landbird population in Denali is unknown; therefore, the variance structure of total count data requires an estimate.

Geographic Scale of Sampling

ABO was limited to sampling the spruce forest habitats near the Denali road corridor for two reasons. First, the initial LTEM program was located within the Rock Creek Drainage, an area primarily dominated by white and black spruce, and NPS requested that additional surveys match these habitats. Second, the point-count surveys had limited funding; therefore, routes were selected based on convenience and feasibility.

Sample Size and Power to Detect Trends

Butcher et al. (1992) proposed national guidelines for avian monitoring programs for federal agencies (e.g., National Park Service, U.S. Forest Service, U.S. Fish and Wildlife Service, and Bureau of Land Management), and suggested the programs should be designed to have a 90 percent probability of detecting a cumulative 50 percent decline (annual decline equals 2.73 percent) in a species over a 25-year period. ABO conducted point-count surveys to determine the sampling intensity necessary to monitor population trends among common passerines within Denali using these power objectives.

Power calculations initially were conducted using data collected during 1993 and 1994 (Paton and Pogson 1995) and later using data from 1993 to 1999 (Benson 2001). Benson (2001) provides a more realistic estimate of power to detect long-term trends to reflect the natural variation among passerine populations over multiple years.

Distance Estimation

Distance estimation is a sampling method primarily used to achieve unbiased estimates of animal densities if certain assumptions are met (Buckland et al. 1993). This method is essentially a partial count with a correction to estimate the total population of animals within a defined area (Thompson et al. 1998). That is, the distance to the animal is used to correct for detection bias.

Beginning in 2000, distance data, i.e., estimated distance to each bird, was recorded by ABO. One of the assumptions of distance estimation methods is that distances are measured without error; consequently, we did not incorporate distance functions into our analyses. Distance estimation is difficult and requires a minimum of two weeks of training. ABO did not have the resources for extended distance training in 2000, but during 2001 distance training was incorporated into a seven-day training program.

Summary of Peer Review

Three USGS scientists completed a peer-review of the Draft Landbird Monitoring Handbook (Payton 1996) in 1997. The major points of the Denali ABO peer review included:

1. What do the point counts in Denali represent?
2. The current program is not well described in the current protocol.
3. What parameters are being estimated?
4. Lack of statistically sound sampling design. Selection of site was due to logistical consideration and you cannot infer anything away from the actual data collection sites due to lack of randomness and a sampling design.
5. What are the tangible products?
6. What are the appropriate statistical analyses of the data?
7. Need to address what data are really being collected on passerines.

8. Unclear goals and purpose of monitoring.
9. What is the sphere of inference for this project?

After reviewing the peer-review comments in 2000, Carol McIntyre met with scientists from the USGS Alaska Science Center and with Boreal Partners in Flight in early 2001 to discuss the future of passerine monitoring in Denali. Most scientists suggested that point counts were a good method to use to assess trends in passerines, but that the current sampling in Denali was inadequate to meet the needs of the park and the statewide off-road breeding bird survey in development by the USGS-Alaska Science Center. Simultaneously, in 2001 and 2002, the Denali LTEM team discussed options for broadening the scope of the Denali LTEM program and in November 2001, the team made a decision to broaden the scope of the Denali LTEM program and to employ statistically valid sampling designs in the program. The Denali LTEM team suggested that we revise the off-road point counts using the minigrid probability-based sampling grid being used for monitoring vegetation in Denali. In 2001, we initiated a pilot-study to assess the use of point counts and the mini-grid sampling design for monitoring passerines in Denali.

What Have We Found out about Landbirds Using Point Counts?

Independence of Sampling Units[2]

ABO tested the assumption that their sampling units (i.e., point-count stations) were biologically independent. Independence of sampling points could have been violated if individuals were counted twice because they were detected at more than one counting station, or if counts from adjacent point-count stations were tightly correlated. ABO determined detection distances of common passerines in spruce forest (Paton and Pogson 1995) and found most species in forested habitats were detected 150 to 250 meters from the observer. These data suggest that point-count stations spaced 250 meters apart are sufficient to avoid double-counting individuals in spruce forest.

Observer Bias

Previous studies indicate that observer bias in point-count surveys could contribute to inaccurate estimates of abundance. The inaccurate estimates would result from differential detection probabilities among observers (Verner and Milne 1989, Sauer et al. 1994) because of differences in experience, alertness, and knowledge. For example, Sauer et al. (1994) indicated that the observer differences in number of individuals counted were found among 50 percent of the 369 bird species examined from BBS data.

Although ABO observers were highly trained, we tested the assumption that abundance estimates were not influenced by differences in observers. No significant difference among observers was detected in frequency of occurrence (FO) estimates or from total count data (Paton and Pogson 1995). Additionally, FO estimates showed more agreement among observers than total counts of species, which further suggests the usefulness of using FO estimates rather than total counts for estimates of abundance. We therefore concluded that trained observers had virtually no effect on biasing FO estimates.

Monitored Species

Power calculations indicated that the current surveys conducted in Denali are adequately monitoring 14 passerine species (Table 12) with minimum power objectives (90 percent power to determine a 50 percent decline over a 25-year period). Additionally, ABO can detect trends in fewer years than previously reported (Paton et al. 1995, Paton and Pogson 1996). For example, American Tree Sparrows are monitored with 90 percent chance of detecting a 24 percent decline in frequency-of-occurrence estimates during a 10-year period.

Power calculations also indicate that biennial surveys should provide sufficient power to detect long-term trends in abundance in 12 of the 14 species currently monitored. Blackpoll Warblers on the Moose Creek Route and Swainson's Thrush could not be monitored with biennial surveys.

Based on seven years of data collected in spruce forests in Denali, species that could be monitored using Butcher's criteria include:

Alder Flycatcher, Gray-cheeked Thrush, Swainson's Thrush, American Robin, Varied Thrush, Yellow-rumped (Myrtle) Warbler, Wilson's Warbler, Orange-crowned Warbler, Blackpoll Warbler, American Tree Sparrow, Savannah Sparrow, Fox Sparrow, Dark-eyed (Slate-colored) Junco, and White-crowned Sparrow [3] (Benson 2001). This list encompasses species representing a variety of migratory strategies (Hayes 1995), including species that are Nearctic-Nearctic migrants (Varied Thrush, American Tree Sparrow, Dark-eyed [Slate-colored] Junco, White-crowned Sparrow), short-distance Neotropical migrants (i.e., those that winter south of the Tropic of Cancer and north of South America; American Robin, Orange-crowned Warbler, Myrtle Warbler) and long-distance Neotropical migrants (i.e., those that winter in South America; Swainson's Thrush).

Summary of Products

To avoid redundancy, the literature citation section of this account contains a list of products and reports.

Status

ABO completed the point count project in 2001 and submitted a "Passerine Monitoring Handbook" to Denali in May 2002 (Weicker and Benson 2002).

In 2002, we began using point counts to monitor passerine birds using the minigrids sampling design (Roland et al. in prep). ABO continues to work with the Denali LTEM program on the minigrids program, providing NPS with highly trained observers and comments on our study design.

Acknowledgments

This account is based on the written record of the point count program as documented in the literature-cited section. Much of this summary was extracted directly from Weicker and Benson (2002).

Table 11. Number of years required to detect trends in avian abundance

Table 1. Number of years required to detect trends in avian abundance using the current protocol (annual surveys) compared with projected power of biennial surveys. Power calculations are based on a 90% probability of detecting an exponential decline of the population at 2.73%/year. Grey highlights indicate species that can not be monitored with biennial surveys. Coefficient of Variation (CV) is calculated from frequency of occurrence estimates from 1993-1999.

			Frequency of Occurrence		Number of Years	
Species	Survey	Points	Mean	CV	Annual Survey	Biennial Survey
Alder Flycatcher	On Road 4	36	0.58	0.10	15	18
Gray-cheeked Thrush	On Road 4	36	0.34	0.17	17	23
	Moose Cr	12	0.38	0.16	25	>25
Swainson's Thrush	On Road 1	50	0.21	0.20	24	>25
	Spruce F	108	0.53	0.18	22	>25
American Robin	On Road 1	50	0.28	0.18	22	28
	Spruce F	108	0.45	0.14	18	25
Varied Thrush	On Road 1	50	0.17	0.20	23	>25
	Spruce F	108	0.47	0.14	20	25
Orange-crowned Warbler	Moose Cr	12	0.79	0.07	12	17
Yellow-rumped Warbler	On Road 1	50	0.26	0.12	15	22
Blackpoll Warbler	Moose	12	0.61	0.16	21	>25
Wilson's Warbler	On Road 1and	86	0.69	0.10	15	18
	Spruce F	108	0.36	0.10	12	16
American Tree Sparrow	On Road 1and	86	0.64	0.06	10	14
	Spruce F	108	0.27	0.18	23	>25
Savannah Sparrow	On Road 1and	86	0.45	0.14	19	22
Fox Sparrow	On Road 4	36	0.72	0.15	20	25
	Moose	12	0.88	0.20	24	>25
White-crowned Sparrow	On Road 1and	86	0.89	0.04	9	10
	Spruce F	108	0.71	0.12	16	20
Dark-eyed Junco	On Road 1	50	0.32	0.08	14	18
	Spruce F	108	0.75	0.06	10	12

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Endnotes

[1] Taken from Paton (1996), Benson (1999), Benson (2001), and Weicker and Benson (2002).
[2] Taken from Weicker and Benson 2002
[3] See Appendix A for scientific names for each bird species.

Landbird Monitoring: Monitoring Avian Productivity and Survivorship

Summary provided by:

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Introduction

The terrestrial wildlife component of the original Denali Long-Term Ecological Monitoring program (LTEM) was proposed to include only two groups in the animal community, small mammals and songbirds (Van Horn et al. 1991). This report summarizes the history of the Monitoring Avian Productivity and Survivorship (MAPS) program that was conducted in Denali National Park and Preserve (Denali) from 1992 until 2002. DeSante et al. (2002) provide a more detailed summary of this project.

Since 1989, the Institute for Bird Populations (IBP) has been coordinating the MAPS program, a cooperative effort among public and private agencies and individual bird banders in North America, to operate a continent-wide network of constant-effort mist-netting and banding stations (DeSante et al. 2002). The purpose of the MAPS program is to provide annual indices of adult population size and post-fledging productivity, as well as estimates of adult survivorship and recruitment into the adult populations, for various landbird species (DeSante et al. 2002). It was expected that information from MAPS would be capable of aiding research and management efforts within Denali to protect and enhance the park's avifauna and ecological integrity (DeSante et al. 2002).[1]

Overview of project history

Project Organization

From the beginning, the park decided to contract one part of the landbird monitoring work with the IBP. Dr. David DeSante, executive director of IBP, was the principal investigator for the MAPS program through its entirety. From 1992-2002, this was arranged via agreements directly between the National Park Service and/or USGS-National Biological Survey (NBS) and IBP. IBP interns conducted all the field work associated with the MAPS program in Denali.

Generally, between $22,000 and $30,000 was allocated each year to the MAPS program. About 50 percent of these funds were used for on-site work and the remainder on data compilation, data entry, and reporting. In-direct costs included 18 percent for overhead costs and 27 percent for general and administration costs.

Throughout the study, IBP usually worked independently of Denali staff. Pat Owen, biological technician, Denali, often helped the IBP interns locate the MAPS station location and set up the stations. For most years, Pat Owen also arranged for housing, associated trainings and bear resistant food containers for the IBP interns. Pat Owen also acted as the park liaison for IBP and MAPS from 1992 until 2000. The various LTEM program managers (Joe Van Horn, Lyman Thorstensen, Penny Knuckles, and Susan Boudreau) provided additional assistance for budget allocations, preparation of annual reports, park orientation, and contracting and field logistics over the years as well. Carol McIntyre, wildlife biologist, Denali, took over the role of park liaison in 2001. Denali provided logistic support including crew housing, NPS hand-held radios, and bear resistant food containers. IBP staff provided their own transportation to and from study sites in Denali.

MAPS interns were responsible for all aspects of field work. They usually arrived in Alaska during the latter part of May and received intensive banding training at the Alaska Bird Observatory's (ABO) migratory bird banding station at Creamer's Field Migratory Bird Refuge in Fairbanks, Alaska.

General Approach to the Project

Detailed descriptions of the field protocols and data analyses methodologies for MAPS are provided in IBP (1997) and DeSante et al. (2002). An overview of these methodologies is provided below. The specific goals for the initial operation of the MAPS program in Denali were:

1. Evaluate the ability and effectiveness of MAPS to provide a useful component of the Denali LTEM program;
2. Determine the effectiveness of various MAPS stations in Denali to provide reliable demographic information on the landbirds of the Alaskan montane environment; and,
3. Develop detailed written protocols for the long-term monitoring of landbird population and demographic parameters for use in Denali's LTEM program, by refining and altering the MAPS protocol to fit the specific needs of Denali.

With few exceptions, all birds captured during the course of the study were identified to species, age, and sex and, if unbanded, were banded with USGS-Biological Resource Division (BRD) aluminum numbered leg bands. Birds were released immediately upon capture and before being banded if situations arose where bird safety would be compromised.

The following data were taken on all birds captured, including recaptures, according to MAPS guidelines using standardized codes and forms:

1. capture code (newly banded, recaptured, band changed, unbanded);
2. band number;
3. species;
4. age and how aged;
5. sex (if possible) and how sexed (if applicable);
6. extent of skull pneumaticization;
7. breeding condition of adults (i.e., presence or absence of a cloacal protuberance or brood patch);

9. extent of juvenal plumage in young birds;
10. extent of body and flight-feather molt;
11. extent of primary-feather wear;
12. fat class;
13. wing chord and weight;
14. date and time of capture (net-run time); and
15. station and net site where captured.

Effort data, i.e., the number and timing of net-hours on each day (period) of operation, also were collected in a standardized manner. In order to make constant-effort comparisons of data, the times of opening and closing the array of mist nets and of beginning each net check were recorded to the nearest ten minutes. The breeding status (confirmed breeder, likely breeder, non-breeder) of each species seen, heard, or captured at each MAPS station on each day of operation was recorded using techniques similar to those employed for breeding bird atlas projects.

For each of the MAPS stations operated, simple habitat maps were prepared identifying up to four major habitat types, as well as the locations of all structures, roads, trails, and streams, were identified and delineated; when suitable maps from previous years were available, these were used. MAP interns classified the pattern and extent of cover of each major habitat type identified at each station, as well as the pattern and extent of cover of each of four major vertical layers of vegetation (upperstory, midstory, understory, and ground cover) in each major habitat type. These were classified into one of twelve pattern types and eleven cover categories according to guidelines spelled out in the MAPS Habitat Structure Assessment Protocol, developed by IBP Landscape Ecologist, Philip Nott .

Overall, the MAPS project has consisted of producing estimates of adult population size, trends in productivity, estimated adult survivorship, mean population size, and productivity values. Estimates also were produced for the relationship between annual change in productivity and annual change in adult captures the following year, and productivity indices and adult survival rates as a function of body mass (DeSante et al. 2002).

Start-up Phase

IBP established five MAPS stations in Denali in 1992. These stations were established along a habitat gradient of forest cover from more heavily forested stations (Rock Creek Watershed, Permafrost) to less heavily forested stations (Hogan Creek and Igloo Creek). Specifically, the five stations established in 1992 were (along the habitat gradient from more to less heavily forested and from east to west):

(1) the Rock Creek station, representing a mature open spruce forest and riparian alder woodland, located in the Rock Creek watershed about 0.4 km north of the main park road;

(2) the Permafrost station, representing mature spruce forest, riparian alder, and wet willow scrub, located just south of the main park road at the “Permafrost” interpretive sign;

(3) the Mile Seven station, representing patchy spruce forest (large patch size), spruce-birch scrub, and wet willow scrub, located just north of the main park road at milepost seven;

(4) the Hogan Creek station, representing patchy spruce forest (small patch size), spruce-birch scrub, and wet willow scrub, located just north of the main park road where it crosses Hogan Creek. The MAPS Program in Denali National Park, and

(5) the Igloo Creek station, representing riparian willow scrub, located on the east (north) side of the main park road along Igloo Creek about five kilometers north (west) of the Igloo Creek campground.

The operation of the Hogan Creek station was discontinued after two periods of operation in 1992 because of a family of Northern Shrikes, the presence of which drastically reduced the breeding bird populations at the station and caused unacceptable mortality levels among birds netted at the station. The four remaining stations established in 1992 were each operated for each of the six years from 1992 to 1997.

Spatial Expansion

In 1997, two new MAPS stations, Strangler Hill and Buhach Creek, were added to the four continuing stations. A further station, Lost Forest on the upper Rock Creek watershed, which had been established in 1993 to "replace" the abandoned Hogan Creek station, was discontinued in 1997. Both new stations were along the McKinley River south of the Denali Park Road at mileposts 83.7 and 69.8, respectively. The Strangler Hill station represents alder-birch scrub, while the Buhach Creek station represents a mix of willow and tundra scrub.

Summary of Peer Review

BRD completed a peer review of the Landbird Monitoring Protocol in 1997 and the following describes the concerns raised by the peer reviewers:

1. The Denali MAPS program lacks a statistically valid sampling design. Data collected at the individual sites are limited in their scope of inference due to non-random placement of stations.
2. There is concern over the precision of the survival estimates and power to detect trends at the park-scale. This is one of the primary limitations of the MAPS program. The most serious limitations are the difficulty in obtaining estimates at smaller spatial scales and inferring patterns beyond the sampled sites.
3. The specific objectives of the MAPS program in Denali have not been stated clearly. The areas of interest are not established, nor are specific target species identified.
4. Sampling design is lacking; stations in Denali were chosen for logistical convenience and inclusion in the continent-wide monitoring program rather than for monitoring landbirds in Denali.
5. It is unlikely that the stations currently run in Denali will ever provide adequate information on the status of Denali's populations, because of both small sample sizes and the locations of the stations.
6. Under the current MAPS operations, it is impossible to identify what populations are being monitored (due to lack of sampling scheme). Under the current MAPS operations, we are not monitoring the demographic parameters of landbirds in Denali, or even populations of landbirds in the eastern

roadside corridor of Denali. The resulting measures of survival and productivity do not necessarily apply to anything beyond the current MAPS sites.

7. There is very high spatial and temporal variability in the productivity indices, suggesting that detection of long-term trends would be difficult.

8. The primary weaknesses with the MAPS protocol in Denali are in the site selection and the ability to yield precise estimates for smaller spatial scales (such as Denali National Park).

9. Detection of population trends at Denali, with the current number of MAPS stations will likely be difficult except for very large changes that are consistent across Denali. Inspection of the existing data set generated by MAPS would provide information for future protocols regarding sampling strategy. Particular attention must be made to the precision of the estimates, their interpretation, and the ability to detect trends given the precision of the estimates and their spatial and temporal variability. Estimating demographic rates is difficult, and detecting trends in these rates is complicated by sample size and sampling strategy.

10. On a continent-wide scale, the monitoring program can gain much by including data collected in Denali in analyses at broader scales, particularly when combined with data from other protected areas in Alaska. On this scale, MAPS provides the potential for monitoring trends in landbirds populations and understanding the factors that are driving the dynamics of these populations. However, MAPS lends little insight into the population trends and dynamics of birds at the park scale.

Summary of Products

To avoid redundancy, a list of reports and publications associated with the project are listed in the bibliography section. IBP has an excellent record in the area of data management and report.

Status

Carol McIntyre became the park lead for all avian projects in 2000. Shortly after taking the lead on these projects, she received a copy of the peer-review of the Denali MAPS program from Karen Oakley. After reviewing the peer-reviewer comments, McIntyre met with scientists from the USGS Alaska Science Center (Colleen Handel and Steve Matsuoka) to discuss the future of MAPS in Denali and the value of MAPS for monitoring birds in Alaska. Concurrently, other agencies were questioning the validity of MAPS and many refuges and parks dropped their MAPS programs completely. Several sessions were held with the Boreal Partners in Flight working group to discuss the future of MAPS in Alaska. Soon after, scientists from the USGS Alaska Science Center and the US Fish and Wildlife Service, Alaska Region, contracted the Institute of Bird Populations to answer specific questions regarding the ability of MAPS to monitor demographic parameters and estimate survival (Matsuoka et al. 2002). This proposal addresses questions on a statewide scale, and results of the analyses do not address questions at a parkwide scale. Results of the analyses, however, will put into perspective the role using MAPS at a statewide scale for estimating the demographic parameters of passerine birds. These results will be useful for determining the future roles of MAPS in Denali.

The objectives for the statewide analyses of MAPS are:

1) Determine if capture rates of adults and juveniles are reliable indices of breeding abundance and breeding success;
2) Determine how adult survival rate and annual productivity vary with habitat, geographic location, and time;
3) Identify which species are being sampled adequately to detect differences in productivity and survival between geographic areas and habitats over time;
4) Identify which species are being sampled adequately to estimate precise temporal trends in survival and productivity; and,
5) Identify those species whose productivity, survival, and associated trends in demographics could be estimated adequately with a modest increase in the number of stations.

The Denali MAPS program was reduced to the three stations on the east side of the park and the one station in Igloo canyon in 2002. This program was discontinued as part of the Denali LTEM program. Future MAPS efforts in Denali hinge on the outcome of the above analyses and direct from the Boreal Partners in Flight working group.

Acknowledgments

This account is based on the written record of the MAPS program as documented in the literature cited section. The results section of this account was extracted directly from DeSante et al. (2002).

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Endnote

[1] The summary reports provide details on the MAPS program in Denali from 1992 to 2002 and are on file in Denali.

Data Management

Data Management

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Introduction

Natural resource data is collected by a number of different programs and activities utilized in the management of Denali National Park and Preserve. The Long-Term Ecological Monitoring Program (LTEM), wildlife, vegetation, fire, and hydrological management programs collect resource information for the overall park. Outside researchers from other agencies, universities, and private organizations working under permit or contract contribute other resource data.

The purpose of the data management function is to provide standards for the management of digital data pertaining to the natural resources at Denali to ensure the protection, reliability, and availability of that data.

Status of Protocols and Reviews

Work on a draft Data Management Protocol began in 1996. We submitted the draft to Alaska Science Center, U.S. Geological Center Biological Resources Division at the same time as all other protocols for peer review. We received comments in March 1997 and incorporated them into the final draft. (*See protocols in Chapter One*.)

Major Changes in Personnel

The initial proposal for the LTEM program at Denali was submitted in 1991 and data collection began the subsequent year. In August of 1994, Jon Paynter (NPS) became the first Denali data manager. The data manager position also had responsibility for the park's GIS program as well as supervision of the curatorial program.

In the fall of 1997, a six-month seasonal position was filled. This position focused on cleanup of the Kennels weather dataset. The following year two additional seasonal positions were extended from their summer appointments to work on dataset cleanup.

In September 1999, Sharon Kim, who transferred from Santa Monica Mountains National Recreations Area (NRA), filled a permanent data management position from the Intake Trainee Program. She was on staff until the spring of 2001 following the completion of her program.

In March 2002, Olga Helmy filled another seasonal position. She assisted in transferring portions of the LTEM program to the Central Alaska Network in addition to data mining.

Dates of Operation

Data management efforts began in September 1994 when the program's data manager came on-board; these efforts continue to this date.

Reference to Reports or Other Documentation

Three documents of note from the program include the Data Management Protocol, which was completed in the spring of 1997, and the Dataset Catalog, which is an ongoing effort at developing metadata for the various LTEM datasets. The final progress report, prepared by Sharon Kim before she left in the spring of 2001, documents her efforts and the current state of the program. The master copy of the LTEM data is kept on the

Geographic Information Systems (GIS) data server at Denali Park Headquarters.

Narrative Presentation of Primary Data from the Component

Initial data management efforts began in 1995 with the addition of the GIS/Data Management position at Denali. Most data collection efforts were already in place prior to any efforts to manage the data. In addition, several datasets in the program (Birds, Air Quality) are part of larger regional or national efforts with their own established procedures.

Data management efforts focused on ensuring the security of the data that was collected. Centralized computer storage was acquired and the datasets are maintained there to this day. A process for maintaining metadata was obtained initially through early versions of the Dataset Catalog program developed by the Inventory and Monitoring Program in Ft. Collins, Colo. Subsequent upgrades to the program have been maintained since then.

The Data Management Protocol established a framework and procedures for collection and data entry, documentation, quality assurance, access, and security. The Protocol underwent peer review and was finalized in 1997.

Several efforts at data cleanup and normalization occurred throughout the period with seasonal technicians. LTEM staff worked on the Kennels weather and water chemistry datasets.

In late 1999, the Denali LTEM program began the first attempt to synthesize the separate databases of the various research projects into a single relational database, based on the model of the Channel Islands (CHIS) LTEM database. Because the Denali database must incorporate data that have been collected since 1992 in at least 15 different projects, it has been a very complex procedure. The advantages of having a single relational database for the LTEM data far outweigh the difficulties of locating data on various computers, however, and will ultimately aid future park researchers in obtaining information.

In 2000, most of the database work involved determining the structure of the master database. We focused only on active databases from current projects. By obtaining the data fields from original tables or spreadsheets, and normalizing the structure of the individual project databases, the significance of each data field and relationship to other data fields in the table was made clear. These normalized tables will then be incorporated more readily into the final relational database.

"General tables," such as an Events table or Locations table that will ultimately connect most of the tables together, also were modified from the CHIS database. They are currently in the process of revision to ensure that specific fields important to Denali are included. These general tables will provide the structure into which the normalized databases from the various projects will fit.

Some data collected on a nation-wide or even NPS-wide scale (such as the air quality network data) will not be incorporated into the relational framework. Instead, these data with parameters set from outside of the park must stay intact in their current structure in order to be comparable to data from other parks or other sites. This type of independence is very unusual in typical relational databases, but must be maintained to allow for easy comparison of data across parks or the country.

Also in 2000, we developed and outlined a flowchart for the steps of incorporating the data into the databases. This database is unusual for database design because there are at least 15 remarkably unrelated databases that need to be merged into a single entity. While all of the projects fall under the LTEM umbrella, much of the collected data is independent of other projects.

In 2001, this merging between the normalized databases and the generalized tables began and continues. This effort goes a step beyond setting up the overall structure and begins the process of changing the actual data within the data fields themselves; for example, making sure all date formats are consistent across the various projects. This will take much time and will catch potential errors and possible inconsistencies in the collected data. Eventually, user-friendly forms and reports will be made from the database tables. Until the basic structures of the tables have been formed, however, these items will be secondary tasks.

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Chapter 3

Lessons Learned

This final chapter of the report deals *with what we have learned about designing and implementing a monitoring program* that may be useful to other parks as they develop their monitoring effort. We offer our philosophical view of monitoring, which we believe will be helpful in thinking about long-term ecological monitoring.

The first task in monitoring is to identify the goal. The Denali Long-Term Ecological Monitoring Program (LTEM) has one single goal: *"To help park managers protect the resources of Denali by providing the ecological context for resource preservation decisions."* One of the most fundamental elements we have learned from the experience at Denali National Park and Preserve (Denali) is that a monitoring program must include feedback loops to ensure that the park superintendent receives monitoring results in time to develop scientifically sound decisions.

The next task is to transform the goal into measurable objectives. In our experience, these objectives state what is to be done, when, where, and why it is to be done, and who will do it. The results should be *attainable* and *measurable*. Continue to revise your design work until you have *measurable objectives*.

Before you can implement the objectives, you must create a *conceptual ecological model* of the system. One of the most important things we have learned from the experience at Denali has involved the value of *conceptual ecological models* as an organizing framework. You will learn many things in the process of building models. Build your own conceptual models and get everyone involved in brainstorming and distilling all details in the monitoring program. Ecological monitoring necessarily involves people of different disciplines, and we therefore see the world in slightly (or profoundly) different ways. This is both good (we need the different views to see the whole ecosystem), and bad (we have a difficult time understanding things with which we are not familiar). Building the models together or having the willingness to learn about models built by others provides the framework for an integrated program.

Remember: involving a diverse group of participants from the beginning increases the breadth of the discussion and may circumvent future conflicts.

Another excellent benefit of modeling is the value of models as *communication devices*. The models promote communication within the monitoring team, as well as with managers, interpreters, and the public. The success of a model depends largely on the knowledge and expertise of the staff.

Suggested guidelines include:

- Do your homework and do a good job of it.
- Identify the purpose of the model clearly.
- Learn what others know and have written about your ecosystem.
- Organize and synthesize that information.
- Make new monitoring information available to others; this helps ensure that the model will evolve with better understanding of the ecological changes.

What do we monitor? This step also influences the previous discussion of *goals* and *conceptual ecological models*. You may find that deciding what to monitor and the most appropriate protocols to use will present a truly daunting task. Persevere. And remember that monitoring components must be chosen to address management as well as ecological concerns (Noss 1990, Silsbee and Peterson 1993).

Perhaps as important as deciding *what to monitor* is determining *how to monitor*. Involve a statistician from the beginning. A statistician can help you develop a sampling scheme that will support your measurable objectives. This is extremely important because at this point you may realize that your objectives cannot be met with the current available resources (staff, funding, infrastructure).

Take some time to *become acquainted with the monitoring literature*. While this isn't rocket science, long-term monitoring is more difficult to achieve than you might think. We found that we repeated the same mistakes (e.g., vague objectives, poor sampling design, measurement error problems due to lack of quality controls, lack of reporting). You can avoid some of these problems by having a general understanding of the science of monitoring. Many of these problems relate to the design of studies intended as long term. So, in addition to reading the monitoring literature, take a statistician (or two) to lunch and keep the relationship going. Such statisticians will help keep you honest about the choices you make in the design phase.

Define your terms. There are several types of monitoring floating around out there. Define the type of monitoring you intend to do and what you expect the monitoring program to produce. All terms should relate to the objectives you seek. Clearly define or explain the goals of your monitoring program.

Pay attention to *data organization and management*. You will need to design monitoring methods to ensure that the data are consistent and comparable among observers, collection periods, and, if applicable, between monitoring programs. The documentation of metadata is extremely important.

Reporting is critical. There is vast room for improvement in how we report data so that it has meaning for park superintendents, park staff, and the public. Standard scientific reporting mechanisms do not communicate monitoring data to these important audiences. Put some effort into thinking about how you will communicate results to all your audiences. We found it important to engage in public outreach. For example, develop publications for a variety of audiences, develop interpretative materials, and provide briefing statements for the park and local communities.

Become familiar with existing monitoring methods; however, adopt them cautiously. *The methods and design you use must match your objectives.* If your objectives differ from someone else's, those methods may not be appropriate for you. Note differences in scales of space, time, staff, and funding among programs.

As you continue through the design process, consider *cost, relevancy,* and *statistics* at all times. Ignore any one of them at your peril. This is the "tripartite requirement for ecologically relevant, statistically credible, and cost-effective monitoring methods" of Hinds (1984).

Recognize the value of a sampling design based on probability versus sampling based on judgment. But do not forget the value of professional judgment at appropriate stages of design and synthesis.

Be explicit about your priorities and document that thinking process in writing. What did you decide NOT to do because other things seemed more important? Leave an electronic paper trail for this. You will need to explain your reasoning to the folks who come later.

The standard party line is to *do inventories first*, before setting up monitoring. This is actually a good idea. Try to do it if you can. Inventories can provide the baseline for monitoring.

Recognize the *true costs* of monitoring. It costs more to do it correctly than you might expect. You will probably need to decide between doing a few things well and many things poorly. In this light, we found that we underestimated most often the costs of properly managing, analyzing, interpreting, and reporting monitoring data. We seemed to have the money to get into the field, but shortchanged the costs of actually doing something meaningful with the data.

Apply quality assurance procedures to all aspects of monitoring, from the design phase through implementation.

Publish protocols and keep them current. Keep testing and work out the bugs.

Finally, yet importantly: *Do not underestimate the importance of maintaining good working relationships within the monitoring team* (park staff, researchers, other agencies, public, elders). Establish good lines of communication. If you do not have the right people involved, or if the people dynamics get out of whack, the program will have a difficult time.

What would we do differently knowing what we know now?

1. Hire a full-time monitoring coordinator from the beginning.
2. Involve a statistician and data manager from the beginning.
3. Define program goals and objectives.
4. Develop objectives that are attainable and measurable.
5. Develop conceptual ecological models more fully prior to selecting monitoring components and starting data collection.
6. Make sure that the parameters you are measuring are linked to your objectives and not just to an isolated and related parameter.
7. Have complete support from the park superintendent.
8. Link monitoring results to decisionmaking.

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Appendices

Appendix 1. Acronyms and Abbreviations

Appendix 2. Contributors for this report

Acronyms and Abbreviations

ABO	Alaska Bird Observatory
ABSC	formerly BRD and NBS now Alaska Biological Science Center
ADT	Alaska daylight savings time
AKSO	Alaska Systems Support Office
ARO	Alaska Regional Office
BRD	Biological Resources Division
BBS	Breeding Bird Survey
CAKN	Central Alaska Monitoring “Vital Signs” Network
CASTNet	Clean Air Status and Trends Network
CBOM	Coarse benthic organic mater
CRREL	Cold Region Research and Engineering Laboratory
DECORANA	DEtrended CORrespondence ANAlysis
D-net	Different type of net
EPA	Environmental Protection Agency
FO	frequency of occurrences
FY	fiscal year
GIS	geographic information system
GPS	geographic positioning system
I&M	Inventory and Monitoring

IMPROVE	Interagency Monitoring of Protected Visual Environments
LTEM	Long-Term Ecological Monitoring
MAPS	Monitoring Avian Productivity and Survivorship
NBS	National Biological Survey
NCR	*Natural Resource Challenge*
NPS	National Park System
NRCS	Natural Resources Conservation Service
SCS	Soil Conservation Service
SWE	Snow Water Equivalent
TWINSPAN	Two-Way Indicator Species Analysis
UAF	University of Alaska Fairbanks
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WASO	Washington Office

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