

Alaska Park Science

National Park Service
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Alaska Regional Office
Anchorage, Alaska



Crossing Boundaries in a Changing Environment



PROCEEDINGS OF THE
*Central Alaska Park
Science Symposium*



*September 12-14, 2006
Denali Park, Alaska*

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*Parks featured in this
issue of Alaska Park Science*



This edition of the *Alaska Park Science* journal is devoted to summaries of scientific and scholarly presentations given September 12-14, 2006, at the *Central Alaska Park Science Symposium*.

This event was the second in a planned series of four Alaska Park Science Symposia. *The Glacier Bay Science Symposium*, held in Juneau, Alaska, in October 2004 was the first in this series (Anonymous 2004, Piatt and Gende 2007). A third symposium, *Park Science in the Arctic*, is planned for October 2008 in Fairbanks Alaska (ARCUS), and a fourth symposium is proposed to focus on science in Alaska's coastal parks in 2010.

Our purpose in producing these proceedings was to provide readers with succinct summaries of a cross section of studies relevant to the national parks in Central Alaska and surrounding areas (Denali National Park and Preserve, Wrangell St-Elias National Park and Preserve, and Yukon-Charley Rivers National Preserve). In producing these summaries, the authors have sought to provide readers with enough detail to understand their main objectives, findings, and conclusions of their studies. Readers seeking additional details are referred to the references listed after each article. The original symposium program, with the original abstracts of these and many other presentations, is also available through the Internet (APSS 2006).

More than 100 authors and co-authors created and delivered presentations at the *Central Alaska Park Science Symposium*. Symposium participants, other scientists and scholars also peer-reviewed the summaries. This

symposium and proceedings would never have happened without their contributions and the participation of many other individuals and organizations. The symposium planning committee members, principal support staff, and sponsors are listed in the symposium program and abstracts (APSS 2006). Page five of these proceedings lists the *Alaska Park Science* journal staff, board members, and proceedings sponsors. We hope that you find the articles to be both interesting and informative, and that this issue will be used for several years as a reference about science in Central Alaska.



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References

- Anonymous. 2004.
Glacier Bay Science Symposium.
Alaska Park Science 3(2):40-41.
- APSS (Alaska Park Science Symposium). 2006.
Program and Abstracts.
http://www.nps.gov/akso/apss_06.pdf
- ARCUS. Park Science in the Arctic—Alaska Park Science Symposium 2008.
http://siempre.arcus.org/4DACTION/wi_cal_getEvent/670
- Piatt, John F., and Scott M. Gende. 2007.
Proceedings of the Fourth Glacier Bay Science Symposium. USGS Scientific Investigations Report 2007-5047. <http://pubs.usgs.gov/sir/2007/5047/>

Cover: Water testing in Yukon-Charley Rivers National Preserve, August 2005. National Park Service photo.



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Photo by Roger Ruess



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Current (top) and potential future (left) view of the Tanana River floodplain, Interior Alaska.

KEYNOTE ADDRESS

Alaska Parks in a Warming Climate: Conserving a Changing Future

by F. Stuart Chapin, III

Alaska's national parks can make a unique contribution in defining the future role of the National Park Service and the way in which the United States and other countries respond to global environmental and ecological changes. The mission of the NPS is "to conserve the scenery, and the natural and historic objects and wildlife therein, and to provide for the enjoyment of the same, so as to leave them unimpaired for the enjoyment of future generations." How is it possible to conserve these things if the climate that determines their basic properties is changing in a directional fashion over time? What should be the roles of national parks in a rapidly changing world? These are the challenges I would like to address. I suggest that we must accept that changes will continue to occur and that it is important to plan for change. In so doing, the parks could serve as an important role model for society in learning how to live with change. This is very different from viewing parks as "museums of nature" that are protected from the changes that are occurring elsewhere in the world. Attempting to preserve museums of nature would be a dangerous approach in a directionally changing world because it would place these parks far from their natural balance with climatic and social driving forces that govern their fundamental properties.

Air temperature in Alaska is increasing as rapidly as any place on Earth (Figure 1). The rate of warming in Alaska has increased (Chapin et al. 2005) and is projected to increase even more rapidly in the future (ACIA 2005). Temperature is increasing most rapidly in winter, so we should expect more frequent winter thaw events and winter rains that produce ice layers that influence animal access to their

winter food. The mountain glaciers of the world are shrinking, with the largest decreases occurring in Alaska (Figure 2), a trend that will also likely continue.

As climate warms, trees expand into alpine areas, and tundra becomes more shrubby (Sturm et al. 2001, Lloyd et al. 2003, Wilmsking et al. 2004). These ecological changes have many important consequences. They alter the vistas that bring people to Alaska parks. They increase the energy absorbed by vegetation and its transfer to the atmosphere, contributing to the high-latitude amplification of climate warming (Chapin et al. 2005). Increases in shrubs shade out lichens, an important winter forage for caribou (Cornelissen et al. 2001). Not all of these habitat changes are unfavorable for wildlife. Increases in willow biomass from warming and from increased fire activity improve habitat for moose. Although the precise nature of these changes and the rates at which they will occur are uncertain, it is quite clear that the ecology and landscape character of Alaska national parks, which the Park Service is tasked with conserving, will continue to change, probably more rapidly than they have in the past.

Park visitation, which can also affect parks, has also been increasing for several reasons. Human population is increasing in Alaska, nationally, and globally. In addition, human transformation of the earth's surface shrinks the areal extent of remaining wilderness. Together these trends tend to increase pressure on the remaining wilderness. As people have more leisure time, there will likely be increased interest in experiencing places like the national parks of Alaska. It therefore seems inevitable that park visitation will continue to increase, causing both direct

visitor impacts on parks and pressures for development in the surrounding regions.

How can Alaska parks address these issues, given that the effects are largely caused by human behavior that is dispersed globally and whose impacts, in terms of climate warming, are amplified at high latitudes? One potential role for Alaska's national parks is to demonstrate clearly the consequences of warming and to tell this story very convincingly to park visitors and to the public at large. Alaska parks are some of the best examples of ecosystems that are undergoing dramatic change. Consequently, parks could play a very important role in documenting and in educating their visitors about change. This redefinition of the educational role of Alaska's national parks might identify the major causes of change and the processes that underlie the dynamics of change. An important goal of such an

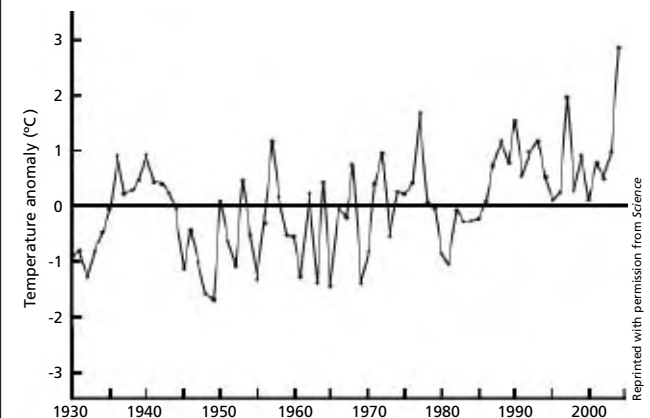


Figure 1. Change in average air temperature of Alaska (Chapin et al. 2005).

education program might be to demonstrate how human actions throughout the world are affecting the Earth System so strongly as to have environmental and ecological consequences even in parks and monuments that are remote from direct population pressures and protected from most types of direct human impacts.

Developing a broader perspective on change is important but will not be sufficient. If warming continues, parks must alter their approach to managing wilderness. This may require fundamentally redefining the nature of the resources that the Park Service is tasked to protect for the future, i.e., the resources that will remain for future generations to enjoy. If past trends continue, there will inevitably be changes in species composition as a result of new arrivals and some disappearances. Perhaps the role of the NPS is not to attempt to prevent these changes from occurring, but to preserve biodiversity and its functional consequences in a broad sense. Perhaps it is more important to provide the opportunity for landscape processes to adjust to externally driven change (e.g., more wildfire) rather than to maintain a landscape that is increasingly out of equilibrium with its climatic determinants.

Managing for diversity and ecological dynamics rather than for the current habitat structure and population sizes will require the development of new kinds of science and

The thawing of permafrost and flooding of glacial rivers are other disturbances that are likely to increase. The combined impact of all climate-related disturbances is likely to create quite a different future landscape than we see today.

new perspectives on management. For example, it will require an understanding of the properties of migration corridors by which species arrive and those aspects of population dynamics that influence dispersal. What types of corridors will maintain functional diversity by allowing functionally similar species to arrive as some current species decline in abundance? How can corridors be designed or barriers established that will reduce the likelihood of spread of functionally different species (e.g., weeds or nitrogen-fixing plants) into parks? Can elevation gradients be viewed as opportunities for current species to migrate successfully over short distances to maintain their current relationship to climate, thereby reducing their likelihood of loss? Is it feasible to define and manage for aesthetic values, rather than attempting to preserve static landscapes? As species composition and ecosystem boundaries (e.g., treeline) continue to shift, it may be more appropriate for the Park Service to preserve an opportunity for people to maintain their sense of identity with nature and culture rather than attempt to preserve a particular landscape structure. This requires a focus on sustaining landscape dynamics rather than current vistas—managing to foster flexibility rather than to prevent changes from occurring.

Managing of migratory corridors to facilitate biological adjustment to climate change will require innovative thinking. Most Alaska parks have dramatic topographic climatic gradients that occur over short distances that could allow climatically sensitive species to maintain their current relationship to climate. Species migration is nothing new. It has been a common response to past climatic changes. However, in the past, species have typically had hundreds or thousands of years to adjust to a magnitude of climate change that is now occurring in a few decades. An important role for current biological monitoring programs is to

document species shifts that may already be occurring. Documentation of factors that facilitate species migration could provide a basis for landscape management that creates corridors for elevational migration of climatically sensitive threatened species. This is one example of ways in which understanding the dynamics of change can contribute to broad goals of conserving biodiversity and other natural values for future generations.

Managing landscape-scale disturbances such as pest outbreaks and wildfire has been, and will continue to be, an important management issue in Alaska national parks. Many disturbances will become more frequent as climate continues to warm. For example, in the Kenai Peninsula, warming allowed the spruce bark beetle to shift from a 2-year to a 1-year life cycle, causing a threshold change in biology of this insect species and its interaction with its host tree (Berg et al. 2006). This resulted in one of the largest naturally occurring insect outbreaks in North America.

Fire regime is also changing. Climate warming has caused an increase not only in the average temperature but also in the number of extremely warm days, which increases the extent of wildfire and other temperature-related disturbances. The area burned in western North America has doubled in the last 40 years (Kasischke and Turetsky 2006). The last 15 years account for half of the large fire years in Alaska's 50-year fire record as a result of regional warming and drying, a trend that is likely to continue in the future. These changes in fire regime have important implications for migration corridors. For example, lichens require about 80-100 years to recover after fire, so, as fire risk increases in a warming climate, policies to suppress wildfires to preserve critical corridors for caribou migration warrant consideration. Alternatively, the migration of other species, e.g., moose, may be favored

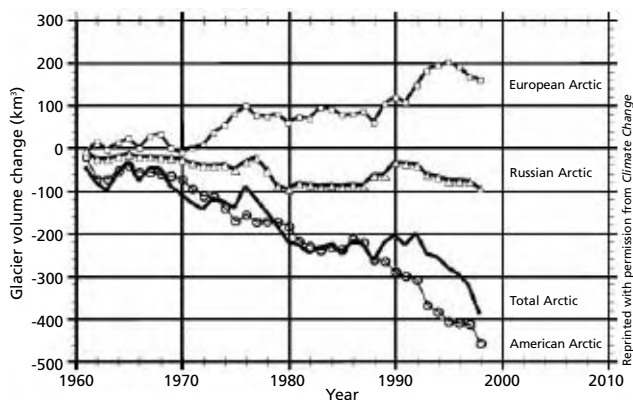


Figure 2. Trends in glacial volume for different arctic regions (Hinzman et al. 2005).

by increased fire frequency.

The thawing of permafrost and flooding of glacial rivers are other disturbances that are likely to increase. The combined impact of all climate-related disturbances is likely to create quite a different future landscape than we see today. These future landscapes are not necessarily less functional or “worse” than the landscapes of today, but they will be different. The Park Service can play an important role in understanding and explaining these landscape changes.

Given the increasing frequency of many of Alaska’s naturally occurring types of disturbance, the management of disturbance will be an important tool for managing landscapes for the long term at large spatial scales. For example, fire managers have been quite successful in suppressing wildfire in populated portions of the state relative to more remote regions, where most fires are allowed to burn (*Figure 3*). This reduction in area burned has occurred despite an increase in human ignitions and a lengthening of the time when ignitions occur. Although wildfire management has generally focused on reducing risk to life and property in densely populated areas, it can also be used as a tool to manage landscapes for conservation goals. Fire suppression can protect critical caribou migration corridors in a fire-prone landscape. On the other hand, allowing wildfire to burn can create buffers that reduce the likelihood of future fires. The shrubby and deciduous vegetation that dominates after fire is less flammable than late-successional spruce forests (*Figure 4*). These are only two examples of ways in which the management of natural processes can be used to design landscapes that conserve resource values for future generations.

Given the importance of managing national parks for the long term over large spatial scales, it is useful to think about the interaction between parks and their surroundings. Some of the ways that parks interact with the surrounding matrix may be undesirable as a result of development and pollution occurring near parks. This concentration of human activity also increases human ignitions and produces more fires that spread into parks than might be expected based on climate and vegetation. Similarly, hunt-



Figure 3. Photograph of wildfire in Alaska black spruce forest.

ing of migratory wildlife in the matrix surrounding parks can influence population dynamics within parks. Park managers are generally well aware of these issues and manage activities in parks accordingly. As climate change and species migration become increasingly important to parks, collaborative arrangements with communities and the managers of adjacent lands will have increasing impact on the dynamics that occur within park boundaries. The continually evolving land ownership and management rules in Alaska may provide opportunities to plan creatively to influence changes that are likely to occur in the matrix around parks. In addition, development pressures around

most Alaska parks are still relatively modest, compared to what can be expected in a few decades. The magnificent landscapes that characterize Alaska parks attract both people that recognize potentials for economic development and others who are more interested in sustaining the current wilderness character of the landscape. Partnerships to plan and manage the matrix that surrounds Alaska parks are probably at least as important as the management of parks themselves.

Alaska national parks have inadvertently been thrust into a leadership role in redefining Wilderness in a way that includes people (*Chapin et al. 2004*). The maps of Alaska

ecosystems and cultural groups are virtually identical because ecology shapes culture, and indigenous peoples have managed the lands in which they live. Because of these tight linkages, ecology and cultures cannot really be separated. Consequently, if parks are dedicated to conserving landscapes, this also provides opportunities to conserve the cultural roots of the people that inhabit these lands. Many (but not all) Alaska parks are tasked by legislation to foster these social-ecological linkages by allowing local residents continued access to traditional subsistence hunting and fishing opportunities. This is quite different than wilderness as defined by the Wilderness Act: “a place where man is a visitor and does not remain”. This legislative definition is based, in part, on impressions of early settlers in the western U.S. who observed an unoccupied land that had been depopulated by disease prior to or coincident with the arrival of white settlers.

Managing an inhabited wilderness is not an easy task,

because the technology of subsistence use is constantly changing, just as it always has, most recently as a result of cultural and technological adjustments to western influences. Athabascan people in Interior Alaska, for example, used to live in small mobile family bands that moved regularly in response to seasonal and successional changes in availability of subsistence resources (*Natcher et al. 2007*). When a large fire occurred, these bands simply moved to new areas where subsistence opportunities were better. Now, people that live a subsistence lifestyle are locked in place by airports, schools, churches, health centers, etc. (*Huntington et al. 2006, Natcher et al. 2007*). To some extent, this reduction in mobility can be compensated by modern transport (e.g., snow machines and motorboats). Innovation and adaptation have always been important to the success of Alaska indigenous cultures, but many of the recent technological innovations (e.g., snow machines) are also used for recreation in ways that many people view as inconsistent

with wilderness. There is no easy answer to the resulting controversies. However, regulations regarding use of motorized transport in parks have deep cultural implications that warrant consideration.

Management of disturbance is particularly challenging in the context of social-ecological change. Subsistence resources show relatively predictable rates of recovery after wildfire. Blueberries recover quickly, marten and moose peak about 15-30 years after wildfire, and caribou require 80-100 years to recover. A typical response of wildlife managers to these observations is to say “We have to maintain fire on the landscape in order to maintain this diversity of wildlife.” On the other hand, a subsistence hunter who is locked in place by infrastructure is likely to say “It will be a generation before moose return to this landscape, so how can I teach my children about their cultural ties to the land if fires are allowed to burn?” Clearly the use of disturbance for landscape management has important cultural connotations and requires active engagement of people who live on and use the land. Constructive solutions to these multiple concerns may involve careful attention to the configuration of fire on the landscape relative to the locations of human harvest.

Alaska parks are also important to non-residents, even to those people who may never visit them. As global wilderness continues to shrink, non-use or non-consumptive use of wilderness may become increasingly valued. Currently about half the world’s population lives in cities, a proportion that will likely increase (*MEA 2005*). An important educational opportunity and challenge is to convey the importance of wilderness to people everywhere on Earth and to help reconnect these people to the land.

Change is not going to be simple. The changes described above will interact in complex and often unpredictable ways. This provides the Park Service with both an obligation and an opportunity to be at the forefront of learning about the complexities of adjusting to change. The changes faced by Alaska national parks are a microcosm of trends that are occurring globally. Being the steward of a constantly changing treasure provides the Park Service many educa-



Photo by Stuart Chapin

Figure 4. Patch of deciduous forest that did not burn despite fires that converged on it from all sides during the 2004 Boundary fire near Fairbanks.

tional and management opportunities to play a constructive role in reducing detrimental changes and finding ways to foster constructive change.

Given that things are changing so quickly, it is an opportunity for the Park Service to rethink and redefine its goals. Conservation of biodiversity requires a very different strategy now than in the past. Conserving biodiversity and human connections to the land will require a long-term perspective. Although we cannot describe in detail the specific landscape that we seek to conserve, we know a lot about the dynamics of change and their implications for effective management. It involves managing the matrix, for the long term, for corridors that will allow species to move along climatic gradients as climate changes. The Park Service has several important roles to play in educating the public about change, in developing partnerships to foster cultural adjustments, and in developing new mental models for society globally to live with change.

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References

- ACIA. 2005.
Arctic Climate Impact Assessment.
Cambridge University Press. Cambridge.
- Berg, E.E., J.D. Henry, C.L. Fastie, A.D. De Volder, and S. Matsuoka. 2006.
Long-term histories of spruce beetle outbreaks in spruce forests on the western Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationships with summer temperature.
Forest Ecology and Management 227:219-232.
- Chapin, F.S., III, L. Henry, and L. DeWilde. 2004.
Wilderness in a changing Alaska: Managing for resilience.
International Journal of Wilderness 10:9-13.
- Chapin, F.S., III, M. Sturm, M.C. Serreze, J.P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L.D. Hinzman, G. Jia, C.-L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker. 2005.
Role of land-surface changes in arctic summer warming.
Science 310:657-660.
- Cornelissen, J.H.C., T.V. Callaghan, J.M. Alatalo, A. Michelsen, E. Graglia, A.E. Hartley, D.S. Hik, S.E. Hobbie, M.C. Press, C.H. Robinson, G.H.R. Henry, G.R. Shaver, G.K. Phoenix, D. Gwynn Jones, S. Jonasson, F.S. Chapin, III, U. Molau, C. Neill, J.A. Lee, J.M. Melillo, B. Sveinbjornsson, and R. Aerts. 2001.
Global change and arctic ecosystems: Is lichen decline a function of increases in vascular plant biomass?
Journal of Ecology 89:984-994.
- Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin, III, M.B. Dyrurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, M. Nolan, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa. 2005.
Evidence and implications of recent climate change in northern Alaska and other arctic regions.
Climatic Change 72:251-298.
- Huntington, H.P., S.F. Trainor, D.C. Natcher, O. Huntington, L. DeWilde, and F.S. Chapin, III. 2006.
The significance of context in community-based research: Understanding discussions about wildfire in Huslia, Alaska.
Ecology and Society 11:
<http://www.ecologyandsociety.org/vol11/iss11/art40/>
- Kasischke, E.S., and M.R. Turetsky. 2006.
Recent changes in the fire regime across the North American boreal region- spatial and temporal patterns of burning across Canada and Alaska.
Geophysical Research Letters 33:doi:10.1029/2006GL025677.
- Lloyd, A.H., T.S. Rupp, C.L. Fastie, and A.M. Starfield. 2003.
Patterns and dynamics of treeline advance on the Seward Peninsula, Alaska.
Journal of Geophysical Research 107:doi: 8110.1029/2001JD000852.
- Millennium Ecosystem Assessment. 2005.
Ecosystems and Human Well-being: Synthesis.
Island Press. Washington.
- Natcher, D.C., M. Calef, O. Huntington, S. Trainor, H.P. Huntington, L. DeWilde, S. Rupp, and F.S. Chapin, III. 2007.
Factors contributing to the cultural and spatial variability of landscape burning by Native Peoples of Interior Alaska.
Ecology and Society 12:
<http://www.ecologyandsociety.org/vol12/iss11/art17/>.
- Sturm, M., C. Racine, and K. Tape. 2001.
Increasing shrub abundance in the Arctic.
Nature 411:546-547.
- Wilmking, M., G.P. Juday, V. Barber, and H. Zald. 2004.
Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds.
Global Change Biology 10:1-13.

Synthesis



Crossing Boundaries in a Changing Environment: A Synthesis

by Alexander M. Milner

Introduction

Paul Anderson, Superintendent of Denali National Park and Preserve, stated in his opening address to the symposium “The national parks of central Alaska need your mind, your skills, ideas and dedication, and they need your hearts”. It was evident over the three days of the meeting that this was forthcoming, particularly the dedication shown by many researchers with a clear passion for working in this region. This aspect of research should not be underestimated as a powerful force in driving excellent science. Although the title of the symposium was “Crossing Boundaries in a Changing Environment”, it was evident on attempting to synthesize the papers that certain key themes emerged throughout the symposium into which they could be grouped as summarized in Figure 1. This synthesis focuses mostly on the oral papers and apologies to any authors not included; this is no reflection on their content, just on which coat hanger theme to hang it on.

Historical Perspectives

Confucius said “Study the past if you would define the future.” A number of presentations highlighted the value of historical records and of long term studies in understanding critical processes and environmental variability in these regions. Snow cover patterns dating back 80 years (*McClure and Sousanes 2006*) and long term weather records for central Alaska of up to 100 years (Sousanes, this issue) informed us about climate variability in a changing environment and with links to understanding ecosystem processes. McIntyre (*this issue*) discussed variability in the bird populations of Denali National Park and Preserve (Denali) using a century of observations. The 1,500-year record of temperature and glacial response from sediments of Iceberg Lake in Wrangell-St. Elias gave us a unique insight into evidence that the late twentieth

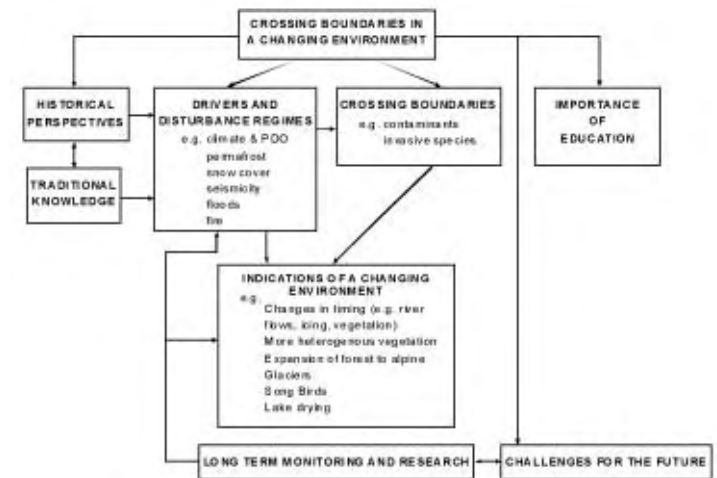


Figure 1. Key themes that emerged during the conference.

century in Alaska has warmed more quickly than in any other period including the Medieval Warm Period (*Loso et al. 2006*).

Traditional Knowledge

The immense importance and value of the use of traditional knowledge was evident throughout the symposium. This included native involvement in studies of beluga whales in Yakutat Bay (*Bonin et al. 2006*), the drying of Interior Alaska lakes (*Larsen 2006*), the Upper Tanana

subsistence fisheries (*Friend, this issue*), the Chisana Caribou Herd (*Adams et al. 2006*) and the Yukon Ice Patch Project (*Hare 2006*). It is critical that traditional knowledge be incorporated into scientific studies, with particular reference to long term knowledge on the changing environment as there is a potential wealth of information to be tapped. This exchange should also not be one-way, as results of studies should be communicated back to the native communities in a manner that can be utilized in policy decisions.



National Park Service photo

Approximately 7% of the boreal landscape has recently degraded and potentially 50-70% of the landscape has permafrost that can degrade.

Drivers and Disturbance Regimes

A number of papers discussed the **major drivers** in a changing environment including climate, snow cover, hydrology, glacier accumulation/ablation, and permafrost dynamics. Large climate gradients across Alaska create a range of permafrost temperatures and ground ice conditions. Permafrost has been degrading in both continuous (cold) and discontinuous (warm) permafrost conditions. Approximately 7% of the boreal landscape has recently degraded and potentially 50-70% of the landscape has permafrost that can degrade (*Jorgenson et al. 2006*). Other drivers include plate tectonics and faulting (*Brease et al. 2006*, *Haussler 2006*).

A major driver in a changing environment of Interior Alaska parks is disturbance regimes, which play a key role in structuring landscapes and determining patterns of distribution and abundance of organisms. Major disturbance drivers include flood events, an increase in seismicity along the Denali Fault (*Hansen et al. 2006*) and overflights by military aircraft (*Lawler and Griffith 2006*). Disturbance events affecting the coastline of Wrangell-St. Elias and nearby Glacier Bay include coastal erosion, extreme seismicity/faulting, giant waves/tsunamis, glacier advance and retreat, rapid sedimentation and jokullhaups (*Molnia 2006*).

Fire is well known as a disturbance in central Alaska and an essential component for maintaining ecosystem diversity. The total area that has burned in the last 50 years has doubled and models indicate increased burning in the next 100 years (*Rupp 2006*).

A number of papers highlighted the role of the major climate drivers, like the Pacific Decadal Oscillation, in determining air temperature, small mammal populations (*Rexstad et al., this issue*), and stream macroinvertebrate communities in unstable channels through its influence on winter snowpack and spring runoff (*Milner et al. 2006*). Interestingly, the mean biomass of voles is greater than that of bears (*Rexstad et al., this issue*) illustrating the importance of smaller fauna, as well as the charismatic megafauna, in park ecosystems.

Changing Environments and Indicators

A major theme that emerged from the symposium due to changing environments was that the **timing of key events** will almost inevitably change. Some examples provided in papers were spring flows in the Yukon River (Eberl 2006), the period of icing on lakes and rivers with a likely reduction, the earlier greening of vegetation and the duration of the winter snow pack. The extent and severity of winter regimes are a key element of ecosystems in Interior Alaska and amelioration due to changing climate may benefit many species and communities although some species will suffer as superior competitors move into the area.

The use of **indicators** to document this changing environment is important, and a number were identified throughout the symposium. This included the appearance of a more heterogeneous pattern of vegetation post-fire, which will provide for increased moose browse availability (Allen and Weddle 2006). This heterogeneity invokes the concept of disturbance and patch dynamics, whereby patches in different stages of recovery from disturbance, permit a greater diversity of landscape habitats and community structure, than if disturbance was less apparent. Roland (2006) outlined the expansion over time of the forest into alpine areas and of vegetation on open gravel river bars through the process of repeat photography. This forest expansion can reduce lichen abundance (Walton et al. 2006) and thus influence food availability for herbivores. Changing populations of songbirds (McIntyre, *this issue*) and peregrine falcons (Guldager et al. 2006) provide further examples of indicators of a changing environment.

Ninety-four percent of Alaska glaciers are thinning and the rate has recently doubled (Echlemeyer 2006). However not all Alaska's glaciers are thinning, for example, the Hubbard Glacier is showing extensive sedimentation rates of 8.2 feet/year (2.5 m/yr) and the Kahiltna Glacier is showing a slightly positive mass balance (Adema, *this issue*). Meltwaters from Alaska's glaciers contribute substantially to sea level rise, and in the 2002-04 period con-

tributed more than the Greenland ice sheet (Echlemeyer 2006). Other indicators include the drying of lakes as outlined by Larsen (2006) and Roland (2006).

Crossing Boundaries

Alaska is not immune from trans-boundary pollutants as Landers et al (2006) illustrated with the case of Burial Lake where levels of mercury in fish were reported to exceed 300 ng/g, above the EPA criterion for human consumption. Blakesley (*this issue*) highlighted the industrial and agricultural contaminants from other continents in Denali, albeit in small amounts. Wurtz et al. (*this issue*) discussed the invasive sweetclover, *Melilotus alba*, which has moved from roads in Alaska to glacial river floodplains with potential effects on native species. Other species have potentially become invasive, probably due to climate change. There is a challenge in identifying the routes of transmission that cross boundaries and the effects on ecosystems of these invasive species.

Long term Monitoring and Research in Wilderness

The Inventory and Monitoring (I & M) program for the Central Alaska Network (CAKN) was outlined by McCluskie (2006). This program has an incredibly important role to play in our understanding of the consequences of a changing environment in the central parks of Alaska. While it is important that networks focus on issues important to their region, this would appear to be a unique opportunity to cross boundaries within Alaska and measure key variables across networks that would provide excellent comparative data to inform future research and management decisions. This opportunity should not be lost.

While most of the data reported was collected by professionals, we heard how the Tri-Valley School students were the first to make systematic ice and snow measurements at Horseshoe Lake in Denali National Park and Preserve (Jeffries et al. 2006). The use of students and other volunteers may be important resource in the future, particularly to maintain long term observations in accessible locations.



Ninety-four percent of Alaska glaciers are thinning and the rate of thinning has recently doubled.

Sharman et al. (*this issue*) outlined ideas on undertaking research in wilderness and proposed a matrix mechanism balancing impacts and benefits to decide whether to permit research in Glacier Bay National Park and Preserve. It was not clear whether this was suggested as a potential approach that should be adopted by all Alaska parks. However one has to be careful that some variable that may seem of no apparent benefit at present (and thus the research denied using the matrix), could, in a changing environment, be extremely important in the future. In addition long term research, which this symposium has demonstrated to be of such importance, needs a level playing field to ensure that it can continue uninterrupted, particularly when substantial investment in time and resources have already been committed.

Challenges for the Future

During the course of the symposium, it became evident that the changing environment was going to create challenges for the future. This involves an increasing human population from which Alaska is not immune. A number of presentations highlighted visitors and their experiences in parks (Knotek *et al.*, *this issue*; Taylor and Fix 2006; Watson *et al.* 2006), mechanisms for developing indicators of carrying capacity (Manning and Halo 2006) and managing subsistence ORV use in Denali (Tranel and Lindholm, *this issue*). A key question is what role can the NPS play in mitigating threats beyond their boundaries? Chapin (*this issue*) in his keynote encouraged the National Park Service to inspire people to be concerned about issues beyond



An increasing human population in Alaska will create future challenges for our Alaska national parks.

National Park Service photo by John Hourd

their own backyards through thinking outside the box and to actively manage the matrix around the parks. Chapin suggests that this changing landscape requires a new more dynamic definition of resources and values to be preserved by parks.

It is clear that NPS education programs need to help people better understand threats to park services, and Morris (2006) discussed education with relation to interpreting climate change. Schneider and Brewster (2006) outlined “Project Jukebox” where the University of Alaska Fairbanks has been making a variety of material including oral histories for a number of Alaska parks available on the Internet to provide park visitors and managers with the key background and depth of knowledge critical for expanding their understanding of parks and their regions.

It is clear that major changes in the habitat structure available for plants, insects, birds, and mammals will occur and the quality, abundance, and spatial distribution of food for herbivores will change (Roland 2006). Some key questions to be addressed include:

- How will food-webs and predator-prey relationships (e.g. Haber, *this issue*; Gardner *et al.* 2006) alter with a changing environment?
- What will be the influence on “Hotspots” of biodiversity (e.g. Kittlitz’s Murrelets, Kissling *et al.*, *this issue*) and habitat (e.g. Ice patches for caribou)?
- What are the key feedbacks (both positive and negative) in a changing environment? (e.g. snow and albedo effects; forest expansion changing microclimates and enhancing local climate warming)
- What are the ecosystem effects of these changing windows? (for example; earlier greening, earlier senescence and thinner ice all affect caribou populations)

Modelling is likely to be an important tool for predicting future change and several papers incorporating modeling approaches, for example for fire prediction (Rupp 2006) and for small mammals (Rexstad *et al.*, *this issue*). Soil cover maps are important tools for the prediction of fire prone



National Park Service photo

Soil cover maps are important tools for the prediction of fire prone areas.

areas, soils with permafrost, and potential vegetation (Clark, *this issue*). It will be necessary to explore new models for living with this change. There is no doubt that many challenges lie ahead for both scientists and managers and communication between these groups is vital for the well being of central parks in Alaska. The complexity of these landscapes and the detailed interactions between them was clearly illustrated by the stunning and spectacular quilt of Denali’s systems displayed at the symposium (Tyrrell and Paynter, *this issue*)—this was indeed a highlight of the meeting. Fiorillo *et al.* (*this issue*) provided a fascinating insight into the first record of fossil footprints of Late Cretaceous vertebrates in Denali—a final question would be “But what will be the dominant footprint on the central parks of Alaska 100 years from now?” We need to accurately answer this question to correctly interpret and manage these dynamic landscapes in a changing environment.

References

The following references can be found in:

**2006 Alaska Park Science Symposium:
Program & Abstracts; Sept. 12-14, 2006;
Denali National Park and Preserve.**
(http://www.nps.gov/akso/apss_06.pdf)

**Adams, L., R. Farnell, M. Oakley, G. Roffler,
J. McLelland, L. Larocque, and M. Reid.**
*The Chisana caribou recovery project: assessing
population dynamics and captive rearing.*

Allen, J., and L. Weddle.
*Post fire vegetation and moose browse
utilization on recent fires in Denali National Park
and Preserve.*

**Bonin, C., W. Lucey, E. Henniger,
and G. O'Corry Crowe.**
*The ecology, status and stock identity of beluga
whales in Yakutat Bay.*

Brease, P., B. Csejtey, C.T. Wrucke, and A.B. Ford.
*The Denali Fault: does it set its sights on
Gunsight Pass?*

Eberl, D.
Quantitative mineralogy of the Yukon River system.

Echelmeyer, K.
*What's happening to the glaciers of Alaska's
National Parks.*

Gardner, C., J. Lawler, and Xi Chen.
*Landscape scale wolverine distribution and habitat
use in interior Alaska: identification of key habitat
parameters.*

Guldager, N., S. Ambrose, and C. Florian.
*American peregrine falcon monitoring along the
upper Yukon River, Alaska, 1973-2005.*

Haeussler, P.
*Mountains of the western Alaska Range: when,
why and how they are formed.*

Hansen, R., N. Ruppert, and L. Burris.
Earthquake monitoring in Denali National Park.

Hare, G.
*The Yukon Ice Patch Research Project: Investigating
Nature's Delicate Balance.*

**Jeffries, M., P. Gallego, DeBalauw, K. Morris,
and D. Norris-Tull.**
*Lake ice and snow study in Denali National Park
and Preserve promotes elementary school science
education.*

**Jorgenson, T., T. Osterkamp, Y. Shur, M. Kanevsky,
and V. Tumskey.**
*Monitoring permafrost degradation in Alaska's
National Parks.*

**Landers, D.H., S. Simonich, D. Campbell, L. Geiser,
M. Erway, T. Blett, and B. Rice.**
*Impacts of historic and current-use chemicals in
western National Parks.*

Larsen, A.
*Understanding a dynamic system; monitoring the
limnology of interior Alaska lakes and wetlands.*

Lawler, J., and B. Griffith.
*Dall's sheep behaviour in relation to military
overflights in interior Alaska.*

Loo, M., R.S. Anderson, S.P. Anderson, and D.F. Doak.
*A 1500-year record of temperature and glacial
response from Iceberg Lake.*

Manning, R., and J. Hallo.
*Indicators and standards of quality: a framework
for measuring and managing the carrying capacity
of the Denali Park Road.*

MacCluskie, M.
*Ecological monitoring in the Central Alaska
Network; the program and purpose.*

McClure, R. and P. Sousanes.
*Understanding snow cover patterns in the central
Alaska network.*

Milner, A.M., S.C. Conn, and L. Brown.
*Persistence and stability of macroinvertebrate
communities in streams of Denali National Park,
Alaska: implications for biological monitoring.*
- see also *Freshwater Biology* (2006) 51:373-387.

Molnia, B.
*Coastline dynamics of Wrangell-St. Elias
National Park and adjacent Glacier Bay National
Park, Alaska.*

Morris, J.
*Arranging for change: interpreting climate change
in National Parks.*

Roland, C.
*Repeat photographs reveal a changing landscape
in Denali National Park.*

Rupp, S.
*Past, present and future fire regimes in
interior Alaska.*

Schneider, W., and K. Brewster.
Project Jukebox: bridging the gap.

Taylor, S., and P. Fix.
*Visitor preferences for interpretation at Kennecott
National Historic Landmark.*

Walton, J., C. Roland, and C.P.H. Mulder.
*Nonvascular vegetation along an elevational
gradient in Denali National Park and Preserve.*

Watson, A., K. Knotek, and N. Christensen.
*Wilderness at arm's length: fly-in recreation
visitors to Denali.*

Monitoring a Changing Climate





National Park Service photo by Robert A. Winfree

Long-term Air Quality Monitoring in Denali National Park and Preserve

by Andrea Blakesley

Abstract

Air quality monitoring in Denali National Park and Preserve (Denali) has been ongoing for nearly three decades. The first monitoring instruments were installed in 1980 as part of a nationwide rural air quality monitoring network designed to track changes in atmospheric contaminant deposition in rainwater and snow. As other monitoring networks developed to address specific air quality concerns, instruments were added to the Denali monitoring station. The park is now part of four separate interagency and National Park Service air quality monitoring networks. While Denali's air quality is consistently among the cleanest recorded in the nationwide monitoring networks, small amounts of international airborne contaminants are measured in the park each year. With global pollution projected to increase over time, Denali's clean air is dependent on international as well as national efforts to limit emission increases. As a prominent wilderness tourist destination, the park may help inspire global citizens to protect clean air partly because it is an integral part of Denali's intact ecosystem.

Introduction

The Clean Air Act and the National Park Service Organic Act require park managers to protect air quality in Denali National Park and Preserve. So far, this has not been an unduly daunting task, since the air in Denali is among the cleanest in the country. When the first air quality monitoring instruments were installed in the park in 1980, it was assumed that the measurements in Denali would reveal a simple story, documenting background conditions similar to what might have existed in the contiguous 48 states before the industrial revolution. Instead, a second story emerged, hidden in the consistently low airborne contaminant measurements collected at the site. Emission sources far from the park influence the annual cycle of contaminant concentrations, and are linked to the park through intercontinental transport pathways.

In addition to directly measuring contaminant concentrations in air, snow and rain, the National Park Service also collects and makes available to the public real-time photographic visibility data. The Denali visibility web camera operates during the summer months, archiving high-resolution images of the Alaska Range vista. Lower-resolution images are posted to an educational NPS web page via satellite.

Methods

The National Park Service Air Resources Division operates a nationwide air quality monitoring network, comprised of several separate internal and interagency monitoring networks. They are, in order of installation in Denali: the National Atmospheric Deposition Network (NADP), the Interagency Monitoring of Protected Visual Environments Program (IMPROVE), the National Park Service Gaseous Pollutant Monitoring Network, and the Clean Air Status and Trends Network (CASTNet). The NADP program measures deposition of airborne contaminants

in precipitation. The IMPROVE network samples fine particles and select gases that cause visibility impairment, by collecting samples on filters, and the CASTNet program uses filter samples to model deposition of airborne contaminants to ecosystems in the absence of precipitation. The NPS Gaseous Pollutant Monitoring Network continuously measures ground-level ozone in Denali, recording hourly values. The NPS also measures

meteorological parameters that help interpret air quality data, such as wind speed and direction, temperature, and relative humidity. Each nationwide air quality monitoring network maintains a web site that provides an overview of sample design and methods, as well as public access to validated data. There are links to these sites on the NPS Air Resources Division web site at <http://www2.nature.nps.gov/air/>.



Figure 1. This archived image from the Denali visibility web camera shows windblown silt on the Thorofare River Bar.

Results

As was expected at the outset of monitoring, results from each monitoring network show that the air in Denali is exceptionally clean on most days. During summer, however, it is not unusual for naturally-occurring smoke from wildland fires to significantly decrease visibility throughout Interior Alaska, including Denali.

Concentrations of anthropogenic airborne contaminants, while low, show a strong seasonal trend, with peaks often occurring in the winter and early spring. This pattern is consistent with international transport of airborne contaminants to Alaska via transport pathways over the Arctic and Pacific Oceans (Wilcox 2001).

Discussion and Conclusions

Park managers can best prevent and mitigate human-caused ecosystem impairment within park boundaries. However, this does not mean that the agency's influence stops at the borders of the park or even the country. In addition to conducting research and monitoring which supports the regulatory process, the NPS can help mitigate threats beyond park boundaries through education and inspiration. Some of the ways in which parks help inspire people to minimize collective human impacts:

- National parks inspire people to be concerned about issues beyond their own backyards.
- Park science and education programs help people better understand threats to park resources.
- People care about parks. International threats to national parks can motivate people to support international solutions to global problems.
- Parks are symbols of unimpaired wilderness. Contaminant threats to park ecosystems may inspire public concern at a lower threshold than threats to non-park lands.
- National parks can promote energy efficiency and sustainability to encourage people to reduce their impact on the global environment.

The Denali ecosystem is predominantly intact and pristine, compared to many protected areas outside Alaska. The park atmosphere is no exception. At present, the air in Denali is generally cleaner than in most parks and wilderness areas throughout the country. It is not, however, free from anthropogenic contaminants. In addition to local and regional sources, airborne contaminants from sources on other continents are currently transported into the park in small amounts on a predictable annual cycle. As global development continues to increase along with a growing human population, emissions from international source areas are likely to increase as well. If park air quality is to remain the spectacular natural resource it is today, efforts to limit emission increases will need to be global as well as national.

Acknowledgements

The Denali air quality monitoring program would not be possible without the support of numerous dedicated personnel associated with the NPS Air Resources Division, the various nationwide air quality monitoring networks, and associated network contractors. Field staff include Pamela

Sousanes, Nikki DeMers, Phil Brease, Chad Hults, and Guy Adema. Thanks are due to Christine Shaver for her vision and leadership of the NPS Air Resources Division.

References

National Park Service Air Resources Division. 2002.

Air Quality in the National Parks.
Second Edition. Lakewood, Colorado.

Wilcox, Walter James II. 2001.

The origin and composition of aerosols in the Alaskan airshed. Master of Science Thesis.
University of Alaska Fairbanks.

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National Park Service photo

Figure 2. The Denali air quality monitoring shelter is located near park headquarters because it requires reliable power, a telephone line, and year-round access.

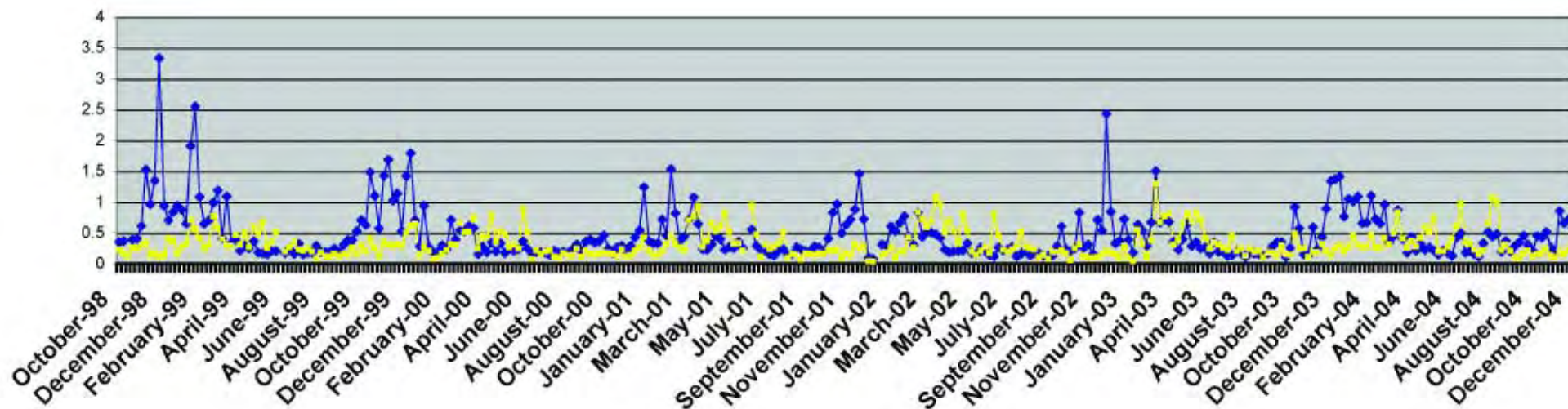
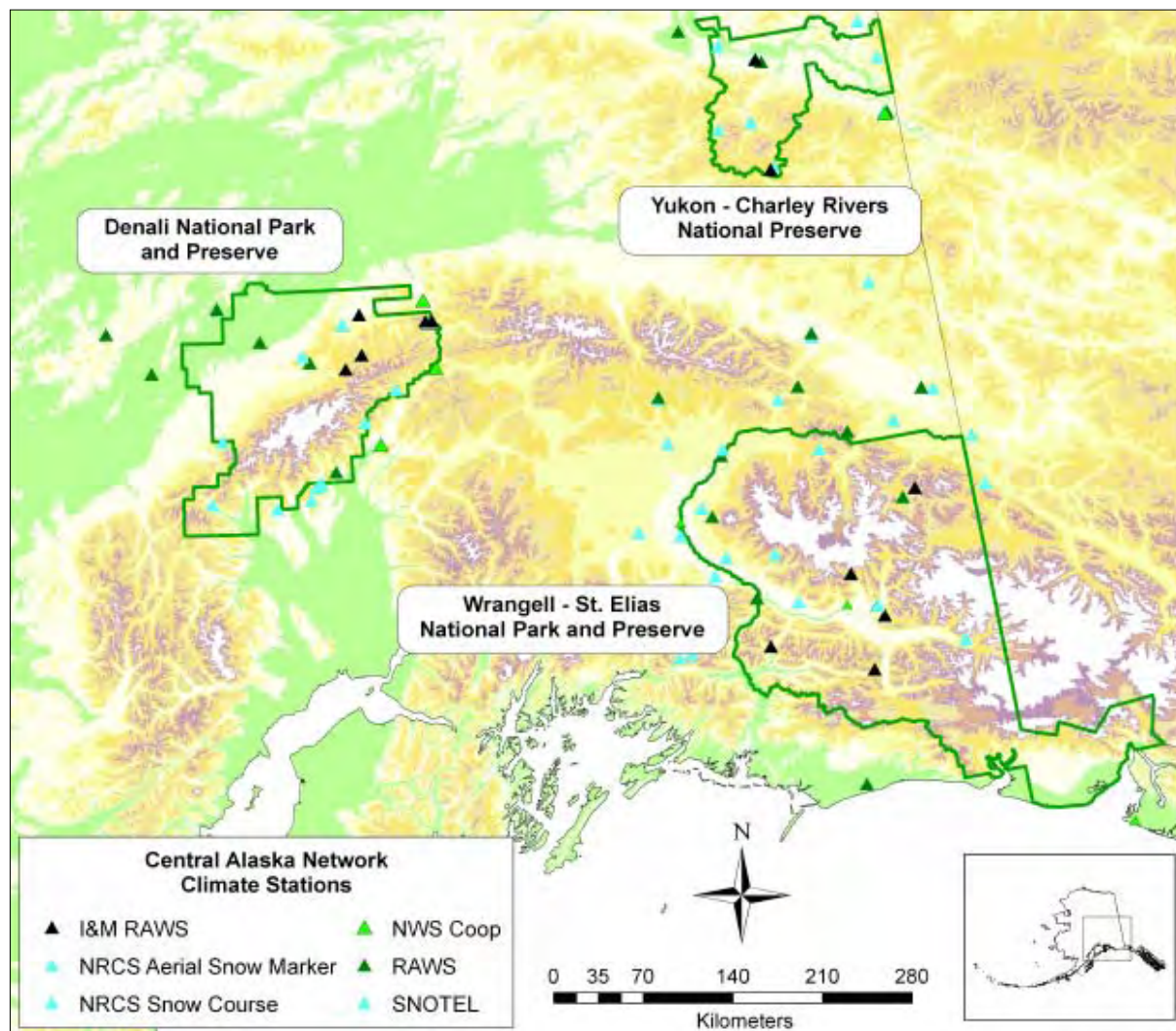


Figure 3. Weekly concentrations of sulfate (yellow line) and sulfur dioxide (blue line) from CASTNet filters show an annual maximum in the winter and early spring. Units are micrograms per cubic meter.

Monitoring Seasonal and Long-term Climate Changes and Extremes in the Central Alaska Network

by Pamela J. Sousanes



Abstract

Climate is a primary driver of ecological change and an important component of the Central Alaska Inventory and Monitoring Network (CAKN). By monitoring seasonal and long-term climate patterns in the region, we can correlate climate changes and extremes to other variations in the ecosystem, such as changes in permafrost extent or vegetation composition. As part of the monitoring effort, the CAKN staff worked with the Western Regional Climate Center (WRCC) and Dr. Richard Keen to produce a climate station inventory and baseline climate data analysis for the region. The initial results from the analysis highlight the correlation among the sites in the network and the relationships between the long-term station data and different climate indices that affect the region. It also describes the variability of climate within the defined period of record and points out the large numbers of factors that influence the regional climate.

Figure 1. Locations of climate stations in the Central Alaska Network.

Introduction

The Central Alaska Inventory and Monitoring Network (CAKN) covers 21 million acres in Denali National Park and Preserve, Wrangell-St. Elias National Park and Preserve, and Yukon-Charley Rivers National Preserve. Climate in this vast area is extremely variable, ranging from a mild maritime climate along the Gulf of Alaska to a continental interior climate characterized by large variations in seasonal temperatures. Understanding how these climate patterns vary on both a spatial and temporal scale will help us to understand the myriad of ecological changes we are seeing in the parks. The objective of the climate monitoring program is to record weather conditions at representative sites in order to identify long and short term trends, provide reliable climate data to other researchers, and to participate in larger scale climate monitoring and modeling efforts (Sousanes 2004). The location of climate sites in and around the three parks is shown in Figure 1.

Dr. Kelly Redmond, and the staff at the WRCC, compiled an inventory of climate stations for the network (Redmond and Simeral 2006), and Dr. Richard Keen, a climatologist from the University of Colorado, was contracted to provide a baseline climate analysis for the region. The preliminary results from the climate data analysis highlight relationships between the available long-term station data and climate indices such as the Pacific Decadal Oscillation (PDO) and the North Pacific (NP) Index. With this ground work done, the CAKN climate monitoring program is now poised to detect changes in climate by comparing future data from the stations with this baseline data.

Methods

The results from the analysis are based on long-term data sets or a combination of stations within and near the three units of the CAKN. Eagle, McKinley Park, and Gulkana are three stations with records greater than 80 years that are used in this analysis along with six other stations in the region, including Fairbanks, Talkeetna, Cordova, Valdez, Yakutat, and combinations of stations

The objective of the climate monitoring program is to record weather conditions at representative sites in order to identify long and short term trends, provide reliable climate data to other researchers, and to participate in larger scale climate monitoring and modeling efforts.

including McCarthy/Kennecott/Chitina and Fort Yukon/Circle/Central. For temperature analysis, monthly and annual time series were compiled. Because the Central Alaska region includes coastal areas where the annual, seasonal, and daily temperatures fluctuate less than those at interior sites such as Eagle, using station means was not useful for region-wide analysis, but determining annual average temperature departure from normals allowed for region-wide correlations. The normalized departure for each year at each station is given by:

$$\text{Normalized Departure} = \frac{(\text{Annual temperature} - 1971-2000 \text{ normal})}{\text{Standard Deviation of annual temps}}$$

Records of precipitation are especially important for documenting climate and understanding climate effects on ecosystems, but measuring precipitation, where most of the precipitation comes in the form of snow, and where it is windy, is technically quite difficult. The only long-term station available for analysis in CAKN for year-round precipitation is the National Weather Service (NWS) site at McKinley Park; all of the other long-term sites have large data gaps. However, there are over 30 sites that measure snow and snow water equivalent (SWE) in the network that have long enough records for analysis. These sites are from a combination of the Natural Resources Conservation Service (NRCS) snow telemetry (SNOTEL) and snow course sites and NWS cooperative sites. Following the methodology used by the NRCS National Water and Climate Center (NWCC), the individual SWE for each site is expressed as a percent of the 1971-2000 average for that site and month.

Results

Temperature

The variability among departure from normal temperatures from the CAKN long-term stations is consistent across the region. For summer (June-August) temperatures over the period of record, the correlations between the individual long term stations and the average of all nine stations range from 0.65 to 0.89. For winter (December-February) temperatures, the correlations are even better, ranging from 0.84 to 0.94. Correlations for annual mean temperatures range from 0.77 to 0.92. Figure 2 shows the departure from normal for annual temperatures plotted with a 5-year moving average. A five-year average is used to emphasize the decadal variability associated with changes in the regional atmospheric and oceanic circulations.

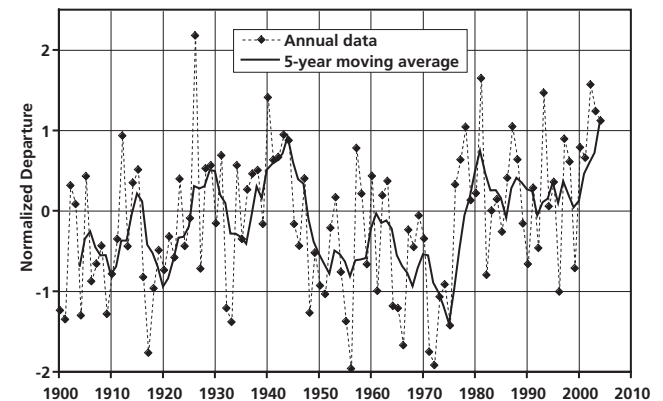


Figure 2. Normalized Central Alaska Network regional annual temperatures. Average of nine stations with 5-year moving average.

Precipitation

The focus for the analysis is on snow and SWE. The average correlation coefficient for SWE of 19 sites in Denali is 0.83; for the 18 sites in Wrangell-St. Elias the average correlation coefficient is 0.65, and for the nine sites in Yukon-Charley the average is 0.87. There is good correlation among sites in a single park, and the annual variations in SWE are consistent between the three parks (Figure 3). The respective correlations between Denali, Yukon-Charley, and Wrangell-St. Elias and the three unit average is 0.89, 0.87, and 0.90. Because the variations of SWE in the three units are so well correlated, the average SWE for all units combined can be used for analyzing the possible causes of variation across the network.

Discussion and Conclusions

Climate Variability and Atmospheric and Oceanic Climate Indices

In order to explain climate variations, and in particular temperature variations in the CAKN, we looked for correlations between temperature and larger scale atmospheric and oceanic circulations. Many studies show that temper-

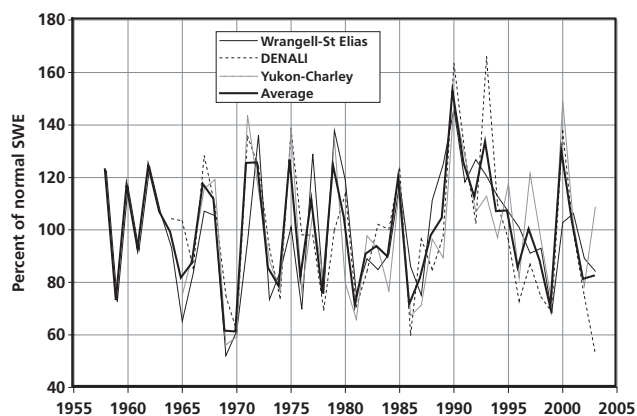


Figure 3. Percent of normal Snow Water Equivalent (SWE) from Denali, Wrangell-St. Elias and Yukon-Charley Rivers, and the average of the three parks combined.

ature changes in the region coincide with shifts in the Pacific Decadal Oscillation (PDO), which is a pattern of Pacific sea surface temperatures that shifts phases on a decadal time scale, usually about 20 to 30 years. During a warm, or positive, phase, the west Pacific becomes cool and part of the eastern ocean warms; during a cool or negative phase, the opposite pattern occurs (Mantua *et al.* 1997). In 1976, the North Pacific region, including Alaska, underwent a dramatic shift to a warmer climate with dramatic increases in winter and spring temperatures, and lesser increases in summer and autumn, when compared to the previous 25-year period (Hartmann and Wendler 2005, Serreze *et al.* 2000). The North Pacific (NP) climate index is closely correlated with the PDO and is a measure of the sea level pressure over the region; it is used as an indicator of the strength of the Aleutian Low.

The strongest and most consistent of the observed correlations for the CAKN analysis, as in the other studies mentioned above, is between annual, and especially winter, temperature and the PDO and the NP index (Table 1). During the period 1947-1976 the Aleutian Low was relatively weak, allowing arctic air masses to engulf Alaska leading to cold winters. From 1923-1946 and from 1977 to the present, the Aleutian Low has been stronger, pushing mild maritime air into the state. The long-term temperature records used in the CAKN analyses span through two of these regime shifts. The mean annual temperatures for the nine long-term stations during the first warm phase (1923-1946) of the PDO was 31.7°F (-0.2°C), for the cool phase (1946-1977) was 29.9°F (-1.2°C), and for the second warm phase was 32.0°F (0°C). So, although the decades since 1977 have averaged two degrees F warmer than the previous three decades, those decades were in turn two degrees F colder than 1923-1945 (Figure 4). Therefore, the net change in annual temperatures since 1920 is less than 0.5 degree F. These results highlight the importance of defining the period of record when analyzing long-term trends. If a 30-year record were analyzed it would show significant warming in the region, but

Index	CAKN Winter Temperatures (Dec-Jan-Feb)	CAKN Summer Temperatures (Jun-Jul-Aug)
North Pacific	-0.72*	-0.34
Pacific Decadal Oscillation	0.67*	0.22

* Significant at the .01 level

Table 1. Correlations between 5-year moving averages of Central Alaska Network winter and summer temperatures and the North Pacific and Pacific Decadal Oscillation climate indices, with significance levels noted.

with 80 years of data the large decadal variability of the climate becomes more apparent.

This paper does not go into detail regarding correlations with other climate indices; however the correlation with the PDO and winter temperatures is the most obvious. The correlations between precipitation (as SWE) and climate indices are weak and require further investigation, but the coherence among sites in the network will make it easier to detect changes and patterns in the region. There are many other factors influencing the climate of the central Alaska region, including potential effects from arctic Alaska, where terrestrial changes in summer albedo are contributing to high-latitude warming trends (Chapin *et al.* 2005). In many places in the Central Alaska region only a small shift in temperatures will change the climatic regime from one where temperatures are near freezing to one where temperatures are slightly above freezing. This phase change from ice to water limits a variety of biophysical processes, which operate on multiple spatial and temporal scales (Hinzman *et al.* 2005).

Management Implications

Park management faces an increasing challenge to protect park resources in the face of climate change. The recent climate inventory and analysis gives perspective to the large scale processes that affect the regional climate and will help us to understand and interpret future climate

variability. The climate monitoring component of CAKN is now set up to provide web-based climate data and analysis tools that can be used to track climate through time, and relate climate changes and extreme events to other ecological and community processes. These data are available at <http://www.wrcc.dri.edu/NPS.html>.

Acknowledgements

The data analysis for this report was done by Dr. Richard Keen; a final report will be available in 2007. The inventory report compiled by Dr. Kelly Redmond and David Simeral was funded by the National Park Service Inventory and Monitoring Program.

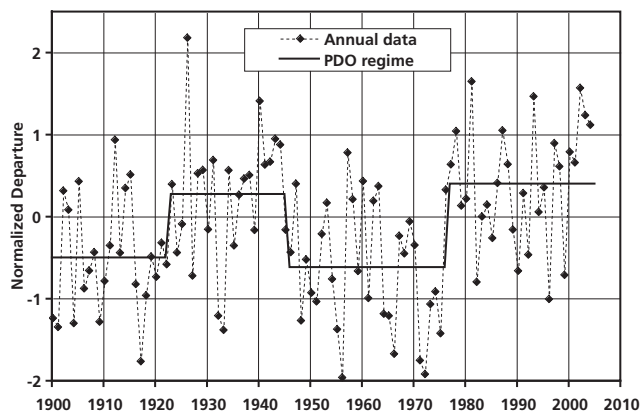


Figure 4. Normalized Central Alaska Network regional annual temperatures of all nine stations with Pacific Decadal Oscillation (PDO) regimes superimposed.



A summer rain shower in Denali National Park and Preserve.

References

- Chapin, F.S., et al. 2005.
Role of land-surface changes in arctic summer warming. Science 310: 657-660.
- Hartmann, B., and G. Wendler. 2005.
The significance of the 1976 pacific shift in the climatology of Alaska. Journal of Climate 18: 4824-4839.
- Hinzman, Larry D., N.D. Bettez, R.W. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa. 2005.
Evidence and implications of recent climate change in northern Alaska and other arctic regions. Climatic Change 72: 251-298.
- Mantua, N., S. Hare, Y. Zhang, J. Wallace, and R. Francis. 1997.
A Pacific Interdecadal Climate Oscillation with impacts on salmon production. Bulletin of American Meteorological Society 78: 1069-1079.
- Redmond, K.T., and D.B. Simeral. 2006.
Weather and Climate Inventory, National Park Service, Central Alaska Network. Natural Resource Technical Report NPS/CAKN/NRTR 2006/004. National Park Service. Fort Collins, Colorado.
- Serreze, M., et al. 2000.
Observational evidence of recent change in the northern high-latitude environment. Climatic Change 46: 159-207.
- Sousanes, P.J. 2004.
Climate Monitoring Protocol for the Central Alaska Network. General Technical Report. Central Alaska Inventory and Monitoring Network. Denali Park, AK.

Physical Environment and Sciences





National Park Service photo with inset photo by Bradford Washburn, UAF Rasmuson Library

Glacier Monitoring in Denali National Park and Preserve

by Guy Adema



Abstract

Glaciers are a major feature in Denali National Park and Preserve (Denali), covering about one million acres—17% of the park. Glacier behavior in Denali varies from steady

flow glaciers controlled primarily by topography and climate, to erratic surge-type glaciers. This variety offers opportunities to monitor glacier dynamics dominated by climate as well as those that are influenced by other factors. A formal glacier monitoring program began in Denali in 1991 as part of the National Park Service's Long-term Ecological Monitoring Program, in cooperation with the U.S. Geological Survey and the Geophysical Institute at the University of Alaska Fairbanks.

Top: Figure 1. Over 1 million acres of Denali National Park are covered by ice.

Left: Re-occupation of historic photo sites provides insight to the magnitude and distribution of glacier change since the early 1900s.

The fundamental aspect of the program is an “index” method, or single point mass balance monitoring. Two index monitoring sites are maintained in Denali, on the Kahiltna and Muldrow glaciers. Both monitoring sites are at or near the equilibrium line altitude (ELA) and attempt to measure conditions on the south and north sides of the Alaska Range, respectively. Since monitoring began in 1991, the Kahiltna glacier index site has had a slightly positive mass balance and a variable velocity that ranges from 590 to 820 feet per year (180-250 m/yr). Seasonal balances are on the order of +/- one meter of water equivalency per year. During the same time period, the Traleika glacier has shown a consistently negative mass balance within a slightly narrower range of seasonal balances, with flow rates between 66 and 230 feet per year (20-70 m/yr). These data, combined with glacial extent measurements and reconstruction of historical photos, have documented significant change in Denali's glacial system.

Introduction

The objective of the glacier-monitoring program in Denali is to establish 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 identify the effects of these changes on other related systems, such as the discharge of glacier-fed rivers.

In May 1990, the National Park Service (NPS) proposed



Figure 2. Glacier index measurement sites include fixed stakes which are surveyed twice per year to calculate mass balance, movement rates, and changes in surface elevation.

global climate change research on Alaska-region glaciers in park units. An informal workgroup of specialists from Denali, the U.S. Geological Survey (USGS), and the University of Alaska Fairbanks (UAF) began scoping what a sustainable monitoring program might look like, applying experience from existing glacier monitoring and research programs. In early 1991, the NPS held a glacier research workshop in Alaska to develop recommendations about glacier monitoring (*Sturm 1991*). Seventy people—representing universities, federal and state agencies, and 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 glacier monitoring system, examined the nature of this system, and how it would fit in with ongoing or planned research programs at Denali. A steering committee was formed to develop an interdisciplinary group of interested parties to pursue the objectives for the newly conceived permanent coordinating group for North American Glacier Observations. The glacier monitoring ideas identified at the conference and refined by the steering committee, evolved into the glacier monitoring program at Denali.

By March 1991, specialists from USGS, UAF and Denali targeted two glaciers to monitor, representing two

distinct climatic zones in the park, the Traleika and the Kahiltna glaciers. In order to keep the measurements relatively simple and sustainable for long-term monitoring, the designed program uses 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. Index site data can then be compared to trends measured on other glaciers.

An index site is a fixed site on a glacier where a single pole, 1 inch (2.5 cm) in diameter and 20 to 40 feet (6-12 m) long, is melted into the ice near the equilibrium line (ELA) of the proposed glaciers. The proposed glaciers all met the required criteria of having a simple geometry, spanning a large elevation range, being in a distinct climatic region, and being representative of other glaciers in the area.

Site selection, installation, and monitoring of survey monuments on the Kahiltna and Traleika glaciers were completed in the spring of 1991. It continued as a cooperative program with the USGS—specifically, Larry Mayo—from 1991 to 1997. Keith Echelmeyer (UAF) has also been an instrumental cooperator with the program since its inception, helping with program development, technical assistance, field advisement, and informal review.

The index site measurements are just one element of the glacier monitoring program at Denali. Contemporaneous to the initiation of index monitoring, a comprehensive program was envisioned that also included:

- (1) establishing photo points for monitoring glacial surface and termini changes,
- (2) terminus surveys,
- (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.

This glacier monitoring vision was included in a larger NPS effort to institutionalize monitoring of ecosystem

change—the Long-term Ecological Monitoring Program. Denali would become a prototype park for the NPS Long-term Ecological Monitoring Program in 1992. A glacier monitoring element was incorporated into the conceptual watershed model because of glacial presence in many headwaters in Alaska's ecosystems, their role in shaping the physical environment, and their importance as early indicators of global climate change. Glacier monitoring became a part of the Denali's prototype monitoring effort, and glaciers have been identified as a vital sign in the subsequent NPS Central Alaska Network Inventory and Monitoring Program.

The glacier monitoring program has expanded to include many of the elements originally envisioned in a comprehensive program. In addition to index site measurements, glacial extent measurements (field and remotely-sensed), surge activity monitoring, change detection observed through comparative photography, and discharge monitoring activities have been implemented.

Methods

Index Site Measurements

A formal field manual for conducting index site measurements was completed in 2001 that describes the necessary elements for data collection and processing. Two times per year, at the end of the accumulation season and at the end of the ablation season, the index stakes on the Kahiltna and Traleika glaciers are surveyed and test pits are dug near the sites. The data are interpreted for single-point mass balance, surface velocity, and surface elevation change. Data collection has evolved from traditional surveying to survey-grade GPS measurements (*Figure 2*).

Glacial Extent Measurements

Changes in glacial extent are documented in two ways. Field-based termini measurements are performed on a number of glaciers on a rotating basis, with each being visited about every 10 years. In order to gain a better idea of change across the entire park, remotely-sensed images are interpreted for glacial extent and provide an overall,

long-term quantification of change. The park-wide data series currently consists of 1950s USGS black and white aerial photography, 1980s aerial high altitude photography, cloudless, full-coverage, 2001 LandSat Thematic Mapper Scene, and most recently, one meter resolution IKONOS imagery that is currently being acquired. The imagery is manually analyzed and glacier extents are digitized.

Comparative Photography

Through a cooperative effort with USGS, historic photos have been acquired from the early 1900s through the 1970s, taken by early explorers, NPS personnel, scientists, and visitors. We select high quality images for reproduction based on content and identifiable landforms. The sites are revisited and the photos are reproduced as accurately as possible. Accurate reproductions allow for estimates of volume and extent change, as well as providing powerful interpretive images.

Glacier Surge Event Monitoring

About half of Denali's glaciers are surge-type glaciers, which alternate between normal and surging flow regimes. The processes that control surge activity are not well understood, but the most commonly accepted theories relate surging to sub-glacial hydrologic processes. When glacial surges occur, the NPS monitors the activity and collects

basic data to help understand the processes involved, including movement rates, surge-front measurements, and photographic documentation. One of the most highly visible surge-type glaciers is the Muldrow Glacier, viewed by most park visitors from the Eielson Visitor Center. Its surge cycle suggests that it could surge in the relatively near future. In preparation, we have taken actions to collect data to better understand and interpret the potentially dramatic change to the landscape. Movement targets have been installed on the glacier, photopoints have been created, a discharge gauge was installed, and LIDAR data has been collected to provide a digital elevation model (DEM) of the glacier's surface. LIDAR is an optical range finding technology operated from an airplane which produces high resolution terrain information with vertical accuracies less than 1 foot (0.3 m), allowing for accurate surface change calculations and change detection.

Results

Index Site Data Highlights

Preliminary mass balance data from the Kahiltna and Traleika glacier index sites appear in Figures 3 and 4, respectively. 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 3), though Traleika Glacier (Figure 4) has been consistently negative throughout the study. Flow rates for Kahiltna Glacier have been steady at approximately 656 feet (200 m) per year and the glacier has thinned by about 10 feet (3 m) since 1991. The Traleika Glacier, however, has exhibited much more interesting behavior. The surface height of Traleika Glacier has increased some 82 feet (25 m) 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 may thicken and increase in 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.

Another interesting finding appears in the anti-correlation between the annual mass balances of Kahiltna and Traleika Glaciers. Comparison of the equilibrium line altitudes (ELA) 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

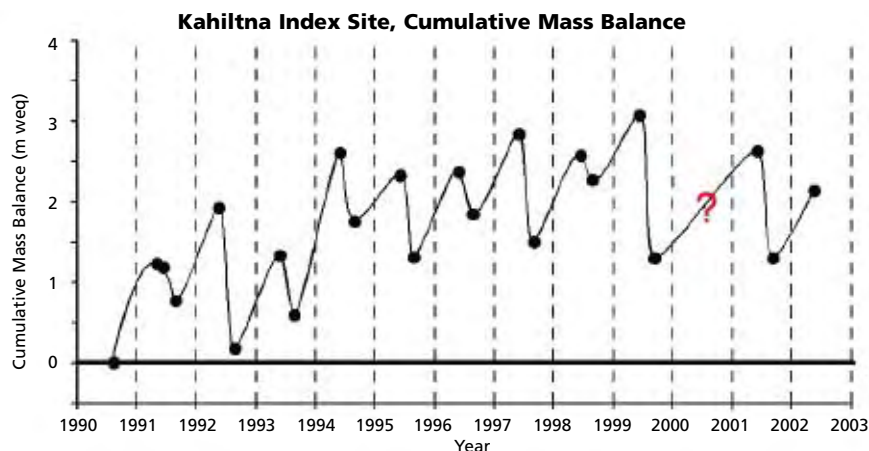


Figure 3. The Kahiltna Glacier index site has shown a slightly positive mass balance since 1990, expected as the site is slightly above the equilibrium line.

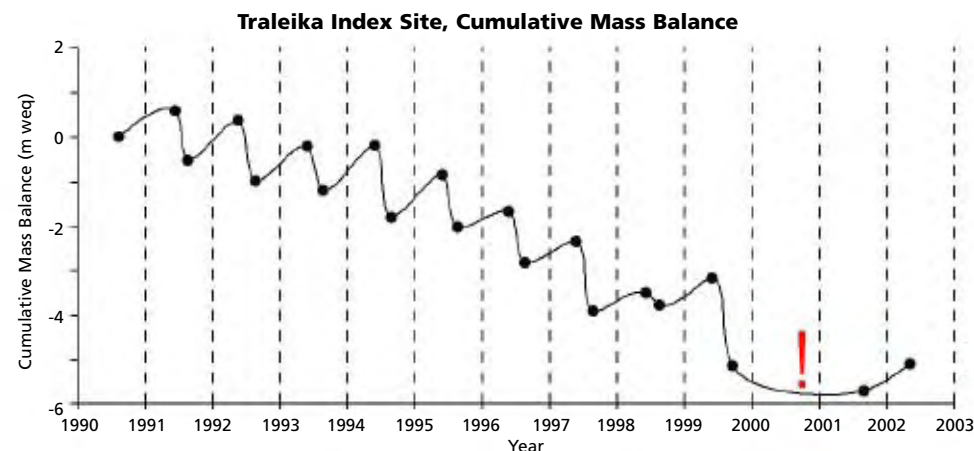


Figure 4. The Traleika Glacier shows a steady negative mass balance since 1990.

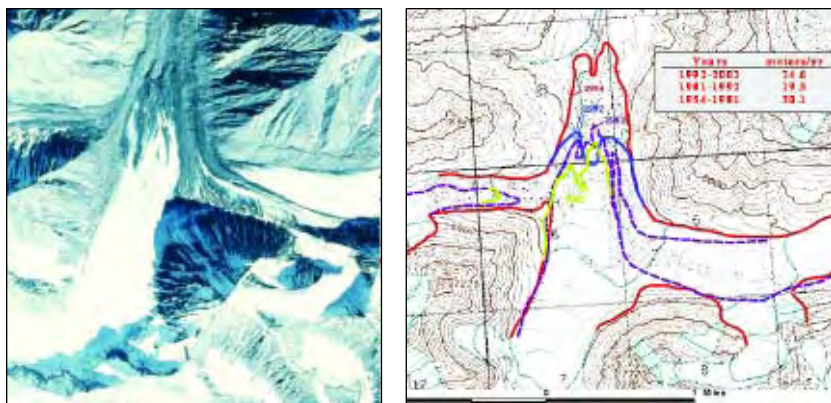


Figure 5. The terminus of the Middle Fork Toklat Glacier has retreated at an average rate of 82.3 feet (24.7 m) meters per year since 1954.

high ELA on Kahiltna Glacier in 1992 was the result of a coating of volcanic ash from the eruption of Mt. Spurr (south of the park 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.

Glacial Extent

No named Denali glaciers are in an advancing state. Most are actively downwasting and retreating. The rates of retreat are slower than in coastal areas due to a thin veneer of moraine material that insulates the ice and slows retreat. A comprehensive inventory comparing park-wide imagery from 1954, the 1980s, 2001, and 2005-2007 is in process that will help quantify the change. Figure 5 shows the Middle Fork Toklat Glacier, it has an average retreat rate of 79 feet (24 m) per year, for the years 1992 to 2002.

Cursory volume loss estimates of the Middle Fork Toklat glacier were calculated by comparing centerline elevation data surveyed in August 2002, compared with USGS elevation data taken from 1954 aerial photography. The area of the glacier surface was taken from the terminus study measured in the field August 2002 and aerial

photos. The total volume change from 1954-2002 is $-1.17 \times 10^{10} \text{ ft}^3$ ($-3.30 \times 10^8 \text{ m}^3$). The rate of volume change is $-2.43 \times 10^8 \text{ ft}^3/\text{yr}$ ($-6.88 \times 10^6 \text{ m}^3/\text{yr}$). Longitudinal surveys on the East Fork Toklat glacier also indicate a loss of over 10 feet (3 m) per year of water equivalency. Further analysis is expected to reveal similar results on other lower elevation glaciers. The data from our coarse measurements are consistent with that of Arendt et al. (2002), which calculated volume loss of glaciers around Alaska.

Detailed elevation data (LIDAR) was collected in 2006 on the Muldrow and Traleika glaciers for comparison with 1976 topographic maps made by Bradford Washburn. The data will provide a comprehensive view of volume change for a complete glacier system.

Comparative Photography

Re-creating historic photos has proved a powerful tool for understanding glacial change. Figure 6 shows the Teklenika Glacier has lost almost 900 feet (274 m) vertically and has retreated significantly between 1919 and 2004. We are continually collecting additional historic photos and find similar change across the lower elevations of the park, dramatically highlighting the rate of glacial change in Denali and the resulting landscape effects.

Surge Monitoring

During the surge of the Tokositna Glacier in 2001, maximum ice velocities of over 6.5 feet (2 m) 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 et al. (2002) and were also published in multiple newspaper articles and television broadcasts in 2001. The park surveys surge-type glaciers in late winter each year to detect surge activity. Glacier movement and discharge measurements on the Muldrow Glacier will provide detailed data in the event of a surge.

Conclusions

A glacier monitoring program is in place at Denali National Park and Preserve that is designed to observe and quantify the primary trends affecting the park's glaciers. Through analysis of the mass balance, photographs, and glacial extent records, trends of Denali's glaciers will be recorded and available for broad-scale relations to climatic and ecological changes. The glaciers of Denali will prove a valuable measure of the rate and impact of climate change.

Acknowledgements

Many personnel have been closely involved with glacier monitoring since inception, including Keith Echelmeyer, Phil Brease, Larry Mayo, Jamie Roush, Adam Bucki, Chad Hults, Paul Atkinson and Pam Sousanes. The Denali Center for Resources Science and Learning and the Central Alaska Network Inventory and Monitoring Program infrastructures have allowed the program to operate successfully for 15 years.

References

- Arendt, Anthony A., Keith A. Echelmeyer, William D. Harrison, Craig S. Lingle, Virginia B. Valentine. 2002. *Rapid wastage of Alaska glaciers and their contribution to rising sea level*. Science 297:382-386.
- Echelmeyer, Keith, Martin Truffer, Vi Valentine, Guy Adema, G. Williams. 2002. *Recent glacier surges in Alaska and northwestern Canada: support for ideas on surging*. Presentation abstract from IGS International Symposium on Fast Glacier Flow, Yakutat, AK, June 10-14, 2002.
- Sturm, Matthew. 1991. Report on the Glacier Research Workshop, February 5-7, 1991. Eagle River, Alaska.

Applications of the Soil-Ecological Survey of Denali National Park and Preserve

by Mark Clark

Abstract

A soil and ecological survey of Denali National Park and Preserve (Denali) was completed by the Natural Resources Conservation Service in 2004 (*Clark and Duffy 2004*). Products included digital maps, tabular soils information, a detailed soils report, as well as a database with 2,100 field stops. This soil-ecological survey is a multi-disciplinary effort that incorporates soil, hydrologic, and vegetation information into a variety of products. This baseline information is fundamental to an understanding of the natural resources of Denali and provides a critical element for land use decisions on national park lands.

Application of the survey information includes basic distribution maps for a variety of natural resources such as soils with permafrost, wildlife habitat, prediction of fire-prone areas, surficial geology, landforms, and identification of plant communities that are likely to have rare and endangered plant species, to mention a few. Three examples of specific application of survey products are provided. The first example illustrates basic distribution maps of soils with permafrost within three feet (1 m) of the soil's surface. The second example illustrates the modeling capabilities of the information. In this example, soils with permafrost have been categorized based on sensitivity to surface disturbance or increasing air temperatures associated with regional climate change. The final example illustrates the distribution of soil map units that support a plant community with a plant rarely observed in the park, Selkirk's violet (*Viola selkirkii*).

Introduction

USDA-Natural Resources Conservation Service (NRCS) completed a soil-ecological site inventory for Denali National Park and Preserve in 2004 (*Clark and Duffy 2004*). The project provides detailed digital soil maps at 1:63,360 scale and tabular documentation as well as descriptive information of soil, vegetation, and ecological sites. A map based ecological hierarchy based on ECOMAP (*Bailey et al. 1994*) provides park-wide ecological information at a variety of different landscape resolutions. Products provided include a comprehensive set of soil and vegetation field data from over 2,100 points that were entered into a Microsoft Access database and a variety of GIS general theme maps that include hydric soils, vegetation, perma-

frost, landforms, and soil processes. Products are available on-line at the NRCS web soil survey website:

<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

The spatial and tabular data and manuscript jointly provide baseline soil and vegetative resource information that serves as basic resource information for Denali. Landscape modelers may use the data to establish areas of critical wildlife habitat, answer watershed issues, better understand the potential uses and limitations of soils, and illustrate the distribution of plant communities as well as individual plant species in Denali. Researchers can extrapolate their research to similar landscapes elsewhere by tying research to specific ecological sites.

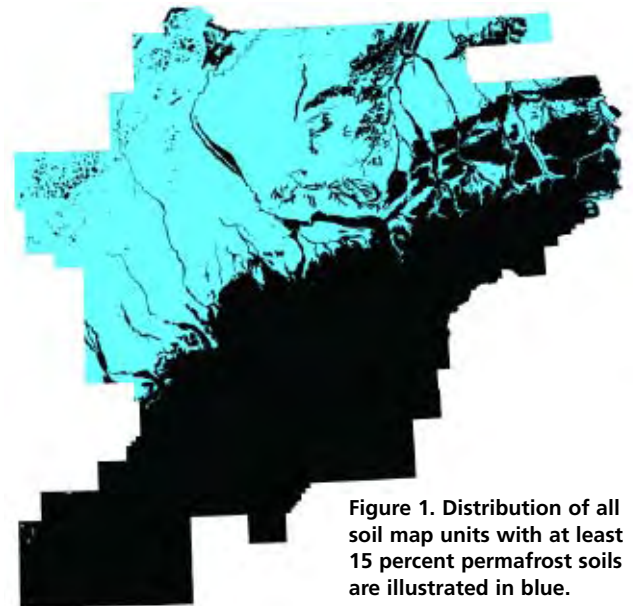


Figure 1. Distribution of all soil map units with at least 15 percent permafrost soils are illustrated in blue.

Application Examples

Specific applications of the survey products are described below. Figures 1 and 2 illustrate the distribution of soil map units with permafrost soils using two slightly different criteria. Figure 1 illustrates map units containing soil components with permafrost that comprise 15% or more of the map unit. The total distribution of map units that meet these criteria encompasses 2.3 million acres or about 38% of the park. Figure 2 illustrates the distribution of map units with varying percentages of soils with permafrost based on four categories: those containing no soils with permafrost; those containing 1-14% soils with permafrost, those containing 15-79% soils with permafrost; and those containing 80% soils with permafrost. Total acreage for the second example is slightly higher due to the addition of soil map units with less than 15% permafrost.

The next example is the modeling of the loss of per-

mafrost from soils based on soil sensitivity to surface disturbance or increasing air temperatures associated with regional climate change. Permafrost is sensitive to changing surface soil temperatures with changing site characteristics such as changing regional climate, vegetation, and snow cover (*Osterkamp and Romanovsky 1999*). Soil characteristics such as the amount of organic mat disturbed and soil texture are also important in determining the persistence or loss of permafrost following fire. Soils with a high sand and rock fragment content conduct heat effectively and are most likely to experience significant lowering of permafrost. Conductivity of heat increases in soils as particle sizes increase (*Jury et al. 1991*). A crude model consisting of three categories of sensitivity based on these thermal soil properties is described and illustrated below.

Soils described as highly sensitive are those that warm rapidly and have an associated subsidence or thawing of

permafrost (*Figure 3*) following significant reduction in the thickness of the surface organic mat as a result of fire. These soils consist of less than 3 feet (1 m) of loamy alluvium over sandy and gravelly alluvium on terraces and alluvial fans. Permafrost drops below 6.5 feet (2 m) of the ground surface within one to three years following fire.

Soils with permafrost are described as moderately sensitive to a reduction in the organic mat thickness as a result of wildfire (*Figure 4*) based on the following criteria. Soils are loamy throughout with 10-35% rock fragments in the upper 3 feet (1 m) of soil. These include soils on till plains, all positions on glaciated low mountains, and on lower mountain slopes of non-glaciated mountains. These soils have intermediate levels of thermal conductivity attributed to the moderate level of rock fragments and loamy soil matrix, which conducts heat at a slower rate than soils of the first group. Loss of permafrost below 6.5

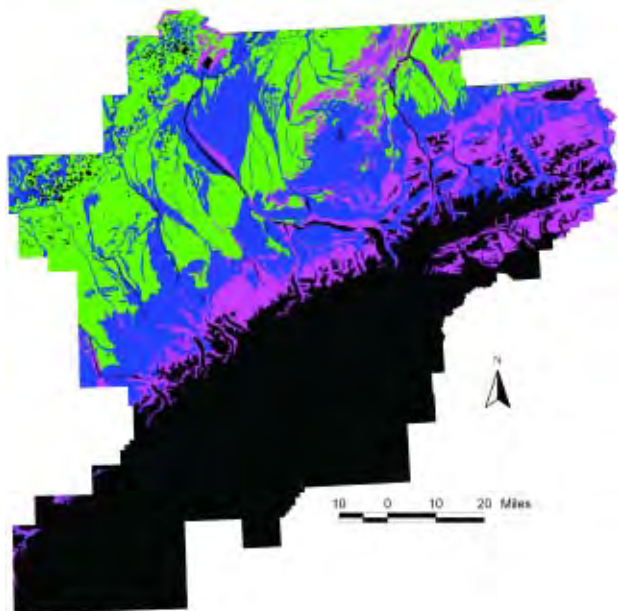


Figure 2. Distribution of four categories of soil map units with permafrost soils including; (black) no permafrost, (pink) 1 to 14 percent, (blue) 15 to 79 percent and (green) 80-100 percent of the unit consists of permafrost soils.



Figure 3. Soils with permafrost that are highly sensitive to disturbance or temperature change are represented in red and total 292,042 acres or about four percent of Denali. Blue areas represent soil map units consisting of over 15 percent permafrost soils.



Figure 4. Soils with permafrost that are moderately sensitive to disturbance or temperature change are represented in red and total 1,100,094 acres or 18 percent of Denali. Blue areas represent soil map units consisting of over 15 percent permafrost soils.

feet (2 m) within three to five years following fire is commonly observed.

Soils with permafrost that are considered to have a low sensitivity to thaw after fire (Figure 5) are based on the following criteria. Soils consist of rock-free silty or loamy materials over 3 feet (1 m) thick on loess mantled plains, hills, and terraces. The relatively fine textured surface layers have low thermal conductivity properties and therefore a slower temperature change following fire or other surface disturbance. Lowering of permafrost in the soil profile occurs following disturbance; however, lowering below a depth of 6.5 feet (2 m) is rare unless associated with massive ice degradation.

Extrapolation of research to areas of similar ecological site or habitat is provided in the final example. Selkirk's violet (*Viola selkirkii*) occupies a very limited habitat along the southern part of Denali National Park and Preserve and is considered rare. The frequency of occurrence ranges from 9-14% of field stops (29 of 301) in favored habitats in the southern part of the park. Plant communities associated with the occurrence of Selkirk's violet include Barclay willow/herbaceous meadow mosaic, Sitka alder/tall herbaceous meadow mosaic and riparian poplar and riparian alder types. By linking Selkirk's violet to these favored communities and associated ecological sites a spatial representation can be created of areas where the probability is high that Selkirk's violet may be observed (Figure 6).

Summary

The soil-ecological survey of Denali National Park and Preserve provides a spatial representation of soil and vegetation resources of the area. This information is valuable to resource planners in terms of understanding soils, vegetation, hydrology, and landforms of the area. Researchers may use the information as a tool to extrapolate research to similar ecological sites throughout Denali National Park. Modelers will find the various soil properties and vegetation attributes of the data useful in understanding habitat patterns and their extent as well as identifying environmentally unique and sensitive areas.



Figure 5. Soils with permafrost with low sensitivity to disturbance or temperature change are represented in red and total 968,061 acres or about 16 percent of Denali. Blue areas represent soil map units consisting of over 15 percent permafrost soils.

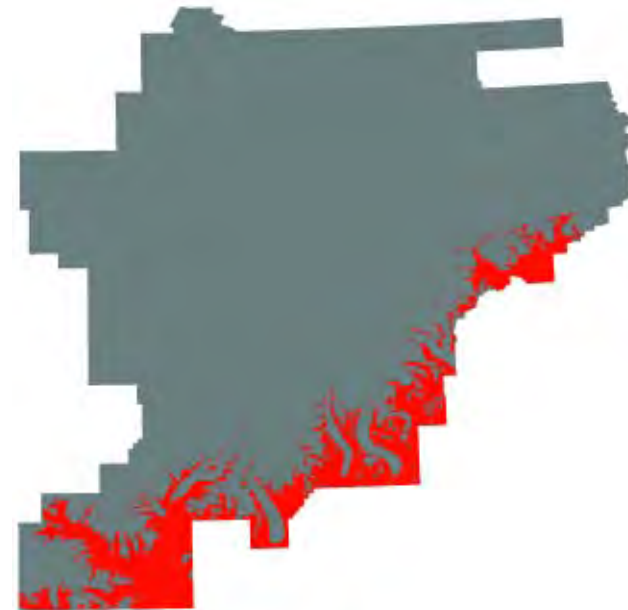


Figure 6. Distribution of soils and plant communities associated with the occurrence of Selkirk's violet is represented in red.

References

- Bailey, R. G., P. E. Avers, T. King, and W. H. McNab, eds. 1994. *Ecoregions and Subregions of the United States (map)*. 1:7,500,000. USDA Forest Service. Washington, DC. With supplementary table of map unit descriptions, compiled and edited by W.H. McNab and R.G. Bailey.
- Clark, M. H., and M. Duffy. 2004. *Soil Survey of Denali National Park and Preserve Area, Alaska*. Available on Web Soil Survey. <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>
- Jury, W. A., W. R. Gardner, and W. H. Gardner. 1991. *Soil physics*. John Wiley and Sons, Inc. New York.
- Osterkamp, T.E., and V.E. Romanovsky. 1999. *Evidence for warming and thawing of discontinuous permafrost in Alaska*. *Permafrost and Periglacial Processes* 10:17-37.

Using Radiocarbon to Detect Change in Ecosystem Carbon Cycling in Response to Permafrost Thawing

by Edward A.G. Schuur, Jason G. Vogel, Kathryn G. Crummer, Koushik Dutta, Hanna Lee, Christian Trucco, and James Sickman

Abstract

There are more than 450 billion tons of carbon frozen in permafrost in high latitude ecosystems. This carbon is now subject to release into the atmosphere due to climate warming and permafrost thawing. Radiocarbon measurements of ecosystem carbon losses provide the means to measure whether old carbon is released in response to permafrost thawing. Radiocarbon values of ecosystem carbon losses showed a significant contribution from old carbon in areas where the permafrost has been observed to thaw. These measurements made at observation locations through time will be a useful long-term monitoring tool for detecting significant changes in the carbon cycle due to permafrost thawing.

Introduction

At least 450 billion tons of soil carbon (C) are estimated to be stored in high latitude ecosystems (Gorham 1991). This represents almost one-third of the soil carbon stored in terrestrial ecosystems globally, and is several orders of magnitude greater than current annual anthropogenic carbon dioxide (CO₂) emissions (IPCC 2001). Latitudinal gradients of soil carbon, field experiments, and laboratory incubations all show that soil carbon cycling in these northern ecosystems is likely to be strongly influenced by the effect of cold temperatures on rates of decomposition of soil organic matter. This ‘old’ soil carbon, climatically protected from microbial decomposition in frozen or waterlogged soil, has been accumulating in these ecosystems throughout the Holocene since retreat of the last major ice sheets (Harden *et al.* 1992).

Climate change scenarios predict that the greatest magnitude of warming will occur at high latitudes. This predicted warming is supported by observational evidence over the last 25 years and is associated with warmer ground temperatures, permafrost (permanently frozen soil) thawing, and thermokarst (ground subsidence as a result of ground ice thawing) (ACIA 2004). Permafrost thawing and thermokarst have the potential to alter ecosystem carbon cycling by changing the vegetation structure and growth rates, and by altering soil microbial decomposition rates. Together, these changes in plant and soil processes can alter the balance of carbon cycling processes in these ecosystems and cause feedbacks to climate change.

Our overall research program is designed to answer three main questions:

- 1) Does permafrost thawing cause a net release of carbon from the ecosystem to the atmosphere?
- 2) Is the source of this carbon release from old carbon that comprises the bulk of the soil carbon pool?
- 3) What is the relative importance of old carbon export in water compared to direct respiration losses from land?

This summary addresses our use of radiocarbon measurements to determine the age of carbon lost from ecosystems in order to detect significant changes ecosystem carbon cycling that are a result of permafrost thawing and thermokarst formation.

Methods

Site Description This summary describes measurements made in the Eight Mile Lake Watershed (63° 52' 42.1" N, 149° 15' 12.9" W) on the north slope of the Alaska Range (Figure 1). Ground temperature in a borehole has been monitored for several decades at this site, before and after the permafrost was observed to thaw (Osterkamp and Romanovsky 1999). In this watershed, our study has defined three sites that represent differing amounts of disturbance from permafrost thawing based on observations of the vegetation and the borehole measurements:

- Site 1) tussock tundra typical of arctic ecosystems, dominated by the sedge *Eriophorum vaginatum* and *Sphagnum spp* mosses.
- Site 2) a site near the borehole used for permafrost temperatures where the vegetation composition has been shifting to include more shrub species, such as *Vaccinium uliginosum* and *Rubus chamaemorus*.

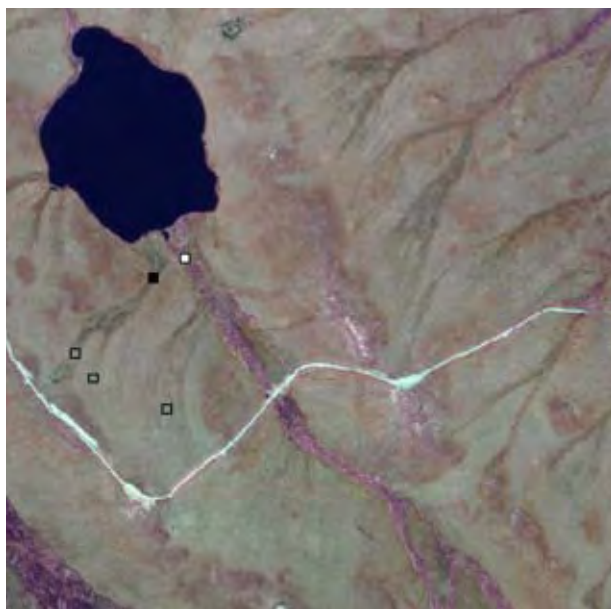


Figure 1. Aerial photo showing sampling locations: ecosystem respiration (grey), thermokarst drainage (black), and the main stream (white) in the Eight Mile Lake watershed. The white line is the Stampede Road.

- Site 3) a site located where permafrost thawed more than several decades ago, now largely dominated by shrub species (Schuur *et al.* 2007).

These three sites are a natural experimental gradient representing the long-term effects of permafrost thawing on carbon loss.

Radiocarbon: Detecting the Loss of Old Carbon

The $^{14}\text{C}/^{12}\text{C}$ isotope ratio of ecosystem carbon reflects the rate of exchange between carbon pools and the atmosphere. Nuclear bomb testing conducted in the 1960s enriched background levels of ^{14}C to approximately two times the normal atmospheric levels of radiocarbon (Figure 2a) (Levin and Hessheimer 2000). Following the test ban treaty, the level of radiocarbon in the atmosphere decreased as ^{14}C was transferred into the ocean, vegetation, and soils, accompanied by the continuing dilution of the atmosphere by fossil

fuel combustion. The enrichment of ecosystem carbon with “bomb” ^{14}C records a history of carbon uptake by these ecosystems in the time since weapons testing (Trumbore 2000). Surface organic matter that has incorporated significant bomb carbon has positive isotopic delta values relative to the 1895 wood standard. Radiocarbon is expressed in units of permil (‰) as compared to wood from the year 1895, the standard primary radiocarbon reference material.

Over longer time scales, the natural decay rate of ^{14}C acts as an atomic clock as radioactive decay causes older carbon stored deeper in the soil and permafrost to be depleted in ^{14}C . Thus, soil organic matter frozen in permafrost generally has negative delta values. In turn, carbon lost by terrestrial ecosystems when permafrost thaws, either directly respired as CO_2 to the atmosphere, or indirectly lost through water as dissolved inorganic or dissolved organic carbon (DIC, DOC) will reflect the age of carbon decomposed by bacteria and fungi. The radiocarbon imprint of old carbon on ecosystem carbon losses will help determine whether significant changes in ecosystem carbon cycling are occurring in response to permafrost thawing.

Radiocarbon: Measurements All radiocarbon measurements were made using a similar processing methodology that differed slightly depending on the original form of the carbon (CO_2 , DIC, DOC). Briefly, dark chambers were placed over the soil and air was drawn through a molecular sieve that quantitatively traps ecosystem-respired CO_2 until ~ 1.0 mg of $\text{CO}_2\text{-C}$ was adsorbed. Gas wells installed in the soil were used to trap soil air at different depths in the soil profile in the same manner. For water samples, DIC was collected by bubbling water samples with a CO_2 -free air headspace, while trapping evolved CO_2 on a molecular sieve. In the laboratory, the molecular sieve traps were heated to 625°C , which desorbs CO_2 for radiocarbon analysis. Radiocarbon content of DOC was measured on water samples that were filtered and acidified in the field, then freeze-dried and combusted in the laboratory. Carbon dioxide from the molecular sieves and the DOC was purified, graphitized, and analyzed for ^{14}C content.

Results

Ecosystem carbon loss is primarily generated by plant and microbial respiration (CO_2 , DIC), and by direct leaching of DOC. Respiration from each source has a particular radiocarbon value depending on the residence time (or age) of carbon in the ecosystem (Figure 2b). Carbon respired by plants has a radiocarbon value largely similar to, or sometimes slightly higher than, the contemporary atmosphere (Schuur and Trumbore 2006). The radiocarbon value of heterotrophic respiration is more complex. Recent plant detritus (leaves, roots, stems, etc.) has higher radiocarbon values because the bomb pulse labeled growing plant parts over the past 40 years. Microbial decomposition of these substrates will release carbon with radiocarbon values elevated relative to the atmosphere. The only material with radiocarbon values below the current atmosphere is carbon present in the ecosystem long enough for radioactive decay. This so-called ‘old’ carbon can be as little as 50 years old (pre bomb), up to 10,000 years old, or even older.

Radiocarbon measurements of carbon losses from the

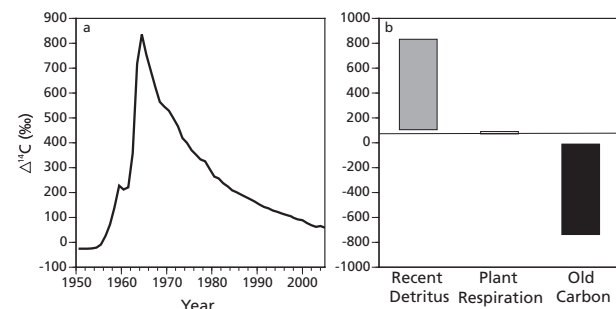


Figure 2. (a) Atmospheric content of radiocarbon in carbon dioxide during the bomb period. Radiocarbon ($\Delta^{14}\text{C}$) is expressed in units of permil (‰) compared to a pre-bomb material that is defined as having a value of zero. (b) Generalized values for possible respiration sources. The atmospheric value of $+63\text{‰}$ for the year 2004 is depicted by the line on the graphs. Because radiocarbon in the atmosphere is currently declining, plant respiration is very close or slightly above current atmospheric values whereas detritus fixed over the past 50 years is enriched in radiocarbon up to $+900\text{‰}$. Old soil C (>60 years) is the only source of C that could bring total ecosystem respiration below the atmospheric value.

Eight Mile Lake watershed reflect a mixture of these three component sources (plant, recent detritus, old C) that change in their relative proportion. Radiocarbon values of ecosystem respired CO_2 ranged from +30 to +60‰ and were at or below atmospheric value (Figure 3a). These values were generally lower than DIC values that ranged from +50 to +105‰, generally above the atmospheric value (Figure 3b). Subsequent measurements of ecosystem respiration at other time points (data not shown) did show radiocarbon values above atmospheric, revealing that temporal variation can be important. Radiocarbon measurements of DOC from two locations in the watershed showed both the temporal and the spatial trends (Figure 3c). Almost all measurements of DOC were below the atmospheric value, with the lowest values occurring in the early season and generally increasing by about 30‰ throughout the growing season. Water collected directly from thermokarst runoff was typically about 40‰ more depleted in radiocarbon throughout the growing season compared to the main stream.

Discussion

In most ecosystems, the proportional contribution of plant carbon typically comprises ~30-70% of CO_2 loss

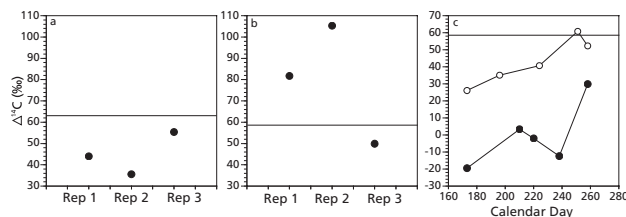


Figure 3. (a) Terrestrial ecosystem respiration from replicate chambers relative to the atmospheric value in July 2004 (solid line). (b) Dissolved inorganic carbon from three locations at the main stream that enters Eight Mile Lake relative to the atmospheric value in July 2005 (solid line). (c) Dissolved organic carbon at two locations in the watershed in 2005: the main stream (open circles) and a smaller surface runoff stream that directly drains the thermokarst area (closed circles). Note that the scale is different for the last graph, and the atmospheric value differs in 2004 and 2005.

to the atmosphere, heterotrophic decomposition of recent litter comprises the majority of the remainder, with old carbon typically contributing perhaps <10%. Our measurements demonstrate that a significant amount of ecosystem respiration is derived from old C, enough to isotopically offset the contribution of carbon from plants and detritus to bring the bulk respiration radiocarbon below the atmospheric value. It is especially noteworthy since all other ecosystems where respiration radiocarbon has been measured, including a range of boreal, temperate, and tropical forests, and Mediterranean grasslands, have respiration values above atmospheric values because the contribution from old carbon is generally small relative to recent detritus and plant respiration (Trumbore *et al.* 2000). Our data are compelling evidence that high latitude ecosystems may be already be undergoing significant losses of old C. The radiocarbon of DOC confirmed this trend. Water draining directly from thermokarst areas contained more old carbon than the main stream, suggesting that permafrost thawing was releasing old carbon into the aquatic ecosystem. We did not detect a large contribution of old carbon as DIC, which suggests that the DOC may be stable. However, our measurements were too limited at this point to make this last conclusion with any certainty.

Management Implications

Changes in ecosystem carbon cycling and storage have the potential to be an important indication of overall ecosystem functioning. However, detecting these changes over time is often difficult due to high temporal variability in carbon cycling processes and the difficulty of measuring proportionally small changes in carbon stocks. Radiocarbon measurements may prove to be an important integrative tool for detecting these changes. Because radiocarbon changes as a function of age of carbon in the ecosystem, it is useful for detecting the contribution of old carbon that has previously been frozen in permafrost and isolated from the modern carbon cycle. The best application of radiocarbon might be as a monitoring tool where measurements of ecosystem carbon losses could be made through time at

observation locations. The impact of thawing permafrost on carbon cycling should be reflected in these loss pathways appearing more depleted in radiocarbon as inputs of old carbon increase. These data could be monitored for trends through time and in relation to climatic fluctuations to detect significant change.

References

- ACIA. 2004.**
Impacts of a warming climate: Arctic climate impact assessment. Cambridge University Press. Cambridge, United Kingdom.
- Gorham, E. 1991.**
Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications 1:182-195.
- Harden, J.W., E.T. Sundquist, R.F. Stallard, and R.K. Marks. 1992.**
Dynamics of soil carbon during deglaciation of the Laurentide Ice sheet. Science 258:1921-1924.
- IPCC. 2001.**
Climate Change 2001: The Scientific Basis. Contributions of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York, NY.
- Levin, I. and V. Heshaimer. 2000.**
Radiocarbon—A unique tracer of global carbon cycle dynamics. Radiocarbon 42:69-80.
- Osterkamp, T.E., and V.E. Romanovsky. 1999.**
Evidence for warming and thawing of discontinuous permafrost in Alaska. Permafrost and Periglacial Processes 10:17-37.
- Schuur, E.A.G., K.G. Crummer, J.G. Vogel, and M.C. Mack. 2007.**
Plant species composition and aboveground net primary productivity following permafrost thawing in Alaskan tundra. Ecosystems DOI: 10.1007/s10021-007-9024-0
- Trumbore, S.E. 2000.**
Age of soil organic matter and soil respiration: Radiocarbon constraints on belowground C dynamics. Ecological Applications 10:399-411.

A Baseline Study of Permafrost in the Toklat Basin, Denali National Park and Preserve

by Larissa C. Yocum, Guy W. Adema, Chad K. Hults

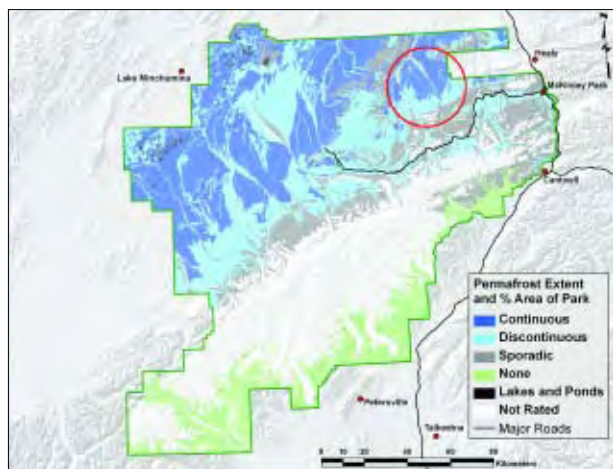


Figure 1. Permafrost extent of Denali National Park and Preserve. Toklat Basin study area is circled in red.

Abstract

The Toklat Basin is a remote and intact ecosystem in northeastern Denali National Park and Preserve (Denali). Until recently, natural and physical resource baseline data of the basin were sparse. We conducted a reconnaissance survey of surficial geology, permafrost, and permafrost-related features over two field seasons and found the Toklat Basin to be a permafrost-rich environment with many geomorphic features indicative of thawing permafrost.

Introduction

In 2003, the National Park Service (NPS) began baseline studies of a remote region of Denali known as the Toklat Basin (*Figure 1*). The basin, an area of approximately 160,000 acres (64,750 hectares), is an intact ecosystem in the northeastern part of the park. Before these studies, most of the natural and physical resources of the Toklat Basin had never been inventoried. Components of the project included surveys of vegetation, large and small mammals, fish, and avian populations. Also included was a surficial geology and permafrost component.

The Toklat Basin is a large alluvial plain underlain by continuous and discontinuous permafrost. Permafrost is the dominant geomorphic process in the basin and is defined as soil or rock that remains at or below 32° F (0° C) for at least two consecutive years. The presence of permafrost in the Toklat Basin was known prior to this study, but information on the extent of permafrost, its status, and related features was minimal. Our reconnaissance survey was conducted over two field seasons beginning in 2003.

Methods

We selected field sites in the Toklat Basin based on analyzing a variety of maps and remote sensing imagery. This included 1:60,000 color infrared photographs from the Alaska High Altitude Aerial Photography program, 1:6,000 low altitude aerial photographs of the Stampede Trail corridor (which bisects the basin), Landsat ETM+, SPOT, and IKONOS satellite imagery, and various U.S. Geological Survey topographic and geologic maps. We also referenced

newly available soils data generated by a joint NPS - Natural Resources Conservation Service six-year soils survey of Denali (*Clark and Duffy 2004*). One of the many geospatial products generated from this survey was a permafrost map of the entire park (*Figure 1*). Once in the field, aerial reconnaissance provided for observation of previously unknown permafrost features. Field investigations at 75 sites around the Toklat Basin included soil pit analysis, geomorphology description, and depth to frozen ground measurements (*Figure 2*).

A depth to frozen ground (DTFG) survey helped to understand how the depth of permafrost below the ground surface varied across the Toklat Basin landscape. This helicopter-assisted systematic survey involved flying to 92 points covering about 150 square miles (388 km²). Each point was approximately 1.4 miles (2.3 km) apart along a northwest-southeast transect and 2 miles (3.2 km) apart on an east-west transect. We took three measurements with a metal rod at each point which were spaced 6.5 feet (2 m) apart and then averaged the results. Most measurements were taken after June 23 and before August 31 when the active layer, that seasonally freezes and thaws, has typically thawed.

Results

We observed that the Toklat Basin is a permafrost-rich environment with many characteristic features of patterned ground in arctic and subarctic areas. These include ice-wedge polygons, thermokarst depressions and ponds, solifluction lobes, beaded streams, palsas, drunken forests, nonsorted stripes and nonsorted circles.

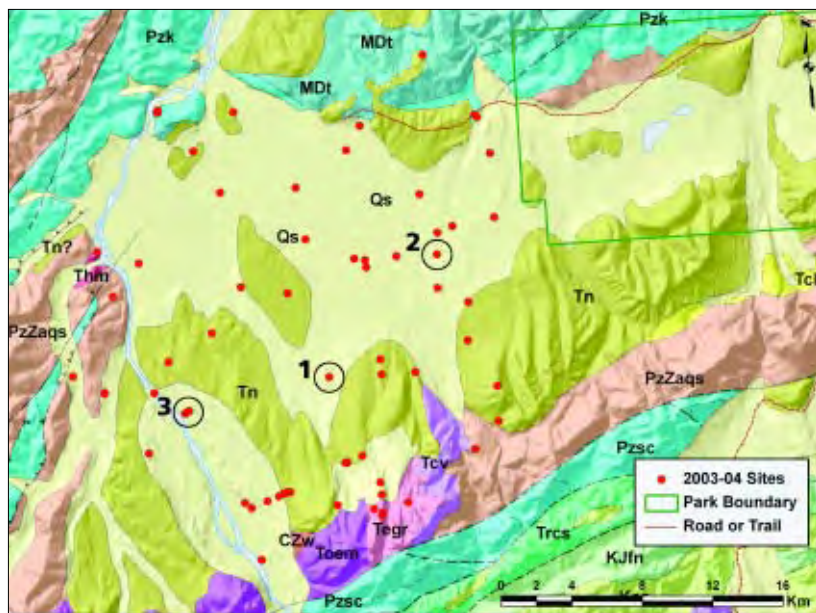


Figure 2. Geologic map of study area (Wilson et al. 1998) showing locations of field investigation sites. Quaternary sediments (Qs – light tan in color) and Nenana gravel (Tn – tan in color) are the two dominant geologic units of the Toklat Basin. Sites labeled 1, 2, and 3 refer to thermokarsts depicted in Figure 6.

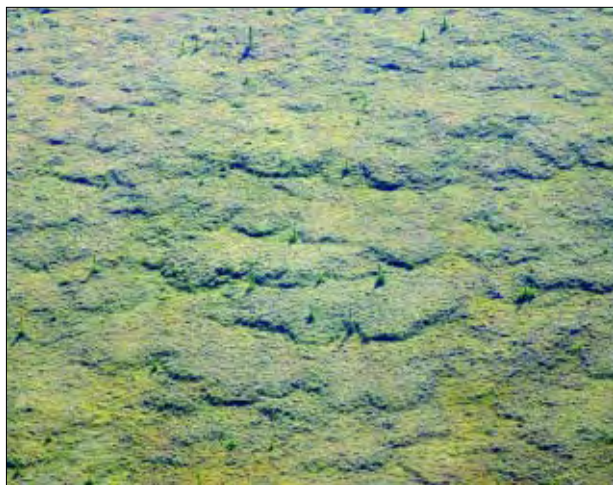


Figure 3. Solifluction lobes, caused by the slow downslope movement of unfrozen, saturated soil over a more stable substrate, are typical of north-facing slopes.

Solifluction lobes are caused by the slow downslope movement of unfrozen, saturated soil over a more stable substrate (such as frozen ground) and are typical of north-facing slopes in the Toklat Basin (Figure 3). *Beaded streams* are streams that link pools or small lakes. They are characteristic of permafrost areas that are underlain by ice wedges. The “beads” form at the junction of thawing ice-wedge polygons. *Palsas* are ice-cored, peat-covered mounds and are common in boggy areas of the basin (Figure 4). A *drunken forest* describes trees that lean at odd angles due to movement or collapse of saturated soil. *Nonsorted circles* (sometimes called mud or frost boils) and *nonsorted stripes* form



Figure 4. Palsas, ice-cored, peat-covered mounds, are common in boggy areas.

“Hook’s Hole” was the only thermokarst we observed in a forested area in the Toklat Basin. It was also unique because it was the only large thermokarst that we found located in a previously glaciated area.

due to frost sorting and frost heave. Nonsorted circles and stripes are more common in the southern part of the basin where terrain gradients are higher and rockier.

Ice-wedge polygons refer to the polygonal array of ice wedges that form as a result of repeated annual contraction of the ground in winter and subsequent freezing of water in the fissures or cracks created by contraction (Figure 5). Over time, a nascent ice-filled crack grows into an ice wedge, thicker at the top than at the bottom. *Thermokarst* refers to the ground subsidence and depressions that typically occur when ice-wedge polygons melt and frozen ground thaws (Figure 6).

Standing water due to impenetrable, frozen ground was very common in the Toklat Basin, particularly in the northern half. This is due to the dominance of Quaternary sediments—which, in the basin, consist of fine-grained clays and silts that retain moisture and result in poorly-drained soils (Figure 2). Nenana gravel comprises much of the southern half of the basin and is better drained, due to the coarser-grained sands, pebbles, and cobbles that are characteristic of this geologic unit.

We found numerous thermokarst depressions throughout the Toklat Basin. Figures 6a and b show the “Wigand Creek” thermokarst, one of the largest thermokarsts we observed in the southern part of the Toklat Basin. The distinctive polygonal pattern of ground collapse is due to ice-wedge polygons that have melted over time. There has been significant ground collapse that has occurred at this site and curtains of tundra hang down from the normal ground surface covering exposed, intact ice wedges. Stream capture from nearby Wigand Creek could be con-



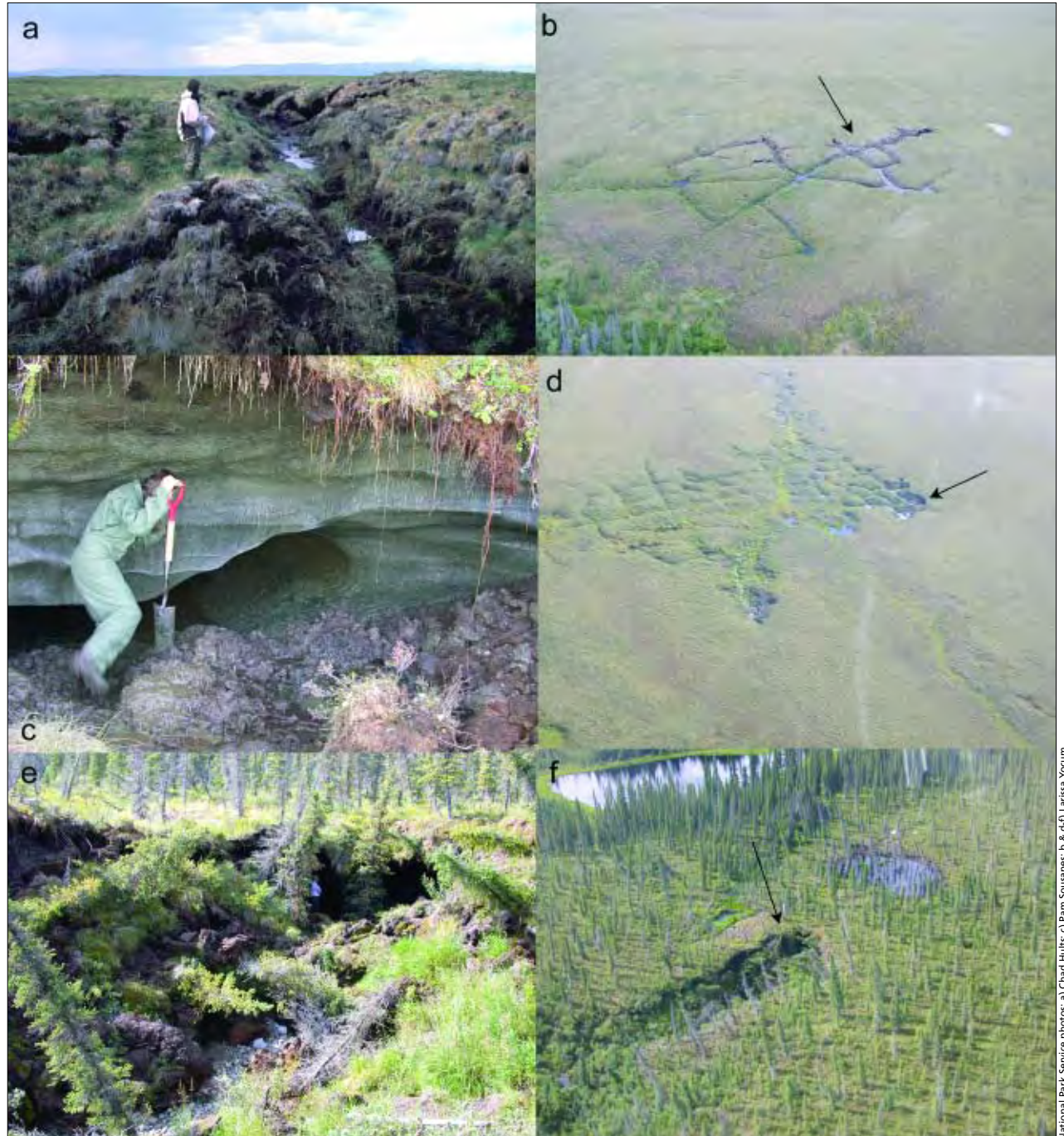
National Park Service photo by Chad Hults

Figure 5. Aerial view of ice-wedge polygons in the Toklat Basin. Over one-third of the Toklat Basin displays visible ice-wedge polygons.

tributing to its growth.

The “Boundary” thermokarst exhibits numerous mounds that have formed from melted ice wedges and subsequent ground collapse (*Figure 6c-d*). Exposed ice wedges are apparent at the western edge of the thermokarst, including a 25-ft wide (7.6 m) ice wedge exposure. Formerly frozen Quaternary sediments that were once above the level of the ice wedge are now thawed and have collapsed 10 feet (3 m) below normal ground surface. We observed fine-grained Quaternary sediments above and at the sides of the ice wedge, while Nenana gravel was exposed below the ice wedge. The “Wigand Creek” thermokarst exhibited the same strata.

Figure 6. (Right) Three of many thermokarsts identified in the Toklat Basin: (a-b) Wigand Creek Thermokarst, (c-d) Boundary Thermokarst, and (e-f) Hook’s Hole (Labeled 1, 2, and 3, respectively, in Figure 2.) Arrows in aerial photographs point to locations of ground photographs.



National Park Service photos: a) Chad Hults; c) Pam Sousane; b & d-f) Larissa Yocum

“Hook’s Hole” consists of a cave-like space underneath the ground surface with exposed massive ice rising over 13 feet (4 m) in height (Figure 6e-f). A thaw pond, containing dead trees standing at odd angles, was present on the normal ground surface about 30 feet (10 m) from the entrance to “Hook’s Hole”. A peat sample obtained from near the ice margins produced a radiocarbon age of approximately 12,000 years before present. “Hook’s Hole” was the only thermokarst we observed in a forested area in the Toklat Basin. It was also unique because it was the only large thermokarst that we found located in a previously glaciated area.

We combined all depth to frozen ground data available (75 field sites, 92 DTFG survey points, and 150 DTFG measurements from vegetation grid studies) to generate a contour map of DTFG in the Toklat Basin (Figures 7-8). We used natural neighbor interpolation (NNI) to create this preliminary map. NNI takes areas that contain data and approximates the value of nearby areas that contain no data. By using this method, we were able to approximate values of areas with no DTFG data and create a representation of depth to frozen ground in the Toklat Basin. Since we needed to take into account the two major rivers that

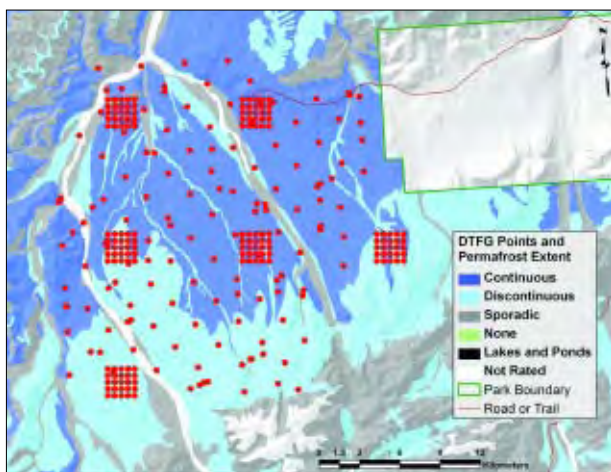


Figure 7. All physical science survey and vegetation grid points in the Toklat Basin that contain DTFG data.

bisect the basin, DTFG data were manually generated and digitized for the Toklat and the East Fork of the Toklat Rivers. The data were assigned as areas containing no permafrost then added to the other 317 DTFG measurements before generating the DTFG contour map. As a result, the rivers are shown as north-south trending linear red areas (Figure 8) representing very deep permafrost or a permafrost-free zone.

Discussion and Conclusions

The Toklat Basin in Denali provides an excellent opportunity to study permafrost processes and patterned ground in subarctic Alaska. The lack of continuous forest cover in the basin allows permafrost features to be easily visible and, therefore, easily monitored over time. Permafrost-dominated landscapes further west in the park are mostly forested making it much more difficult to study patterned ground from the air.

In our studies, we found permafrost to be a dominant geomorphic process in the Toklat Basin due to a variety of factors. These include fine-grained soils that are poorly drained, a predominant low-grade, north-facing aspect, a thick, insulative vegetation cover, low snow and high

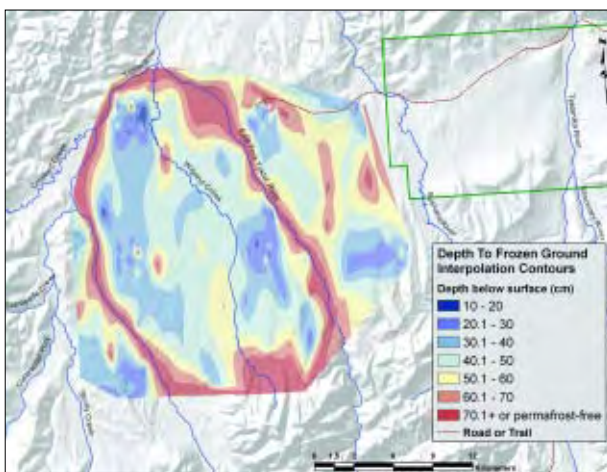


Figure 8. All DTFG data were combined to generate a preliminary DTFG contour map of the Toklat Basin.

The Toklat Basin in Denali provides an excellent opportunity to study permafrost processes and patterned ground in subarctic Alaska. The lack of continuous forest cover in the basin allows permafrost features to be easily visible and, therefore, easily monitored over time.

winds that reduce snow cover allowing cold temperatures to penetrate the ground more deeply, and a low mean annual air temperature.

Management Implications

Numerous thermokarsts and thawing ice-wedge polygons demonstrate that the Toklat Basin is a fragile permafrost environment, vulnerable to the warming effects of climate change and to human activities that destroy overlying ground cover. Knowledge of the role of permafrost in the Toklat Basin will allow for a more complete understanding of the ecosystem, and more informed, science-based management.

Acknowledgements

The authors would like to thank Jon Paynter for GIS and technical support, Carl Roland and James Walton for providing Central Alaska Network vegetation grid data, and G. Matt Hook for field assistance, finding Hook’s Hole, and for flying us to every corner of the Toklat Basin.

References

- Clark, M.H., and M. S. Duffy. 2004. *Soil Survey of Denali National Park Area, Alaska*. USDA–Natural Resources Conservation Service.
- Wilson, F.H., J.H. Dover, D.C. Bradley, F.R. Weber, T.K. Bundtzen, and P.J. Haeussler. 1998. *Geologic Map of Central (Interior) Alaska*. U.S. Geological Survey Open-File Report 98-133.

Dinosauria and Fossil Aves Footprints from the Lower Cantwell Formation (latest Cretaceous), Denali National Park and Preserve

by Anthony R. Fiorillo, Paul J. McCarthy, Brent H. Breithaupt, and Phil F. Brease

Abstract

The Cantwell Formation (Late Cretaceous to Early Tertiary) is a thick rock unit that crops out in much of the central part of Denali National Park and Preserve (Denali). The lower part of this succession is dominantly comprised of fine-grained channel and floodplain sedimentary facies, including crevasse splay, crevasse delta, levee, and minor lacustrine and palustrine components. Floodplain deposits contain abundant evidence of weak pedogenesis, including root traces, blocky structure, iron oxide mottles and nodules, suggesting widespread poorly drained conditions in a highly aggradational setting. The upper Cantwell succession is largely volcanic. The lower Cantwell Formation correlates in age with the famous dinosaur-bearing rocks of the Prince Creek Formation of the North Slope of Alaska, as well as the dinosaur-bearing Chignik Formation of Aniakchak National Park in southwestern Alaska.

Several new Mesozoic-aged vertebrate fossil sites have been discovered in Denali. These sites are located in the Igloo Creek/Tattler Creek area and the northern side of Double Mountain. Some sites contain individual tracks while other localities contain hundreds of tracks. The most frequent footprint type found among all sites is the track of a medium-sized theropod. The tracks attributable to this animal measure 8-10 inches (20-25 cm) in length. Additional theropod tracks range from small tracks (4-5.5 in/10-14 cm in length) to very large tracks (over 20 in/50 cm in length). In addition to the more common theropod tracks, there are two sites that contain tracks attributable to hadrosaurs.

An exceptional site contains several hundred tracks attributable to a medium-sized wading bird. The morphology of the tracks indicates the substrate was still very wet when these birds walked on the surface. Nearly circular depressions attributable to probe-style feeding by these ancient shorebirds are also preserved at this site. These footprints demonstrate that the Cantwell Formation has great potential as a fossil vertebrate-bearing rock unit. Further, the assembling of Beringia through accretion began in the Cretaceous and these discoveries highlight the biological diversity of Beringia.

Introduction

A paleontological investigation of the Cantwell Formation (Late Cretaceous to Early Tertiary) in Denali National Park and Preserve has been initiated by the National Park Service. This thick rock unit crops out in much of the central part of Denali and is particularly

visible along much of the eastern length of the park road. Here we summarize the preliminary paleontological and sedimentological results of this survey and briefly describe the first records of Mesozoic-aged fossil vertebrates from this rock unit.

Geologic Background

The Cantwell Formation is thousands of meters thick and is comprised of an upper, dominantly volcanic unit and a lower, dominantly fluvial sedimentary unit (*Kirschner 1994, Ridgway et al. 1997*). Pollen analysis for the lower Cantwell Formation shows that these sedimentary rocks were deposited during the late Cretaceous (late Campanian or early Maastrichtian) (*Ridgway et al. 1997*). Sedimentation was dominated by alluvial fan, braided stream and lacustrine settings (*Ridgway et al. 1997*). Given that the southern margin of Alaska was near its current latitude during the Cretaceous (*Hillhouse and Coe 1994*), the basin in which the Cantwell Formation was deposited was near its present latitude at the time of deposition as well.

The lower part of the Cantwell Formation is dominantly comprised of fine-grained channel and floodplain sedimentary facies. Floodplain deposits contain abundant evidence of weakly developed fossil soils (paleosols), including root traces, blocky structures, iron oxide mottles and nodules, suggesting widespread poorly drained conditions in a highly aggradational setting. Periodic larger floods deposited thin beds of coarse-grained conglomerate onto these fine-grained floodplains (*Ridgway et al. 1997*). The lower Cantwell Formation correlates in age with the well known dinosaur-bearing rocks of the Prince Creek



Photo by Anthony R. Fiorillo

Figure 1. Right pes, or hind foot, impression of a medium sized theropod track from outcrop of the lower Cantwell Formation along Igloo Creek, Denali National Park.

Formation of the North Slope of Alaska, as well as the dinosaur-bearing Chignik Formation of Aniakchak National Park in southwestern Alaska.

There are two areas of interest in this report, the Tattler Creek/Igloo Creek area and the northern flank of Double Mountain. The Cantwell Formation in the Igloo Creek/Tattler Creek area can be characterized as consisting largely of sandstones and siltstones. There is a coarsening upward trend in this area that is likely evidence of a major river channel moving closer to the site. In addition there is evidence of regular sedimentation on floodplains punctu-

ated by hiatuses with brief periods of soil formation. The Cantwell Formation along the northern flanks of Double Mountain has a thick sequence of finer grained sediments than those found in the Igloo Creek/Tattler Creek area. Ridgway et al. (1997) attribute these finer grained rocks to a marine influenced coastal lowland environment.

Footprint Discussion

As part of an ongoing paleontological survey of the Cantwell Formation, several Mesozoic aged vertebrate fossil sites have been discovered in Denali (Fiorillo et al.

2006). Thus far the survey has discovered 20 fossil footprint localities. These sites are located in the Igloo Creek/Tattler Creek area and on the northside of Double Mountain. Some sites contain individual tracks while other localities contain hundreds of tracks. The most frequent footprint type found among all sites is the tracks of a medium-sized theropod (Figure 1). The tracks attributable to this animal measure approximately 8-10 inches (20-25) cm in length. This length provides an estimated hip height of approximately 35 inches (90 cm) and a body length of approximately 10 feet (3 m) (*sensu* Thulborn 1989). Additional theropod tracks range from small tracks (4-5.5 in/10-14 cm in length) to very large tracks (over 20 in/50 cm in length). In addition to the more common theropod tracks, there are two sites that contain tracks attributable to hadrosaurs.

The second area of study, on the north side of Double Mountain, has, in addition to the tracks of the medium-sized theropod, produced hundreds of tracks attributable to medium-sized wading birds, approximately the size of a modern Willet or American Avocet. The morphology of these fossil tracks shows a thin, web-like connection between the toes that starts at the base of the tracks and extends approximately a third to halfway towards the ends of the toes. Whereas it might appear that these features represent webbing between the toes of these Cretaceous birds, these types of marks in modern shorebirds is indicative of a substrate that is relatively deep mud (Elbroch and Marks 2001), hence these Cretaceous birds likely walked on a similar surface. There are also numerous small, nearly circular depressions, approximately 0.12 in (3 mm) in diameter, on the same bedding plane. These features are likely the feeding traces of these shore birds. Bill lengths of modern shorebirds vary in order to exploit various depths in the mud and sand for different food items such as worms, bivalves, and crustaceans (Gill 1989), but diet can include items other than invertebrates. The sanderling (*Calidris alba*), for example, consumes seeds, plant buds, algae and mosses in addition to invertebrates (Richards 1988). Though there is evidence of invertebrate

bioturbation in the finely laminated sediments containing these bird tracks at Double Mountain, more precise determination of potential food items for these Cretaceous birds is unavailable at this time.

Summary

Denali National Park and Preserve is an exciting, rich, new area for dinosaur studies. The Cantwell Formation within the park contains the first record of dinosaurs in the Alaska Range. This record consists of tracks of small, medium, large, and very large-sized theropods, as well as hadrosaurs. In addition, the Cantwell Formation contains the first record of fossil Aves. Further, this occurrence of fossil birds records feeding behavior in these presumed ancient shorebirds. Combined this new suite of Mesozoic fossil vertebrate sites add to the understanding of biodiversity in Alaska during the Cretaceous at the beginning of the land bridge referred to as Beringia (Hopkins 1967, Fiorillo *in press*) because the Cantwell Formation correlates with other rock units in Alaska that produce dinosaur remains such as the Prince Creek Formation of northern Alaska (Parrish *et al.* 1987; Fiorillo and Gangloff 2000, 2001; Gangloff *et al.* 2005) and the Chignik Formation of southwestern Alaska (Fiorillo and Parrish 2004). Thus, further work will provide the opportunity for a more detailed regional paleoecological and paleoenvironmental understanding of an ancient high latitude terrestrial ecosystem on a greenhouse Earth.

Acknowledgements

Foremost, we thank the NPS Alaska System Support Office and Denali National Park and Preserve for their logistical support for this project. In particular, we thank Russell Kucinski and Linda Stromquist. We also gratefully acknowledge the support of the Museum of Nature and Science (formerly the Dallas Museum of Natural History), American Airlines, and Whole Earth Provision Company, for support in the field.

References

- Elbroch, M., and E. Marks. 2001.
Bird Tracks and Sign.
Stackpole Books. Mechanicsburg.
- Fiorillo, A.R. *in press*.
Cretaceous dinosaurs of Alaska: Implications for the origins of Beringia. In *The Terrane Puzzle: new perspectives on paleontology and stratigraphy from the North American Cordillera* edited by R.B. Blodgett and G. Stanley. Geological Society of America. Special Paper. Boulder, Colorado.
- Fiorillo, A.R., B. Breithaupt, and P.J. McCarthy. 2006.
Dinosauria and Aves fossil footprints from the lower Cantwell Formation (Upper Cretaceous), Denali National Park, Alaska.
Journal of Vertebrate Paleontology, Supplement 65:61A.
- Fiorillo, A.R., and R.A. Gangloff. 2000.
Theropod teeth from the Prince Creek Formation (Cretaceous) of northern Alaska, with speculations on arctic dinosaur paleoecology.
Journal of Vertebrate Paleontology 20:675-682.
- Fiorillo, A.R., and R.A. Gangloff. 2001.
The caribou migration model for Arctic hadrosaurs (Ornithischia: Dinosauria): a reassessment.
Historical Biology 15:323-334.
- Fiorillo, A.R., and J.T. Parrish. 2004.
The first record of a Cretaceous dinosaur from western Alaska.
Cretaceous Research 25:453-458.
- Gangloff, R.A., A.R. Fiorillo, and D.W. Norton. 2005.
The first pachycephalosaurine (Dinosauria) from the paleo-arctic of Alaska and its paleogeographic implications.
Journal of Paleontology 79:997-1001.
- Gill, F.B. 1989.
Ornithology.
W.H. Freeman. New York.
- Hillhouse, J.W., and R.S. Coe. 1994.
Paleomagnetic data from Alaska.
In *Geology of Alaska, The Geology of North America*, v. G-1, edited by G. Plafker and H.C. Berg. Geological Society of America. Boulder, Colorado. Pp. 797-812.
- Hopkins, D.M. (ed.). 1967.
The Bering Land Bridge.
Stanford. Stanford University Press. P. 495.
- Kirschner, C.E. 1994.
Interior basins of Alaska. In *Geology of Alaska, The Geology of North America*, v. G-1, edited by G. Plafker and H.C. Berg. Geological Society of America. Boulder, Colorado. Pp. 469-493.
- Parrish, M.J., J.T. Parrish, J.H. Hutchinson, and R.A. Spicer. 1987.
Late Cretaceous vertebrate fossils from the North Slope of Alaska and implications for dinosaur ecology.
Palaos 2:377-389.
- Richards, A. 1988.
Shorebirds: a complete guide to their behavior and migrations.
Gallery Books. New York.
- Ridgway, K.D., J.M. Trop, and A.R. Sweet. 1997.
Thrust-top basin formation along a suture zone, Cantwell basin, Alaska Range: implications for the development of the Denali fault system.
Geological Society of American Bulletin 109:505-523.
- Thulborn, R.A. 1989.
The gaits of dinosaurs. In *Dinosaur Tracks and Traces* edited by D.D. Gillette and M.G. Lockley. Cambridge University Press. Cambridge. Pp. 39-50.

Landscape and Wildlife Ecology





Photo by Tom Walker

Interpreting Denali's Landcover Types with Fabric (Quilt)

by Lucy Tyrrell and Jon Paynter

Abstract

Denali Quilters created a quilt (129 x 130.5 inches, or approximately 3.3 meters square) to interpret Denali National Park and Preserve's landcover types at large and small scales. The central map is a satellite image of 23 landcover types (13,600 colored fabric pixels). Twenty-two blocks surround the map, each depicting a close-up view of selected plants and animals (e.g., nose and curl of horn of Dall sheep among mountain avens and rock) found in a cover type (e.g., Dwarf Shrub-Rock). The machine quilting outlines the park's boundary, highlights drainages and topographic lines, and depicts animal tracks. The quilt combines art and science.

In this close up view of part of the quilt, the fabric pixels and the stitches (quilting) that hold the layers of the quilt together are visible. One pixel measures 3/4 inch (2 cm). Curving lines quilted in brown thread show the rugged topography in the "Snow and Ice" (sparkling white pixels) and "Bare Ground" (mottled tan pixels) of the Alaska Range. Rivers, quilted in blue thread, flow from the mountains to the northwest lowlands of "Woodland Spruce" and "Stunted Spruce" (green pixels).

Introduction

Over approximately four years, 2002-2006, Denali Quilters designed and created a quilt to interpret Denali National Park and Preserve's landcover types at large and small scales. The two scales depicted in the quilt are ones not commonly experienced by the average visitor riding a bus into the park: the view from a satellite and the close-up view, as if looking through a macro lens. The finished quilt measures 129 x 130-1/2 inches (~3.3 x 3.3 m) (*Figure 1*).

Methods

The basis for the central portion of the quilt is a composite map of several satellite images covering the park's six million acres, in which 23 landcover types have been classified (*Stevens et al. 2001*) (*Figure 2*). The map includes a 10-mile buffer around the park boundary.

To select pixel size, using the park GIS (Geographic Information System), we enlarged the pixel size of the raster landcover map to a size large enough to be practical to sew using fabric, yet not lose the definition of some landscape features (e.g., the Alaska Range). The total number of pixels was also an important consideration. We experimented with 3/4-, 1-, 1-1/2-, and 2-inch (2-, 2.5-, 4-, and 5-cm) pixels which would have meant a total of 13,600, 11,235, 4,970, or 2,756 squares of fabric, i.e., the fabric pixels, respectively (*Figure 3*). The size of the quilt map was set to be about eight feet (2.4 meters) on a side.

"Cloud" pixels (where the landcover was obscured by clouds) were included in the original landcover mapping project, but were eliminated for the quilt map. We changed each of the 18 cloud pixels to the predominant landcover type in the immediate vicinity.



Figure 1. Denali Landcover Quilt.

Cotton fabrics were carefully selected to match the colors that researchers had used when previously classifying the composite satellite image into landcover types. However, we substituted black for brown for the “burn” landcover type so someone with red-green color blindness could easily discriminate burn pixels from those of the other landcover types. Print fabrics were chosen to add interest; however, only fabrics with a small print design were used, so all pixels cut from one fabric would look similar.

As an aid to converting the paper map to the fabric map, we printed a paper map with a grid overlay marking every ten pixels both horizontally and vertically. Columns were labeled A-M, and Rows 1-13. We marked each 100-pixel subunit with its identifying column and row (e.g., A6, D10) and then cut along the grid lines. Denali Quilters tallied for each of the 136 map subunits how many fabric pixels of each color were needed. Denali Quilters packaged fabric pixels for each subunit into Ziploc bags, along with the paper subunit map “pattern” to show pixel arrangement. During these steps, the quilt became informally known as the “Pixel Project”.

To facilitate sewing of subunits, quilters arranged the fabric pixels (100) to match the subunit map, and then sewed them together by rows. They steamed completed subunits to a uniform size before stitching them together into larger “superunits”. Finally the superunits were assembled as the entire map.

To form the border of 22 blocks around the map, each quilter was randomly assigned a landcover type and created her own block design. The quilt committee provided guidance about block dimensions and condensed information about each landcover type (*Stevens et al. 2001*), along with a list of common plants and animals. The goal was to have blocks show selected aspects of a landcover type—from a close-up, *not* a landscape viewpoint.

Cheryl Schikora, of Chatty Ladies Quilting Studio in Fairbanks, used a 14-foot (4.3-meter) long-arm quilting machine to quilt together the layers (quilt top, batting, and backing) following guidance and illustrations provided by

Denali Quilters. In July 2006, as a completion rite for this challenging project, Denali Quilters gathered around the quilt and many hands stitched the black binding.

Results

We selected a pixel size of 3/4 inch (2 cm) for a total of 13,600 pixels in the map. The map scale is one inch (2.5 cm) on the quilt equals 1.5 miles (~1.8 km) on the ground. The fabrics match colors that park staff selected when previously classifying the composite image into landcover types.

Not only is the fabric map accurate in terms of construction from a satellite image and fabric colors that match those used by the landcover mapping project, the machine quilting also adds accurate map features. The quilting stitches show the park boundary and Park Road (black thread), major river drainages and lakes (blue), and topographic lines at a contour interval of 2,500 feet (~1,000 m) (brown). The two tallest peaks (Foraker and McKinley) are each indicated with a summit symbol. Because two of the major large mammals (wolf and caribou) had not been included

in the border blocks, tracks of these two species were subtly quilted using a trapunto technique (stitches make the tracks slightly three-dimensional) in the white background surrounding the map (Figure 6). As with any map, the quilt map includes a landcover legend (key), map scale, and compass rose.

Twenty-two blocks surround the map, each depicting a close-up view of selected plants and animals (e.g., nose and curl of horn of Dall sheep (*Ovis dalli dalli*) among mountain aven (*Dryas* spp) and rock) found in a landcover type (e.g., Dwarf Shrub-Rock) (Figure 4). As much as possible, the border blocks were arranged around the map to reflect the elevation and geography of the landcover types. Lowland boreal types are located at the bottom of the map, while sub-alpine shrub and tundra cover types were arranged in the side borders,

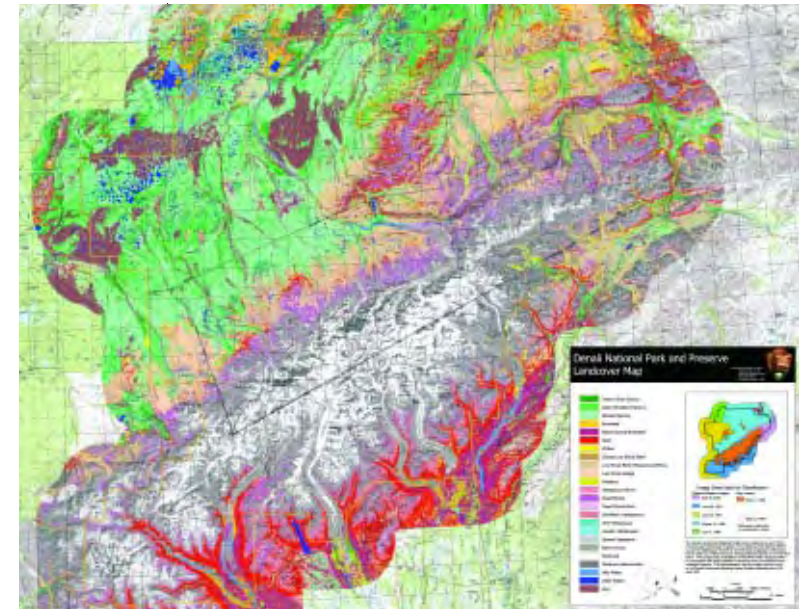


Figure 2. This landcover type map of Denali National Park and Preserve (Stevens et al. 2001) was the basis of the landcover quilt.

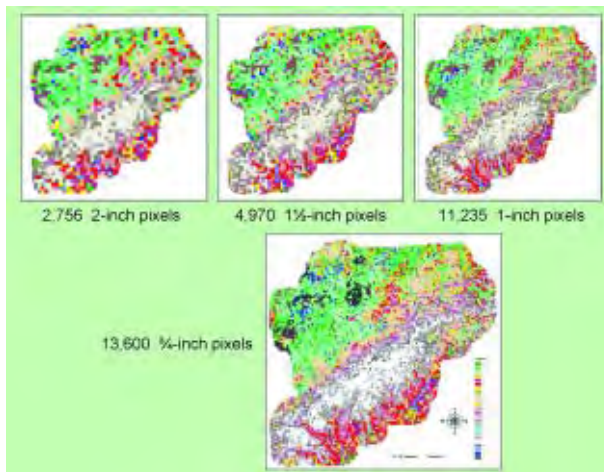


Figure 3. Geographic Information Systems (GIS) software was used to change the pixel size and pixel number of the landcover map, in order to create several options for the map part of the quilt.



Figure 4. This border block (left) illustrates "Dwarf Shrub - Rock". Quilters were instructed to create a close up view of each landcover type (here mountain avenes and the nose of a Dall sheep are visible) rather than a landscape view (e.g., the scene of two Dall sheep on the rocky alpine slopes typical of the Dwarf Shrub - Rock cover type as in the foreground of the photo at right).



Figure 5. "Burn" landcover type. Two blackened spruce trees stand after a wildfire has swept to the horizon and only a few lingering flames persist (upper panel). After a few years, the charred trees have lost limbs but are surrounded by colors of fireweed and bluebells (lower panel).

and high elevation alpine types in the upper row. The blocks on the left side of the map tend to be landcover types that occur only south of the Alaska Range and those on the right side of the map tend to be types that are primarily north of the Alaska Range.

Denali Quilters depicted physical features (ice, rock, braided streams) as well as biological features (trees, shrubs, flowering plants, lichens, fungi, mammals, and birds) present in landcover types. Recognizable by species in the blocks are ten mammals, eight birds, four trees, and 24 other plants. Not surprisingly, several common plants and animals were portrayed in more than one block. Thus the quilt reflects the ecological reality that many species including blueberry, dwarf and shrub birch, mountain avens, cotton grass sedge, white-crowned sparrow, red-backed vole, moose, and bear occur in more than one landcover type.

Denali Quilters invested approximately 1,000 person-hours to plan and create the quilt top, prepare the backing, and whipstitch the binding. Approximately 100 additional hours were spent quilting the layers together and creating the sleeve for hanging the quilt.

Discussion and Conclusions

The Denali Landcover Quilt is a lesson in contrasts—it shows large and small scales; it showcases high-tech GIS and low-tech hand sewing; it melds the tradition of making quilts to share stories and a new-fangled 14-foot (4.3-meter) long-arm quilting machine; and it renders an artistic expression of science, yet demands scientific accuracy in its portrayal of Denali landcover types.

Denali Quilters has decided to loan the quilt where it can be displayed on a long-term basis to foster learning about quilting, maps and scale, GIS technology, satellite imagery, landcover types, vegetation, wildlife habitat, and

natural history. In its combination of science and art, the spirit of the Denali Landcover Quilt extends an invitation to viewers to take a closer look at Denali and explore both what can be learned from the fabric creation and from stepping into its wild landscapes.

Acknowledgements

Denali Quilters (approximately 40 members) designed, cut, and sewed the quilt top (map and borders), and completed the binding. Cheryl Schikora (Chatty Ladies Quilting Studio of Fairbanks) quilted the layers together.

Lucy Tyrrell conceived the idea for the project while viewing a small wall quilt displayed as part of a poster at the 2004 Ecological Society of America Meeting (Zobel and Zobel 2002). The Zobel quilt depicted an oblique aerial map of the ecosystems of Cascade Head Preserve in Oregon.

We relied heavily on Denali's landcover mapping project (Stevens *et al.* 2001), not only for the GIS map classified by landcover types, but also for photographs and information about

each landcover type. Assistance with lists of common plants and animals for each landcover type was provided by Denali National Park Service staff, including Carol McIntyre, Tom Meier, Pat Owen, and Carl Roland.

References

- Stevens, Jennifer L., Keith Boggs, Ann Garibaldi, Jess Grunblatt, and Todd Helt. 2001. *Denali National Park and Preserve Landcover Mapping Project*. Earth Satellite Corporation. Rockville, MD. Volumes 1 and 2.
- Zobel, Donald, and Priscilla Zobel. 2002. *Cascade Head, Oregon—Interpreting ecological properties and research to the public*. Poster abstract in Abstracts: 87th Annual Meeting of Ecological Society of America, Tucson, Arizona.



Figure 6. Closeup of trapunto technique (raised effect created by surrounding stitches) used to quilt caribou tracks (shown here) and wolf tracks into the white background of the map part of the quilt.

Photo by Tom Walker

Cadmium Mobility and Bioaccumulation by Willow

by Larry P. Gough, Paul J. Lamothe, Richard F. Sanzolone, James G. Crock, Andrea L. Foster

Abstract

Biogeochemical investigations of cadmium (Cd) bioavailability are being conducted in mineralized and non-mineralized areas in order to understand the mechanisms by which willow (*Salix*) bioaccumulates Cd, and ultimately to evaluate the importance of this phenomenon to the health of browsing animals. Within Denali National Park and Preserve (Denali) sites included the historic Mt. Eielson and Kantishna Mining Districts that contain both disturbed and undisturbed mineralized areas. Soils collected included the A, B, and C horizons. Plants collected included diamondleaf and grayleaf willow as well as green alder, feather moss, and soil lichen. Willow growing in soils developed from base metal-rich bedrock bioaccumulated Cd in concentrations 4- to 10-times higher than willow growing in non-mineralized soil. Cd levels in willow were as much as 10-100 times greater than those found in other plants collected from the same area. Mineralized areas are particularly important loci for the natural occurrence of potentially harmful levels of Cd in browse willow.

Introduction

In this study we compared the mobilization and uptake of Cd by willow (*Salix*) and other plant species in a non-mineralized area (Yukon-Tanana Upland, YTU) and a mineralized area (Mt. Eielson/Kantishna, Denali), (Figures 1 and 2). Cd occurs naturally in certain minerals (e.g., sphalerite) and in plants it is a nonessential heavy metal and a powerful enzyme inhibitor. In ruminants, Cd, copper (Cu), and zinc (Zn) are often mutually antagonistic: exposure to Cd lowers Cu status and exposure to Zn lowers Cd status (Underwood and Suttle, 1999; Frank et al., 2000). All three metals induce the production of metallothionein, a group of proteins that bind the metals in animal tissue. Unlike Cu and Zn, Cd has a biological half-life measured in years (thus potentially accumulating over time), showing highest concentrations in kidney tissue. In a study of white-tailed ptarmigan in Colorado, Larison et al. (2000) found that a diet of willow buds, having mean Cd concentrations as low as 2.1 ppm (dry weight basis), resulted in renal tubular damage and increased chick mortality. They proposed that non-anthropogenic Cd poisoning might be more widespread than previously suspected. We hypothesize that Cd bioaccumulation by willow, in areas naturally high in Cd, may be detrimental to the health of moose

(Gough et al., 2002) by being directly toxic (nephropathy; poor bone construction) and/or by inducing Cu deficiency (Frank et al., 2000).



Figure 1. Map of study areas in Alaska. The area within DENA included the Mt. Eielson and Kantishna mining districts.

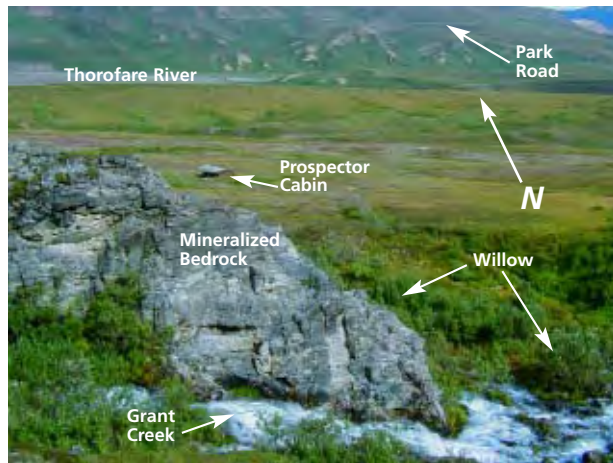


Figure 2. The Mt. Eielson Mining District with Grant Creek and typical mineralized bedrock in the foreground, a historic cabin dating to the days of mineral prospecting in the district in the near background, and the Thorofare River and the park road in the far background.

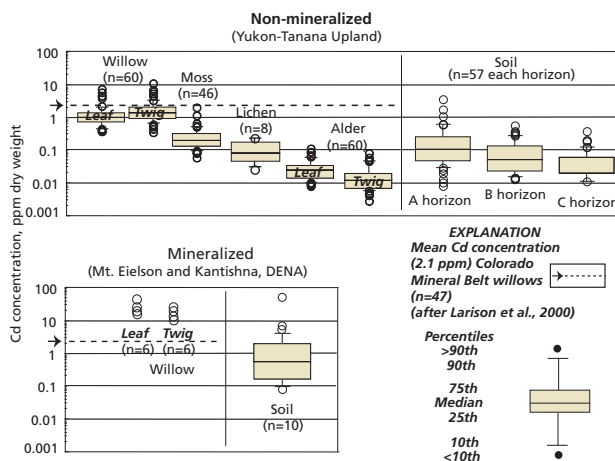


Figure 3. Box plots of the concentration of Cd (plotted on a log scale) in plants and soils from a non-mineralized area (Yukon-Tanana Upland) and from the mineralized Mt. Eielson and Kantishna Mining Districts, Alaska. Arrows indicate mean Cd concentration (2.1 ppm) in willow found to be toxic to ptarmigan in the Colorado Mineral District (Larison et al. 2000).

Methods

Samples of plants, soils, and waters were collected from 57 non-mineralized (in YTU) and six mineralized sites (in Denali) (Figure 1). Sites were in both boreal forest and tundra vegetation zones. Plants collected included the stems and leaves of *Salix planifolia* ssp. *pulchra* (diamondleaf willow) and *S. glauca* (grayleaf willow) as well as green alder (*Alnus crispa*), feather moss (*Hylocomium splendens*), and a soil lichen (*Cetraria islandica*). Soils collected were mainly mature, silty Inceptisols and Gelisols from moderately- to well-drained southerly exposures, and possessed a mixture of residuum and loess.

Chemical analyses were performed in the Denver, Colorado Laboratories of the U.S. Geological Survey (Taggart 2002). Analytical duplicates, blanks, and standard reference materials were analyzed to assess data reliability. Total element concentrations were determined by inductively coupled plasma-mass spectrometry (ICP-MS) following four-acid total dissolution. Powder X-ray diffraction analysis was used to determine soil mineralogy. The speciation of Cd in willow is being investigated using X-ray absorption fine structure (XAFS) spectroscopy (Foster et al. 2004).

The mode of occurrence of Cd in soil was determined by sequential-partial extraction using the methods of Tessier et al. (1979), Chao and Zhou (1983), and Hall et al. (1996). Extractions are identified as follows: Fraction I—1 M magnesium chloride, pH 7.0 (target is water-soluble, adsorbed and exchangeable ions); Fraction II—1 M sodium acetate in acetic acid buffered to pH 5 (target is carbonate mineral phases); Fraction III—0.25 M hydroxylamine hydrochloride in 0.25 N hydrochloric acid (target is amorphous Fe and Mn oxides); Fraction IV—4 N hydrochloric acid in boiling water bath with occasional agitation for 45 minutes (target is crystalline iron (Fe), manganese (Mn), and aluminum (Al) oxides, secondary and mono-sulfides, some hydrolysis of organic matter, and minor attack on edges of silicate minerals); and Fraction V—four-acid (hydrofluoric, hydrochloric, perchloric, and nitric) total dissolution of residue (target is silicates and

other residual minerals).

Surface water at each site (when available) was collected, filtered (<0.45 μ m) and acidified with ultrapure nitric acid. Measurements of pH, conductivity, alkalinity, and temperature were made at each site. Multi-element determinations on water samples were made using ICP-MS.

Results

The bioaccumulation of Cd appeared to be pervasive within the genus *Salix* (willow). Cd concentrations in leaf and stem (twig) material are commonly similar (Figure 3). Cadmium concentrations in leaf can exceed 30–35 times that of soil (Granel et al. 2002). The efficacy of willow to bioaccumulate Cd is due to a number of attributes including high biomass production and high water-use (Gough et al. 1999). However, these features alone are inadequate to explain Cd bioaccumulation because other woody species (e.g., poplar) also have these traits but do not necessarily accumulate Cd. We hypothesize that willow might possess a metal-specific transport molecule that, if not unique to willow, is either concentrated in willow or functions more efficiently in willow. Our work thus far has shown that willow tissue (native and plantation-grown), examined using XAFS, possesses both an “inorganic” (Cd complexed to oxygen or nitrogen) and an “organic” (sulfur-bonded Cd) form (Foster et al. 2004).

Total soil Cd concentrations ranged from about 0.009 to 4.5 ppm (the A, B, and C soil horizons combined) in the non-mineralized area and from 0.09 to 51 ppm in the Mt. Eielson/Kantishna area (for comparison, crustal abundance is approximately 0.1 ppm) (Emsley 1991). In the non-mineralized areas, no difference in total Cd was seen in soils developed over different lithologic (bedrock) units. In mineralized areas, Cd mean concentrations varied by mineralization type with the greatest Cd concentrations at sites containing sphalerite. Cd concentrations decrease with depth at both mineralized and non-mineralized sites, with the means in mineralized areas larger than in non-mineralized areas (Figure 3). At individual non-mineralized sites, this decrease in concentration with depth is consis-

tent, whereas at individual mineralized sites this trend was not so apparent. The decrease in Cd concentration with depth correlates with soil organic matter in non-mineralized soils ($r = 0.61$).

In order to better understand the physical and chemical association of Cd in mineralized soils, a sequence of five extractions were applied to selected samples. The scheme used extractants that increase in the aggressiveness with which they attack soil exchange sites and mineral structure. Such schemes provided insight into the speciation of trace elements in solid phases. The extraction scheme removed an average of 91% of the total soil Cd. Operationally defined speciation could be evaluated by looking at major phase constituents released in each extraction (Figure 4). For example, the second extraction targeting carbonate minerals removed 32% of the total calcium (Ca) in a sample high in calcite and 54% of the total Cd. Cadmium removed by the first three extractions ranges from 55 to 100% (mean 76%) of the total. Figure 4 shows that a greater percentage of the total soil Cd was more available at the surface than at depth in these soils, especially in non-mineralized areas.

The range in concentration of Cd in surface waters, collected from Grant Creek, Mt. Eielson, was 0.06-0.08 $\mu\text{g/L}$ ($n = 4$). In contrast, Cd concentrations in the non-mineralized YTU were all $<0.02 \mu\text{g/L}$ ($n=41$), the analytical detection limit (Bronwen Wang, USGS Alaska Science Center, personal communication). In the mineralized areas, elevated Cd concentrations in water were found at sites having high Cd in soils; however, soils elevated in Cd did not always have detectable Cd in associated waters.

The total median Cd concentration (dry weight basis) in willow ($n=6$) from mineralized areas was 12.5 ppm in leaves and 10.5 ppm in twigs. Willow ($n=60$) from the YTU had median leaf and twig concentrations of about 1.0 ppm and 1.5 ppm, respectively (Figure 3). In contrast, leaf and twig material from another shrub browse species (alder) had a median Cd value of <0.04 ppm. Plantation-grown willow, cultivated under controlled conditions that

Both diamondleaf and grayleaf willow are significant bioaccumulators of Cd in their leaf and twig tissue. Even in non-mineralized areas, willow was found to have 10- to as much as 100-times the concentration of Cd compared to several other plant species, including moss and lichen.

were dosed with 0.18 mM (20 ppm Cd) Cd-nitrate, had similar Cd levels as willows collected in mineralized areas.

Discussion and Management Implications

Both diamondleaf and grayleaf willow are significant bioaccumulators of Cd in their leaf and twig tissue. Even in non-mineralized areas, willow was found to have 10- to as much as 100-times the concentration of Cd compared to several other plant species, including moss and lichen. In the mineralized areas of Denali that were examined, the Cd levels in willow generally exceeded 10 ppm; the median concentration in non-mineralized areas was about 1 ppm. Willow leaves high in Cd are shed in the fall and upon decay a large proportion of the Cd is released and sorbed onto cation exchange sites such as clays and soil organic matter. In this form it is readily available for uptake by willow explaining the importance of biocycling to the distribution of Cd in cold, high latitude soils.

Diamondleaf and grayleaf willow are found in a variety of habitats. Typically they occur in upland boreal forests, as part of the shrub understory, and in dense, nearly uniform stands in alpine and arctic tundra. Willow palatability and browse preference is apparently linked to the presence or absence of specific tannins and phenyl glycosides (Molvar et al. 1993) and these two willow species are a favorite browse for moose throughout the year. Because willow is a bioaccumu-

lator of Cd, and because Cd is potentially toxic and known to have a long residence time in mammalian kidney tissue, we find it interesting to speculate on the possible long-term health effects of Cd in natural, Cd-rich areas. In Table 1 we compare the concentration of Cd, Cu, and Zn in the liver and kidney of 17 road-kill moose, collected in a non-mineralized area of Alaska, to diseased moose from Sweden (Frank et al. 2000). Concentrations of all three metals were lower in both liver and kidney tissue in the Alaska samples. Publication of metal levels in possibly diseased moose from Alaska are pending (Julie Maier, University of Alaska, personal communication).

Although a direct aetiological connection between high

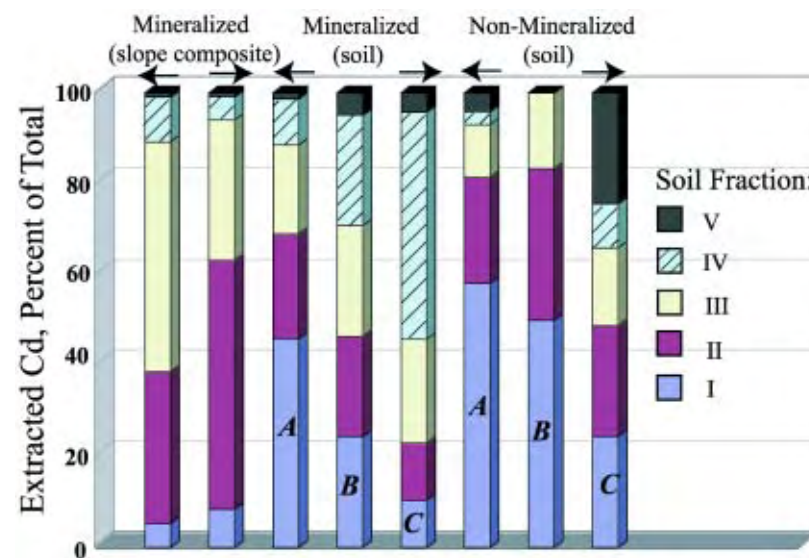


Figure 4. Sequential partial-extraction of two samples of unconsolidated slope material and six soil samples from Mt. Eielson, Denali. See Results section for a description of the five fractions. A, B, and C indicate soil horizon samples.

Cd in browse, high Cd in renal tissue, and the well-being of ptarmigan has been demonstrated (Larison *et al.* 2000), its connection to the health of moose remains a research question. Game management practices should be cognizant of this potential health impact, however, especially in areas of broad-regional mineralization or where base-metal mine-dumps are revegetated with willow as these areas might be expected to be high in bioavailable Cd.

Acknowledgements

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	Minimum	Maximum	Mean
Moose liver	ALASKA (n = 4)		
Cd, mg/kg	0.02	5.7	1.7
Cu, mg/kg	0.51	7.4	3.2
Zn, mg/kg	16	56	28
Moose liver	SWEDEN (n = 14)*		
Cd, mg/kg	0.68	4.4	1.9
Cu, mg/kg	3.2	28	11
Zn, mg/kg	22	151	67
Moose kidney	ALASKA (n = 17)		
Cd, mg/kg	0.27	6.5	2.3
Cu, mg/kg	2.2	3.5	2.8
Zn, mg/kg	17	29	21
Moose kidney	SWEDEN (n = 14)*		
Cd, mg/kg	5.1	27	12
Cu, mg/kg	2.3	26	5.5
Zn, mg/kg	30	86	49

*From Frank *et al.* 2000

Table 1. The concentration (mg/kg, wet weight basis) of Cd, Cu, and Zn in moose liver and kidney tissue from Alaska and Sweden. All Alaska samples are from road-kill animals collected in the Kenai Peninsula and the Matanuska-Susitna Valley; samples from Sweden are from “affected animals” showing Cu-deficiency disease symptoms (Frank *et al.*, 2000).

References

- Chao, T.T., and L. Zhou. 1983.
Extraction techniques for selective dissolution of amorphous iron oxides from soils and sediments. Soil Science Society of America Journal 47:225-232.
- Emsley, J. 1991.
The Elements. Clarendon Press. Oxford, UK.
- Foster, A.L., L.P. Gough, C.M. Ager, P.F. Lamothe, and R.F. Sanzalone. 2004.
X-ray absorption spectroscopy study of cadmium species in natural and greenhouse-grown willow (Salix) species: Proceedings of the 31st. Annual SSRL User's Meeting, Palo Alto, CA. (http://www-conf.slac.stanford.edu/ssrl/2004/reg/abs_list.asp#env)
- Frank, A., R. Danielsson, and B. Jones. 2000.
The ‘mysterious’ disease in Swedish moose. Concentrations of trace elements in liver and kidneys and clinical chemistry. Comparison with experimental molybdenosis and copper deficiency in the goat. The Science of the Total Environment 249 (1):107-122.
- Gough, L.P., J.G. Crock, W.C. Day, and J. Vohden. 1999.
Biogeochemistry of As and Cd, Fortymile River watershed, east-central Alaska. U.S. Geological Survey Professional Paper 1633:109-126.
- Gough, L.P., J.G. Crock, and W.C. Day. 2002.
Cadmium accumulation in browse vegetation, Alaska—implication for animal health. In *Geology and Health—Closing the Gap*, edited by H.C.W. Skinner and A. Berger. Oxford University Press. pp. 77-78.
- Granel, T., B. Robinson, T. Mills, B. Clotier, S. Green, and L. Fung. 2002.
Cadmium accumulation by willow clones used for soil conservation, stock fodder, and phytoremediation. Australian Journal of Soil Research 40:1331-1337.
- Hall, G.E.M., J.E. Vaive, and A.I. MacLaurin. 1996.
Analytical aspects of the application of sodium pyrophosphate reagent in the specific extraction of labile organic component of humus and soils. Journal of Geochemical Exploration 56:23-26.
- Larison, J.R., G.E. Likens, J.W. Fitzpatrick, and J.G. Crock. 2000.
Cadmium toxicity among wildlife in the Colorado Rocky Mountains. Nature 406:181-183.
- Molvær, E.M., R.T. Bowyer, and V. Van Ballenberghe. 1993.
Moose herbivory, browse quality, and nutrient cycling in an Alaskan treeline community. Oecologia 94:472-479.
- Taggart, J.E., ed. 2002.
Analytical methods for chemical analysis of geologic and other materials. U.S. Geological Survey Open-File Report 02-223.
- Tessier, A., P.G.C. Campbell, and M. Bisson. 1979.
Sequential extraction procedure for the speciation of particulate trace metals. Analytical Chemistry 51:844-850.
- Underwood, E.J., and N.F. Suttle. 1999.
The Mineral Nutrition of Livestock. CABI Publishing. New York.

Alaska at the Crossroads of Migration: Space-Based Ornithology

by J. L. Deppe, K. Wessels, and J. A. Smith

Abstract

Understanding bird migration on a global scale is one of the most compelling and challenging problems of modern biology. Each year multitudes of migratory birds travel between breeding grounds in Alaska and wintering grounds in the Americas, Asia, and Australia. Here we present the conceptual framework for a spatially explicit, individual-based biophysical migration model driven by dynamic remote sensing observations of atmospheric and land surface conditions to simulate migration routes, timing, energy budgets, and probability of survival. Understanding temporal and spatial patterns of bird migration will provide insight into pressing conservation and human health issues related to this taxonomic group.

Introduction

Each year millions of birds migrate extensive distances between their breeding and wintering grounds. These migratory journeys are comprised of extended flights interrupted by stopover periods during which birds refuel, rest, molt, and seek shelter from unfavorable weather conditions and predators. Successful migration depends on the availability of favorable atmospheric conditions aloft and suitable habitat during stopovers. Our ability to understand bird migration has generally been hindered by the large geographic scale of migratory movements and the short time period during which migration takes place. However, advances in remote sensing now provide us with near real-time measurements of atmospheric and land surface conditions at high spatial resolution over entire continents, offering new tools and approaches for understanding bird migration (*Table 1*).

Although migration has fascinated biologists and bird watchers for centuries, population declines in many migratory bird species during the past several decades and the recent emergence of H5N1 Avian Influenza have intensified our interest in this phenomenon. A major concern of conservation biologists is that human-induced changes in climate and land surface conditions along migratory routes, as well as on the breeding and wintering

MODIS (TERRA and/or AQUA)		
Surface temperature	1 km	8 Days
Snow cover	500 m	8 Days
Net photosynthesis (PSN)	1 km	8 Days
Leaf area index/Fraction photosynthetically active radiation	1 km	8 Days
Enhanced vegetation index (EVI)	1 km	16 Days
Normalized difference vegetation index (NDVI)	250 m	16 Days
Land cover dynamics (phenology)	1 km	Annual
Land cover type	1 km	Annual
Vegetation continuous fields	500 m	Annual
Vegetation cover conversion	500 m	5 Years
Data assimilation products (NCEP/NARR/GMAO/GDAS)		
Wind fields	Variable	3 hr
Precipitation	Variable	3 hr
Soil moisture (catchment model)	Variable	Daily

Table 1. Remote sensing products used as inputs into bird migration and habitat suitability models and their respective spatial and temporal resolution.

grounds, may negatively impact migratory bird populations by reducing the quantity and quality of habitat or altering the timing of birds' activities. For example, how do changes in the distribution, abundance, and/or quality of stopover habitat influence migratory routes, passage dates, dates of arrival and physical condition upon arrival at breeding and wintering grounds, and probability of survival? Human health officials, resource managers, and public policy makers are interested in the role migratory birds play in the global dispersal of avian-borne diseases and the identification of precise migratory routes of infected species. While general migratory flyways are recognized, such abstractions provide little guidance in identifying high-risk areas for focused surveillance and

mitigation efforts.

Alaska is a nexus of migratory bird activity. Over 60% of the species that regularly breed in Alaska migrate to wintering grounds in the Americas, Oceania, and Asia. Many of these species, particularly shorebirds and waterfowl, are susceptible to Avian Influenza (USGS National Wildlife Health Center) and represent a potential vector for the spread of this and other avian-borne viruses. Alaska's diverse aquatic and terrestrial ecosystems provide impor-

tant breeding and stopover habitat for migratory birds. Coastal habitats and meadows are used as stopover/staging sites by millions of shorebirds each year (*Alaska Shorebird Working Group 2000*), and interior forest, riparian corridors, and shrublands offer stopover habitat for landbirds (*Boreal Partners in Flight Working Group 1999*). Human-induced loss and alteration of these habitats is expected to have a negative impact on migratory bird populations. Timber harvesting, mining, urbanization, road

construction, recreational activities, and oil drilling may eliminate key stopover sites and/or reduce habitat quality. Furthermore, climate-induced changes in land surface and atmospheric conditions in Alaska are expected to be pronounced (*Calef et al. 2005*), and the effects of global warming, manifested as longer growing seasons, warmer winters, greater productivity, changing wetland and boreal forest distributions, and changing fire regimes, are already evident (*Keyser et al. 2000, Rupp et al. 2000, Jorgenson et al. 2001, Riordan et al. 2006*). Such changes in environmental conditions and processes will alter the distribution, abundance, and quality of breeding and stopover habitat for Alaska migrants as well as impact the timing of migrants' activities (*Bairlein and Hüppop 2004, Roland and McIntyre 2006*).

Objectives

The objectives of our research are twofold:

- to develop and evaluate a spatially explicit, individual-based biophysical simulation model driven by near real-time atmospheric and land surface conditions to describe temporal and spatial migration patterns, and
- to use our model to provide insight into the complex relationships among animal movement, climate, habitat change, and disease dispersal.

Concept-driven individual-based simulation models offer a valuable tool for studying bird migration, because they integrate information on migrant ecology, physiology, and behavior with remote sensing data on atmospheric and land surface conditions (*Simons et al. 2000, Erni et al. 2003*). Such models allow us to assimilate information about processes that take place at multiple spatial and temporal scales to understand global and hemispheric migration as a whole. While there are gaps in our current understanding of large-scale migration patterns and processes, the comprehensive development of the model will provide guidance for future research efforts in this

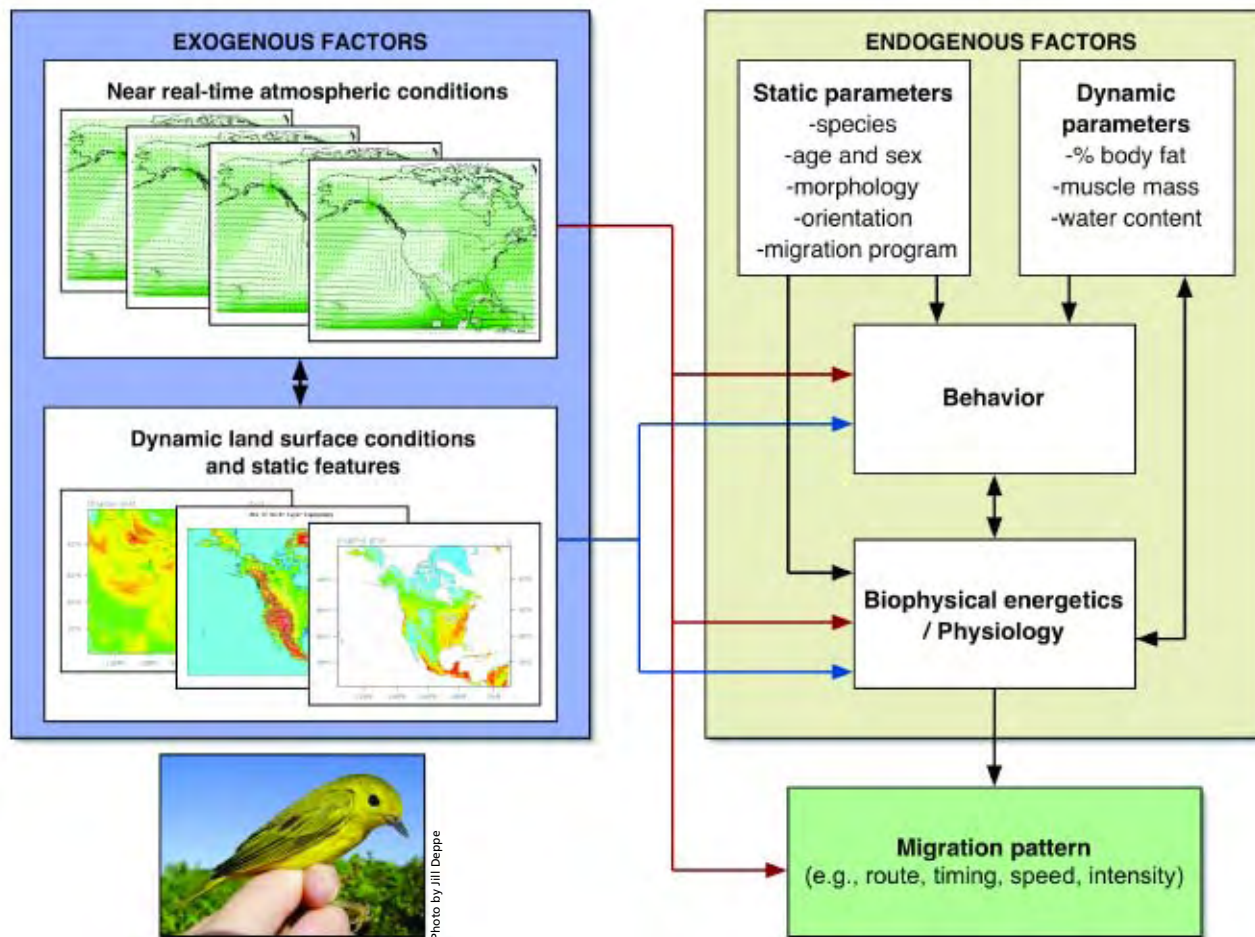


Figure 1. Modeling framework illustrating the general factors that influence bird migration and their interactions.

area and identify relevant questions and hypotheses that need to be addressed to further our knowledge of bird migration. Once validated and refined, the migration model may be used to evaluate our second objective and provide insight into conservation- and health-related questions. Here, we provide a coarse conceptual view of our bird migration model by outlining the general factors that interact to shape bird migration.

Migration Model Framework

Large-scale bird migration patterns are strongly influenced by exogenous factors that are unrelated to the bird. These factors may be divided into two main categories—atmospheric and land surface conditions/attributes (Figure 1, blue box). Dynamic atmospheric conditions, such as wind, precipitation, temperature, and cloud cover impact migration patterns (Gauthreaux *et al.* 2005, Cochran and Wikelski 2005). These conditions shape migration patterns directly through their influence on migration direction and speed (Gauthreaux and Able 1970, Butler *et al.* 1997) and indirectly through their impact on birds' activity budgets and energy balance, which in turn determine migrants' flight range and overall migration speed (total number of days to reach endpoint) (Figure 2) (Berthold 2001, Cochran and Wikelski 2005). Land surface attributes (e.g., land cover), as well as temporally dynamic conditions, such as soil moisture, temperature, and leaf cover, influence migration patterns via their impact on habitat quality and, in turn, migrants' behavior, energy budget, and survival (Bairlein and Hüppop 2004, Smith *et al.* 2007). Topographic features such as mountains or coastlines represent ecological barriers and function as landmarks to guide birds while aloft (Berthold 2001).

Endogenous factors related to the bird itself also influence migration patterns (Figure 1, brown box). Static parameters, including species, sex, age (static during a migratory period), morphology, and inherited migration programs and orientation, influence birds' behavior, ecology and physiology during migration (Woodrey 2000, Berthold 2001). Dynamic endogenous characteristics,

such as fat load, muscle mass, and water content, also influence migrants' behavior and energy dynamics but, unlike static parameters, are themselves modified as a consequence of birds' activities and environmental conditions (Moore and Aborn 2000, Smith *et al.* 2007).

Behavioral decisions are dependent upon exogenous and endogenous factors. An individual's activity budget, habitat choice, static and dynamic endogenous characteristics, and atmospheric and land surface conditions interact to determine an individual's energetic state and survival. The precise outcome of this interaction is mediated by the bird's physiology. By keeping track of a bird's activity, physical condition, and location over the course of a migration period, individual-based simulations may project the migratory route, date of passage or arrival, physical condition at key stopover sites or endpoints, overall speed of migration (km/day), intensity of migration for a population of simulated birds, and likelihood of survival (based on energy and time constraints).

A Closer Look at Flight Physiology and Wind

At the core of any bird migration model is a biophysical sub-model that describes how birds burn energy, primarily from fat but also protein, while in flight. The flight model estimates the maximum distance a bird can fly based on its morphology, physiology, energy load, and atmospheric conditions. Simulations using morphological and physiological parameters of virtual birds illustrate the general relationship between fat load and potential migration distance (Figure 2): as the amount of fat increases, a bird can fly farther (Pennycuik 1998). This association highlights how habitat quality may influence large-scale migration patterns. Birds occupying higher quality habitat on breeding, winter, and/or stopover sites may accumulate

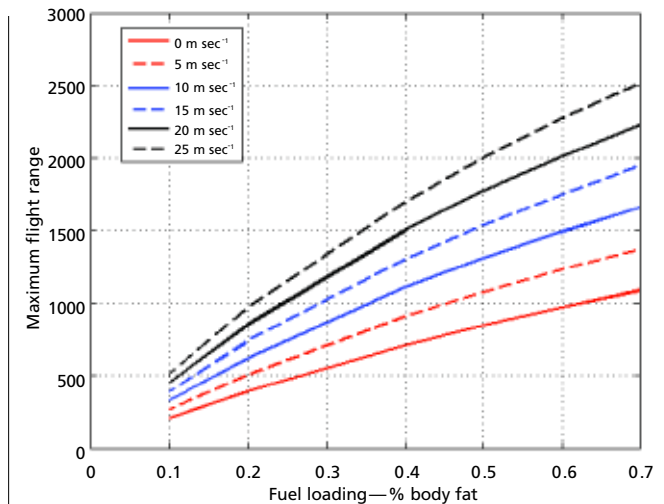


Figure 2. Estimated maximum flight ranges of virtual birds with variable fat loads and tail wind velocities; all other flight parameters held constant (Pennycuik 1998). As percent body fat, or energy load, increases, birds are able to fly longer distances, and faster tail winds result in higher maximum flight ranges for any given fat load. Birds are assumed to fly until they exhaust their fat reserves.



Blackpoll warblers are champion migrants. Some birds migrate more than 4,900 miles from their breeding grounds in Alaska to wintering grounds in South America. During fall migration most individuals are hypothesized to make overwater flights up to 1,800 miles from the northeastern United States to northern South America.

Static parameters, including species, sex, age (static during a migratory period), morphology, and inherited migration programs and orientation, influence birds' behavior, ecology and physiology during migration.

more fat and be able to fly farther.

Wind has a significant impact on large-scale migration patterns. Tail winds assist migrants by reducing energy consumption, increasing speed, and/or increasing potential flight ranges (Figure 2), whereas head winds have the opposite effect and may prevent migrants from flying at all. Additionally, wind exerts a direct influence on the direction of migration; for example, crosswinds may cause birds to drift off course. Wind conditions experienced by



Figure 3. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) Model predicts the movement of air parcels and is used here to illustrate the wind structure experienced by migratory birds originating at Denali National Park and Preserve. HYSPLIT analysis shown here was run directly on NOAA's Real-time Environmental Applications and Display System (READY) website. Trajectories were modeled using the FNL data set with 6-hr and 119 mi (191 km) resolution. The red, blue and green lines illustrate wind conditions at 0.3, 0.6 and 0.9 mi (500, 1000 and 1500 m) above ground level, respectively, for a 7-day period beginning August 1 2001.

migratory birds aloft are dynamic and complex. Particle trajectory models, such as NOAA's HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model (<http://www.arl.noaa.gov/ready/hysplit4.html>) are valuable in exploring and quantifying short-term dynamics in wind structure in three dimensions plus time along a bird's migratory route (Figure 3). Such models have been used to describe the wind conditions associated with migratory departure events from Alaska (Gill *et al.* 2005) and the seasonal migration strategies that birds use during migration over the Gulf of Mexico (Gauthreaux *et al.* 2005).

Future Challenges

The role of static and/or dynamic characteristics of the land surface in shaping migration patterns has received relatively little attention (Tankersley and Orvis 2003). Dynamic (e.g., soil moisture, leaf cover) and seasonally static features (e.g., land cover class) influence migrant distributions as well as birds' rate of fat deposition, potential flight ranges, and overall migration speed. Remote sensing data from NASA combined with empirical data on the occurrence and abundance of migratory birds can be integrated to develop dynamic habitat suitability models for en-route migrant birds and enhance our ability to model foraging energetics and behavior at stopover sites (Table 1).

A critical future step is the validation and refinement of the overall migration simulation model and its component parts using field data. Satellite tracking of individuals provides excellent data on migratory routes of large birds (McIntyre *et al.* 2006), and progress is underway to develop similar technologies for small birds (Wikelski *et al.* 2007). We can test the overall migration model by comparing observed migration routes and timing of migration to probabilistic routes and passage/arrival dates predicted by the model. Field data on migrant abundances (e.g., number of captures/net-hour, number of birds/day), mean and range of passage dates, and energetic condition (fat levels, mass, muscular atrophy) collected from banding stations and count



U.S. Fish & Wildlife Service photo by Tim Bowman

Many shorebirds like the bar-tailed godwit migrate extensive distances. Bar-tailed godwits nest in the treeless tundra and coastal and alpine meadows of Alaska and spend the nonbreeding season in marshes, sandy beaches, and inland wetlands and fields of Australasia.

surveys at stopover sites (see Skagen *et al.* 1999, Deppe and Rotenberry 2005), as well as the dates of arrival and physical condition of birds upon arrival at their Alaska breeding grounds, can be used to validate and fine-tune the model by comparing spatially-explicit predicted and observed values.

Once validated and refined, we can use the migration model to explore conservation and health-related issues pertaining to bird migration in Alaska including:

- How do the environmental changes observed in Alaska, such as permafrost degradation, thermokarst draining of tundra ponds, erosion, submergence, sedimentation, salinization of coastal ponds, changing fire regimes, longer growing seasons, greater productivity, and warmer winters alter the quality, abundance, size, and spacing among suitable stopover sites for Alaska migrants?

- How do such habitat alterations impact spatial and temporal patterns of migration, birds' probability of survival, and population growth?
- If a bird tests positive for an avian-borne virus, where was that bird in the days prior to capture, and if released after sample collection, where is that bird likely to have gone?

Ecological modeling of habitat suitability based on historical and current remote sensing data can be used to map the spatial distribution and abundance of stopover habitat, as well as quantify changes in habitat availability. We can then perform simulations of bird migration through environments reflecting current, historical, and forecasted land surface conditions and compare the predicted migration patterns to identify negative impacts. Answers to these and similar questions are critical for conserving migratory bird species and maintaining the biological integrity of global ecosystems.

Management Implications for Alaska's National Parks

The fundamental objective of our migration model is to understand migration as a whole, in other words, understand connectivity among stopover sites and stages of the annual cycle and identify the large-scale factors and processes shaping migration patterns. An effective conservation strategy for this group requires a holistic approach under which breeding, winter, and stopover habitat along species' entire fall and spring migratory routes need to be protected. Management activities at the level of individual national parks may contribute to the conservation of migratory birds by reducing particular sources of ecological stress. The tested and refined migration model may be used by park managers to provide insight into how historical, current, and future activities or changes in land surface conditions within individual Alaska national parks, such as Denali National Park and Preserve, or networks of protected areas, may impact large-scale migration patterns, such as migration routes



U.S. Fish & Wildlife Service photo by Donna Dewhurst

Semipalmated plover, a medium- to long-distance migrant, breeds throughout Alaska and winters along the Pacific and Atlantic coasts of the southern United States, Mexico, and Central and South America. In Alaska the species breeds in riverine alluvia and gravel beaches, and during migration it occupies silt tidal flats and sandy beaches (Alaska Shorebird Working Group 2000).

and birds' probability of survival. Additionally, the model may be used to generate probabilistic estimates of the spatial and temporal movement of disease-infected birds through Alaska that can be used by park managers to estimate the risks proposed to wildlife within park boundaries and plan focused surveillance and mitigation efforts.

Acknowledgements

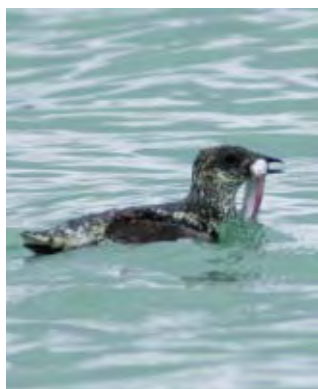
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References

- Alaska Shorebird Working Group. 2000.**
A Conservation Plan for Alaska Shorebirds.
Unpublished report, Alaska Shorebird Working Group.
Available through U.S. Fish and Wildlife Service,
Migratory Bird Management, Anchorage, Alaska.
- Bairlein, F., and O. Hüppop. 2004.**
Migratory fuelling and global climate change.
Advances in Ecological Research 35: 33-47.
- Berthold, P. 2001.**
Bird migration: a general survey.
Oxford University Press. New York.
- Boreal Partners in Flight Working Group. 1999.**
Landbird Conservation Plan for Alaska Biogeographic Regions, Version 1.0. Unpublished report,
U.S. Fish and Wildlife Service, Anchorage, Alaska.
- Butler, R.W., T.D. Williams, N. Warnock,
and M.A. Bishop. 1997.**
Wind assistance: a requirement for migration of shorebirds. *Auk* 114:456-466.
- Calef, M.P., A.D. McGuire, H.E. Epstein, T.S. Rupp,
and H.H. Shugart. 2005.**
Analysis of vegetation distribution in interior Alaska and sensitivity to climate change using a logistic regression approach.
Journal of Biogeography 32:863-878.
- Cochran, W. W., and M. Wikelski. 2005.**
Individual Migratory tactics of New World Catharus thrushes: current knowledge and future tracking options from space. In *Birds of two worlds: the ecology and evolution of migration*, edited by R. Greenberg and P.P. Marra. Johns Hopkins University Press. Baltimore, Maryland. Pages 274-289.
- Deppe, J.L., and J.T. Rotenberry. 2005.**
Temporal patterns in fall migrant communities in Yucatan, Mexico. *Condor* 107:228-243.
- Erni, B., F. Liechti and B. Bruderer. 2003.**
How does a first year passerine migrant find its way? Simulating migration mechanisms and behavioural adaptations. *OIKOS* 103:333-340.
- Gauthreaux, Jr., S.A., and K.P. Able. 1970.**
Wind and the direction of nocturnal songbird migration. *Nature* 228:476-477.
- Gauthreaux, Jr., S.A., J.E. Michi, and C.G. Belser. 2005.**
The temporal and spatial structure of the atmosphere and its influence on bird migration strategies. In *Birds of two worlds: the ecology and evolution of migration*, edited by R. Greenberg and P.P. Marra. John Hopkins University Press. Baltimore, Maryland. Pages 182-192.
- Gill, Jr., R.E., T. Piersma, G. Hufford, R. Servranckx, and A. Riegen. 2005.**
Crossing the ultimate ecological barrier: evidence for an 11,000-km-long nonstop flight from Alaska to New Zealand and Eastern Australia by Bar-tailed Godwits. *Condor* 107:1-20.
- Jorgenson, M.T., C.H. Racine, J.C. Walters, and T.E. Osterkamp. 2001.**
Permafrost degradation and ecological changes associated with a warming climate in central Alaska. *Climate Change* 48:551-579.
- Keyser, A.R., J.S. Kimball, R.R. Nemani, and S.W. Running. 2000.**
Simulating the effects of climate change on the carbon balance of North American high-latitude forests. *Global Change Biology* 6: 185-195.
- McIntyre, C., K. Steenhof, M.N. Kochert, and M.W. Collopy. 2006.**
Long-term Golden Eagle studies.
Alaska Park Science 5(1):42-45.
- Moore, F.R., and D.A. Aborn. 2000.**
Mechanisms of en route habitat selection: how do migrants make habitat decisions during stopover? *Studies in Avian Biology* 20:34-42.
- Pennycuik, C.J. 1998.**
Computer simulation of fat and muscle burn in long-distance bird migration.
Journal of Theoretical Biology 191:47-61.
- Riordan, B., D. Verbyla, and A.D. McGuire. 2006.**
Shrinking ponds in subarctic Alaska based on 1950-2002 remotely sensed images.
Journal of Geophysical Research 111:1-11.
- Roland, C., and C. McIntyre. 2006.**
Integrated monitoring of physical environment, plant, and bird communities in Denali.
Alaska Park Science 5(1):46-48.
- Rupp, T.S., F.S. Chapin III, and A.M. Starfield. 2000.**
Response of subarctic vegetation to transient climatic change on the Seward Peninsula in north-west Alaska. *Global Change Biology* 6:541-555.
- Simons, T.R., S.A. Pearson, and F.R. Moore. 2000.**
Application of spatial models to the stopover ecology of trans-Gulf migrants.
Studies in Avian Biology 20:4-14.
- Skagen, S.K., P.B. Sharpe, R.G. Waltermire, and M.B. Dillon. 1999.**
Biogeographical profiles of shorebird migration in midcontinental North America.
USGS/BRD Biological Science Report USGS/BRD/BSR 2000-0003. <http://www.fort.usgs.gov/shorebirds>
- Smith, R.J., F.R. Moore, and C.A. May. 2007.**
Stopover habitat along the shoreline of northern Lake Huron, Michigan: emergent aquatic insects as a food resource for spring migrating landbirds. *Auk* 124:107-121.
- Tankersley, Jr., R.T., and K. Orvis. 2003.**
Modeling the geography of migratory pathways and stopover habitats for Neotropical migratory birds. *Conservation Ecology* 7:7
(URL: <http://www.consecol.org/vol7/iss1/art7>).
- USGS National Wildlife Health Center. 2006.**
http://www.nwhc.usgs.gov/disease_information/avian_influenza/affected_species_chart.jsp.
- Wikelski, M., R. Kays, J. Kasdin, K. Thorup, J.A. Smith, W.W. Cochran, and G.W. Swenson. 2007.**
Going wild: what a global small animal tracking system could do for experimental biologists.
Journal of Experimental Biology (In Press).
- Woodrey, M.S. 2000.**
Age-dependent aspects of stopover biology of passerine migrants.
Studies in Avian Biology 20:43-52.

Recommendations for Monitoring Kittlitz's Murrelets in Icy Bay

by Michelle Kissling, Mason Reid, Paul M. Lukacs, Scott M. Gende, and Stephen B. Lewis



National Park Service photo by Mason Reid

Abstract

Kittlitz's murrelet is a rare, non-colonial seabird often associated with tidewater glaciers and a recent candidate under the Endangered Species Act. We conducted

at-sea surveys during summer 2005 to understand the spatial and temporal variation in the abundance of Kittlitz's murrelets in order to develop a long-term monitoring plan for this species. Total abundance ($N \pm SE$; 1317 ± 294) peaked from 3-16 July, but decreased dramatically thereafter. The greatest densities were observed consistently in Taan Fjord along with the majority of fish-holding birds. We conclude that Tann Fjord offers not only suitable foraging conditions, but also proximity to nesting habitat. We recommend a long-term monitoring approach for this declining species in Icy Bay.

Introduction

The Kittlitz's murrelet (*Brachyramphus brevirostris*; hereafter KIMU) is one of the rarest and least understood seabirds in the world. This non-colonial species is most closely related to the marbled murrelet, though these species diverged approximately two million years ago at the beginning of the Pleistocene Epoch (Friesen *et al.* 1996). The species range likely extends from the Okhotsk Sea, throughout the Bering Sea, to northern southeast Alaska, with highest densities in the northern Gulf of Alaska (Day *et al.* 1999).

Limited data exist to assess the conservation status of KIMU. The world population of KIMU was recently estimated to be between 9,500 and 26,500 birds (U.S. Fish and Wildlife Service 2004). Based on results of at-sea surveys in four core population areas, KIMU have declined up to 84% (-18% per year) in the last few decades across its range (U.S. Fish and Wildlife Service 2004). What's more, very little is known regarding the ecology and demographic changes in this species. To date, less than 35 nest sites have been found worldwide and thus little information exists to identify suitable breeding habitat and conditions contributing to variation in survival and nesting success. In response to documented declines, the U.S. Fish and Wildlife Service listed the KIMU as a candidate species under the Endangered Species Act in May 2004 (69 FR 24875 24904). Speculated causes include oil pollution, gill-net mortality, and reduced availability of preferred forage fish (Piatt and Anderson 1996, van Vliet and McAllister 1994).

A comprehensive monitoring program is critically important for this species for several reasons. First, the existing data from some of the core areas are characterized by small sample sizes and relatively imprecise estimates.

Ascertaining the degree of annual variation in populations within and among areas will contribute to our understanding of population dynamics. Second, a well-developed monitoring design will elucidate insight into habitat characteristics that influence the temporal and spatial changes in KIMU distribution and abundance. Finally, at-sea estimates of demographic parameters, including reproductive rates, will ultimately be necessary to identify areas that support successful breeding and possibly serve as a source population for other declining areas.

The overall goal of this study was to gather information for developing a long-term monitoring plan. Icy Bay, a core population area during the breeding season, encompasses a highly dynamic glacial environment. Designing a successful monitoring program requires information about optimal timing for surveys, spatial variability, and detectability of birds under different survey conditions. Since this species is closely associated with tidewater glaciers and glaciated fjords, it was necessary to consider the implications of monitoring populations in such dynamic glacial environments.

Methods

Icy Bay (60° 01' N, 141° 20' W) is a coastal fjord 68 miles (110 km) northwest of Yakutat, Alaska. Much of the upper bay is part of Wrangell-St. Elias National Park. Icy Bay includes a shallow outer bay, adjacent to the Gulf of Alaska, and a deep inner bay. Four fjords radiate from inner Icy Bay, and each has an active tidewater glacier at its head. Taan Fjord is the only consistently accessible fiord; Guyot, Yahtse, and Tsaa Fjords are typically dominated with ice pack and floes. The entire bay is approximately 93 square miles (240 km²).

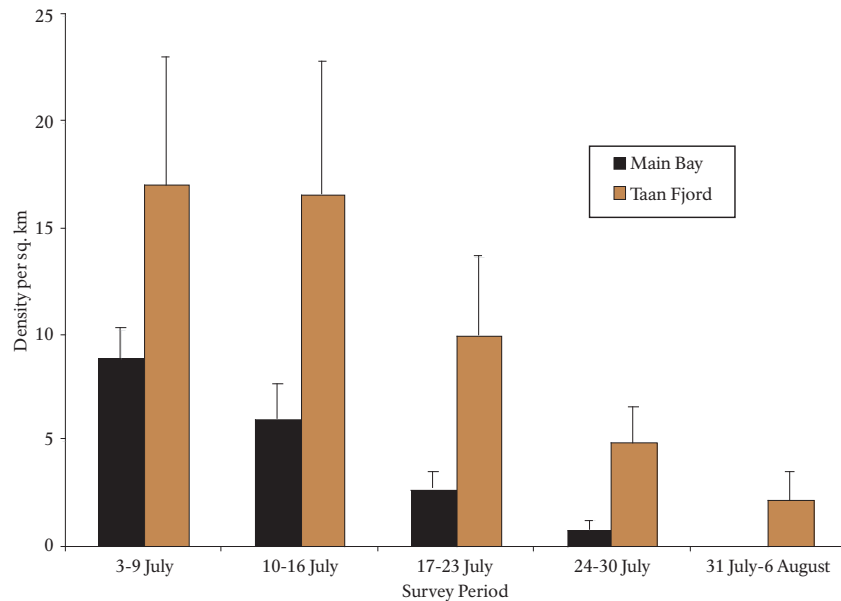


Figure 1. Densities (birds/km²±SE) of Kittlitz's murrelets in Taan Fjord and Main Bay across all five survey periods, Icy Bay, Alaska, 2005.



National Park Service photo by Mason Reid

At-sea surveys were conducted in Icy Bay from 2 July to 5 August 2005. Two types of transects were established in two sampling strata. Shoreline transects were located within 656 feet (200 m) of shore and were run parallel to shore (total length = 57.5 miles/92.6 km). Pelagic transects (n=17) were perpendicular to shore, located approximately 1.2 miles (2 km) apart, varied in length according to width of the bay or fjord, and ended at 656 feet (200 m) offshore (following *Kuletz and Kendall 1998*). We subdivided Icy Bay into two distinct geographical units—Inner Main Bay (42 mi²/110 km²) and Taan Fjord (9 mi²/24 km²)—because each could be surveyed in one day. Surveys were conducted during five, one-week survey periods. Surveys occurred between 7:00 am and 9:00 pm, using a 18-foot (5.5-m) boat moving at a speed of about 6 mph (10 km/hr). For each observation, number of birds, age category, location (air or water), activity (e.g., flying, on water), and distance from the transect line were recorded. Sea condition (Beaufort scale), precipitation, ice cover (%), and swell (nearest meter) were estimated every 30 minutes or as conditions changed. We recorded data using a voice-activated recording system that was integrated with a GPS unit, which stamped each observation with a location and time (see *Fischer and Larned 2004* for details). Tidal stage (ebb or flood; vertical water) and

current strength (horizontal water) were estimated using the same method as Day and Nigro (2000) with one exception; relative current tidal strength was multiplied by the maximum tidal height. We estimated density using detection distance data in Program Distance (*Thomas et al. 2006*).

We then generated an optimal monitoring program using our empirically-derived estimates of variation and detection probability to generate realistic bounds on parameter estimates. We calculated the power to detect a decline in KIMU density of 5 and 10% per year given spatial variation with a coefficient of variation (CV) of 25% and 50% and detection probability variation ranging from a CV of 5-30%. We considered power to detect the trend for a monitoring duration of 5-40 years. For the power estimates, we performed 500 simulation replicates for each combination of rate of decline, spatial variation, detection probability variation, and number of years. We fit a log-linear trend weighted by the inverse of the variance of each density estimate to each simulated survey and determined if that estimated trend was statistically less than zero ($p < 0.05$).

Results

During the five-week period, we recorded 880 *Brachyramphus murrelets*, of which 794 (90%) were KIMU. The overall population estimate ($N \pm SE$) during the peak period (3–9 July) was $1,317 \pm 294$ birds, decreasing to 68 ± 37 birds by the last survey period (31 July–6 August). Average group size over all survey periods was 1.65 birds. We found the highest densities of KIMU in Taan Fjord during the first two survey intervals (*Figure 1*). However, throughout the surveys, KIMU were spatially clumped with concentrations of birds in a few consistent 'hotspots'.

Over the five week period, we recorded 37 fish-holding KIMU. Six were observed during systematic surveys and 31 were recorded opportunistically. We observed all fish-holding KIMU between 5 July and 4 August; most (46%) were observed during the first survey period, decreasing during the remaining intervals (11%, 5%, 24%, and 14%, respectively). Thirty-three (89%) of fish-holding birds

were observed in Taan Fjord.

We aged 775 (98%) KIMU as definite after-hatch-year (AHY) birds and 10 as probable AHY birds; only nine were aged as probable HY birds during systematic surveys. We recorded nine additional probable HY birds opportunistically. All probable HY KIMU were observed from 4 July –4 August with 28% recorded in the first survey period, followed by 11%, 17%, 17%, and 28%, respectively. Fourteen (89%) HY birds were observed in Taan Fjord and all HY murrelets were located within 984 feet (300 m) of shore.

Discussion and conclusions

KIMU densities estimated during this study are among the highest ever recorded for this species. Based on our results, the population in Icy Bay represents 5-14% of the estimated world population (U.S. Fish and Wildlife Service 2004). Similarly, the variance estimates are astoundingly low compared to those calculated in Prince William Sound and Glacier Bay (U. S. Fish and Wildlife Service 2004). Yet, the estimated population size of Kittlitz's murrelets in Icy Bay in 2002 was $2,098 \pm 373$ birds (U.S. Fish and Wildlife Service, Juneau Field Office, unpublished data) compared to the 2005 peak estimate of $1,317 \pm 294$ birds, suggesting a 37% decline over the three year period. However, abundance estimates varied dramatically among the five survey periods, suggesting that survey timing is critically important for ascertaining annual changes in abundance within glacial fjords.

Management implications

The factors that influence the spatial and temporal variability of KIMU should be considered when developing a monitoring program. Our results provide insight into this variability and allow us to make some recommendations for monitoring. First, monitoring surveys should occur during the first two weeks of July given the population peak during these periods. Second, the pelagic transect allowed us to account for variability across space that could not occur with shoreline transects. Yet a high degree

of clumping will ultimately be a limiting factor in generating precise estimates of abundance. Given these considerations, our simulations and corresponding power analyses demonstrate that to detect an annual decline of 10% with a power of 0.9, we would need to monitor for 10-15 years (Figure 2). We strongly suggest surveying annually in Icy Bay given the importance of this area for KIMU and lack of information about inter-annual variation. To do this, it would require conducting two bay-wide surveys (~65 km each) with two survey crews to reduce temporal variation.

Finally, our surveys suggested that generating productivity indices for KIMU is not feasible at this point. We identified a tremendous amount of variability in plumage characteristics that limited our ability to age birds on the water with confidence. Future work should focus on molt and plumage characteristics of different aged birds.

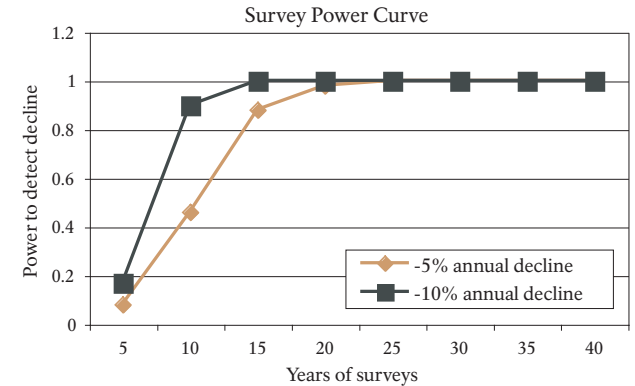


Figure 2. Results of power simulations designed to detect a decline of Kittlitz's murrelets in Icy Bay over a 5-40 year monitoring period given certain spatial variation and variability in detection probabilities.

References

- Day, R. H., K. J. Kuletz, and D. A. Nigro. 1999. Kittlitz's murrelet *Brachyramphus brevirostris*. The Birds of North America, No. 435.
- Day, R. H., and D. A. Nigro. 2000. Feeding ecology of Kittlitz's and Marbled murrelets in Prince William Sound, Alaska. Waterbirds 23:1-14.
- Fischer, J. B. and W. W. Larned. 2004. Summer distribution of marine birds in the Western Beaufort Sea. Arctic 57:143-159.
- Friesen, V. L., J. F. Piatt, and A. J. Baker. 1996. Evidence from cytochrome b sequences and allozymes for a 'new' species of alcid: the long-billed murrelet (*Brachyramphus perdix*). Condor 98:681-690.
- Kuletz, K. J., and S. J. Kendall. 1998. A productivity index for marbled murrelets in Alaska based on surveys at sea. Journal of Wildlife Management 62:446-460.
- Piatt, J. F. and P. Anderson. 1996. Response of common murrelets to the Exxon Valdez oil spill and long-term changes in the Gulf of Alaska marine ecosystem. American Fisheries Society Symposium 18:720-737.
- Thomas, L., J. L. Laake, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. R. Anderson, K. P. Burnham, S. L. Hedley, J. H. Pollard, and J. R. B. Bishop. 2006. Distance 5 release 3. Research Unit for Wildlife Population Assessment. University of St. Andrews, UK. <http://www.ruwpa.st-and.ac.uk/distance/>
- U.S. Fish and Wildlife Service. 2004. Candidate and listing priority assignment form for Kittlitz's Murrelet. U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, Alaska. 38pp.
- van Vliet, G. B. and M. McAllister. 1994. Kittlitz's murrelet: the species most impacted by direct mortality from the Exxon Valdez oil spill? Pacific Seabirds 21:5-6.

Apparent Changes in Abundance and Distribution of Birds in Denali National Park and Preserve

by Carol L. McIntyre



U.S. Fish & Wildlife Service photo by Donna Dewhurst

Abstract

Charles Sheldon, Olaus Murie, Adolph Murie, and Joseph Dixon made observations of the bird life in the Denali National Park (Denali) region from 1906 to 1962 and reported their observations in various articles, books, and field notes. While Sheldon provided the first descriptions of this region's bird life, Joseph Dixon and Adolph Murie provided the most comprehensive descriptions of the region's bird life. To identify possible changes in Denali's bird life over the last century, I compared historic bird observations made by Joseph Dixon and Adolph Murie with con-

Figure 1. The tiny orange-crowned warbler is one of the most common warblers in Denali.

temporary bird observations made between 2001 and 2006 through several long-term monitoring programs in Denali and by long time Denali naturalists. My preliminary comparisons suggest that distribution and abundance of many species has changed within the last century. For instance, Dixon and Murie considered whimbrels as common and regular breeders in areas now dissected by the Denali Park road, but we rarely encountered whimbrels within 0.5 mile of the Denali Park road in the last 10 years. Further, Dixon and Murie rarely encountered orange-crowned warblers during the breeding season in Denali, but they were one of the most common species encountered on our standardized bird surveys in the last decade. Although direct comparisons between historic and contemporary observations are impossible due to methodological differences, my preliminary investigations suggest that historic observations are valuable for identifying apparent changes, building hypotheses to explore cause of change, and planning future studies of Denali's birdlife.

Introduction

Denali National Park and Preserve (Denali) sits at the geographic center of Alaska. Advancing and retreating glaciers formed the contemporary landscapes of Denali (Hooe *et al.* 2006), resulting in a diversity of habitats used by many species of birds. The landscapes of Denali are dynamic, and scientists expect that landscape scale changes in this region may accelerate as arctic and subarctic ecosystems respond to a warming climate (Chapin *et al.* 2005, Hooe *et al.* 2006).

Currently, at least 119 species of birds nest in Denali, including 28 resident and 91 migratory species. Adequately describing the abundance and distribution of birds that live in this region and monitoring their population trends is challenging due to the remoteness and vast size of Denali, and to limited funding opportunities. Early naturalists and scientists that explored the Mount McKinley National Park region described their travels and bird observations in a series of books and scientific papers (Sheldon 1909, 1930, Dixon 1938, O. Murie 1924 and A. Murie 1946, 1963). Together, the field notes and documents of these naturalists and scientists “afford a valuable faunal history” of this region (Murie 1946) and can help Denali’s scientists identify changes that have occurred since these earlier biological surveys and studies.

The saying that “a picture tells a thousand words” is clearly illustrated by the ongoing research projects comparing historic and contemporary photographs of glaciers and landscape patterns in Denali. These comparisons provide clear evidence that Denali’s glaciers and landscapes are changing. Unfortunately, comparing historic and contemporary bird observations is more difficult than comparing photographs of the same areas since the methods and terms to describe the abundance and distribution of birds has changed over time. However, used in the proper context, historic observations offer some insight into broad scale changes in Denali’s bird life over the last century. The purpose of this paper is to describe and compare the historic and contemporary observations of two species of birds in Denali, to describe some of the values and limitations of

historic data, and to explain why Denali’s contemporary bird monitoring programs are providing reliable information on actual, rather than apparent, changes in Denali’s birdlife.

Methods

The study area was limited to the northeastern portion of Denali, the area where most historic and many contemporary field studies have occurred. Historic observations are limited to those made by Dixon from May 19 to July 29, 1926 (accompanied by George Wright) and May 16 to August 31, 1932 (Dixon 1938) and by Murie over many years between 1922 and 1962 (Murie 1946, 1963). Contemporary observations are limited to Breeding Bird Surveys (BBS) conducted along the Denali Park road, the Denali off-road point transect surveys (PTS), and during other fieldwork conducted by the author and other long-time Denali naturalists between 2001 and 2006.

It is beyond the scope of this paper to compare changes in all species of birds between historic and contemporary times. Therefore, I limited this paper to two species that appeared to have changed in either their distribution or abundance between the two periods: whimbrel (*Numenius phaeopus*) and orange-crowned warbler (*Vermivora celata*). I did not include comparisons of historic and contemporary observations of trumpeter swan (*Cygnus buccinators*) or peregrine falcon (*Falco peregrinus*), two species that have increased both in numbers and in area occupied in Denali in the last four decades, because Dixon (1938) and Murie (1946, 1963) did not mention them in their respective accounts. Readers interested in learning more about trumpeter swans in Denali are referred to McIntyre (2006).

Results

Whimbrel

Whimbrels, previously known as Hudsonian curlew, are large, migratory shorebirds that nest on the tundra. They arrive in the Denali region in early May and depart in August. Whimbrels have a large decurved bill and unique vocalizations (loud, nerve-racking cries) (Dixon 1938); thus, they are difficult to confuse with other shorebird species of this region.

Historic observations. Dixon and Murie considered whimbrels as common breeding birds in Denali. Dixon (1938) found whimbrels “breeding in fair numbers on wet tundra areas in the higher passes of the Mount McKinley region between Savage River and Copper Mountain” and suggested that whimbrels “occur commonly and are regular breeders in the McKinley region”. Murie (1963) stated that the whimbrel was a “rather conspicuous nesting bird

Species that have decreased in abundance or shifted their distribution
American Golden Plover (<i>Pluvialis dominica</i>)
Red-necked Phalarope (<i>Phalaropus lobatus</i>)
Bank Swallow (<i>Riparia riparia</i>)
Northern Wheatear (<i>Oenanthe oenanthe</i>)
Lapland Longspur (<i>Calcarius lapponicus</i>)
Rusty Blackbird (<i>Euphagus carolinus</i>)
Species that have increased in abundance or shifted their distribution
Wilson's Snipe (<i>Gallinago delicata</i>)
Black-billed Magpie (<i>Pica hudsonia</i>)
Ruby-crowned Kinglet (<i>Regulus calendula</i>)
Savannah Sparrow (<i>Passerculus sandwichensis</i>)
Lincoln's Sparrow (<i>Melospiza lincolnii</i>)
Species that exhibited no change in abundance or distribution
Merlin (<i>Falco columbarius</i>)
Golden Eagle (<i>Aquila chrysaetos</i>)

Table 1. A sample of species that have either increased or decreased in abundance, shifted their distribution, or exhibited no change in abundance or distribution between historic observation (1922 to 1962) and contemporary observations (2001 to 2006) in Denali National Park and Preserve, Alaska.

in the low, rolling, open tundra, among sedge hummocks” and “along the [Denali Park] road it is often seen between Savage and Sanctuary rivers, and it has been seen quite often between East Fork and Toklat rivers, and from the Muldrow Glacier to Wonder Lake”.

Contemporary observations. Contemporary observations suggest that whimbrels are rarely encountered along the park road, except during early to mid-May in the Wonder Lake area. Between 2001 and 2006, we detected whimbrels two times during standardized BBS (two in 2001, one in 2002) and four times during the PTS. During the same time period, whimbrels were frequently observed between mile 80 and 82 along the Denali Park road, but they moved away from the park road after mid-May (during the nesting season) (F. Wittwer and S. Senner, personal communication).

Several whimbrel colonies were encountered along the Sanctuary River and east of the Denali Park road near mile 80, but both colonies were more than 0.5 miles from and out of sight of the Denali Park road.

Orange-crowned Warbler

Orange-crowned warblers (Figure 1) are tiny, greenish-yellow songbirds that arrive in Denali from mid to late May and depart from mid-August to early September. They lack wing bars and have a unique high-pitched trilling call. It is difficult to confuse orange-crowned warblers with other warbler species that occur in this region.

Historic observations. Dixon and Murie considered orange-crowned warblers as migrants that passed through the area, but that did not breed in Denali. Dixon (1938) stated that “Our experience both in 1926 and in 1932 leads us to believe that the orange-crowned warbler which Wright saw in a spruce wood on Savage River on May 21, 1926, at 2,800 feet altitude, was merely a late migrant passing through the McKinley region to its breeding ground farther north in the Yukon Valley. Repeated search in the McKinley region, both in 1926 and

in 1932, failed to reveal any breeding birds of this species in the park in summer.” Further, Murie (1963) did not list orange-crowned warblers as a breeding species in Denali; rather, he stated that this species was “noted in May and June, and in August, during migration” and “has been reported to nest rather commonly on the lower Yukon River”.

Contemporary observations. Contemporary observations suggest that orange-crowned warblers are one of the most common warbler species in Denali, and that they are common breeders. Between 2001 and 2006, we encountered 73 to 174 orange-crowned warblers annually on the BBS routes and 21 to 189 orange-crowned warblers annually on the PTS. Additionally, orange-crowned warblers, including many young of the year, were one of the

most commonly captured warblers at constant-effort mist netting stations operated in Denali from 1993 to 2001 (DeSante et al. 2002) and at the Denali Institute Migration Station operated on Camp Denali property from 1998 to 2005 (Phillips 2006).

Discussion and Conclusions

It is beyond the scope of this paper to determine the magnitude of change and factors driving the changes in Denali’s bird life. Rather, the purpose of this paper is to provide a brief summary of some of my initial investigations and comparisons.

By comparing historic and contemporary observations of whimbrel and orange-crowned warblers, I found multiple sources of evidence to suggest that either the distribution or abundance of these species has changed in the study area. In response, I explored the scientific

literature to determine the population status of whimbrel and orange-crowned warblers in Interior Alaska during the period from 1926 to 1963. Unfortunately, these efforts revealed little in regards to these species during that period. For instance, there are no data available to determine if orange-crowned warblers were less common in Alaska during the period from 1926 to 1963; however, Gabrielson and Lincoln (1959) suggest that orange-crowned warblers were commonly encountered in other regions of interior Alaska during this period. Further, the U.S. Shorebird Conservation Plan lists whimbrel as a “Species of High Concern,” based on population trend, relative abundance, threats on non-breeding grounds, and non-breeding distribution.

While my preliminary investigations suggest that at least two species have substantially changed their distribution or abundance in the last century, I found evidence to suggest that other species have changed as well (Table 1). It is beyond the scope of this paper to describe results of all my comparisons, but these findings suggest that more research is clearly warranted to determine how Denali bird life changes over time.

Management Implications

Birds are an important component of Denali’s ecosystems; their high body temperature, rapid metabolism, and high ecological position in most food webs make them a good indicator of the effects of local and regional changes in ecosystems (Fancy and Sauer 2000). Detecting changes in the abundance and distribution of birds in Denali is difficult due to the large size, remote nature, and diversity of habitats of the park and preserve. Despite these challenges, we are starting to gain a better understanding of the diversity, abundance, and distribution of birds living in Denali through many projects and long-term

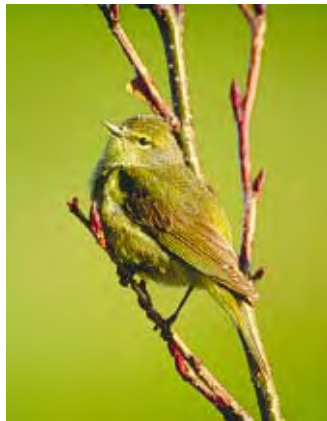


Photo courtesy of Ken Whitten

Orange-crowned warbler.

Birds are an important component of Denali’s ecosystems; their high body temperature, rapid metabolism, and high ecological position in most food webs make them a good indicator of the effects of local and regional changes in ecosystems.

observations. While historic observations are useful for identifying apparent change, our contemporary bird monitoring programs are designed to detect actual, rather than apparent, change. Most important are our long-term monitoring projects of golden eagles and passerine birds conducted through the Central Alaska Network Vital Signs Monitoring Program (MacCluskie and Oakley 2005) and the U.S. Fish and Wildlife Service's trumpeter swan surveys (McIntyre 2006). These long-term data sets, based on robust and repeatable methodologies, provide reliable information that will allow Denali's scientists and managers to detect changes in different species in Denali and develop programs to investigate factors driving the changes. Moreover, because Denali's ongoing passerine monitoring program is integrated with vegetation, soil, and permafrost monitoring, we can explore how birds respond to changes in the landscape and delineate relationships among physical and biological elements in Denali (Roland and McIntyre 2006). As a result, our contemporary bird monitoring programs are establishing foundations for effective long-term monitoring of park resources that will allow us to better understand and manage these resources in the future (Roland and McIntyre 2006).

Acknowledgments

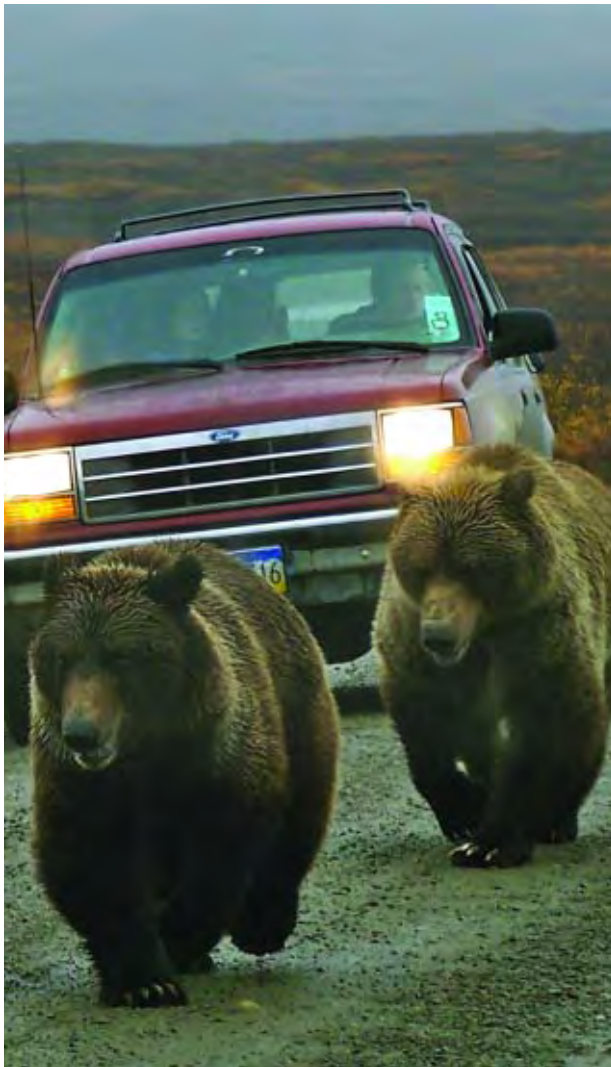
I thank all the field technicians who have helped collect data on Denali's birds, the Alaska Bird Observatory for assisting with long-term monitoring projects in Denali, Jane Bryant for providing copies of Joseph Dixon's field notes, and Bruce Lee, Alan Seegert, Stan Senner, and Fritz Wittwer for providing information on their bird observations. I also thank Ken Whitten for permission to use his photograph of the orange-crowned warbler in this article. Denali National Park and Preserve and the National Park Service Vital Signs Monitoring Program, Central Alaska Network, provided funding for Denali's contemporary bird studies.

References

- Chapin, F.S., III, M. Sturm, M.C. Serreze, J.P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L.D. Hinzman, G. Jia, C.-L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker. 2005. *Role of Land-Surface Changes in Arctic Summer Warming*. Science 310 (5748):657-660.
- DeSante, D.F., P. Pyle, and D.R. O'Grady. 2002. *Ten-year (1992-2001) report of the Monitoring Avian Productivity and Survivorship (MAPS) Program in Denali National Park*. Final Report. The Institute for Bird Populations. Point Reyes Station, CA.
- Dixon, J.S. 1938. *Fauna of the National Parks of the United States*. Birds and Mammals of Mount McKinley National Park, Fauna Series No. 3. United States Department of the Interior.
- Fancy, S., and J. Sauers. 2000. *Recommended Methods for Inventorying and Monitoring Landbirds in National Parks*. <http://science.nature.nps.gov/im/monitor/protocols/npsbird.doc>
- Gabrielson, I.N., and F.C. Lincoln. 1959. *The birds of Alaska*. Wildlife Management Institute. Washington, D.C.
- Hooge, P., G. Adema, T. Meier, C. Roland, P. Brease, P. Sousanes, and L. Tyrrell. 2006. *Ecological overview of Denali National Park and Preserve*. Alaska Park Science 5(1): 7-13.
- MacCluskie, M., and K. Oakley. 2005. *Vital Signs Monitoring Plan, Central Alaska Network, August 1, 2005*. National Park Service. Fairbanks, Alaska.
- McIntyre, C.L. 2006. *Changes in the abundance and distribution of Trumpeter Swans in Denali National Park and Preserve, Alaska*. Alaska Park Science 1(2):24-29.
- Murie, A. 1946. *Observations of the birds of Mount McKinley National Park*. Condor 48:253-261.
- Murie, A. 1963. *Birds of Mount McKinley*. Mount McKinley Natural History Association. McKinley Park, Alaska.
- Murie, O.J. 1924. *Nesting records of Wandering Tattler and Surfbird in Alaska*. Auk 41: 231-237.
- Phillips, L. 2006. *Analytical Review of Data Collected at the Denali Institute Migration Station (DIMS), 1998-2005*. Unpublished report submitted to the Alaska Natural History Association and Murie Science and Learning Center. Denali Park, Alaska.
- Roland, C., and C. McIntyre. 2006. *Integrated monitoring of physical environment, plant, and bird communities in Denali*. Alaska Park Science 5(1): 46-48.
- Sheldon, C. 1909. *List of birds observed along the upper Toklat River near Mount McKinley, Alaska, 1907-1908*. Auk 26: 66-70.
- Sheldon, C. 1930. *Wilderness of Denali*. Charles Scribner's Sons. Chicago, Illinois.

Grizzly Bear Population Ecology in Denali National Park and Preserve

by Patricia A. Owen and Richard D. Mace



National Park Service photo by Robert A. Winfree

Abstract

Study of a naturally regulated population of grizzly bears in Denali National Park and Preserve has been ongoing since 1988. Vital rates were calculated based on observations of adult and subadult females, yearlings and cubs. Productivity by female grizzly bears (0.35), mean litter size (2.02), and adult female and cub mortality have remained relatively stable. Mortality of spring cubs is high, averaging near 0.65 and near 0.40 for yearlings. Mortality of adult females is about 0.04 and about 0.07 for subadult females. The population trend (λ) determined from the calculated vital rates indicates a population that is likely to be decreasing slightly.

Introduction

Grizzly bears (*Ursus arctos*) provide viewing opportunities for visitors to Denali National Park and Preserve (Denali) both along the one road into the park and in the backcountry and provide an important resource the park is mandated to protect. Monitoring of grizzly bears is conducted by following and observing radio-instrumented individuals. Conventional radio telemetry is used to locate bears and determine number of cubs born to marked females and survival of bears in selected age classes.

Methods

Grizzly bears were captured by aerial darting from a helicopter to attach radio collars and radio tracked approximately twice per month from den emergence in Spring to den entrance in Fall. Visual observations from fixed-wing aircraft and from the ground were used to determine whether bears died, cast their radio collar, or exhibited collar failure. Counts of attendant young were made during two periods (pre- and post- 30 June). Cubs and yearlings that were seen pre-30 June, but not observed during later observation attempts were considered dead (no yearling dispersal). We were unable to verify the fate of 2 and 3 year old bears that were not radio-collared. These bears could have either died or dispersed, and thus were omitted from analyses. We estimated the survival rate of four age classes of grizzly bears: adults (6+ years old), independent subadults (2-5 years old), yearlings (1 year old), and cubs of the year (<1 year old). The methods of Hovey and McLellan (1996) were used for analyses.

Annual survival rates for radioed bears were estimated using censored telemetry data. Each radioed bear accumulated “radio-days.” A bear that survived an entire year achieved 365 radio-days for that year. Bears that either died or shed their collars earlier in the year tallied less days, as estimated from telemetry. The total days that each individual female accumulated over the course of the study were transcribed into years of monitoring.

The reproductive rate of grizzly bears was defined as the number of female cubs born divided by the interbirth interval. Litter sizes were assumed to be 50% female. The interbirth interval was defined as the number of years that young were with their mother plus any additional years prior to the next litter. For analyses, the age of first reproduction was set at 6 years, and the maximum age a female could attain was 35 years. Instances where the complete litter was lost were termed “whole litter losses.” Partial litter losses were those cases where some of the cubs in a litter survived the year.

Population trend (finite rate of increase, λ) was determined by mathematically contrasting survival and reproductive rates using a derivation of the Lotka equation (Eberhardt *et al.* 1994, Hovey and McLellan 1996). Four parameters were used to calculate λ : adult, subadult, yearling and cub survival, age of first reproduction, litter size, and interbirth interval. A λ value of 1.0 denotes a stable population. Values < 1.0 infer a declining

Fate of Cub Litters	Number	Percent
Unknown	3	4
Whole litter loss	41	54
Partial litter loss	12	16
No litter loss	20	26
Total litters	76	100

Table 1. Fate of litters of grizzly bear cubs in Denali National Park and Preserve, Alaska, 1988-2005.

population, while those above 1.0 indicate a population that is increasing. Confidence intervals for these vital rates were determined by bootstrapping procedures (Efron and Gong 1983).

Results

We documented the birth of 154 cubs from 76 litters born to 31 females. Mean litter size was 2.03 cubs/litter (CI = 1.88 – 2.17 years). An interbirth interval could be calculated in 45 instances and averaged 2.86 years (CI = 2.45-3.27). Most litters were of 2 cubs (61.0%). Three cub litters were more common (21.0%) than those with one cub (18.0%). Litter size increased as females aged, and then appeared to decline after 20 years of age.

Age of first reproduction averaged 6.7 years and varied from 5 to 9 years. The oldest bear known to have cubs was 28 years. Our estimate of female reproductive rate in Denali was 0.3477. We documented the fate of cub-of-year

litters in all but 3 cases. No cub deaths were observed in 20 cases (26.0%). Conversely, in 54.0% of the cases, female grizzly bears exhibited complete loss of cub litters, which was greater than the number of partial losses. Sixty-six percent of the cub deaths occurred prior to 1 July.

We followed the fate of 39 adult female grizzly bears. Eleven of these adults died. Mean survival rate of females was estimated to be 0.9572 (mortality rate = 0.04). Relatively fewer subadult females were monitored (20 individuals for 42 radio-years), and 3 of these subadults died. Mean survival rate for subadult females was 0.9309 (mortality rate = 0.07). Yearling and cub survival rates were lower than for older bears, averaging 0.5983 and 0.3514 respectively). Ninety-nine of 148 cubs died, and 20 of 54 yearlings died. The mortality rate for yearlings averaged 0.40 while that of cubs whose fate was known, averaged 0.65. Known deaths of bears in all age classes were due to natural causes. No bears were removed by harvest or for management purposes.

Our estimate of population trend (λ), given the vital rate estimates, was 0.9963 (CI = 0.9716 - 1.0268). These data indicate, within 95% confidence intervals, that the

Parameter	Estimate				
	Sample Size	Point Estimate	Lower 95% CI	Upper 95% CI	SE
Adult survival	39/251*	0.96	0.94	0.98	0.01
Subadult survival	20/42	0.96	0.82	1.00	0.04
Yearling survival	54/39	0.60	0.46	0.74	0.07
Cub survival	148	0.35	0.28	0.43	0.04
Age first parturition	fixed	6.0			
Litter sex ratio	fixed	50:50			
Reproductive rate ^b		0.35	0.29	0.43	0.04
Maximum age	fixed	35			
Lambda		0.9963	0.9617	1.0268	0.0166

* Number of individuals sampled/years monitored.

^b Reproductive rate for female cubs only

Table 2. Vital rates of grizzly bears in Denali National Park and Preserve, Alaska, 1988-2005.

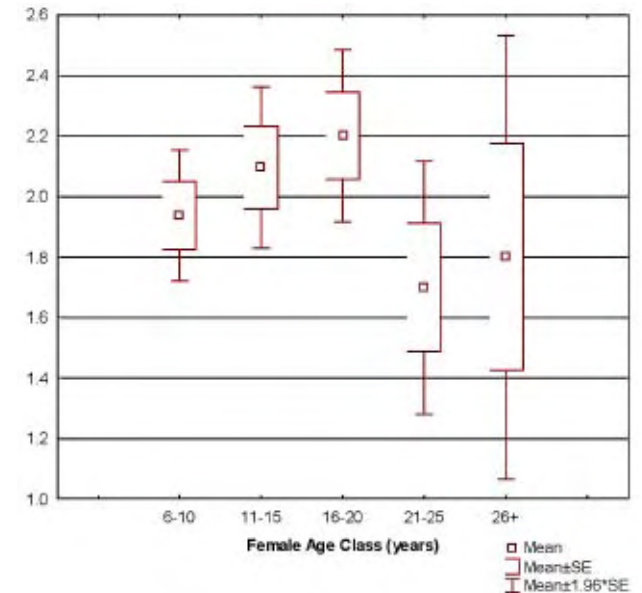


Figure 1. Female age classes and litter size for grizzly bears in Denali National Park and Preserve, Alaska, 1988-2005.

population could be declining at an annual rate of approximately 3.8%, or growing at a maximum annual rate of 2.7%. The mean lambda indicates a population decline of 0.37% annually. Forty percent of 5000 replications of the data suggested a growing population ($\lambda > 1.0$), while 60% of the lambda estimates suggested a stable to declining population within Denali.

Discussion and Conclusions

We obtained essentially the same survival rate for cubs as did an earlier work in Denali by Keay (2001). This is not unexpected since we used the same radioed sample of bears with an additional 6 years of data. Cub survival in Denali (35%) was similar to other non-hunted populations in North America such as Katmai (34%) (Miller *et al.* 2003) and Yellowstone National Park (49%) (Schwartz *et al.* 2006). For comparison, cub survival in the Susitna area of Alaska, where hunting for grizzly bears is allowed, was 67% (Miller *et al.* 2003). Cub survival within the recovery zone of the Greater Yellowstone Ecosystem, but outside of Yellowstone Park itself was 83%. In western Montana, Mace and Waller (1996) estimated cub survival to be 79%.

Low cub survival in non-hunted areas, such as national parks and wildlife preserves, where populations are at near capacity, is believed indicative of density-dependence population regulation. Although not confirmed, high cub and yearling mortality in Denali is believed to be a result

of either starvation or predation as was the case for Yellowstone National Park (Schwartz *et al.* 2006). No cubs were known to have been removed from the system by man during the study. Although density-dependent regulation is suspected, the fact is that the causes of most cub and yearling deaths remain unresolved. Miller (1990) cautions that density regulated deaths should not be assumed unless specific cause of death can be determined. Unfortunately, due to logistics, determining the cause of such deaths in the field remains elusive.

Our estimate of adult female survival (96%) was close to Keay's (2001) earlier work of 97%. Annual survival rates for adults that are $\geq 95\%$ are indicative of lightly hunted or non-hunted populations. Our results deviate from Keay's (2001) previous work for yearling and subadult survival. These differences may be due to our larger sample sizes for these classes, longer duration, different methods, and larger sample size.

Our estimate of population trend in Denali, suggests a generally stable population with a mean estimate of $\lambda = 0.9963$. However, within the bounds of probability, there is a greater likelihood that the population is decreasing at a maximum rate of approximately 3.8% annually, than that the bear population is growing. A stable to decreasing population is likely given the low survival of cubs and yearlings. The mean estimated birth rate in Denali of 0.6954 (reproductive rate of $.3477 \times 2$), was similar to the observed annual mortality rate for cubs (0.6486). These metrics suggest that birth and death rates were nearly equal.

Management Implications

This is one of the longest running studies of a naturally regulated population of grizzly bears. Vital rates calculated indicate regulation of the grizzly bear population in Denali National Park and Preserve is likely density dependent. Given that the population trend appears to be decreasing, long term monitoring of this system should continue. Effort should be made to determine the cause of high mortality in cubs and yearlings to verify density dependent regulation.

Acknowledgements

Many pilots deserve our appreciation for safe flights over the years. We also thank the many observers who assisted in data collection.

References

- Eberhardt, L., B. M. Blanchard, and R. R. Knight. 1994. Population trend of the Yellowstone grizzly bear as estimated from reproductive and survival rates. Canadian Journal of Zoology 72:360-363.
- Efron, B., and G. Gong. 1983. A Leisurely Look at the Bootstrap, the Jackknife, and Cross-Validation. The American Statistician, Vol. 37(1):36-48
- Hovey, F.W. and B. N. McLellan. 1996. Estimating population growth of grizzly bears from the Flathead River drainage using computer simulations of reproductive and survival rates. Canadian Journal of Zoology 74:1409-1416.
- Keay, J. A. 2001. Grizzly bear population ecology and monitoring: Denali National Park and Preserve, Alaska. Report of project development and findings 2001. Alaska Biological Science Center, Anchorage, AK.
- Mace, R. D. and J. S. Waller. 1998. Demography and population trend of grizzly bears in the Swan Mountains Montana. Conservation Biology 12:1005-1016.
- Miller, S.D. 1990. Population management of bears in North America. Ursus. 8:357-373.
- Miller, S.D., R. A. Sellers, and J.A. Keay. 2003. Effects of hunting on grizzly bear survival and litter sizes in Alaska. Ursus. 14:130-152
- Schwartz, C. C., M.A. Haroldson, R.B. Harris, S. Cherry, K.A. Keating, D. Moody, and C. Servheen. 2006. Temporal, spatial, and environmental influences on the demographics of grizzly bears in the greater Yellowstone Ecosystem. Wildlife Monograph 161.

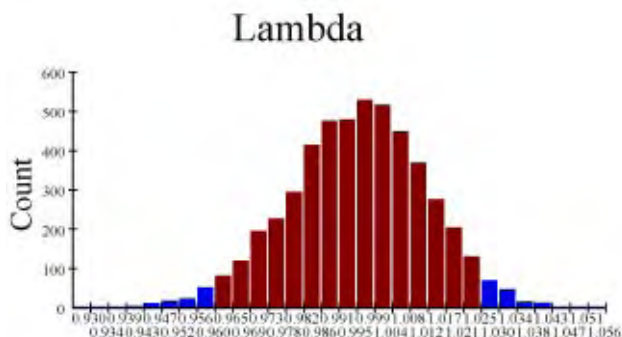


Figure 2. Results of 5000 bootstrap estimates of lambda for grizzly bears in Denali National Park and Preserve, Alaska, 1988-2005. A lambda value of 1.0 denotes a stable population.

Dynamics of Small Mammal Populations in the Rock Creek Watershed, Denali National Park and Preserve

by Eric Rexstad and Edward Debevec

Abstract

Through a 14 year mark-recapture study we have tracked the dynamics of small mammal populations in a watershed at the east end of Denali National Park and Preserve. In addition to tracking changes in density of the three most commonly caught species, we built predictive models attempting to predict density of *Clethrionomys* using meteorological variables collected by National Park Service personnel at park headquarters, less than 3 miles (5km) from the study site. Our predictive model was able to explain ~80% of the variation in annual estimates of *Clethrionomys* density. The most influential variable in the model was date of spring onset.

Introduction

Small mammals are found near the base of the food chain in boreal forest ecosystems. They are called primary (or first order) consumers as they convert plant biomass into animal biomass. In turn, they are preyed upon by a host of carnivores higher up the food chain (Boonstra *et al.* 2001). Consequently changes in the abundance or density of small mammals will subsequently be experienced by the species that prey upon them. At the same time, population dynamics of this group of species can readily be estimated by fairly small field crews using fairly basic equipment, traveling largely on foot (Rexstad 1996). Life history characteristics of small mammals (short life spans, high reproductive rates, and movements restricted to less than 2 miles (4km)) cause population numbers to be reflective of local conditions. The combination of these circumstances makes small mammal populations excellent candidates for detecting change in boreal ecosystems.

Our project focused on producing annual estimates of population size of the most commonly encountered small mammal species: northern red-backed vole (*Clethrionomys rutilus*), tundra vole (*Microtus oeconomus*), and singing vole (*Microtus miurus*). In addition to documenting the patterns of change in these species, we attempted to model the dynamics of the most common species, the northern red-backed vole, using meteorological variables. The predictive model will serve two purposes: a) postulate possible changes to the small mammal community induced by future climate change, and b) identify departures from model predictions that may be caused by non-meteorological factors that could be susceptible to management action.

Methods

This study has been conducted annually in the Rock Creek watershed, north of the headquarters complex in Denali National Park and Preserve since 1992. Data collection protocols are described in Rexstad (1996) and consist of capturing animals using baited Sherman live traps; identifying their sex, species, and mass; placing a passive



National Park Service photo

The northern red-backed vole (*Clethrionomys rutilus*) is a primary consumer whose abundance is linked with carnivores higher up in the food chain.

integrated transponder tag into them using a hypodermic needle; and releasing them at the capture location. Recapture of marked individuals during a sampling period provides information that allows estimation of capture probability and movement distance that in turn permits the estimation of animal density using the method developed by Efford (2004).

In most years of the project, data were collected throughout the snowfree period (June-early September), but in this manuscript, we report only on data collected

during the final sampling period of each field season; i.e., data obtained between the last week of August and the first week of September. The data used to produce the density estimates presented herein were from a set of sentinel plots, consisting of a total of 400 Sherman traps sampled for a period of no less than four days for a total of 12 sampling occasions.

The estimates of density were produced using Efford’s (2004) techniques of inverse prediction. Along with the estimates of density, measures of precision or confidence

intervals were computed. The number of animals caught was merely a fraction of the total number of animals in the population. An estimate of the probability of capture of individuals in the population enabled us to transform the number of animals caught to an estimate of number of animals in the population. Furthermore, animals caught in traps that are deployed in some geometric configuration are not necessarily animals that are resident in the area where the traps are laid. Animals may move into or through the trap deployment area, hence the area sampled by the trapping configuration must also be estimated. Both of these estimates and their associated measures of uncertainty contribute to our estimate of small mammal density, and likewise to our uncertainty in estimates of density. All estimates provided herein will also possess measures of uncertainty.

Having estimated density for each year of our study, we went on to construct predictive models for northern red-backed vole density using meteorological data collected at park headquarters. As the number of possible models that could be built from a set of meteorological

Coefficient	Estimate	SE (estimate)
Intercept	86.44	17.866
Spring onset	-0.54	0.124
Summer dryness	-1.51	0.365
Spring dampness	-0.69	0.258
Onset:dryness interaction	0.01	0.003

Table 1. Analysis of variance table showing estimated coefficients and measures of precision for fitted generalized linear model predicting northern red-backed vole density as a function of meteorological predictors.

factors is nearly infinite, we restrained our modeling enthusiasm by restricting possible meteorological factors to those tempered by our understanding of small mammal life history. Our guiding principles in selecting meteorological variables were

- young northern red-backed vole born early in the summer are themselves capable of reproducing in their first summer of life,
- northern red-backed voles prefer moist conditions to move undetected through vegetation and as a positive influence on their food supply (Carrier and Krebs 2002), and
- damp and cool early summer conditions can be detrimental to survival of early litters who face thermoregulatory stress (Heikura 1977).

We derived three meteorological variables consistent with our biological premises. Spring onset index was the Julian date on which a cumulative degree-day measure was reached. A summer dryness index was the percentage of days between mid-June and the end of August when there was no precipitation. Spring dampness and coolness was inferred from the March Pacific Decadal Oscillation index (Mantua et al. 1997). These predictors were fit to northern red-backed vole density using generalized linear modeling (McCullough and Nelder 1989, R Development core team 2006). The model employed a log link function,

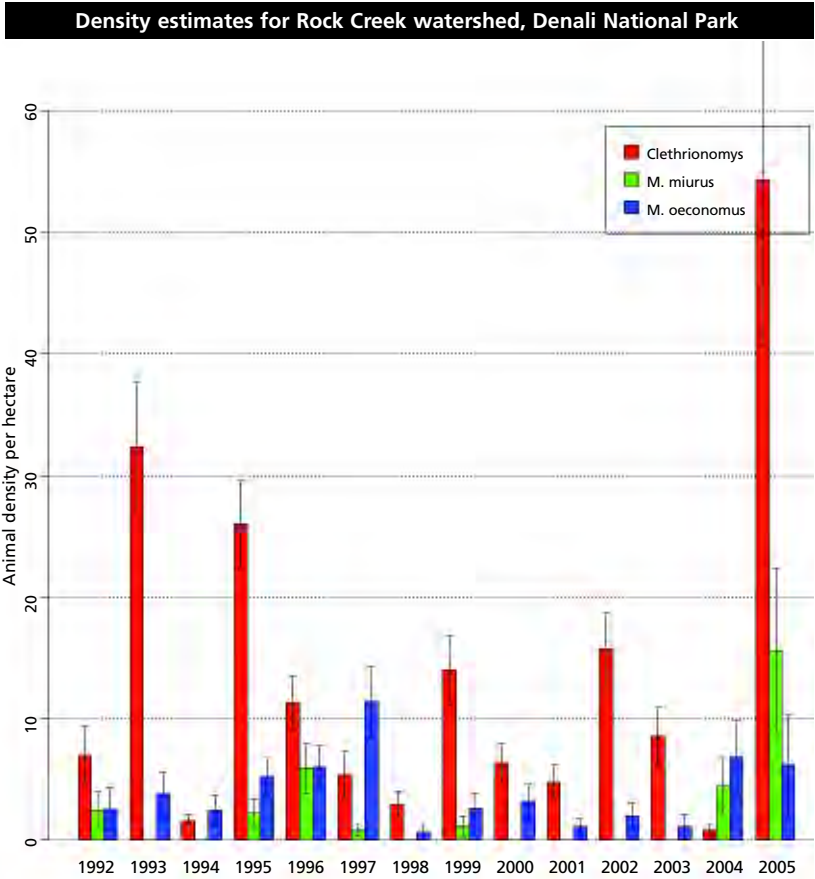


Figure 1. Density estimates (individuals/ha⁻¹) for the three most common species encountered in the Rock Creek watershed—northern red-backed voles (red), singing voles (green), and tundra voles (blue). Confidence intervals (95%) are also depicted.

and assumed a gamma-distributed error structure. Model selection was performed using Akaike's Information Criterion adjusted for small samples because sample size in this context is defined as the number of years of data; although each data point itself may have been estimated from many hundreds of northern red-backed vole captures.

Results

Our ability to estimate density of northern red-backed vole in the Rock Creek watershed was quite good; i.e., the average coefficient of variation in our density estimates were ~14% for northern red-backed vole. In contrast, the average coefficient of variation for *Microtus oeconomus* was twice as large at 28%, fundamentally because many fewer *Microtus oeconomus* were captured. The pattern of end of field season density estimates (and confidence intervals) is shown in Figure 1.

The most common species, the northern red-backed vole experienced fluctuations in density in excess of 1.5 orders of magnitude; with point estimates ranging from 0.8 individuals ha^{-1} to 50 individuals ha^{-1} . Remarkably those extremes in estimated density occurred in consecutive years (2004 and 2005).

Our modeling work showed that all of the meteorological variables were influential in explaining variability in northern red-backed vole density. The model incorporating spring onset, summer dryness, and spring dampness as main effects (along with an interaction of spring onset and summer dryness) had the lowest AICc of the suite of 8 models fit to the data. This model explained ~80% of the variability in northern red-backed vole density. The coefficients associated with each of the predictors in the model are given in Table 1. Note that the signs of the coefficients associated with spring onset and summer dryness are both negative implying an inverse correlation between each factor and northern red-backed vole density; e.g., a late spring (large onset index) results in small predicted northern red-backed vole density. Similarly, a large summer dryness index implies a small predicted northern red-backed vole density. This also holds for the spring

Our sampling protocol and density estimation methods provide a sound method for producing measures of status and trend for small mammals in a watershed in Denali National Park and Preserve. This allows park staff to be informed not only about the current state of small mammal populations, but it affords a context into which to place each annual estimate.

dampness PDO index. However the coefficient of the interaction term involving spring onset and summer dryness carries a positive sign. This term in the model attempts to ameliorate the large northern red-backed vole density that would be predicted when spring onset is early and summers are not dry.

A visual assessment can be seen in Figure 2. Note the magnitude of uncertainty in the density estimates (designated as observed in Figure 2) compared to the magnitude of uncertainty in our model results (predicted). It stands to reason that our predicted densities cannot be more precise than the information that was used to construct the model. Nevertheless, confidence intervals of observed (from data) and predicted (from density estimates) overlap for each year.

Discussion and Conclusions

Our sampling protocol and density estimation methods provide a sound method for producing measures of status and trend for small mammals in a watershed in Denali National Park and Preserve. This allows park staff to be informed not only about the current state of small mammal populations, but it affords a context into which to place each annual estimate. The two most extreme estimates of northern red-backed vole density occurred at the end of the time series we report here; had there not been a preceding 12 years of density estimates, it would have been very difficult to interpret the swing from 0.8 individuals ha^{-1} to 50 individuals ha^{-1} in a single year. We also express satisfaction at the precision with which we can estimate northern red-backed vole density. A coefficient of variation of 15% is sufficiently accurate to validly differentiate pattern from noise.

Our predictive modeling work to understand density of northern red-backed vole is gratifying, but at the same time disquieting. We conducted this modeling exercise 7 years ago, and derived a predictive model based on a different suite of meteorological variables that was equally competent in its ability to explain variation in northern red-backed vole density (Debevec and Rexstad 1999). Unfortunately the model derived in 1999, when applied to the observed densities in 2004 and 2005 failed utterly to

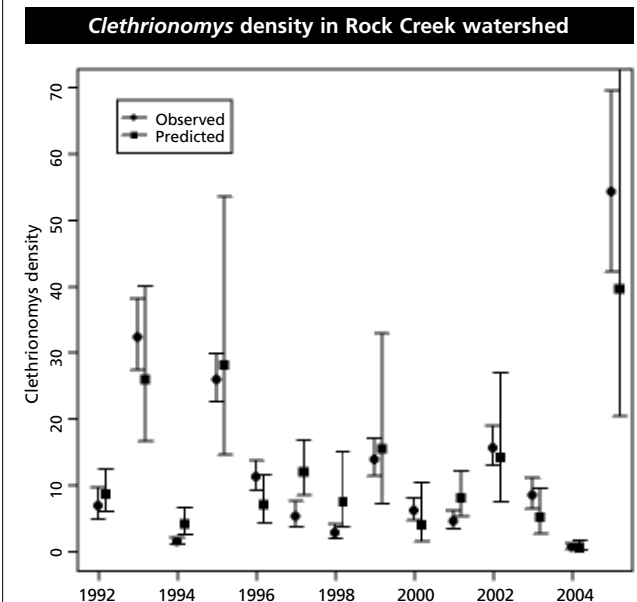


Figure 2. Densities of northern red-backed voles derived from mark-recapture data (circles) and predicted northern red-backed vole densities as estimated from meteorological variables shown in Table 1 (squares). Confidence intervals (95%) are also depicted.

predict those extreme events. The lesson here is that continued monitoring is the only way, short of manipulative experiments of meteorological conditions, to continue to refine our understanding of the forces that act upon these biological systems.

Management Implications

It is our contention that it is fundamental to produce estimates of population attributes, such as density, along with measures of precision to provide managers with an appreciation of the biological resources they manage. The measures of precision are necessary as they permit assessment of whether the pattern in the time series is attributable to changes in the processes that govern the animal population being studied, or whether the observed pattern is simply inherent stochasticity.

Beyond documenting a time series of population attributes, it is necessary to attempt to explain the patterns contained in a time series. In the case of small mammal population dynamics that we have shown are related to meteorological phenomena, resource managers will need a combination not just of the time series of population density, but also the predictive model to be able to deduce when small mammal populations are responding to phenomenon not contained in the model, and perhaps in the domain of the manager to influence.

Acknowledgements

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References

- Boonstra, R, C.J. Krebs, B.S. Gilbert, and S. Schweiger. 2001. *Herbivores: voles and mice*. In *Ecosystem dynamics of the boreal forest*, edited by C.J. Krebs, S. Boutin, and R. Boonstra, Oxford University Press. New York. Pages 215-239
- Carrier, P., and C.J. Krebs. 2002. *Trophic effects of rainfall on Clethrionomys rutilus voles: an experimental test in a xeric boreal forest in the Yukon Territory*. Canadian Journal of Zoology 80:821-829.
- Debevec, E.M., and E. Rexstad. 1999. *Modeling temporal patterns in microtine abundance in Denali National Park and Preserve*. Poster presentation at Arctic Division AAAS annual meeting.
- Efford, M. 2004. *Density estimation in live-trapping studies*. Oikos 106:598-610.
- Heikura, K. 1977. *Effects of climatic factors on the field vole Microtus agrestis*. Oikos 29:607-615.
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. *A Pacific interdecadal climate oscillation with impacts on salmon production*. Bulletin of the American Meteorological Society 78:1069-1079.
- McCullough, P., and J.A. Nelder. 1989. *Generalised linear models*. Chapman & Hall. London, UK
- R Development Core Team. 2006. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org>.
- Rexstad, E. 1996. *Small mammal sampling protocol for long-term ecological monitoring program, Denali National Park and Preserve*. Unpublished report.



Voles were captured live using baited traps, like this one.

Wolf Foraging and Related Social Variations in Denali National Park

by Gordon C. Haber

Abstract

Groups of wolves in central areas of Denali National Park migrate seasonally to northeastern caribou wintering areas, leading to much competition and strife with resident northeastern wolves and other migrants. Groups in the eastern area generally remain within year-round territories; the more diverse prey base of this area facilitates social and other non-migratory adaptations to seasonal and longer-term caribou declines and attracts fewer migrating wolves. Predictably, group turnover rates are much lower in the eastern area, and there are high levels of cooperation within these groups. Groups are the primary wolf functional units in all three areas.



Photo courtesy of Gordon Haber

Introduction

In Denali National Park and Preserve (Denali), groups of migrating wolves that depend on caribou compete seasonally with groups that interact with moose and caribou primarily in fixed areas over annual (biological-year) time steps. Other groups interact with caribou, moose, and sheep in fixed areas without this seasonal competition (no wolf migrations). Caribou migrate predictably across much of the region for decades, then shift their ranges within the region and to other regions (*Haber 1977, Mech et al 1998*).

These foraging-related variations provide examples of the multiple- and cross-scale spatial-temporal interactions that characterize systems in general and are important to recognize for research and management purposes (*Gunderson and Holling 2002*). They can also help to clarify the biological and management significance of wolf social groups.

In previous publications (*Haber 1996, 1999*), I pointed to the decades-old Toklat and Savage groups of Denali in questioning the view that groups are generally short-lived and thus relatively unimportant. I argued that it is more accurate to think in terms of mixed mosaics of persistent and shorter-lived groups—that groups, rather than populations, are the primary functional units under natural conditions. [A “group” of wolves means a family or extended family in this paper, with the exception of the three as yet non-reproducing and apparently unrelated Eagle wolves in winter 2005-06 (*Figure 2*)]. Here, I consider details of the Denali foraging variations, what they imply about the varying extents to which the wolves develop and maintain social groups, and the significance of these groups.

Methods

I obtained wolf and prey data by summer ground observation at dens, rendezvous sites, and elsewhere in one of the areas (eastern—*Figure 1*) from 1966–2006, and by year-round aerial observation throughout all three areas. My field methods, data analyses, and the study area are described in detail in Haber (1977, 2002); the study area is also described in Mech et al. (1998). The most intensive winter observations were from small aircraft in 1969–1975

and 1995–2006. I conducted the 1995–2006 winter wolf observations for the most part at aerial radio-tracking locations that amounted to point samples. I conducted the 1969–1975 winter observations during “continuous-interval” samples: I located wolves—primarily two eastern groups, Savage and Toklat (East Fork)—by aerial snow-tracking on as many consecutive days as possible, directly observing them for prolonged periods and searching their intervening trails for evidence of all ungulate kills, winter kills, most ungulate tests, and other behavior. These intervals added up to a total sample of 2,666 miles (4,291 km) of the wolves’ activities across a virtually complete range of winter conditions in Denali (Haber 1977).

I delineated wolf territories subjectively by considering movements, radio tracking locations, behavior (e.g., often more aggressive or more tentative during extraterritorial forays), geographic features, and other field information. The more commonly used “95% minimum polygon” method subjectively excludes 5% of the locations even though many more than 5% could come from extraterritorial forays (*Figure 2*).

Results and Discussion

Figure 1 highlights three areas of differing wolf foraging patterns—eastern, central, and northeastern—and the territories of 80–100 wolves in 15 groups throughout Denali north

of the Alaska Range as of April 2006. Sixty-two of these wolves in eight groups resided in the three areas.

The two major eastern groups maintain year-round territories. They embark on sporadic extraterritorial winter forays, but these are seldom related to any regular ungulate movements and often follow periods of good within-territory hunting success. Sometimes, such as in the early 1970s and at present, a small offshoot group forms in the westernmost area, where ungulate availability is more of a cross between the eastern and central areas (thus the overlap in area boundaries). The current offshoot group (*orange territory in Figure 1*) embarks on particularly erratic winter extraterritorial forays, and like the early 1970s offshoot, appears unlikely to survive very long (Haber 1977, 2002, *present study*; Mech et al 1998; Meier et al 2006).

The eastern area coincides closely with the only major sheep habitat in Denali and includes moderate densities of moose that are generally highest in an eastward direction. Caribou migrate into the area during spring and summer and depart primarily to the west by fall. Wolves of this area hunt caribou regularly but sheep lightly, if at all, during summer. They rely heavily on sheep as well as moose the rest of the year, while the caribou are absent (Haber 1977, 2002, *present study*; Mech et al 1998).

Within the central area, there is usually a higher spring-fall abundance of caribou, albeit with varying major local scarcities. There are essentially no sheep and, other than in the northeastern portion, only low year-round densities of moose (Haber 1977, *present study*; Mech et al 1998; *unpublished National Park Service moose censuses*). By early-mid winter in most years, central groups have little choice but to migrate up to 70–80 miles (113–129 km) northeastward, often more than once per winter, to a traditional Denali caribou wintering area (Haber 1977) where they hunt and scavenge moose as well as caribou. Figure 2 shows examples of these northeastward wolf migrations.

Wolves of the northeastern area receive an abundance of caribou most winters but also high-risk competition from the migrating wolves. Numbers of wolves and groups of wolves typically double or triple due to central migrants

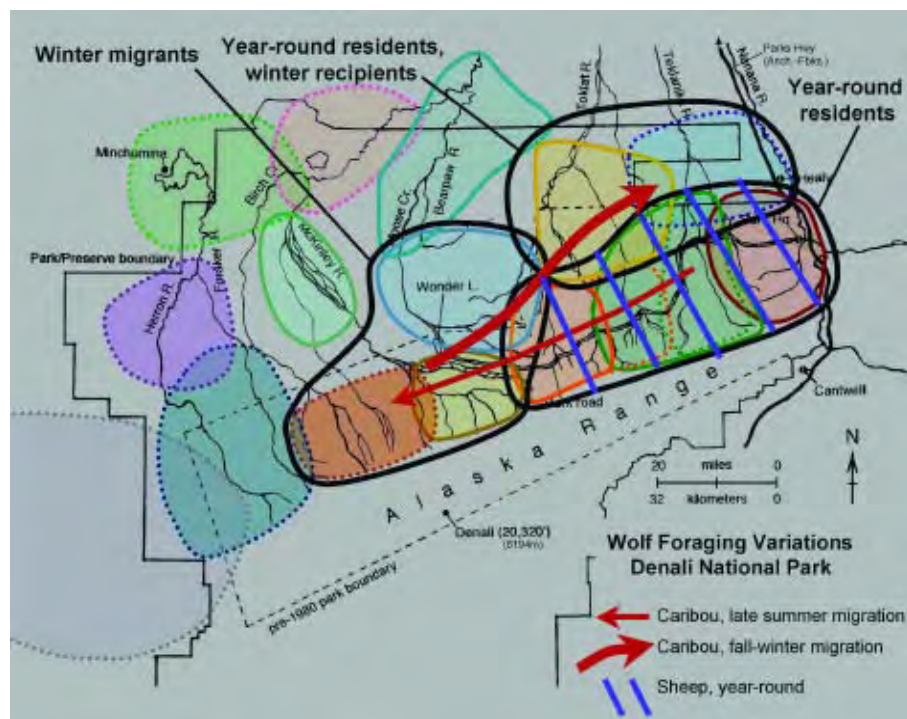


Figure 1. Wolves respond to differing winter foraging circumstances across three large areas of Denali National Park. In the eastern area, they remain primarily within year-round territories where they are able to hunt sheep as well as moose after most caribou leave. In the central area where there are no sheep and lower moose densities, they migrate northeastward with caribou, resulting in high competition and strife with the year-round northeastern residents and other migrant groups. Territories of 15 groups of wolves as of April 2006 are shown; the seven with dotted boundaries are somewhat speculative due to recent interruptions in radio-collar contact. The dotted green (Toklat/East Fork) and orange (Toklat West/Grant Creek) boundaries in the eastern area represent a contraction and expansion of territories following the trapping and shooting losses of the experienced Toklat adults in 2005.

alone; wolves from the north and probably east add to the total. In winter 2005-06, for example, 21 wolves in three migrating central groups added temporarily to the total of 13 wolves in the two major resident groups. The northeastern wolves do not reciprocate when most of the caribou return to the central area in late winter-early spring (*Mech et al 1998, present study*), apparently because of spring-summer denning constraints (attending immobile young at dens and rendezvous sites). They subsist on the relative few remaining caribou and low-moderate densities of moose.

The eastern wolves also maintained year-round territories during my 1969-1974 observations, despite more pronounced seasonal and longer-term caribou declines (*Haber 1977*). I did not follow the central wolves closely enough in 1969-1974 to determine how they responded to these changes. Figure 3 summarizes details of the eastern responses to the larger pre-1971 seasonal caribou departures and the final stage of an overall decline from at least 20,000-30,000 caribou in the 1920s-1930s to 8,000-9,000

in the 1950s-1960s to the current low stable state of 1,000-3,000 as of 1972.

Toklat was well established when I began my research in 1966 and is still present (*Figure 1, green eastern group*). National Park Service biologists, pilots, photographers, and others have also observed Toklat regularly since the late 1970s, and this group has been radio-collared continuously since 1986. Savage likewise was well established when I began my research in 1966. The 12 Savage wolves disappeared in winter 1982-83 while there were indications of possible illegal aerial hunting but not of any natural causes. Savage ranged east of the Toklat territory, within a larger version of the reddish territory shown in Figure 1.

When caribou numbers decreased to about 3,000 in 1971, there was an obvious summer scarcity of caribou for the eastern wolves, especially Toklat, compared to at least the previous five years. This was due to an abbreviated (more pulsed) westward migration from the then major southeastern calving area as well as the actual decline

(*Haber 1977*). The vertical dashed lines in Figure 3 identify this threshold.

Toklat changed in major social ways during this period. Before 1971, Toklat began the winters at a larger size and lost more wolves by the end of each winter. It had a loose social structure year-round; two males even seemed to be “co-alfas.” During these winters there were frequent separations into two or three temporary subgroups of varying combinations, most of which (75-100%) included experienced adults. Subgroups hunted the lower densities of resident moose and sheep and scattered remaining caribou in different areas of the 1,000-square-mile (2,600 km²) territory. By summer 1971, one of the two co-alpha males and at least two other adults or yearlings formed the offshoot (“Wonder Lake”) group noted earlier in the western third of the territory (*Haber 1977*), somewhat west of where the current Toklat offshoot formed in 1996-2003.

Toklat began each of the next two winters at a smaller size but was more cohesive (only about one-third as much

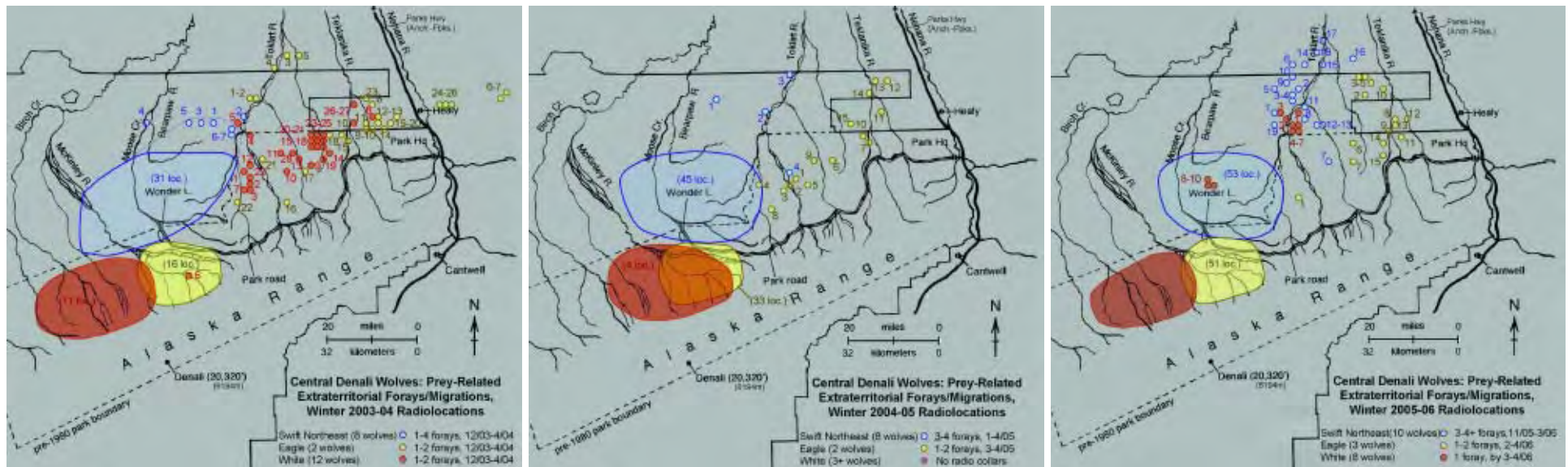


Figure 2. Examples of winter migrations, central Denali wolves, 2003-2006. Numbers indicate sequences of migratory locations and (in parentheses) locations within territories. The radio-collared White wolves died in summer 2004 (red-brown group on map). Regular contact was not reestablished with White until the alpha male was collared in March 2006 while this group was on a migration (location 1). Contact was lost again a month later when Swift Northeast (blue) intercepted White in its territory and killed the alpha male (location 10). Swift Northeast shifted eastward into a vacancy created when a smaller group died out in early 2003. (White is also known as Straightaway, Swift Northeast as McKinley Slough, and Eagle as Turtle Hill).

temporary winter splitting) and maintained about the same late winter size. The number of subgroups increased in the third winter (1973-74), but fewer of these subgroups (60-70%) included experienced adults. This coincided with an increased early winter group size, similar to circumstances of the age-dominance winter splitting in the cohesive Savage group.

Savage was afforded less access to caribou and thus was less affected by the seasonal and longer term caribou declines. After recovering to a normal size from shooting losses in 1968, Savage maintained a stable late winter size via a form of winter splitting that less often separated the core adults from each other (maintained more cohesion) but more often left young, inexperienced wolves on their own at a disadvantage, such that more died or dispersed. The frequency of this splitting was correlated with early

winter group size. Savage's winter foraging rates (meals/miles/days) changed little if at all during the 1969-1974 observations. Savage foraged two to three times more efficiently than Toklat amidst two to three times higher moose and sheep densities.

The foregoing suggests that under natural conditions there should be more turnover among the central and northeastern than the eastern groups. The former are subject to high risks from migration-related competition (recipients as well as migrants), and their prey bases are less diverse and of generally lower density. Data from Mech et al. (1998) and the present study indicate that there were 11-14 groups in the central area and 11 groups in the northeastern area over the last 20 years, but only 8-9 in the eastern area over the last 40 years. Each of the three areas usually supports 2-3 groups at a time (Figure 1). Known

or likely human impacts (trapping, shooting, collaring deaths) in 1-2 central, 3-4 northeastern, and at least 3 eastern terminations fall well short of accounting for these differences. Migration is a foraging strategy of last resort for Denali wolves from this standpoint, a solution to be expected only when there are no social or other alternatives.

It also follows that the longevity of the eastern groups should facilitate high levels of cooperation.

Cooperative hunting tactics were important to both Savage and Toklat because of the difficulty and danger posed by their physically superior prey, especially moose (Haber 1977). Behavioral observations as well as hunting success rates confirmed that it was usually much more difficult to capture and kill moose and sheep than caribou. Young wolves of these moose- and sheep-oriented groups required prolonged learning (two to three years) for hunting proficiency (Haber 1977). This implies higher overall levels of sociality than in the more caribou-oriented central and northeastern groups.

The eastern groups also exhibited sophisticated cooperative breeding behavior, including altruistic helping, although not much is known about any differences in this aspect of their sociality relative to the other groups.

Helpers, typically young females, often assist breeders as an artifact of their own potential direct fitness gains, such as from "practicing" for motherhood or delaying dispersal until resource conditions improve. However, much of the helping I observed in Savage and Toklat also appeared to be altruistic. It was commonplace for high-ranking, experienced males and females as well as young adults and yearlings to assist breeders, and even for breeders to assist other breeders (Haber 1977, *present study*).

For example, the second-ranking Savage male (Figure 4) was a capable wolf with an obvious desire to mate (Haber 1977). Yet, despite good prey conditions in surrounding areas, for at least three to four of his prime reproductive years he led most of the group's activities but deferred breeding to the alpha male. If he was the alpha male's sibling, as I suspected, this was kin selection at work; if

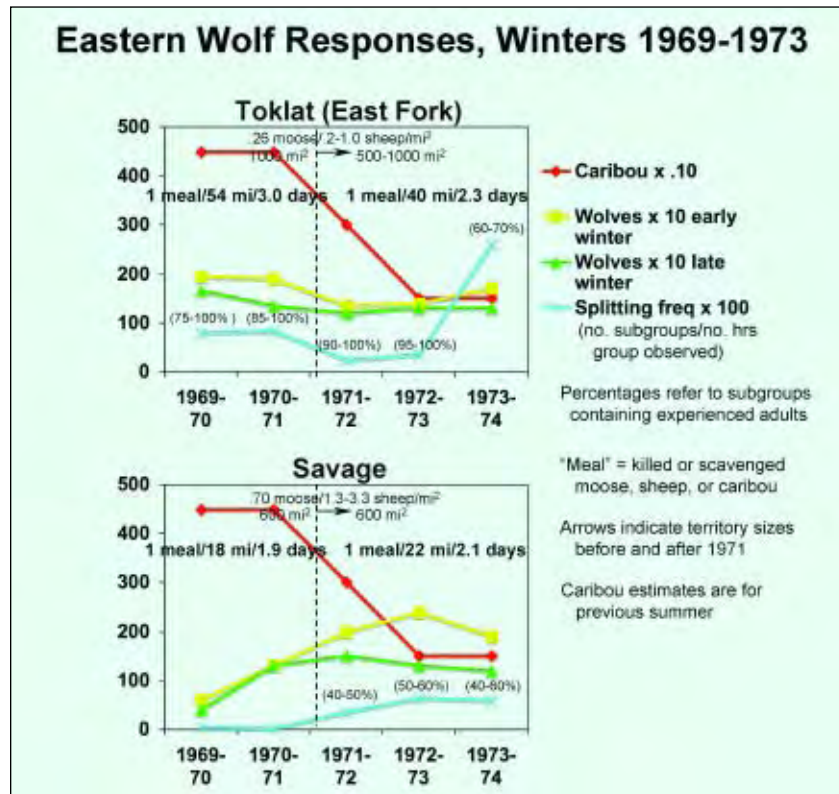


Figure 3. Prior to 1971, at least 4,000-5,000 caribou migrated out of the Toklat wolves' territory each summer. Instead of following, Toklat foraged amidst the lowered overall prey densities by often splitting into "experienced" subgroups. Summer group sizes decreased as caribou availability decreased sharply in 1971 and 1972. However, late-winter sizes remained about the same with a more cohesive social structure (fewer separations between experienced wolves). East of Toklat, where there was less access to the caribou but 2-3 times higher moose and sheep densities, Savage maintained about the same late-winter group sizes (after recovering from pre-1970 shooting losses) and higher winter foraging rates throughout the caribou decline. Savage's temporary winter splitting reduced large early-winter group sizes while maintaining the core social structure, by more often separating only the least experienced wolves. All data are from Haber (1977).

he was unrelated, it was likely some form of reciprocity (Clutton-Brock 2002, Nowak 2006). In 2001, two newcomer sibling males from 170 miles (275 km) away took over Toklat less than three months after the established alpha male died during radio collaring (Haber 2002). One became the new alpha. Both closely attended the unrelated dead male's four pups.

Conclusions and Management Implications

The eastern groups of wolves in Denali National Park and Preserve are long-lasting primary functional units with high levels of sociality, apparently including the ability to adjust socially to major prey changes. The central and northeastern groups interact and mix to a much greater extent, last on average less than half as long, probably do not develop comparable overall levels of sociality, and thus are less distinctive as functional units. There is no evidence for any larger-scale wolf functional units, least of all a Denali-area "population." Data on long range dispersals from Denali (Meier *et al.* 2006) and other observations indicate that the biological population to which Denali wolves belong covers a much larger area, probably extending all the way to the Arctic Ocean.

Agency wolf management policies are based on a population view, usually without reference to actual biological populations. Management emphasis should shift instead to groups, naturally short-lived as well as persistent. Even short-lived functional units are important in the multi-scale scheme of things at Denali and for systems in general. As recently as 2004-2006, Toklat, Margaret (the latest Savage successor), and two northeastern groups suffered heavy trapping and hunting losses on adjacent state lands in the northeastern area east of Savage River. The importance of park groups that venture temporarily to this area from near and far (Figures 1-2) warrants an immediate wolf trapping and hunting closure.

I thank Friends of Animals for funding this research since 1993.



Photo courtesy of Gordon Haber

Figure 4. Extreme cooperation. The beta male of the Savage group was an altruistic helper for at least 3-4 years, leading in most routine activities while deferring breeding to the alpha male, who usually followed passively. In this 1971 photo, the beta male is leading and the alpha male is at the end of the line.

References

- Clutton-Brock, T. 2002.**
Breeding together: Kin selection and mutualism in cooperative vertebrates.
Science 296:69-72.
- Gunderson, L.H., and C.S. Holling. 2002.**
Panarchy: Understanding transformations in human and natural systems.
Island Press. Washington, D.C.
- Haber, G.C. 1977.**
Socio-ecological dynamics of wolves and prey in a subarctic ecosystem. Ph.D. dissertation, Univ. of British Columbia, Vancouver.
- Haber, G.C. 1996.**
Biological, conservation, and ethical implications of exploiting and controlling wolves.
Conservation Biology 10:1068-1081.
- Haber, G.C. 1999.**
A selective view of wolf ecology.
Conservation Biology 13:460-461.
- Haber, G.C. 2002.**
Toklat, Margaret, and Sanctuary: The wolves of eastern Denali. Biological year 2001-02 responses to disruption.
Research report, Denali National Park Resource files.
- Mech, L.D., L.G. Adams, T.J. Meier, J.W. Burch, and B.W. Dale. 1998.**
The wolves of Denali.
University of Minnesota Press.
Minneapolis, Minnesota.
- Meier, T., J. Burch, and L. Adams. 2006.**
Tracking the movements of Denali's wolves.
Alaska Park Science 5(1):30-35.
- Nowak, M.A. 2006.**
Five rules for the evolution of cooperation.
Science 314:1560-1563.

Fisheries and Subsistence





Photo courtesy of University of Alaska Fairbanks, Rasmuson Archives

An American-Canadian Traditional Ecological Knowledge Study of the Upper Tanana River Fisheries

by Connie Friend, Gary Holton and Norman Easton

Abstract

This project examines ethnographic information collected from knowledgeable fishers in seven Native villages in the Upper Tanana River Valley, which runs through eastern Interior Alaska and into the Yukon Territory, Canada. The local governments of five of these villages had expressed concerns regarding the health and status of their fisheries. Researchers combined ethnographic interviews, linguistic documentation and analysis, mapping and survey techniques to provide a historic and contemporary picture of traditional ecological knowledge and subsistence practices among the Upper Tanana fisheries. Research results suggest there is significant local knowledge of natural laws of interdependence linking the various historic and contemporary fisheries in the Upper Tanana drainage. Such information can provide managers with additional information about relationship to place and the interdependence of traditional subsistence users and nature (*See Basso 1996*). Additionally, it provides a temporal and social context for a recent Upper Tanana telemetry study of humpback whitefish (*Coregonus pidschian*) seasonal movements (*Brown 2006*).

Mansfield Fish Weir
circa 1940s or '50s.

Introduction

Native villages began expressing concerns about the health and safety of their subsistence resources, especially fish, about the year 2000. Requests for studies came to the Tetlin National Wildlife Refuge from the villages of Northway, Tetlin, Tanacross, Dot Lake and Healy Lake. A three-year telemetry study of the whitefish (*Coregonus pidschian*) of the Upper Tanana River was begun in 2000 (Brown 2006), and the following year, *A Traditional Ecological Knowledge Study of the Fisheries of the Upper Tanana River* was initiated. Information for this monograph is derived primarily from the latter study (Friend et al. 2007). This paper focuses on a brief history of the fisheries, the historic and contemporary social aspects of the fisheries and the unique relationship of the people with the resource.

Purpose

Our purpose was to document local knowledge developed over generations by indigenous people in seven Upper Tanana villages: Beaver Creek (Canada), Northway, Tetlin, Tok, Tanacross, Dot Lake and Healy Lake (Alaska). Through this process, past and current harvest information, adaptive patterns and especially traditional ecological knowledge regarding fisheries



Photo Tetlin NWR files

Figure 1. Tanana River upstream from Tanacross Village.

resources would be brought forward to assist in management decisions.

Methods

Looking to recent Traditional Ecological Knowledge (TEK) studies that had been done, as well as trying to fill in some of the blanks for the western scientific study, specific questions were asked about seasonal movement, feeding patterns, diet, spawning sites as well as cultural traditions. Over a period of three years, 42 fishers were interviewed. Interviews were a combination of structured and non-structured inquiries done in groups whenever possible, in order for the dynamic to be more interactive. This was especially true for the linguistic component. Researchers also participated in culture camps held at fish camps in four separate fisheries.

Linguistic Discussion

Crucial to the understanding of the Traditional Ecological Knowledge of fisheries is a thorough investigation of the indigenous fish taxonomy. Three distinct Native languages are spoken in the Upper Tanana River drainage: Southern Tutchone (in Canada), Upper Tanana and Tanacross (in Alaska). By including a linguistic component, a more thorough understanding of place names and their significance can be applied and other information gleaned. For example, when considering the generic word for fish, *tuug* (or *tuugn* in Upper Tanana), which is used in similar forms throughout Alaska and elsewhere, the meaning changes from salmon (the most common meaning) to whitefish in the Upper Tanana. Thus, the language re-enforces the priority of whitefish over salmon in the Upper Tanana region (see Figure 1). This is not to say that the Upper Tanana people did not eat salmon. They traveled long distances on foot (summer-long journeys) to the Yukon and Copper rivers to obtain salmon and to trade (Guédon 1974). Today, this practice continues with people visiting both rivers to bring home salmon. Elders also informed us that the Copper River people like to have whitefish for a change in their diet.

Language	Term	Specific meaning
Ahtna	tuk'ae	salmon
Dena'ina	tiq'a	salmon
Deg Xinag	legg	salmon
Upper Kuskokwim	tuk'a	salmon
Koyukon	look'e (tuk'E)	salmon
Gwich'in	tuk	salmon
Lower Tanana	tuk'a	salmon
Tanacross	tuug	whitefish
Upper Tanana	tuugn	whitefish

Figure 2. Athabascan Terms for 'Fish'.

Results and Conclusions

The TEK research in the Upper Tanana conveyed an important message to resource management. The 42 consultants shared a basic belief: by right action and observance of cultural traditions, people would be able to influence natural events to the extent that their needs would be met and the resource—fish, plant or animal—would give itself freely. We have labeled this belief system, *'An Elemental Reciprocal Agreement'*. Central to it are traditional values of sharing, taking only what is needed, being respectful of the resource, and not wasting. This paradigm constitutes an ancient worldview that links the hunter-fisher-gatherer inextricably to the land and provides researchers and management with an ancient paradigm, which can be re-interpreted for present day conservation concerns (Cajete 2000).

Although whole villages are not migrating to fish camps as they once did, the fish camps continue to play a significant role in the lives of the indigenous people of the Upper Tanana today. The fish camps are still a place of laughter (Kawagley 2006) and respect learned. In Tetlin, the young people are taught to hang the fish in the same direction in which they were swimming as a sign of respect. At camp,

young people are taught not to play with their food, nor to take more than they can eat, to have right thoughts and attitudes, to share and not to waste. The traditional culture is taught at fish camp. Rather than being a quaint, out-dated experience, the experience and the teachings are in-depth models of modern conservation principles (Cajete 2000).

To the traditional Upper Tanana Native person, there is a sacredness associated with the land and with the harvesting of foods. Fish camp is considered a sacred place; it is kept clean and treated with respect. Cares that come with living in the fast paced twenty-first century are put aside. A deep joy and connectedness settles in and prevails for a time. Fish camp provides a healing environment for Native people, particularly the elders. This sacred relatedness to the land and to each other is manifested in multiple ways that inform the ethics which govern the traditional Native person's actions. One elder expressed it succinctly:

So when a chief comes to your door, he doesn't have to have an army. She doesn't have to have a judge. He doesn't have to have a warrant. He doesn't have to have accusations of any kind; because in a secular and a sacred society when violations occur on an individual basis, (they) are accepted by the individual. So when you say, 'traditions' today, you're really talking

about an individual covenant and that's when you hear the old people say, not 'Our Law' (but) 'Our Way': our traditions. How that operates on a daily basis is relatively easy to understand. (Friend and De Fries 2005)

In documenting the elders' Traditional Ecological Knowledge, we learned what fish eat, where fish eat, confirmed two spawning ground locations discovered by Brown's telemetry study (2006) and the basis of the 'Elemental Reciprocal Agreement'. Apart from the agreement, we have been learning about the uniqueness of each fishery.

Scottie Creek

The Scottie Creek fisheries became the destination for people who walked there from the Wrangell-St. Elias mountains during two eruptions of Mt. Churchill. The first occurred plus or minus 1,900 years ago and the second, approximately 1,250 years before present (Richter et al. 1995). The Scottie Creek fishery, which has been visited by indigenous people from both Canada and Alaska for millennia, was recognized by elders to have once been a place of natural riches and prosperity. Even salmon (*Oncorhynchus keta* and *O. tshawytscha*), which are rare in the Upper Tanana, were said to have been abundant at Scottie Creek two or three generations ago.

Isaac Juneby, former Chief of Eagle village defines Traditional Knowledge as follows: ...Traditional Knowledge should not be over looked, discounted in addressing cultural resource management simply because it is not written down. Traditional Knowledge is the property of the people who possess it. Traditional Knowledge is respected, used and passed on. Traditional Knowledge also provides the Alaska Natives with an understanding of who they are. (In speech to the Upper Tanana Cultural Resource Summit 2005, see also Berkes 1999).

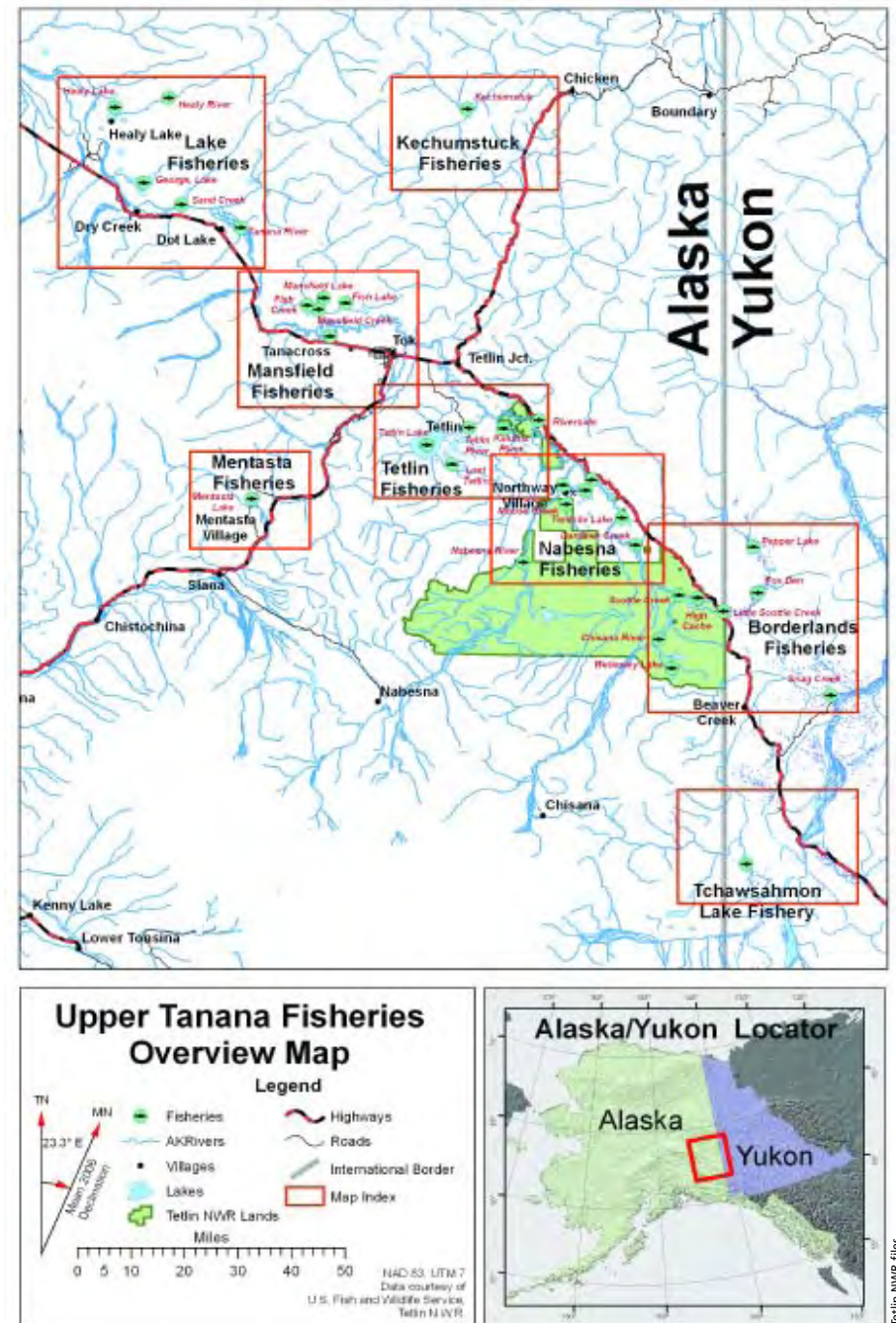


Figure 3. Upper Tanana Fisheries Map

Last Tetlin

The Last Tetlin fishery (Figure 3) has been cited throughout past generations for the succulent, large, fat fish that abound there. In more recent times, there has been a decline in both numbers and the size of these fish (virtually all species). Two years ago there was a run of malnourished and diseased whitefish in the Tetlin River, while at the same time, the lake whitefish were fat and good tasting. One elder believes that part of the cause of the malnourished fish may be the shift in habitat caused by the Denali Fault earthquake in 2002. This earthquake registered 7.9 on the Richter scale (*US Geological Survey Fact Sheet 014-03*) and caused four-foot mud slides on the Tetlin River.

Mansfield and Healy Lake

The Mansfield and Healy Lake fisheries rivaled Last Tetlin in the past for quality whitefish. Tanacross villagers currently cite beavers as building blockages in creeks, which prevent whitefish from coming upriver to spawn and also prevent water flow. Today there are fewer whitefish in



Figure 4. Beaver Creek, Yukon CA Culture Camp attended by Canadians and Alaskans at Pick Handle Lake, Yukon, Canada, Summer 2006.

Mansfield Creek and Lake and the size has decreased according to local fishers.

Numerous deformed fish have been found in the Healy Lake fishery causing concern about contaminants in the water. The military has done some remediation regarding numerous contaminants left in and around the lake more than 50 years ago. The Nabesna fisheries also share this concern as the military impacts to lands and waters in the area have been exposed and somewhat remediated.

Recommendations

By considering the Native paradigm of multifaceted connections to place and resource, managers will be able to

incorporate other avenues of awareness and discernment to evaluate what may be necessary for quality stewardship and sustainability in a variety of circumstances.

Too few youth are receiving the teachings that will help them live lives that support sustainability of the resources. Elder-youth programs and teaching traditional values and activities need to be incorporated into school science programs and education and outreach workshops.

Native elders and leaders need to be encouraged to communicate their unique paradigm to resource managers and coordinators, youth and the general public and to sit on councils that make recommendations to the federal subsistence board.

References

- Basso, Keith H. 1996.**
Wisdom Sits in Places: Landscape and Language Among the Western Apache.
University of New Mexico Press, Albuquerque, NM.
- Berkes, Fikret. 1999.**
Sacred Ecology.
Taylor and Francis. Philadelphia, PA.
- Brown, Randy J. 2006.**
Humpback Whitefish (Coregonus pidschian) of the Upper Tanana River Drainage.
Alaska Fisheries Technical Report Number 90.
Fairbanks Fish and Wildlife Field Office.
Fairbanks, Alaska.
- Cajete, Gregor, Ph.D. 1999.**
Native Science: Natural Laws of Interdependence.
Clear Light Publishers. Santa Fe, New Mexico.
- Friend, C. and De Fries, T. 2005.**
Upper Tanana Cultural Resource Summit, Tok, Alaska.
Sponsored by the Tetlin National Wildlife Refuge, and the Alaska Fire Service
- Friend, C., G. Holton, C. Brown, M. Koskey, N. Easton. 2007 in press.**
A Traditional Ecological Knowledge Study of the Fisheries of the Upper Tanana River.
U.S. Fish and Wildlife Service. Anchorage, Alaska
- Guedon, Marie-Francoise. 1974.**
People of Tetlin, Why Are You Singing?
Paper No. 9 Mercury Series.
Ethnology Division, National Museum of Man, National Museums of Canada. Ottawa, Canada.
- Kawagley, Angayuqaq Oscar. 2006.**
A Yupiaq Worldview: A Pathway to Ecology and Spirit. Second Edition.
Waveland Press, Inc. Long Grove, Illinois.
- Richter, D.H., S.J. Preece, R.G. McGimsey, and J.A. Westgate. 1995.**
Mount Churchill, Alaska: The source of the late Holocene White River ash.
Canadian Journal of Earth Sciences 32:741-748
- U.S. Geological Survey Fact Sheet 014-03. 2003.**
Rupture in South-Central Alaska-The Denali Fault Earthquake of 2002.

Connecting Place with Science: Katie John and the Tanada Creek Fish Weir

by Vicki O. Penwell

When planning field work, researchers generally select the place for their research based on the location of a specific feature or resource. But “place” is more complex than a set of GPS coordinates. When researchers consider place as a complete landscape with natural and human elements and use that landscape as part of their research design, the result will be a more complete investigation with more relevance to the public. In addition, as national parks strive to reconnect people to protected places, recognizing and honoring connections already present establishes trust and collaboration with stake holders. For example, by honoring the connection Elder Katie John of Mentasta has to a specific place and a specific resource, Wrangell-St. Elias National Park and Preserve (Wrangell-St. Elias), through the Tanada Creek Fish Weir, has experienced better relations and greater collaboration with traditional users of park resources.

Nataetde

People are as much a part of the Wrangell-St. Elias landscape as the horizon dominating Wrangell Mountains. Ahtna people have lived in the Copper River basin for at least 6,000 years (Bleakley 2006). Each Ahtna band had a territory that included summer fish camps, winter hunting and trapping camps, and places to harvest other resources. The two most critical resources to the Ahtna were salmon and caribou.

For the Upper Ahtna, *Nataetde*, which is the village now known as Batzulnetas, is an important site both in terms of historic events and the resources available there. The last generation of Ahtna to grow-up at Batzulnetas are now Elders. Thanks to them, park researchers have invaluable access to traditional ecological knowledge. The ties between Elders and Batzulnetas and other traditional seasonal camps in Wrangell-St. Elias are evident in stories associated with the sites. These stories teach cultural norms and values as well as traditions. New stories emerge each year, perpetuating the enduring connections between people and place.

Lieutenant Henry T. Allen visited *Nataetde* during his exploration of the Copper, Tanana, and Koyukuk Rivers in 1885. One of Allen’s assignments was to assess the potential threat posed by natives, so he recorded his observations about the Ahtna and Upper Tanana people whose villages he visited and who served as guides for his expedition. Allen traveled as far up the Copper River as *Nataetde* before turning north toward the Tanana. He arrived at *Nataetde* on June 2, 1885. Allen was met by 45 villagers led by *Bets’ulnii Ta’*, the chief of the village.

Allen stayed only two days in *Nataetde*. There was very little food and the people were anxiously awaiting the arrival of the first salmon of the summer. During Allen’s two-day stay in the village, the first fish arrived. Allen described it as a “rather small silver salmon” that was given

a place of honor on one of the spruce bough shelters. In spite of the promise of hundreds of fish, Allen decided to leave. He left *Nataetde* on June 4 for Suslota Lake where he hoped to find caribou (Cole 1985).

Allen’s maps of the upper Copper River refer to *Nataetde* as Batzulnetas Village (Cole 1985). Since the miners and others who followed him relied on his maps, the name stuck. He probably understood that was not the name of the village but rather the name of the chief, *Bets’ulnii Ta’*, Father of Someone Respects Him (Kari 1986).

Katie John

Katie John is one of Charley and Sarah Sanford’s children. She was born in 1915 near *Sil’ana’* (the Slana River) and grew up at Batzulnetas. Katie spent her youth making the seasonal rounds between summer fish camp at Batzulnetas and hunting and trapping camps. She knows the old ways of harvesting and preparing food and the rules people followed to live together peacefully. Katie calls these “Indian Laws” (Katie John, *personal communication*). According to Katie, breaking rules associated with salmon and salmon harvest is particularly *engii* (taboo), because the Ahtna understand the life-cycle of the salmon, it’s journey to the sea and coming back to die (Kopchak 2005).

One of Katie’s Batzulnetas stories is about her father’s fence across Tanada Creek and the fish traps built for harvesting sockeye salmon. The fence was built of spruce branches and willow. There was an opening in the middle of the fence where her father placed the traps. They were cylinders made of spruce branches and spruce roots and designed so that the salmon could swim into the trap but couldn’t swim back out. A trap could hold as many as 60 salmon. Every so often, the traps would be removed and the fish prepared for drying. The traps stayed out of the creek while fish were processed. During this time, the

salmon could pass through the fence and go to Tanada Lake. In about 1943 a few years prior to Charley Sanford's death, Katie remembers a game warden came to Batzulnetas and told her father he couldn't block the creek like that. This visit proved to be the first collision between "white fella's law" and "Indian law" when it came to managing salmon (Katie John, *personal communication*).

Katie married Fred John in 1932. They raised 14 children and numerous adopted children. Their home was at Mentasta Lake, but Katie and Fred continued to utilize many of the same traditional camps that Katie had as a child. Beginning in about 1950 when children were required to attend school, Fred and Katie reduced their travel but still returned to Batzulnetas for salmon. Then in 1964, the Alaska Board of Fisheries and Game closed subsistence fishing at Batzulnetas. By this time, the Copper River fishery supported large numbers of subsistence, sport, and commercial salmon fishing activities. State managers feared that if too many salmon were harvested up river, it would lead to fewer fish being available to down river consumers (Norris 2002).

Katie John v. State of Alaska and the United States

Following the establishment of Wrangell-St. Elias NP&P, Katie and Doris Charles of Dot Lake decided that they wanted to go back to Batzulnetas to fish. In 1984, Katie and Doris presented their proposal to the Alaska Board of Fisheries. The board denied the proposal. Katie and Doris were told to fish at downriver sites where subsistence fishing was allowed (Norris 2002).

In 1985 Katie and Doris, represented by the Native American Rights Fund (NARF) filed suit against the State of Alaska (*Katie John vs. State of Alaska*). In 1987, the Alaska Board of Fisheries ruled that locals could be issued permits

to harvest 1,000 salmon at Batzulnetas. Then in 1989 the Alaska Supreme Court issued its *McDowell* decision, striking down any preference given to rural native and non-native subsistence users over Alaskans living in urban areas. "The net result of the year's two court decisions was the creation of a subsistence fishery that included Batzulnetas in which all Alaskans could take part, regardless of their rural or urban residency" (Norris 2002).



Katie John and Vicki Penwell, 2006 Day Camp.

In 1990 Katie and Doris filed a new law suit against the federal government. Essentially, *Katie John vs. United States of America* sought to broaden the definition of "public lands" found in the Alaska National Interest Lands Conservation Act (ANILCA) to include navigable waters and specifically for a federal subsistence fishery at Batzulnetas.

On April 20, 1995, Senior Circuit Judge Eugene A. Wright of the Ninth U.S. Court of Appeals issued the court's ruling in favor of Katie John. The Court found that public lands include those navigable waters in which the United States has an interest. On October 1, 1999, after numerous delays, federal agencies began managing subsistence fishing. Alaska Governor Tony Knowles having failed to secure a state constitutional subsistence amendment, visited Katie John at Batzulnetas in August 2001 and told her there would be no further appeals by the state (Norris 2002).

Batzulnetas Culture Camp

In June 1995 Mentasta Lake Village and Cheesh'na Village came together for a Culture Camp to honor Elders, to celebrate the Ninth Circuit Court's decision, and Katie and Doris' acquisition of allotments at Batzulnetas. Village leaders intended the camp to be a one-time event, but according to Wilson Justin, of Mount Sanford Tribal Consortium, the camp was so popular and the demand for additional camps so high, the two villages decided to make

the camp an annual event. In 1996, John Jarvis, then superintendent of Wrangell-St. Elias, received the first invitation to attend Culture Camp, beginning a tradition honored today (Wilson Justin, *personal communication*).

Tanada Creek Fish Weir

In the fall of 1996, Wrangell-St. Elias received funding to install a weir in Tanada Creek just below Batzulnetas. A weir is a fence that blocks the migration of fish upriver with a gate that can be opened to allow the passage of fish. Often, as is the case for the Tanada Creek weir, the gate is part of a large box that allows fish to be trapped and biological sampling done prior to the fish moving upstream. A crew of three or four per shift would access the site using the existing trail from Nabesna Road but would need to cross Katie John's allotment to access the creek and to operate the weir. Katie agreed, and the first Tanada Creek Fish Weir was installed in June 1997.

The original purpose of the weir was to document abundance and run timing of Tanada Lake sockeye salmon stocks, and to ensure that the Batzulnetas subsistence fishery was not having a negative impact on the sustainability of the stocks. Run abundance and timing are still important elements of the research underway at the weir. In addition, park managers use weir data to assess the overall health of sockeye populations in the Copper River upstream of the Gulkana River. Most of the sockeye salmon that migrate up the Copper River spawn outside of the park. The Tanada Lake sockeye salmon stocks are some of the largest to spawn and rear within park/preserve boundaries, so monitoring is a high priority (Veatch and McCormick 2005).

The first weir was a rigid or picket weir. It consisted of a series of galvanized poles connected together to create a fence across the creek. A "box" was installed in an opening in the fence in the channel of the creek. The box had gates at either end that could be opened or closed. During periods when the crew was present, the gates were open allowing fish to pass up stream through the box. The crew manually counted each salmon. Salmon could be trapped in the box so the crew could collect biological data.

Tanada Creek is subject to high water events and the rigid weir did not perform well under flooding conditions.

In 2001, the rigid weir was abandoned in favor of a floating resistance board weir. This design incorporates a system of PVC conduit stringers anchored to a cable on the creek bed. A resistance board attached to the conduit uses the current to keep the stringers afloat.

High water events still posed a problem. In some cases water flooded over the bank of the creek and salmon bypassed the weir entirely. Both as a measure to replicate the weir count and as a fail-safe during flooding, a video monitoring system was installed in 2001. This system was in place adjacent to the weir until 2006 when it was moved to a location approximately one mile upstream from the weir.

Connecting Science and Place

Katie John is 90 years old and still goes to Batzulnetas for the week of Culture Camp. She sleeps in a tent on a pad on the ground each night and says she never sleeps better. Katie told me that she wants her kids to build her a cabin there. She laughed and said she thinks they will not do it because they know she will never want to leave. As Katie tells the story about her father's "fence", she gestures to the creek and uses her hands to simulate building the traps. Each time I hear her words and look at the creek, I can imagine the fence. The smell of smoke from the smoldering fire under the drying salmon and moose reaches me and it is difficult to come back to the present.

During Culture Camp, people meet each other on the trail going to Batzulnetas for camp or going to work at the weir. Usually we stop to talk—how are the bugs, did you get a moose yet, are you staying for lunch? While we sit around the fire together, we share concerns about daily life and always talk about salmon. The Elders tell stories about early days in Batzulnetas. Through these stories, we have learned that the Tanada Creek fishery has changed. The Elders say the fish are smaller and there are not as many. They also say that the area has much more brush than it did years ago.

Eric Veach, Chief of Natural and Cultural Resources for Wrangell-St. Elias, notes that the relationship between the weir and Culture Camp provides him with valuable traditional ecological knowledge about the salmon and the ecology of Tanada Creek. It also provides him with an additional way to assess the needs of subsistence users. By visit-

ing with villagers during the summer rather than waiting until the winter, he has a better understanding of people's fishing goals and of their needs. With salmon as an icon of common interest, a trust-based relationship has developed. Eric and his staff have a strong commitment to the project because they realize that what they are doing has meaning to the people making use of the resource.

Katie's granddaughter, Kathryn Martin, echoes Eric's sentiments. Over the years of watching the weir and getting to know park staff better, she can trust park staff with her concerns. Kathryn thinks that, this positive experience has led park managers to have a higher level of understanding of Ahtna culture and more sensitivity about how decisions might affect traditional practices (*Kathryn Martin, personal communication*).

During the summer of 2006, I spoke with people from Mentasta, Chistochina and Slana about the weir. Without exception, local residents enthusiastically supported the weir. Wilson Justin told me that the park's interest in the Batzulnetas salmon shows people that park management cares about the things that are important to them. People at Culture Camp appreciate that something they had known for so long is being formally studied. Residents of Slana also supported the project. Overall, people expressed pride in the project and assumed that it would always be there in some form or another.

Conclusion

Places are more than points on a map. They are part of peoples' sensory experiences, of the collective memory of a culture and are characters in stories that preserve traditional knowledge. When places are considered in this way, it is easier to understand why Katie John did not want to fish any place but Batzulnetas and why the Tanada Creek Fish Weir accomplishes more than just counting fish.

Researchers and managers can make projects more relevant to people by looking for connections that already exist and considering how projects might enhance those connections. By incorporating opportunities for people to share their knowledge and their stories, research will be more relevant to them and to the public in general.

When peoples' connections to places are honored,

agencies become groups of individuals and more approachable. By honoring connections, management efforts take on a proactive, problem solving role, and people regard research as having practical applications. Honoring the connections of elders and others to these places by making use of and valuing traditional knowledge and individual stories makes parks more relevant and more emotionally accessible to a public increasingly centered in urban areas. Most importantly, honoring existing connections between protected places and people leads to future generations of park stewards.

References

- Bleakley, Geoff, PhD. 2006.** Wrangell-St. Elias National Park and Preserve Historian, Copper Center, Alaska.
- Cole, Terrence, editor. 1985.** *An Expedition to the Copper, Tanana and Koyukuk Rivers in 1885, Lieutenant Henry T. Allen, Second United States Cavalry.* Alaska Northwest Publishing Company. Anchorage, Alaska.
- Justin, Wilson. 2006.** Mount Sanford Tribal Consortium Vice President, Chistochina, Alaska.
- Kari, James. 1986.** *Tat'ahwt'aenn Nenn', The Headwaters People's Country—Narratives of the Upper Ahtna Athabaskans.* Alaska Native Language Center, University of Alaska Fairbanks.
- Kopchak, RJ, Workshop Coordinator. 2005.** *Copper River Salmon Workshop Series, Workshop No. 1.* Anchorage, Alaska.
- Norris, Frank. 2002.** *Alaska Subsistence, A National Park Service Management History.* Alaska Support Office, National Park Service. Anchorage, Alaska.
- Veach, Eric R., and Molly B. McCormick. 2005.** *Abundance and Run Timing of Adult Salmon in Tanada Creek, Wrangell-St. Elias National Park and Preserve, Alaska, 2004.* Wrangell-St. Elias National Park and Preserve. Copper Center, Alaska.

Science for Management





National Park Service photo by Laura Phillips

An Integrated Study of Road Capacity at Denali National Park and Preserve

by Laura Phillips, Philip Hooge, Tom Meier,
Patricia Owen, Carol McIntyre, and Lucy Tyrrell

Abstract

A single, dead-end road provides access to the interior of Denali National Park and Preserve. Traffic on the road is restricted mostly to buses, and a limit of 10,512 vehicle trips per season (typically, May through September) is presently in place. While that limit has not yet been reached, park visitation increases annually and park managers anticipate requests to increase the current limit. In order to evaluate the road traffic limits and the impacts of traffic volume, we have designed a multidisciplinary study to help with the management of park road traffic. Components of our study include describing movements of Dall sheep and grizzly bears in relation to traffic, modeling patterns of vehicle movement, and identifying factors affecting visitor experiences. This research will allow park managers to make informed decisions about managing traffic along the Denali Park Road to protect resources and maintain high quality visitor experiences.

Figure 1. VTS buses stop to allow visitors a view of Mt. McKinley on the Denali Park Road.

Introduction

The 90-mile Denali Park Road, built to access Mount McKinley National Park and the Kantishna mining district, received relatively little use from 1938 until 1971. Use of the road tripled between 1971 and 1972 with completion of State Hwy 3 between Fairbanks and Anchorage. Due to this increase, park managers restricted use of private vehicles along the road beyond the Savage River and implemented a visitor transportation system (VTS) to protect park resources. The VTS relies on a bus fleet to transport visitors along the park road (*Figure 1*). In 1986, Denali's General Management Plan established an annual limit of 10,512 vehicle trips beyond the Savage River. While that limit has not yet been reached, park visitation increases annually and park managers anticipate requests to increase the current annual limit.

We developed a multidisciplinary project to determine the capacity of the Denali Park Road. Components of our study include examining movements of Dall sheep and grizzly bears in relation to traffic and habitat using Global Positioning System (GPS) technology, modeling patterns of vehicle movement using on-board GPS receivers, and implementing visitor surveys to identify factors affecting visitor experiences. Park managers will rely on models developed from study results to determine whether the road is currently over-capacity, at-capacity, or under-capacity.

This paper summarizes the study design and methods established in 2006 to begin integrating various components of the road capacity study and collecting data.

2006 Objectives

- Develop an integrated research design and build partnerships with cooperators to begin data collection.
- Deploy GPS units on 100 VTS and tour buses and 50 National Park Service vehicles using the park road.
- Conduct 120 qualitative visitor experience surveys.
- Capture and fit 20 grizzly bears within the road corridor with GPS collars.
- Develop methods to ground truth GPS data using driving surveys and traffic counters.

Methods

Wildlife movements will be examined to determine the effects of traffic on use of habitats adjacent to the park road or restrictions to migratory movements. GPS data from 20 grizzly bears was downloaded and plotted in ArcGIS (Figure 2).

Cooperators asked 120 visitors a series of qualitative

questions pertaining to their experience on the Denali Park Road to identify indicators of a quality park experience. These indicators will later be used to build a quantitative assessment tool to create social standards for visitor experience.

Examples of survey questions asked include:

- How does the number of vehicles on the Denali Park Road affect your enjoyment of visiting the park?
- Have you seen visitors or vehicles on the Denali Park Road disrupt the natural behavior of wildlife?
- If you could make changes to the Denali Park Road, what would they be?

Traffic simulation will be used to model bus driver behavior, traffic interaction with wildlife sightings, and logistics for vehicle operations. Vehicle locations on the park road were automatically uploaded from on-board GPS units by remote base stations throughout the park. Traffic counters monitored the numbers of vehicles along sections of the park road (Figure 3).

The results of these studies will be used to develop modeling rules that reflect standards for traffic effects on wildlife, quality of visitor experience, and logistical constraints of the current transportation system. These rules will then be input into a dynamic road capacity model that will integrate the modeling rules and determine whether the Denali Park Road is under-capacity, at-capacity, or over-capacity.

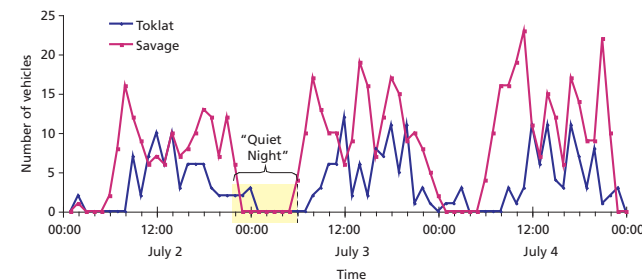


Figure 3. The number of vehicles traveling west on the park road every hour as measured by traffic counters at Savage (mile 15) and Toklat (mile 53) for three days during summer 2006. “Quiet night” refers to an experimental restriction on vehicles traveling the road every Sunday night.

Management Implications

If models suggest that traffic might be increased without negatively affecting park resources or visitor experiences, the park will develop an Environmental Impact Statement to determine alternatives for new traffic patterns and limits. If traffic is increased, the park will implement a Before-After-Control-Impact (BACI) study to assess the impacts of increased traffic on biological, physical, and social indicators. The experimental approach of this study would allow testing of model predictions. This research effort will allow park managers to make informed decisions about managing traffic along the Denali Park Road to protect resources and maintain high quality visitor experiences.

Acknowledgements

We thank our cooperators Robert Manning and Jeff Hallo, University of Vermont; Max Donath, Ted Morris, and John Hourdos, University of Minnesota; Rick Mace, University of Montana; Jim Lawler and John Burch, National Park Service. We also acknowledge the valuable assistance of Amanda Peacock, Jon Paynter, Joe Van Horn, Brad Ebel, Tim Taylor, Phyllis Motsko, Grady Wilson, Joe Durrenburger, Craig Brandt, Jeff Wysong, and Brian Hewitt.

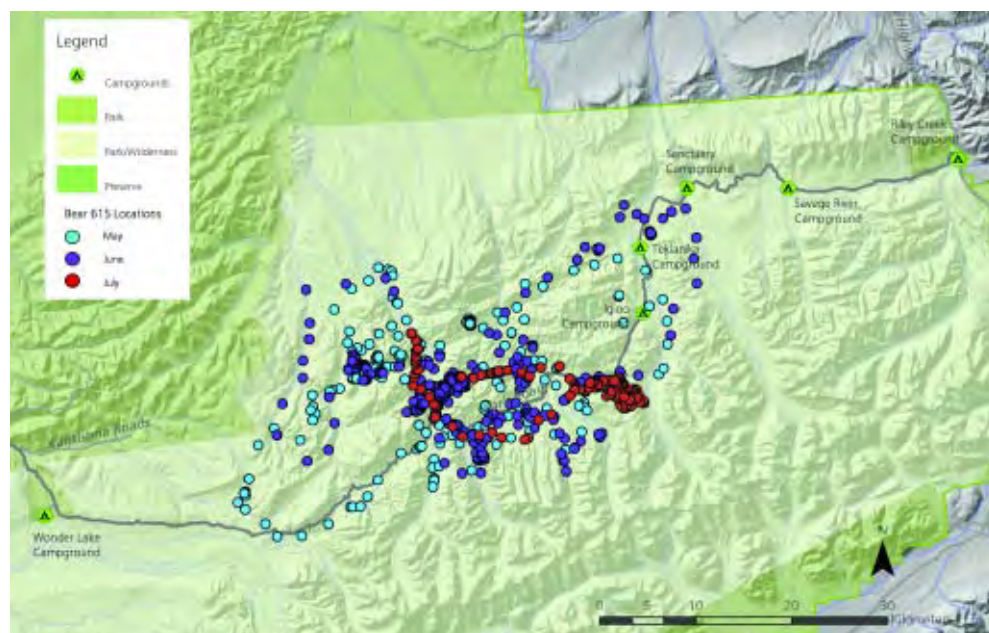


Figure 2. Locations of grizzly bear 615 relative to the Denali Park Road, Summer 2006.

Using Science to Manage Subsistence Off Road Vehicle Use in Denali National Park and Preserve

by Michael J. Tranel and Adrienne Lindholm

Abstract

In July 2005, the NPS made a final determination that the community of Cantwell had used off road vehicles (ORVs) for successive generations for subsistence purposes in portions of the Denali Park additions (traditional use area) before the establishment of the Denali National Monument in 1978. During the subsequent year, the NPS began preparing an environmental assessment that presented several alternatives for managing this use to minimize adverse impacts to park resources while also providing reasonable access for subsistence purposes.

The law and our own NPS Management Policies tell us we need to use good science to support our planning decisions. This paper reviews the extent to which scientific data were used to develop management alternatives for the environmental assessment and predict impacts on park resources and on subsistence users. It also discusses how, in spite of these existing data, a lack of data remained a concern. Finally, it presents recommendations for what can be done differently to improve how we collect and use data to support park planning, management, and environmental impact analysis.

Introduction

In July 2005, the NPS made a final determination that the community of Cantwell had used off road vehicles (ORVs) for successive generations for subsistence purposes in portions of the Denali National Park additions (traditional use area) before the establishment of the Denali National Monument in 1978. The traditional use area was temporarily closed to ORV use during the 2005 and 2006 hunting seasons with the exception of three trails, which are shown in Figure 2. The closure allowed reasonable access to subsistence resources for the residents of Cantwell while protecting park resources and also giving the NPS time to complete the necessary field work and environmental documentation evaluating ORV effects on park resources and values. The NPS now is in the process of completing an environmental assessment to determine



Figure 1. Driving over soft wet soil can damage vegetation and scar the landscape.

how best to manage subsistence ORV use in the Cantwell traditional use area of the park. The NPS is taking this current action to ensure that subsistence ORV use in this area is managed to minimize adverse impacts to park resource values while also providing reasonable access for subsistence purposes.

During the scoping phase of the planning process, a number of resources were identified that could be affected by this project. ORV use causes soil rutting, displacement, and compaction. ORVs can directly affect vegetation, including wetlands, by crushing plants, scarring trees, and exposing roots. The construction of ORV trails could cause the loss of vegetation, and ORV use could displace and

National Park Service photo

disturb wildlife. Such use could also affect natural sounds and opportunities for viewing wildlife. It could indirectly affect adjacent designated park wilderness and directly affect lands considered suitable for wilderness designation. Decisions made in this environmental assessment could also affect subsistence opportunities in the traditional use area. The environmental assessment analyzes impacts from each alternative on these park resources.

The law and our own NPS Management Policies tell us we need to use good science to support our planning decisions. In this case study we address the following two questions:

- What do we mean by using science to manage a park use?
- How can scientific studies and long term monitoring better support the NEPA process?

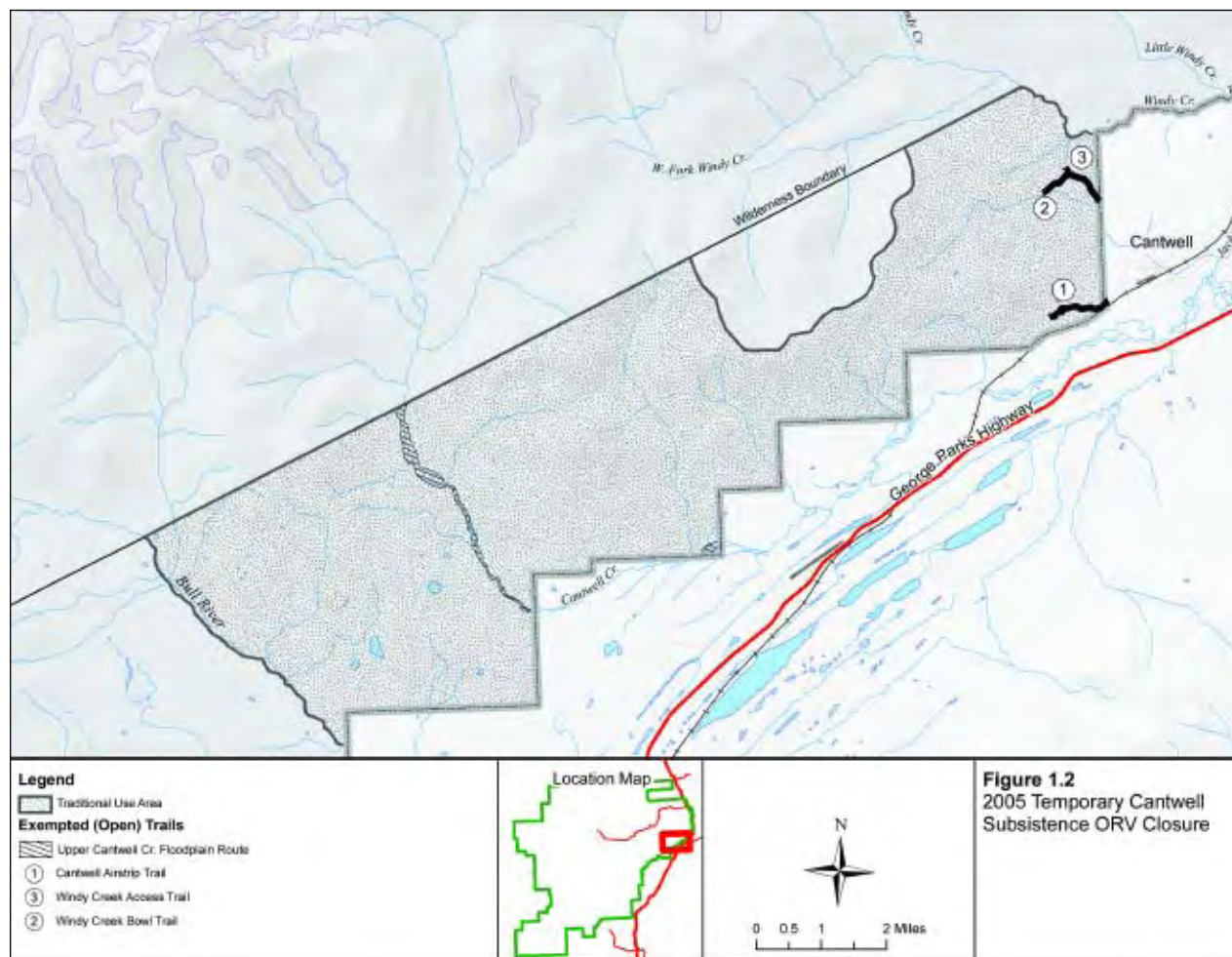


Figure 2. The traditional use area near Cantwell is the focus of the Environmental Assessment that addresses long-term management of ORV use for subsistence purposes.

Using Science to Manage ORV Use

The importance of scientific information to park management decisions has long been recognized. The 1963 Leopold et al. report on wildlife management concluded that: “The need for management, the feasibility of management methods, and evaluation of results must be based upon current and continuing scientific research. Both the research and the management itself should be undertaken only by qualified personnel.”

And that: “Management based on scientific research is, therefore, not only desirable but often essential...” (Leopold et al. 1963)

Effective use of scientific information for management decision-making receives even greater emphasis today. However, it continues to be a challenge, especially with application of the National Environmental Policy Act.

The National Environmental Policy Act states that: “The Congress authorizes and directs that, to the fullest extent possible: (2) all agencies of the Federal Government shall—utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making which may have an impact on man’s environment.” NEPA Sec. 102 [42 USC § 4332] (*US Public Law 1970*)

In preparation for the Cantwell ORV environmental assessment, park scientists did an extensive inventory of the project area in 2005 to document existing ORV trails and impacts. Thorough soils and vegetation mapping also provided background information for the environmental assessment.

All of this information was very useful in developing management alternatives to consider in the environmental assessment. The vegetation mapping was particularly thorough and detailed. However, while the data provided baseline conditions, they did not make it possible to conclude how many ORVs or what type of ORVs created those conditions and therefore were of limited value for predicting future impacts.

Similarly, interviews with a number of subsistence users in the Cantwell area were conducted in the 1990s and more recently in 2004-2005. These interviews provided some general information on which parts of the traditional use area are used for subsistence purposes, as did data collected by the State of Alaska Department of Fish and Game, but the information did not allow conclusions on how many animals were harvested for subsistence each year in the project area, or where and when this use specifically occurred and by what means, such as on foot or on an ORV.

The National Environmental Policy Act also requires documentation of incomplete or unavailable information, which has been done for the Cantwell ORV environmental assessment. In several cases, lack of information required making assumptions in order to analyze the potential future impacts of each management alternative. As new information became available during the process, assumptions affecting predictions about impacts changed, resulting in frustration for authors of the environmental assessment, challenges in making consistent conclusions across various impact topics, and delays in the overall process.

Collecting data concurrent with the NEPA process allowed planners to develop an informed range of alternatives but fell short when it came to analyzing impacts to park resources. Ideally park planners and managers would use science to inform the NEPA process, both in the development of alternatives and in the impacts analysis. To do this would require anticipating conflicts and collecting data before a planning process is initiated to resolve a particular conflict.

How Science and Long Term Monitoring Can Support the NEPA Process

Denali National Park and Preserve has made considerable progress in recent years in its capacity to complete scientific studies and monitor resources that provide critical information for management decisions. However, there are still improvements that can be made in how scientific studies can better support the National Environmental Policy



National Park Service photo

Figure 3. Some of the most severe resource damage has occurred west of Cantwell Creek, where there is a predominance of wetlands on organic soils.

Act process. Most important is improving the ability to predict impacts resulting from human-caused changes.

The National Environmental Policy Act requires that an environmental assessment or environmental impact statement make conclusions on the significance of impacts based on context, intensity, and duration. Summaries about the overall impacts on the resource synthesize information about context, intensity, and duration, which are weighed against each other to produce a final assessment. While each summary reflects a judgment call about the relative importance of the various factors involved, the following descriptors provide a general guide for how summaries are reached.

- **Negligible:** Impacts are generally low intensity, temporary, and do not affect unique resources.
- **Minor:** Impacts tend to be low intensity or of short duration, although common resources may have more intense, longer-term impacts.

- **Moderate:** Impacts can be of any intensity or duration, although common resources are affected by higher intensity, longer impacts while unique resources are affected by medium or low intensity, shorter-duration impacts.
- **Major:** Impacts are generally medium or high intensity, long term, or permanent, and affect important or unique resources.
- **Impairment:** A resource would no longer fulfill the specific purposes identified in the park's establishing legislation or its role in maintaining the natural integrity of the park.

A greater understanding of impact significance would help inform scientific investigations aimed at improving management decisions. Science should be used to explain the context, intensity, and duration of impacts for all park resources identified during scoping.

The lessons learned in completing the Cantwell ORV environmental assessment provide three specific ideas for

improving how scientific investigation and resource monitoring can support the National Environmental Policy Act process and management decision-making.

Investigate causes of baseline conditions:

Baseline conditions were clearly defined for this environmental assessment. However, the lack of information on specific causes of these baseline conditions made it difficult to predict similar impacts in the future, especially the number of ORV passes at a given location that would result in unacceptable changes. In hindsight, it would have been helpful to have worked with the State of Alaska and with the Denali Subsistence Resource Commission to gather the kind of data that would have allowed conclusions on cause and effect in terms of ORVs and their impacts on resources and subsistence harvests (e.g., number of ORV users, types of ORVs used, and the specific places ORVs were used in the project area for subsistence hunting).

Broaden long-term monitoring programs, especially those which help address critical issues:

National Park Service resource managers are limited in many ways, particularly in funding, for long-term monitoring programs. However, ORV use in the Cantwell area has been an important management issue for at least the past 10 years. Recognizing that, it would have been very helpful to monitor some basic components such as the amount of ORV use each hunting season.

Conduct scientific investigations geared toward evaluating significance of impacts:

Understanding that significance of impacts must be described in terms of context, intensity, and duration should make it possible to develop scientific investigations that facilitate such conclusions. Incorporating this need into study design would help considerably with applicability of the conclusions to environmental impact analysis.

Management Implications

In reviewing the two questions raised in this case study, we find the collection and use of scientific information to be increasingly important to making management decisions in Denali National Park and Preserve. While there will always be limited information, it is important to make the best use of the data that are available and to capitalize on resource monitoring programs already underway. More information helps especially in cases of user conflicts and when legal challenges are likely. Scientific studies can better support the National Environmental Policy Act process by ensuring that impact significance (context, intensity, and duration) has been incorporated into the study design. Finally, long-term resource monitoring and scientific investigation must be informed by long-term management planning that anticipates the critical issues. In reviewing the administrative history of Denali and examples from other parks and protected areas, we find that critical issues most often arise from conflicts among competing uses or values (Tranel and Hall 2003). Anticipating these potential conflicts in the future must be integral to any resource stewardship and science programs in the unique national park areas of Alaska.

References

- Leopold, A.S. et al. 1963.**
Wildlife Management in the National Parks.
In America's National Park System: the Critical Documents, edited by Larry M. Dilsaver.
 Rowman & Littlefield Publishers, Inc.
 Lanham, Maryland.
- Tranel, M.J., and A. Hall. 2003.**
Parks as Battlegrounds: Managing Conflicting Values.
In The Full Value of Parks: from Economics to the Intangible, edited by D. Harmon and A. Putney.
 Rowman & Littlefield Publishers, Inc.
 Lanham, Maryland.
- US Public Law 91-190. 1970.**
The National Environmental Policy Act.
 42 Stat. 4321-4347, Section 102.



Figure 4. A track-adapted ORV approaches a damaged slope on the Cantwell Creek floodplain.

National Park Service photo

Diverse Recreation Experiences at Denali National Park and Preserve

by Katie Knotek, Alan Watson, and Neal Christensen



Leopold Institute photo

Abstract

Qualitative interviews were conducted at Denali National Park and Preserve in the 2004 summer use season to improve understanding of re-

creation visitor experiences in the remote southern portion of the park, including Mount McKinley and the surrounding mountains and glaciers. Descriptions of the experiences of visitors to the mountains and glaciers included elements of isolation, self-reliance, and personal risk, whereas experiences of visitors flying over the area were more focused on scenic grandeur, creating memories, taking photographs, and glacier landings. Devising appropriate management direction and monitoring protocol to sustain this diversity of experiences at the same place is a challenge.

Figure 1. (Top) When day use flightseers land on glaciers, they report that the actual sounds, smells and feel of the environment become the defining element of the trip.

Introduction

Denali National Park and Preserve (Denali) is managed as a Conservation System Unit in Alaska under the responsibility of the National Park Service, as outlined by the National Park Service Organic Act, the Alaska National Interest Lands Conservation Act (ANILCA) and other relevant federal guidelines (*Lindholm and Tranel 2005*). According to ANILCA, one of the stated purposes of this park unit and others in Alaska is to provide for the “protection of opportunities for wilderness solitude, outdoor recreation and environmental education” (*Smith et al. 2001*). Denali is home to North America’s highest mountain peak, 20,320-foot (6,193 m) tall Mount McKinley. Mount McKinley and the surrounding mountains and glaciers of the Alaska Range, located in the southern portion of the park, have become a world-renowned destination for mountaineering and scenic air tours. As a result, recreation use in this area of the park has grown dramatically in recent years (*DENA 2005*) making it more of a challenge to protect, as outlined by ANILCA, opportunities for both wilderness solitude and outdoor recreation in an area where diverse visitor experiences occur.

In an effort to assist park planners and managers in better understanding recreation visitor experiences in this portion of the park, a cooperative study between Denali National Park and Preserve, the Aldo Leopold Wilderness Research Institute, and the American Alpine Club was conducted in the summer of 2004. This research, combined with a quantitative visitor survey (*Christensen et al. 2005*), was intended to provide input to establishing appropriate management direction and monitoring protocol in the park’s backcountry management plan.

Methods

Qualitative interviews were conducted with a purposeful sample of both day users and multi-day recreation visitors to the study area, selecting candidates randomly from groups during multi-day sampling periods across the use season (*Christensen et al. 2005*). Day users were visitors on scenic flights and multi-day users were mountaineering climbers and backcountry skiers. There were a total of 34 interviews with day use visitors and 36 interviews with multi-day visitors. Most interviews were conducted in Talkeetna, Alaska, at the air taxi operators’ places of business soon after completion of visits. The interviews followed a semi-structured format, aimed at collecting, in meaningful detail, visitors’ own unique descriptions of their experiences, as well as their perceptions of influences on those experiences. Through qualitative interpretive analysis, multiple reviewers agreed on several recreation



Leopold Institute photo

Figure 2. A sense of isolation is felt immediately by multi-day visitors upon watching their air taxi leave.

experience dimensions and factors of influence for each type of visitor. For this brief overview of the results, some excerpts are presented only as examples of the evidence for a primary set of experience dimensions and factors of influence.

Results

Among the primary elements of the experiences of visitors flying over the park were experiencing the scenic grandeur of Mt. McKinley, creating memories, taking photographs, and landing on a glacier.

The scenic grandeur of Mt. McKinley and the surrounding mountains and glaciers can be overwhelming for day use visitors. As a result, the experience of some day use visitors is largely defined by the opportunity to view outstanding scenery characteristic of an overflight. For example:

But the whole thing was phenomenal... The scenery, everything about it, just looking over the mountains. I'd never seen anything like that before pretty up close ... (Day User)

For other day use visitors, the scenic flight is dominated by the experience of creating memories while flying over the unique environment, memories that will transcend time. Many day use visitors are acutely aware of photographic opportunities during the scenic flight, to the point where taking pictures becomes a primary element of the experience for some visitors. For example:

What did you value about the tour? Oh, just everything we saw. There are memories that, I saw things that were just unbelievable. That's all. I mean, there's memories that I'll never forget. (Day User)

Well, we went all the way around the mountain, went up to the summit, over the summit and came down to the base camps. I got some great pictures. (Day User)

Many day use visitors incorporate a glacier landing into their scenic flight. When they do, this glacier landing becomes the defining element of their experience, because it helps bring the experience to life by providing sensory stimuli – the actual sound, smell and feel of the environment outside the airplane. For example:

But, I mean,... for me I guess the whole glacier landing gave me the experience because then you're actually touching, feeling, smelling if you will, being on a national park. So if you didn't do the landing I would say I wouldn't have experienced it as much. (Day User)

In contrast to the experiences of these day use visitors, some of the primary elements of multi-day experiences included experiences of isolation, self-reliance, and personal risk.

Many multi-day visitors experience a sense of isolation, or remoteness, due to the glacial environment and lack of development in the area. This sense of isolation is felt immediately upon landing on the glacier and watching the air taxi fly away. For example:

It's a different experience than most anywhere else in the world, the mountaineering there ... we've been mountaineering in Peru and Nepal and all over and there if the weather's crappy you can just go for a hike. But here you're on a glacier. You're camped out so you have to probe out your little square area as big as this room and mark it out ... You're just really isolated and you can't just go, oh, it's a bad weather day, let's

go for a hike down to the village... You're not going anywhere. (Multi-day User)

Closely related to the isolation in the Mt. McKinley area is the feeling of self-reliance experienced by several multi-day visitors. Feelings of self-reliance can result from things like the uncertainty of rescues or inadequate weather forecasts. For example:

... you have to be self-reliant out there. I mean I know that rescue is becoming more and more an option, but you're still on your own out there. You make your own decisions and you're just dealing with the mountains all the time. That's what's calling the shots... when you try and go against the grain there you just get smacked. (Multi-day User)

Also, in relation to the isolation of the mountain area and the need to be self-reliant, multi-day visitors' experiences included an element of personal risk, which can be described in terms of the harsh conditions characteristic of the environment. For example:

The cold, the wind, the vast nothingness, you know, just, sort of isolation from everything and then the physical effect of only getting about half as much air with a breath that you normally do down here at sea level make it, make you wonder whether you're going to actually be able to get out of there or not ... it's an interesting experience, which is actually one of the reasons we did it... we needed to have that experience, see what that was like. (Multi-day User)

Discussion and Conclusions

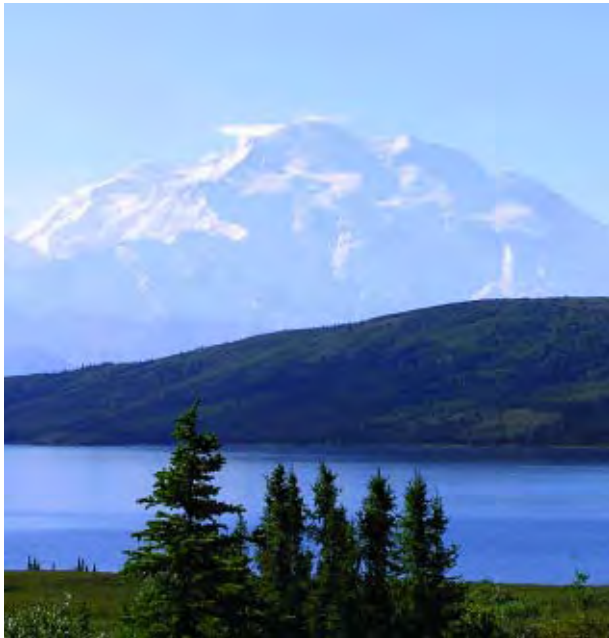
From analysis of the full text of the interviews, it is easy to realize how different the experiences are of the recreation visitors interviewed who were actively engaged in the mountain environment versus those flying over it or landing on a glacier. While most day use visitors interviewed were often captivated by the scenic grandeur of Mount McKinley and the surrounding area, multi-day visitors were overwhelmed more likely by the sense of

What did you value about the tour?

Oh, just everything we saw. There are memories that, I saw things that were just unbelievable. That's all. I mean, there's memories that I'll never forget. (Day User)

isolation that the environment instills in them. Relying on pilots to facilitate their experiences, many of the day use visitors have the ability to focus on creating memories and taking pictures. Multi-day visitors interviewed were more responsible for their own experiences and therefore commonly focused their energy on being self-reliant while in the mountain environment. Day use visitors were often overjoyed with the experience of landing on a backcountry glacier, knowing it is only for a short time, while multi-day visitors commonly faced the realization of the personal risk imposed by living for many days in such an extreme environment.

Just as the experiences of these recreation visitors interviewed differed, so do the factors that influence them. In describing their experiences, these day use visitors often mentioned the positive influence of encountering other planes and interacting with other people, the various aspects of flying and the plane they rode in, the pilots acting as park interpreters or guides, opportunities



National Park Service photo

Figure 3. Mount McKinley with Wonder Lake in the foreground.

to take photographs and the chance to view active climbers on the mountain. In contrast, multi-day visitors more commonly talked about the positive and negative influence of the number of people in the area, inexperienced climbers, mountaineering guides, overflights and the cleanliness of the area.

Management Implications

This kind of information is important and necessary for establishing management direction, setting standards and implementing relevant monitoring for such diverse recreation experiences in one unique place. Managers often establish indicators that represent threats to experiences across different types of user groups. For instance, Limits of Acceptable Change social indicators in the Bob Marshall Wilderness and their standards apply equally for horseback riders and hikers (USFS 1987), and in the Frank Church-River of No Return Wilderness they apply to both rafters and kayakers along the primary rivers and streams (USFS 2003). In Denali, however, the two main user groups in the study area have very different recreation experiences, making selection of common indicators more complex. It actually raises the question of whether a strategy for establishing common indicators is even possible.

More likely, in making decisions about how best to protect and sustain these contrasting experiences, managers at Denali may develop indicators unique to each set of experiences (day use and multi-day use) based upon the factors that influence them. If this is the case, then park staff must grapple with how this management approach corresponds to the park mission and guiding legislation, and how tradeoffs among the selection of indicators will ultimately affect conditions in this portion of the park.

Acknowledgements

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References

- Christensen, N., A. Watson, and K. Kneeshaw. 2005.** *Denali National Park and Preserve: Fly-in recreation visitor study—Ruth Amphitheater, Kahiltna Base Camp, Pika Glacier, Buckskin Glacier, Eldridge Glacier, and other glaciers south of Mt. McKinley.* Final Report to the National Park Service.
- Denali National Park and Preserve (DENA). 2005.** *Denali National Park and Preserve Annual Mountaineering Summary—2005.* Available online: <http://www.nps.gov/dena/home/mountaineering/summaryreports/2005%20Summary.pdf>
- Lindholm, A.A., and M.J. Tranel. 2005.** *Legislative direction for a Conservation System Unit in Alaska.* International Journal of Wilderness 11(2):8-10.
- Smith, A.E., M. Anderson, H. Kendall-Miller, and P. Van Tuyn. 2001.** *Alaska National Interest Lands Conservation Act citizens' guide.* The Wilderness Society. Washington D.C.
- U.S. Department of Agriculture, Forest Service (USFS). 1987.** *The Bob Marshall, Great Bear and Scapegoat Wildernesses Recreation Management Direction.* USDA Forest Service, Flathead, Lolo, Helena, and Lewis and Clark National Forests.
- U.S. Department of Agriculture, Forest Service (USFS). 2003.** *The Frank Church—River of No Return Wilderness Management Plan.* USDA Forest Service, Intermountain Region.

Spread of an Invasive Plant on Alaska's Roads and River Floodplains: A Network Model

by Tricia L. Wurtz, Matthew J. Macander, and Blaine T. Spellman

Abstract

Alaska has few invasive plants, and most of them are found only along the state's limited road system. One of the most-widely distributed invasives in the state, *Melilotus alba*, or sweetclover, has been sown both as a forage crop and as a roadside stabilization species. *Melilotus* has recently been found to have moved from roadsides to the floodplains of at

least three glacial rivers: the lower Stikine, the Matanuska and the Nenana. We are building a network model to examine the spatial relationships between roads, river crossings and downstream public lands of high conservation significance in Interior and Southcentral Alaska. As a case study, we are documenting the distribution of *Melilotus* near river crossings. In 2005, we surveyed 120 bridges along five major highways. When considered together, the distribution data and the network model will identify certain river crossings as critical control points for preventing the movement of *Melilotus* toward particular lands downstream. Moreover, the network model has the potential to function as a general tool to identify present and future critical control points upstream from land units being managed by a variety of different agencies, and for any future invasive species that can disperse via roads and river networks in Alaska.

Introduction

Alaska has few invasive plants. The state's isolation, lack of development and cold climate limit the introduction and success of many invasive species. Invasive species often disperse along road networks (Gelbard and Belnap 2003, Lugo and Gucinski 2000, Parendes and Jones 2000), and Alaska has only 0.02 miles of road per square mile of land area (0.01 km of road per km²), compared to California's 1.08 miles per square mile (0.67 km of road per km²) (Alaska DOT 2002).

Melilotus alba, or sweetclover, has recently become a species of concern in Alaska. *Melilotus* is widely distributed along roadsides around the state, a result of both intentional sowing as a roadside stabilization species, and unintentional transport of seed via contaminated soil and gravel. *Melilotus* has been found along the park roads in Denali National Park and Preserve and adjacent to other national parks in Alaska, lands of unquestionably high conservation value (Densmore et al. 2001). Notably, *Melilotus* has aggressively colonized the floodplain of the lower Stikine River in Southeast Alaska, the lower Matanuska River in Southcentral Alaska, and the upper Nenana River in Interior Alaska (Figure 1). It is likely that *Melilotus* spread onto the floodplains from roads, mines, and agricultural developments upstream. Though many of Alaska's most pristine public lands are located off the road system, they may be vulnerable to invasion by species that gain access to river floodplains from upstream roadside environments.

This project has two objectives. First, we are building a network model to understand the spatial relationships between roads, rivers and public lands of high conserva-



Figure 1. Three rivers (the Stikine, Matanuska and Nenana Rivers) whose floodplains are known to have been colonized by *Melilotus alba*.

tion value in Interior and Southcentral Alaska. Second, we are documenting the current distribution of *Melilotus alba* on roadsides and river floodplains near bridges in the same area. We use the *Melilotus* distribution data as a case study in the application of the network model, to identify critical control points for preventing its spread to conservation units downstream.

Methods

The network model

The network model is supported by several GIS data layers. The river network is modeled using the National Hydrography Dataset (NHD) (USGS 1999); the Alaska Department of Transportation GPS centerline dataset provides a detailed road network (Alaska DOT 2006); and the boundaries of federal and state land designations were obtained from an Administrative Boundaries dataset (Alaska DNR 2001). We started with the assumption that all migration of invasive plants on the river system would be downstream. We then utilized the NHD as our base layer for river networks, since it covers the entire state at a fine scale (1:63,360), and also incorporates a flow network. There is no comprehensive road network dataset available for Alaska, but the Alaska Department of Transportation (AKDOT) provided a draft version of a new GPS road centerline network. It covers the contiguous highway system plus Kodiak and Cordova. Some roads are not included in this dataset—for example, the Denali Park road, state-administered logging roads and private roads—but this road data is the best currently available. We began with the land classification boundaries identified on the Administrative Large Parcel Boundaries dataset, produced by the Alaska Department of Natural Resources (Alaska DNR 2001). We refer to that list of parcel types in aggregate as “conservation units.”

We defined “crossings” as intersections between the NHD-derived streams and rivers network, and the AKDOT road centerline network. NHD sub-region 1904 (the Yukon River drainage) yielded a total of 919 crossings. Crossings identified in the Alaska Milepost, an annually



USDA Forest Service photo by Blaine T. Spellman

Melilotus growing on the roadside of the Parks Highway, near its crossing of Bear Creek.



USDA Forest Service photo by Tricia L. Wurtz

A first-year *Melilotus* plant on the Matanuska River floodplain.



USDA Forest Service photo by Blaine T. Spellman

Melilotus growing along the bank of the Tanana River, at a place where the river parallels the Richardson Highway.



USDA Forest Service photo by Tricia L. Wurtz

Melilotus alba (white flowers) growing with another invasive plant, birdvetch (*Vicia cracca*) along a Fairbanks roadside.

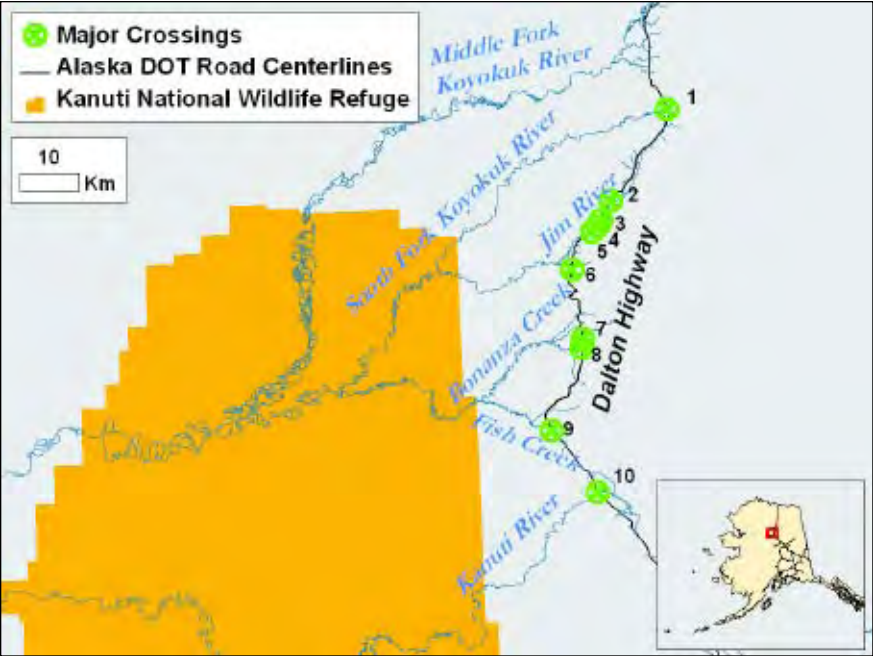


Figure 2. Roadsheds were defined as a group of nearby crossings and their immediate connecting downstream waterways. The major crossing identification numbers shown here correspond to numbers in Table 1.

updated book on Alaska Highways (Morris Communications 2005), and generally corresponding to bridges along major highways, are referred to as “major crossings”. All others are considered “minor crossings”. “Roadsheds” are a group of nearby crossings and their immediate connecting downstream waterways. To identify the conservation units within each roadshed, river flowlines were buffered by 328 feet (100 m) and were then intersected with the Administrative Large Parcel Boundaries.

A case study using *Melilotus alba*

In summer 2005, we visited crossings of portions of five highways in Interior and Southcentral Alaska. These sections of highway included a total of 233 crossings as

derived from the NHD. We surveyed the 120 major crossings that were described in the Milepost, and which were represented on the landscape by a bridge or large culvert. At each crossing, we collected both quantitative and qualitative data on the amount of *Melilotus* occurring on natural floodplain surfaces at the crossing. Each downstream floodplain surface in the vicinity of a sampled crossing was characterized based on its apparent vulnerability to invasion by *Melilotus*. For example, densely vegetated surfaces were given a score of low, while bare silt or gravel floodplains were considered high in their vulnerability to invasion. We also made qualitative assessments of the amount of *Melilotus* occurring on the roadside in the vicinity of the bridge. Places where *Melilotus* was a substantial component of the vegetation on the roadside were given a ranking of high, while places where *Melilotus* was present only as widely scattered individuals were given a ranking of low.

For the purposes of this paper, we have used the Kanuti National Wildlife Refuge as an example, since its roadsheds are entirely located in sub-region 1904, and while it has no direct road access, it is close to one of the surveyed highways. In 2005, we surveyed the 10 southernmost major

Number on Fig. 2	Highway	Milepost	Crossing Name	Distance to Kanuti (km)	Upstream	Downstream	Roadside	Invasability
1	DALTON	156	S FORK KOYUKUK RIVER	80	NONE	NONE	LIGHT	HIGH
2	DALTON	144	JIM RIVER 3	52	NONE	NONE	NONE	HIGH
3	DALTON	142	DOUGLAS CREEK	46	NONE	NONE	NONE	LOW
4	DALTON	142	JIM RIVER 2	45	NONE	NONE	NONE	MOD
5	DALTON	140	JIM RIVER 1	42	NONE	NONE	NONE	LOW
6	DALTON	135	PROSPECT CREEK	36	NONE	NONE	LIGHT	LOW
7	DALTON	125	N FORK BONANZA CREEK	50	NONE	NONE	MOD	LOW
8	DALTON	124	S FORK BONANZA CREEK	47	NONE	NONE	LIGHT	MOD
9	DALTON	113	FISH CREEK	27	NONE	NONE	LIGHT	MOD
10	DALTON	105	KANUTI RIVER	38	NONE	NONE	LIGHT	LOW

Table 1. Major crossings of the Dalton Highway that lead to the Kanuti National Wildlife Refuge. “Milepost” refers to state highway milepost markers nearest the crossing. The “Distance to Kanuti” column gives the total river distance in kilometers from the Dalton Highway to the eastern boundary of the refuge. The last four columns give data collected in 2005 as part of our *Melilotus* survey.

crossings along the Dalton Highway in the Kanuti Roadshed, because as we worked north, *Melilotus* had disappeared from the roadsides at about Milepost 150.

Results

The network model

We have completed compiling the roadsheds for NHD sub-region 1904. The roadshed identification process is currently underway for the portion of NHD Region 1902 that comprises the Matanuska and Susitna River watersheds. When both sub-regions are complete, we will link both sets of roadsheds together, and relate them to conservation unit boundaries.

*A case study using *Melilotus alba**

Of the ten major crossings we surveyed in the roadsheds leading to Kanuti National Wildlife Refuge, none had *Melilotus* on a natural floodplain surface either upstream or downstream of the crossing. Six had *Melilotus* on the roadside immediately adjacent to the crossing. We characterized five of the crossings as moderately or highly vulnerable to invasion by *Melilotus* (Table 1).

Discussion and conclusions

The network model is a work in progress. We are currently working to link the roads, crossings, reaches, roadsheds and conservation units so that the data can readily be summarized based on any of these factors, and so that an end-user can identify a feature (for example, a national park or a national wildlife refuge) and the crossings, upstream road segments and river reaches that are associated with it.

Management implications

In our example with Kanuti National Wildlife Refuge, we identified six major crossings where *Melilotus* was found on the roadside immediately adjacent to the bridge (Figure 2). One of these crossings was ranked as highly vulnerable to invasion, and two were ranked as moderately invasable. Refuge managers will be able to prioritize monitoring and



***Melilotus* seedlings growing in silt on the floodplain of the Matanuska River.**

control efforts based on these results, thereby reducing the vulnerability of the refuge to the introduction of *Melilotus* via its upstream river networks. Future research could examine the characteristics of different floodplain substrates that may make them more or less vulnerable to colonization by a variety of different invasive plant species.

Taken together, the network model and the case study are an effective means of identifying certain river and stream crossings as critical control points for preventing the movement of *Melilotus* toward particular lands downstream. Moreover, when it is complete, the network model will function as a generally applicable tool to identify the critical control points upstream from land units being managed by a variety of different agencies, and for any future invasive species that can disperse via roads and river networks in Alaska.

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References

- Alaska Department of Natural Resources. 2001. Administrative Large Parcel Boundaries. Anchorage, Alaska. ADNR, LRIS. Accessed June 15, 2006 <ftp://ftp.dnr.state.ak.us/asgdc/adnr/adminbnd.zip>.
- Alaska Department of Transportation. 2002. Personal communication with Jeff Roach, Transportation Planner.
- Alaska Department of Transportation. 2006. Preliminary ADOT/Navstar Mapping Corporation Centerline and Feature Inventory Data, May 26, 2006.
- Densmore, R.V., P.C. McKee, and C. Roland. 2001. *Exotic plants in Alaskan National Park Units*. Unpublished report of the U.S. Geological Survey, Alaska Biological Science Center.
- Gelbard, J.L., and J. Belnap. 2003. *Roads as conduits for exotic plant invasions in a semi-arid landscape*. Conservation Biology 17:420-432.
- Lugo, A.E., and H. Gucinski. 2000. *Function, effects, and management of forest roads*. Forest Ecology and Management 133:249-262.
- Morris Communications Company. 2005. *The Milepost: all-the-north travel guide*. Morris Communications Company, LLC. Augusta, GA.
- Parendes, L.A., and J.A. Jones. 2000. *Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest*. Conservation Biology 14:64-75.
- U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency. 1999. National Hydrography Dataset—Medium resolution. U.S. Geological Survey. Reston, Virginia. Accessed June 15, 2006 <http://nhd.usgs.gov>.

Developing a Framework for Evaluating Proposals for Research in Wilderness: Science to Protect and Learn from Parks

by Lewis C. Sharman, Peter Landres, and Susan Boudreau

Abstract

In designated park wilderness, the requirements for scientific research often conflict with requirements designed to protect wilderness resources and values. Managers who wish to realize the benefits of scientific research must have a process by which to evaluate those benefits as well as their associated wilderness impacts. Glacier Bay National Park and Preserve, in collaboration with the Aldo Leopold Wilderness Research Institute and several non-NPS researchers, has drafted a decision process that balances potential impacts to wilderness with potential benefits to wilderness, the park, and science. The park works closely with researchers to minimize wilderness impacts to the greatest possible extent while maximizing potential benefits. This process is applied equally and consistently to all scientists (internal and external), is communicated clearly, and is a means to ensure that permitted research minimally impacts wilderness while providing information that ultimately protects it.

Introduction

Alaska hosts over three-fourths of the nation's designated wilderness, and Americans view their Alaska wilderness as quintessential and definitive—the wildest and least disturbed anywhere. Consequently, wilderness managers in Alaska believe they have a special responsibility to protect it. At the same time, in part because Alaska wilderness parklands comprise some of the continent's (and the world's) last remaining pristine ecosystems, they provide very highly valuable opportunities for scientific research. Park managers, agency policies, and law recognize that research is a valuable and legitimate use of wilderness, yet scientific activity sometimes involves access and methods that are inconsistent with the protection of wilderness resources and/or values. [Although not addressed in this paper, the authors also recognize that wilderness policy can sometimes negatively impact the ability to conduct meaningful scientific research.] This fundamental conflict of protecting wilderness resources from the negative impacts of scientific activity—while simultaneously encouraging research that may ultimately better protect those resources—means that managers must carefully consider whether to approve or deny studies that have the potential for impacts. The “best” scientific activity minimizes negative impacts to wilderness while maximizing scientific benefits; indeed, these benefits can ultimately help protect the very wilderness in which the research is conducted. In this way, wilderness and science are mutually beneficial in that each contributes positively to the other (Figure 1).

This paper summarizes a framework that begins to get at

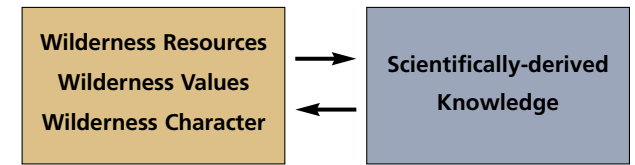


Figure 1. Scientific research and designated wilderness need not be fundamentally conflicting. Research often benefits greatly from the pristine natural conditions provided by wilderness, and this research can provide information that ultimately contributes to the understanding and protection of the wilderness.

the process of evaluating proposals for scientific research in wilderness in terms of net benefit or impact. The goal is for managers to use the framework as a tool that helps them to

- quickly recognize and welcome highly beneficial research;
- reject research activities that carry unacceptable negative impacts; and
- effectively mitigate the remaining “in between” proposals so that wilderness resources and values can be protected while the scientific benefits are optimized.

Focus on Impacts: Varying Approaches

Several wilderness managers have identified the potential for wilderness-research conflict and have proposed general methods for addressing it (*Six et al. 2000, Landres et al. 2003, Parsons 2004, Landres et al. in prep.*). Until recently there has been an agency bias toward focusing on negative impacts associated with scientific activity, at the

expense of explicitly valuing scientific benefits (more about this shortly). Most unit managers who have actually implemented a process to evaluate research proposals with wilderness protection in mind have adopted one of two approaches.

The first can be characterized as a numerical scoring approach, exemplified by that used at Yosemite National Park. Yosemite's Wilderness Research Impact Class Assessment (WRICA 2004), developed by Wilderness Specialist Mark Fincher, assigns points to different levels of impact. By way of a simple worksheet, various field elements (e.g., party size, collections, use of mechanized/motorized equipment or transport, installations) receive points proportional to their amount of impact. These scores are added together to yield a cumulative impact score for the project. Depending on the total number of points, a proposal falls into one of three categories. Class 1 projects involve simple observations made by small numbers of people, are covered by a programmatic Minimum Requirement Analysis (based on the Carhart MRDG described below), and are generally allowed to proceed as proposed. Class 2 projects have limited impact on wilderness resources and may involve some minor Wilderness Act 4(c) exceptions (e.g., use of a mechanized tool in designated wilderness, such as a cordless power drill) (Wilderness Act 1964) that require closer scrutiny by park management. Class 3 projects include at least one significant 4(c) Wilderness Act exception (e.g., motorized access) or otherwise pose significant risk to wilderness values. They require a separate Minimum

(Impact Category 1 Score) + (Impact Category 2 Score) + ... (Impact Category i Score)		
= Cumulative Impacts Score (CIS)		
CIS ≤ x		= Impact Class 1 (Low)
CIS > x and ≤ y		= Impact Class 2 (Moderate)
CIS > y		= Impact Class 3 (High)

Figure 2. The numerical scoring approach: representational algorithm of Yosemite National Park's Wilderness Research Impact Class Assessment (WRICA 2004); x and y thresholds are defined by the park.

Field Crew	Mechanized/Motorized Equipment	Magnitude of Effects
Very large group size (≥12)	2-cycle combustion engines (e.g., chainsaw)	Potential regional or greater effects (e.g., exotic species introduction)
Large group size (7-11)	4-cycle combustion engines (e.g., generator)	Potential effects extend over a broad area within/adjacent to park (e.g., stream manipulation, extensive aircraft use)
Small group size (2-6)	Solar, battery, wind, hydro-, and human-powered mechanical devices (e.g., battery-powered drill)	Potential effects confined to multiple small areas (e.g., several small sampling plots with excavations)
Single individual	No mechanized/motorized devices	Probable effects difficult to detect without prior knowledge (e.g., limited sampling of soil, seasonal plant growth, water)
No personnel onsite		No physical site impacts anticipated (e.g., photographic sampling, sound or climate monitoring)

Figure 3. The matrix approach: simplified schematic of Grand Canyon National Park's Wilderness Impact Matrix (Six et al. 2000). Note the heavy black "severity line". Impacts below the line are generally deemed acceptable, while those above the line indicate substantial issues that must be resolved. Not all impacts categories are shown.

Requirement Analysis, substantial mitigation, and explicit approval by the Park Superintendent. A very general algorithm appears in Figure 2.

The other alternative method utilizes a matrix approach. An excellent example is Grand Canyon National Park's Wilderness Impact Matrix developed by Bob Winfree and others (Six et al. 2000). As with the numerical scoring approach described above, the matrix technique first identifies the various impact types (mechanized/motorized equipment, magnitude of effects, etc.). These categories are the column headings in the two-dimensional matrix (Figure 3). Cells below the column headings represent (from top to bottom) decreasing degrees of impact magnitude. For example, cells in the "Frequency of Disturbance" column decrease in relative magnitude from (at the very top) continuous or near-continuous activity, to (at the bottom) no apparent impact. Thus the matrix becomes the evaluatory tool for the proposal, whereby one cell (degree of impact) for each column (type of impact) is circled. A key element of the grid is the "severity line" that is pre-defined for each impact category. This line is an important cue for evaluators; whenever a project element has the potential to

cause a magnitude of impact that is above the line, managers must take special note and strive to mitigate that impact to a lower level within the column, and without raising other impacts above the severity line if the project is to proceed (Figure 3).

In addition to an internal evaluation, many park units managing designated wilderness incorporate a formal "minimum requirement/minimum tool" process (see Yosemite's WRICA above). Typically, these are some form of the Minimum Requirements Decision Guide developed by the Arthur Carhart National Wilderness Training Center (MRDG 2005). This process first determines whether the proposed activity is indeed necessary. If so, the focus then shifts to determining, via development and consideration of alternatives, how the research objective can be accomplished with the least impact on wilderness.

Glacier Bay's Framework

Glacier Bay staff were favorably impressed by the "at-a-glance" nature of Grand Canyon's method, so we have tentatively adopted a modified version of their matrix approach for evaluating wilderness impacts. We believe

that matrices may be potentially more vulnerable to subjectivity (by nature less quantitative) than numerical scoring, but that this is counterbalanced by the advantages of flexibility and at-a-glance visual integration of the entire project. The matrix can be rapidly filled out by an evaluator, and it is visually intuitive in that one can quickly grasp what elements of a proposal have the greatest potential impacts. Glacier Bay’s version uses a different, somewhat more detailed list of impact categories (column headings), and a color scheme has been substituted for the Grand Canyon “severity line”. The Glacier Bay matrix shows minimally disruptive impacts as beige, those requiring increased scrutiny as blue, and those presenting serious wilderness conflicts requiring substantial mitigation and/or a special administrative waiver as gold (Figure 4).

What About Benefits?

Note that the above discussion has focused almost entirely on negative impacts to wilderness, although the process developed at the Grand Canyon also considered safety and potential impacts to the proposed project (e.g., cost of complying with permit stipulations) in the overall

matrix. Clearly, however, the results of scientific research can also *benefit* wilderness and science in general. It is important to recognize these benefits and to incorporate them into any evaluation of proposals. We believe the current bias toward valuing only impacts derives from agency focus on responsibility to protect wilderness. Policy and management directives of agencies and management units typically take the form of explicit regulation for resource protection but only implicit appreciation of the positive side of scientific research in wilderness.

The historic enabling Proclamation for Glacier Bay National Monument (now Park and Preserve) identifies resources and values central to why it was set aside for protection. These include several features (e.g., tidewater glaciers) and processes (e.g., ecological succession) that the public enjoys directly. It also—and unusually—explicitly identifies as positive values those same features and processes defined as opportunities for scientific research (Coolidge 1925). This mandate is reflected in the long and rich legacy of distinguished scientific inquiry that has been conducted in the park. Glacier Bay managers have always been sensitive to the potential positive values of scientific

research in the park, and we are presently developing a “benefits matrix” as a companion to the impacts matrix. Examples of benefits categories include potential for the research to preserve ecosystem integrity, detect change to avoid calamity, enhance visitor experience of wilderness character, and provide knowledge and understanding in general. This matrix remains to be refined and, finally, a strategy to weigh impacts and benefits must be developed.

Helpful Conceptual Tools

Several general concepts continue to inform completion of the full evaluatory framework:

- *Basic vs. Applied Research.* Basic research is curiosity-driven, is intended to illuminate basic characteristics or processes, and enhances knowledge in general. Applied research focuses on purposefully providing information to address certain issues; in our case, it seeks to directly answer important questions for wilderness/park management in a highly targeted way. Both are legitimate and valuable, but typically applied research that shows potential benefits to park resource management will be valued more highly against its associated impacts than other research where benefits would primarily accrue outside of the park.
- *Urgency and Importance.* Urgency implies time-sensitivity of obtaining the information deriving from the proposed research. If park management requires information quickly, or if science in general requires information quickly to address a problem bigger than the park, then this urgent research should accrue greater benefit. Similarly, if the research will provide information that will help address a particularly important resource concern having severe management implications if not reconciled, then that research will be viewed more favorably with regard to its potential impacts.
- *The Place Test and the Quality Test.* Research is sometimes highly wilderness-dependent (more commonly it is park-dependent), but not always. Assessing whether a proposed project must occur in park wilderness is an application of the Place Test. If the research objectives

Cumulative Days in Field	Means of Access	Installations
40 or more days	Helicopter, fixed-wing aircraft, ORV, snowmachine, airboat, hovercraft Motorized watercraft during closure period	Longevity = greater than 1 season; and/or Size = huge; Discernability = high; and/or Number = lots
8 to 40 days	Motorized watercraft during non-closure season	Longevity = 8 days up to full season; and/or Size = medium; Discernability = moderate; and/or Number = few to many
Up to 7 days	Human-powered (kayak, rowboat, walk, backpack, x-country ski, snowshoe, sled)	Longevity = up to 7 days; and/or Size = small; Discernability = low; and/or Number = 0 to 1
No field visit	N/A	N/A

Severe wilderness impact requiring substantial mitigation and/or administrative waiver. Substantial wilderness impact requiring careful scrutiny and mitigation; may require waiver. Minimal to no wilderness impact.

Figure 4. A portion of Glacier Bay National Park and Preserve’s impacts evaluation matrix (sampled from the full grid).

can be accomplished somewhere outside of designated wilderness, then the work probably should be conducted there. The Quality Test is an assessment of how likely the research, as proposed, will accomplish its stated objectives. This often occurs by way of peer review. Proposed projects scoring poorly on the Quality Test are less likely to produce benefits that mitigate their wilderness impacts.

- *It is the METHODS that create the impacts.* Most valuable research can be conducted in multiple ways. It is important to focus on the methods and tools (helicopters, field installations, ways of marking study plots or animals) rather than the scientific objectives. Methodological approaches can be modified, and the potential impacts of many legitimate research projects can and should be mitigated to allow them to proceed.
- *Cumulative Impacts.* The potential impacts of any single project must be considered within the larger context of all other project impacts occurring within the wilderness. Although the potential impacts associated with one project may not be deemed significant, when combined together with all other impacts associated with all other projects proposed for that wilderness, the cumulative impacts may be substantial indeed. Parks must always be alert to the potential for this “tyranny of small decisions”, while also recognizing that the cumulative impacts of many studies in a large area and over a long period of time can be minimized by careful design and implementation.
- *WHO evaluates?* Evaluation of proposed research projects is typically conducted by park staff. It is important to keep in mind that evaluations should be made from a breadth of perspectives ranging from the very objective scientific to more the value-laden wilderness philosophy/experiential. Both are legitimate and essential, and both must be possessed by the review team.
- *The Decision Matrix.* Ultimately, the critically central question remains: are the benefits worth the impacts? The conceptual benefits:impacts matrix assigns relative weights to potential benefits and associated impacts to

provide guidance for accepting or declining a research proposal (Figure 5). When benefits outweigh impacts, the proposed research is allowed; when the reverse is true, the research is denied or—more frequently—returned to the applicant so that they may modify it to increase its benefits and/or decrease its impacts.

Finally, and perhaps most importantly, it has been our experience that effective communication and negotiation are key. Mitigation to allow coexistence of wilderness quality and scientific activity is our goal (Figure 1). Glacier Bay park staff work closely with scientists to ensure they understand park wilderness values, the importance of minimizing wilderness impacts, optimizing scientific benefits, and how we evaluate proposals to balance them. A great deal of effort is invested in working with prospective researchers to negotiate and facilitate the proposal process. Our goal is to encourage as much high-quality, relevant science as possible while still protecting the park’s precious wilderness resources and values. This is the communication—the give-and-take—between park managers and scientists that leads to the granting of the research permit. Thus we maximize and support excellent research that ultimately contributes to the protection of park wilderness.

	No Benefits	Some Benefits	Lot of Benefits	Very Extensive Benefits
No Impacts	?	A	A	A
Some Impacts	D	?	A	A
Lots of Impacts	D	D	?	A
Very Severe Impacts	D	D	?	?

Figure 5. Decision matrix. “A” indicates acceptance of proposal, and “D” indicates denial. The borderline “?”s are those proposals where effective mitigation of impacts and optimization of benefits may still allow acceptance.

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References

- Coolidge, C., President of the United States. 1925.** Proclamation establishing Glacier Bay National Monument, Alaska.
- Landres, P., J. Alderson, and D.J. Parsons. In Preparation.** *Guidelines for evaluating proposals for scientific activities in wilderness.*
- Landres, P., J. Alderson, and D.J. Parsons. 2003.** *The challenge of doing science in wilderness: historical, legal, and policy context.* George Wright Forum 20(3):42-49.
- Minimum Requirements Decision Guide (MRDG). 2005.** Arthur Carhart National Wilderness Training Center. Missoula, Montana.
- Parsons, D.J. 2004.** *Science and the management of protected areas. In Managing mountain protected areas: challenges and responses for the 21st century, Proceedings of the Mountain Protected Areas Workshop,* edited by D. Harmon and G.L. Worboys. 5th World Parks Congress, Durban, South Africa. Pp. 36-40.
- Six, D.L., P. Alaback, R.A. Winfree, D. Snyder, and A. Hagele. 2000.** *Wilderness for science: pros and cons of using wilderness areas for biological research. In Wilderness science in a time of change conference, Missoula, Montana,* compiled by S.F. McCool, D.N. Cole, W.T. Borrie, and J. O’Loughlin. USDA Forest Service Proceedings RMRS-P-15-VOL-3. Pp. 271-275
- Wilderness Act of 1964.** U.S. Public Law 88-577, 78 Stat. 890.
- Wilderness Research Impact Class Assessment. 2004.** Yosemite National Park, California.

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