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PARK Science

Integrating Research and Resource Management in the National Parks

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
Office of Education and Outreach

THE DENALI PARK ROAD

The effects of traffic volume and driver behavior on wildlife preservation and the visitor experience

- A 16th-century Spanish inscription at Grand Canyon?
- Decline and restoration of whitebark pine at Crater Lake
- Case studies in water resources management
- Landscape-level reviews of habitat modeling and the impacts of human population on Canadian national parks and wildlife

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From the Editor

Theme issues need your help

This issue of *Park Science* takes us to northern latitudes, featuring research in Alaskan and Canadian national parks. A brief series of articles describes the research inputs involved in building a model of Denali Park Road traffic that will be instrumental in designing new vehicle limits that may be placed on this popular route. Two Canadian studies seek to better understand the influence of landscape patterns and human populations on Canadian national parks and wildlife by evaluating and improving the efficacy of existing ecological models. Altogether, these reports highlight the sophistication with which models, informed by research and used by circumspect managers, can help address complex management issues.

We also present several water resource-related "Science Notes" that demonstrate significant developments in applications of water law and various technologies to the understanding and protection of park resources. A departure from our normal natural resource-oriented fare that I think you will enjoy especially is the article about a rock inscription at Grand Canyon and its potential meaning for park history.

Though you'll find these and other topics on the following pages, this edition of *Park Science* was not designed as a theme issue. By contrast, our upcoming spring 2011 and winter 2011–2012 issues will focus on *climate change science* and w*ilderness science and management*, respectively. Both are being planned now and need your consideration.

The climate change issue was originally scheduled for winter 2010–2011, but has been delayed until spring to give more time for expanded participation. I am now seeking abstracts and article proposals and would like to hear from you. This issue will concentrate on understanding, anticipating, adapting to, mitigating, restoring resources affected by, and communicating climate change impacts on our national parks. This is a good opportunity to review the issues, projects, research/policy needs, and information breakthroughs related to climate change at your park and to develop and share usable knowledge on this topic with your colleagues. You will find a prospectus of this theme issue on the *Park Science* Web site. Abstracts/proposals are due 15 November and should be e-mailed to me along with any thoughts or ideas on how to make this issue particularly useful and interesting.

Similarly, we will be covering wilderness-related science and management issues in our winter 2011–2012 edition. A call for abstracts and proposals was circulated in late August with a deadline of 6 January 2011. You can review the prospectus on the *Park Science* Web site. Please e-mail your proposals to Wade Vagias (wade_vagias@nps.gov), guest editor for this issue.

Intentionally or not, *Park Science* reveals themes in our endeavors to understand and manage park resources and values. I welcome your input in the process to develop the upcoming theme issues with the goal of making them as relevant to this mission as possible.

—Jeff Selleck

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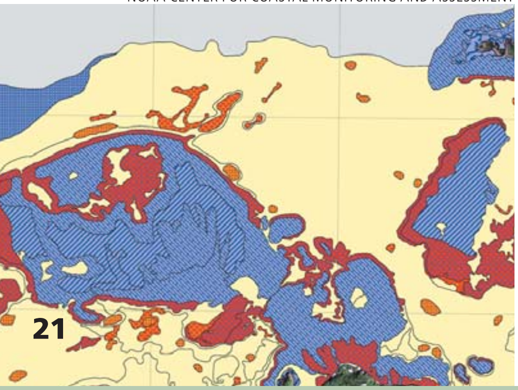
NOAA CENTER FOR COASTAL MONITORING AND ASSESSMENT



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NPS/JOHN HOURDOS

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ON THE COVER

Visitors take in the grandeur of Mt. McKinley, Alaska, from Stoney Pass Overlook along the Denali Park Road. This edition's "In Focus" reports on investigations of vehicular road capacity and related issues for management of the park road.

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NPS

PARKS CANADA

UPCOMING ISSUES

Winter 2010–2011
January 2011 release. Seasonal issue. Contributor's deadline: 27 October.

Spring 2011
May release. Climate change research and park management. Deadline extended: 15 November 2010 for abstracts/article proposals.

Fall 2011
Seasonal issue. October release. Contributor's deadline: 15 May 2011.

Winter 2011–2012
January 2012 release. Topical issue: Wilderness research and management. Abstracts/article proposals due 6 January 2011.

Visit http://www.nature.nps.gov/ParkScience for author guidelines or contact the editor (jeff_selleck@nps.gov or 303-969-2147) to discuss proposals and needs for upcoming issues.

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SCIENCE FEATURE

RESEARCH REPORTS

In This Issue

INDEX OF PARKS AND PROTECTED AREAS DISCUSSED IN THIS ISSUE, BY PAGE NUMBER(S)

Abbreviations

NF	National Forest
NP	National Park
N Pres	National Preserve
NP Res	National Park and Reserve
NRA	National Recreation Area
WSR	Wild and Scenic River

Canada

USA

Comments & Corrections

PARKScience (CONT'D)

Park Science is a research and resource management bulletin of the U.S. National Park Service. It reports the implications of recent and ongoing natural and social science and related cultural research for park planning, management, and policy. Seasonal issues are published in spring and fall, with a thematic issue that explores a topic in depth published annually in summer or winter. The publication serves a broad audience of national park and protected area managers and scientists and provides public outreach. It is funded by the Associate Director for Natural Resource Stewardship and Science through the Natural Resource Preservation Program.

Articles are field-oriented accounts of applied research and resource management topics that are presented in nontechnical language. They translate scientific findings into usable knowledge for park planning and the development of sound management practices for natural resources and visitor enjoyment. The editor and board review content for clarity, completeness, usefulness, scientific and technical soundness, and relevance to NPS policy.

Article inquiries, submissions, and comments should be directed to the editor by e-mail; hard-copy materials should be forwarded to the editorial office. Letters addressing scientific or factual content are welcome and may be edited for length, clarity, and tone.

Park Science is published online at http://www.nature.nps.gov/ParkScience (ISSN 1090-9966). The Web site provides guidelines for article submission, an editorial style guide, an archive and key word searching of back issues, and information on how to subscribe or update your subscription.

Though subscriptions are offered free of charge, voluntary donations help defray production costs. A typical donation is $15 per year. Checks should be made payable to the National Park Service and sent to the editorial office address.

Suggested article citation

Phillips, L. M., P. Hooge, and T. Meier. 2010. An integrated study of road capacity at Denali National Park. Park Science 27(2):28–32.

Printed on recycled paper.

Dear Editor:

I had to comment on a statement in the State of Science article about white-nose syndrome in bats published in the spring edition of Park Science *(27[1]:20–25). Under the section header "NPS-protected resources at stake?" the authors list several national parks including Wind Cave "where caves are important but not primary features." It's kind of complicated at Wind Cave where, according to an official park statement, "we consider the two primary resources at the park to be Wind Cave itself and the wildlife, such as bison, pronghorn, prairie dogs, and black-footed ferret, which are currently rare in prairie ecosystems due to disease and human impact."*

Rodney D. Horrocks
Physical Science Specialist
Wind Cave National Park

The authors regret the misstatement. We have corrected the information in the online sources of Park Science.

—Editor

■ ■ ■

Dear editor,

Though the "Terraphilia" art exhibit at Denver International Airport (DIA) has come and gone, I wonder if any *Park Science* readers traveling through Denver over the summer noticed natural sounds playing along with music in concourse A? The background recording featured a prairie soundscape from Sand Creek Massacre National Historic Site in Colorado. The tape recording was donated for the 33 Ideas Show at DIA by the NPS Natural Sounds Program. It played throughout the show in rotation with another audio piece and drew many appreciative comments. The show was extended until late August.

Karen Treviño
Natural Sounds and Night Skies Programs
NPS Natural Resource Program Center
1201 Oakridge Dr., Suite 350
Fort Collins, CO 80525

20 Years Ago in Park Science

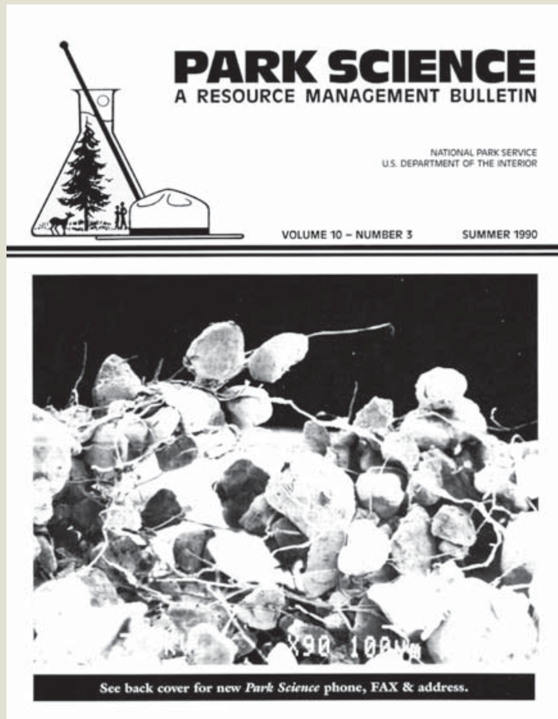
Renewable gravel sources for road maintenance in Denali NP&P

A 90-MILE GRAVEL ROAD FORMS THE MAIN TRANS-portation corridor into Denali National Park and Preserve (DENA). Decisions by previous park managers not to pave this road were based on a desire to maintain a wilderness quality to the road system. Also, it was felt that asphalt pavement might act as a hindrance to migrating wildlife within the park. As such, the gravel roadbed requires long-term material sources for annual maintenance and resurfacing. NPS requirements for in-park material sites impose special constraints upon managers considering source development. Perhaps the most important of these is that the site and method of excavation operations should lend themselves to as close a return to a natural condition as possible. . . .

A research program was initiated in 1988 to provide a detailed and comprehensive analysis of the fluvial processes that occur near and in an alluvial floodplain gravel removal site. The determination of a safe yield for gravel removal and the proper placement of removal sites on the Toklat River floodplain required a two-fold approach.

Computer modeling was employed to note the effect of annual floods on various excavation configurations. . . . The second approach method used in the study was analysis of experimental gravel pits excavated on the Toklat floodplain during the 1988 and 1989 summers. . . .

Based on the study results, it would appear that extraction design based on mimicking natural channels on a braided drainage course will encourage rapid healing and gravel replenishment. It should be noted that terms such as "healing" and even "replenishment" are difficult to quantify, and that estimates of replenished gravel (such as 77%) should be used with caution, and perhaps only in terms of general trends.



Additional hydrologic studies of the Toklat basin are continuing. A complete analysis, based on both empirical observations and mathematical modeling, should allow NPS planners to formulate a practical, yet conservative, gravel extraction management plan to meet park needs while vigorously protecting park resources and promoting rapid site rehabilitation.

Reference

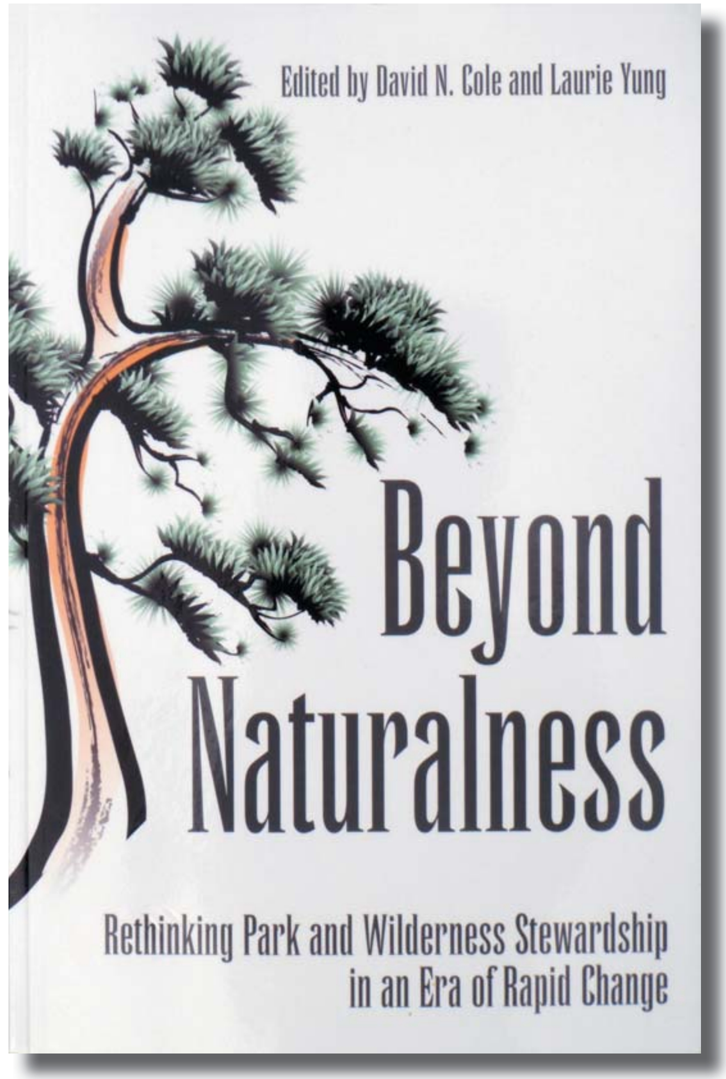
Karle, K. F. 1990. Renewable gravel sources for road maintenance in Denali NP&P. Park Science 10(3):5.

Information Crossfile*

BOOK REVIEWS

Beyond Naturalness: Rethinking Park and Wilderness Stewardship in an Era of Rapid Change

Edited by David N. Cole and Laurie Yung



TIMES ARE CHANGING, AND NOT THE WAY THEY USED TO, the editors of *Beyond Naturalness* explain. We used to think that the landscapes that we set aside to protect here in North America represented conditions that existed since the retreat of the last glaciers, virtually untouched by indigenous humans, and within a familiar range of variation caused by fluctuations in the weather and disturbances such as fire and flood. We believed an equilibrium would persist if only we saw to it that our industrial civilization did not interrupt and destroy it. That understanding guided our goals in managing the land.

We must realize, Cole and Yung tell us, that the changes besetting our landscapes today—climate change, invasions of exotic species, and anthropogenic air and water pollution—are directional. These variations will not swing back to the conditions that existed in the recent past. They are transforming our protected areas into landscapes that we no longer recognize as the old ones. They are leading to conditions that we cannot predict, and land managers must figure out how to think about managing their parks or refuges when the old mandate to protect and conserve is not going to leave the legacy to our posterity that it once promised. The essays in *Beyond Naturalness* were compiled to offer some frameworks to help managers and the agencies that oversee their lands to cope with this new world of uncertainty.

The authors describe four approaches to management, keeping in mind that what we choose to do, or not do, is based on the values that we, as humans, place on the land. The first approach is "autonomous nature," leaving nature alone. Where protected areas are isolated and very remote, there may be no alternative, and these areas then provide an opportunity to observe what happens when we do nothing. Land protected to commemorate past events or periods is managed for "historical fidelity." It may be impossible to maintain this fidelity in the future as weather regimes change and species migrate, so that only very small areas can be preserved with constant maintenance.

The approaches of "ecological integrity" and "resilience" both consider ecosystem structure, function, and composition, but focus on different aspects. To maintain ecological integrity, ecological indicators are selected and monitored (as in the National Park Service's "Vital Signs" monitoring program). Then management intervenes with specific objectives when the system's integrity is determined to be threatened. The latter approach, resilience, focuses on ecosystem function, its ability to recover from disturbance.

Strategies for planning for uncertainty are offered in the last section of *Beyond Naturalness*. An interesting one is scenario planning, taking into account various scenarios that might describe what the future will look like at a particular park. In 2007, the National Park Service convened a group of experts to envision various scenarios for the future of Joshua Tree National Park in California. The three scenarios imagined at the workshop assume different but possible precipitation regimes and their effects on vegetation, wildlife, and fire. The common issues of each scenario were listed. In each case, some species will change their range, fire will increase, and nonnative plants will be problematic. With

*Information Crossfile synopsizes selected publications relevant to natural resource management. Unless noted, articles are not reviewed by reference source author(s).

this much insight into the unknown future, managers can address these issues in their planning.

Cole and Yung complain that in terms of guidance in the age of uncertainty, current policy of land management agencies in the United States, developed to preserve "naturalness," is inadequate to meet today's challenges. The four approaches mentioned above offer some specific goals for management, for example, preserving ecosystem resilience. Cole and Yung recommend a review of current policy and a prioritization of goals, "clarity in purpose, approach, and outcome." At the same time, there must be room for adaptive management as unanticipated situations arise. And they stress that collaboration among agencies is crucial so that ecosystems that reach beyond protected areas, and that may be vital to the survival of migrating species, are not destroyed. For the same reason, the public must be included in decision-making dialogue so that it will understand and support management actions.

The changes besetting our landscapes today—climate change, invasions of exotic species, and anthropogenic air and water pollution—are directional [and] … will not swing back to the conditions that existed in the recent past.

Although Parks Canada has begun to implement some of the kinds of planning presented here, much of the discussion in this volume is in the realm of abstractions because the examples and the outcomes of experiments have not occurred yet. Nonetheless, concepts and recommendations developed in these essays will support managers in thinking outside of the old and vague paradigm of "naturalness" and beginning to anticipate new ones.

Reference

Cole, D. N., and L. Yung, editors. 2010. Beyond naturalness: Rethinking park and wilderness stewardship in an era of rapid change. Island Press, Washington, D.C., USA.

—Betsie Blumberg

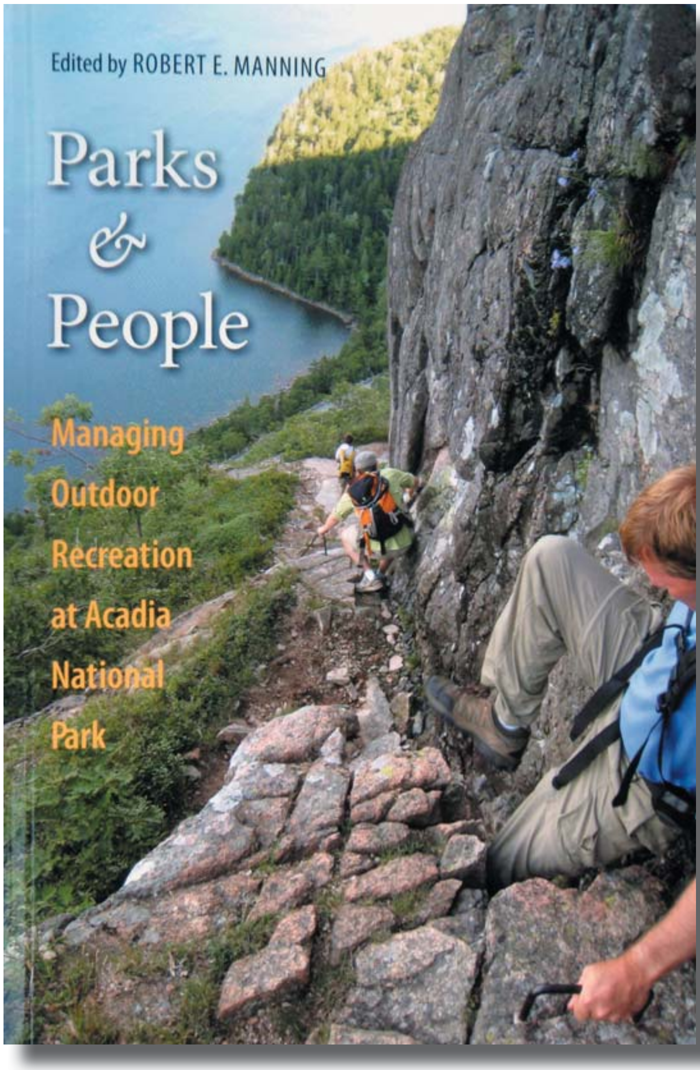
■ ■ ■

Parks and People: Managing Outdoor Recreation at Acadia National Park

Edited by Robert E. Manning

TO DEAL WITH THE NATIONAL PARK SERVICE'S SOMETIMES conflicting mandate to protect and conserve natural resources and at the same time provide a high-quality experience for visitors, the Park Service has developed the Visitor Experience and Resource Protection (VERP) framework. Robert Manning, professor at the Rubenstein School of Environmental and Natural Resources at the University of Vermont, and director of its Park Studies Laboratory, has used this framework to organize the 26 studies in his latest book, *Parks and People: Managing Outdoor Recreation at Acadia National Park*.

Part I of the book, like the VERP process, starts with studies to determine standards of quality for indicators of conditions of park resources and of the visitor experience. These standards are



Many of the studies presented here reveal the complexity of evaluating visitors' responses to surveys asking what they like most and least about the park, and what conditions they suggest managers change.

necessary to achieve managers' objectives or "desired conditions." Part II concerns monitoring the indicators, and in Part III managers act on the data they have collected.

The first and longest section of this book is devoted to indicators, mostly indicators that affect visitor experience. Acadia is one of the 10 most visited of the national parks and therefore managers have given a high priority to research on visitor behavior and expectations; thus, this book is more about social science than natural resource science. Many of the studies presented here reveal the complexity of evaluating visitors' responses to surveys asking what they like most and least about the park, and what conditions they suggest managers change. Responses reflect visitor preconceived standards, their level of education about threats to natural resources, and, among other factors, the level of candor with which they are responding.

The reader quickly notices that most of the studies included in this section are devoted to the visitor experience not so much as it threatens the natural landscape, but as it is threatened by the presence of so many other visitors: crowding. Just when and where does a visitor feel crowded? To define a standard of visitor density that is comfortable to the visitor, the authors of "Crowding in Parks and Outdoor Recreation" (chapter 10) bring to bear research from the fields of sociology and social psychology that explains crowding as a normative concept to visitors. The experience of crowding depends on many variables, including visitor expectations, activities fellow visitors are enjoying (e.g., canoeists are crowded by motorboats while motorboaters may not be crowded by canoeists), location (e.g., backcountry hikers want few people per view [ppv] while those enjoying high-use locations tolerate a much higher level of ppv).

One of the studies, for example, involved defining standards for level of use on the carriage roads, a 50-mile (80 km) system of unpaved roads heavily traveled for hiking, biking, and horseback riding ("Standards of Quality in Parks and Outdoor Recreation," chapter 2). Visitors were shown several photos of a 100-meter (328 ft) stretch of road showing differing numbers of people. Respondents rated the acceptability of the ppv for each picture. The upper limit, results showed, was 14 people per view. Visitors also rated acceptable ppv upon viewing five computer-simulated scenarios of hour-long trips on the roads. From these surveys, managers decided that a high-quality experience would be one that 80% of visitors would rate at +2 on a scale from +4 to −4. Managers determined that 3,000 visitors a day would satisfy this standard, given that people move from high-use to low-use portions of the road and that as they do, the ppv varies from 0 to a maximum of 10. That standard was adopted and then the next step in the VERP framework was initiated: monitoring.

An electronic trail-use counter records the total level of use on the carriage roads. Computer simulations, visitor surveys, and staff observation provide the input to estimate ppv levels. Management action—the third part of the VERP framework—included development of "rules of the road" posted at major entry points to the carriage road, "courtesy patrols" on the roads, and liaisons with local biking groups. These are the management actions surveyed visitors preferred that were undertaken to avoid conflicts that respondents sometimes reported.

In the studies in this collection, visitors are asked not only for their responses to their experiences at Acadia, or for their preferences about conditions, but also about how they would like to be managed when their activities might impinge on others' enjoyment or on natural resources. It is not often that people are asked how, for example, they would like to be directed to protect the landscape (chapter 21). This research certainly provides managers at Acadia with a wealth of material from which to develop plans of action that will offer their much-queried visitors a most enjoyable experience, and these insights will not be lost on managers at other high-use parks.

Reference

Manning, R. E., editor. 2009. Parks and people: Managing outdoor recreation at Acadia National Park. University of Vermont Press, Burlington, USA.

—Betsie Blumberg

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NPS IN PRINT

Park Science earns recognition for excellence

WINNER 2010 APEX® AWARDS FOR PUBLICATION EXCELLENCE

PARK SCIENCE has won an Apex Award of Publication Excellence for 2010. The honor was given as part of the 22nd annual Apex awards competition recognizing excellence in publications work by professional communicators. The awards program is sponsored by Communications Concepts, Inc., publisher of *Writing That Works*, a bimonthly newsletter covering business writing, editing, and publishing for communicators in corporate, nonprofit, agency, and independent settings.

According to the award description, "Contest entries were evaluated based on excellence in editorial content, graphic design, and the success of the entry—in the opinion of the judges—in achieving overall communications effectiveness and excellence." Judges evaluated 3,711 entries in 127 categories (for which they gave 1,232 awards), and indicated they saw "only the most promising publications that professional communicators could enter."

Park Science was up against 625 entries in the "Magazines and Journals" category, of which 198 got honors, and was one of 60 publications to receive an award in the subcategory "Magazines and Journals—Print, More Than 32 Pages."

Editor Jeff Selleck explains that he entered *Park Science* in the contest because of "a very good feeling about the quality of this publication since we reinvigorated it in 2008. That project entailed graphic redesign; full-color printing; careful selection and production of photographs and other illustrations; doing a better job of planning and developing interesting articles in a variety of departments, and editing them to a truly professional standard."

For the competition, Selleck entered the thematic issue on soundscapes (Volume 26, Number 3). "I felt this issue exemplified the high quality we have been working toward with the recent improvements," he said. "I am proud to share this special recognition with all participants in the production and growth of *Park Science* over the years: associate, assistant, guest, copy, and the former editor; contributors; graphic designers; sponsors; editorial board members; and our readers. We have indeed set the bar high."

SUMMARIES

On the road to recovery, gray wolves could be dispatched to balance an ecosystem

THE UNMISTAKABLE HOWL OF A GRAY WOLF (*CANIS* *lupus*) echoing through wilderness is to conservationists the clarion call of a healthy ecosystem. Historically populous in North America and at one time almost hunted to extinction, the gray wolf remains both a powerful symbol of wilderness and a sign that both flora and fauna in a preserved area are thriving. However, bringing wolves to a protected area like a national park can have myriad benefits beyond simply perpetuating the species. Licht et al. (2010) reason that small groups of the gray wolf can be introduced as a top-down restoration tool for a declining ecosystem in which overabundant herbivores destroy critical vegetation. The practice of restoring small predator populations to protected areas has been successful in other parts of the world with apex predators (e.g., lions and African wild dogs). Licht et al. (2010) suggest a shift in how conservationists view the gray wolf. No longer struggling to survive, the wolf could now be used for purposes of ecological restoration, but not before certain policy changes are made, particularly the requirement that restored wolf populations be self-sustaining.

Since the gray wolf was classified as endangered with the induction of the Endangered Species Act in 1973, efforts to build its numbers have focused mainly on protecting large populations in large land areas. Licht et al. (2010) suggest that because gray wolf numbers have increased in the northern Rocky Mountains and Great Lakes regions, leading to those populations being delisted as endangered in 2009, the gray wolf recovery effort has reached a point where experimentation is appropriate.

However, not everyone views the wolf as recovered: the gray wolf was relisted as endangered in August 2010 as a result of a federal lawsuit brought by Defenders of Wildlife and other conservation groups. The current legal quandary notwithstanding, Licht et al. (2010) nonetheless forward the notion that the introduction of small, non-self-sustaining populations of wolves to land areas smaller than those used in typical recovery efforts could benefit the ecology of the area. Those benefits go beyond reducing deer and elk populations and improving their demographics to include increased plant biomass, more abundant carrion for scavengers, and an overall trophic (or nutrient) cascade in the plant and animal communities. On the human side, opportunities for scientific research abound and a protected area might see increased tourism (Yellowstone National Park saw ecotourism spending increase by $35 million following the introduction of wolves in the mid-1990s).

A necessity for any wolf population undertaking is close management. The authors suggest a combination of tools be considered, all with their particular pros and cons, as a necessary investment in species management: real-time animal tracking via satellite technology, control by contraceptive, and use of real or virtual barriers.

In conclusion, the authors argue that the overall ecological, economic, societal, and aesthetic potential of gray wolves is not being fully used because of legal and other constraints from the current wolf recovery paradigm, and because of a lack of understanding by resource managers of the full suite of these benefits. Even as the political climate surrounding wolves remains tempestuous, there seems to be great potential in throwing ecosystem restoration duties, quite literally, to the wolves.

Reference

Licht, D. S., J. J. Millspaugh, K. E. Kunkel, C. O. Kochanny, and R. O. Peterson. 2010. Using small populations of wolves for ecosystem restoration and stewardship. Bioscience 60(2):147–153.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck; reviewed by D. S. Licht

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Species surrogacy put to the test

AS SOUL MASTER MARVIN GAYE ONCE SANG, "AIN'T nothing like the real thing, baby." Species surrogacy—using the dynamic of one species to represent the dynamic of another—may not be the data mine it is purported to be, though it has been used historically and is still prevalent in conservation biology. A new study of more than 72,000 bird observations affirms that data about a particular species should be statistically verified and not extrapolated from the behavior and demographics of a different, albeit similar, species. The merits of species surrogacy, a little-tested yet core concept in conservation biology, were called into question by Cushman et al. (2010) and the results are both enlightening and not particularly surprising, given the complexity of any given ecosystem. Resource managers on a small research budget should prepare to be disappointed.

The encompassing question is: Can the abundance of a species be inferred from monitoring the abundance of a different species? Cushman et al. (2010) say that effective species surrogate relationships "appear to be rare." Across two spatial scales (plot and subbasin), neither migratory habits, nor microhabitat association, nor functional grouping created a compelling basis for surrogacy. In a typical grouping (e.g., birds that dwell in an open-canopy forest), the best indicator species explained only 8.8% (range 0.6–35.6%) of variances in abundance. For instance, the western bluebird (*Sialia mexicana*) has the "strongest" surrogacy, but still explained no more than 18.2% of within-group abundance variance—in this case for birds dwelling in open-canopy forests.

Dynamic similarities between indicator species and other species within their possible explanatory groups were few and insignificant, questioning the usefulness of both guild-indicator (species grouping) and management-indicator (locality) concepts. Without an exact hypothesis and explicit links between a top-down and a bottom-up control, the monitoring of any one species cannot be linked to conclusions about a particular ecosystem, only to information about the species itself. As in all things scientific, Cushman et al. (2010) emphasize that the utility of the surrogacy concept must be "demonstrated rather than assumed."

Reference

Cushman, S. A., K. S. McKelvey, B. R. Noon, and K. McGarigal. 2010. Use of abundance of one species as a surrogate for abundance of others. Conservation Biology 24(3):830–840.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Research synthesis: The general performance of interhabitat corridors

ANY RESTRICTIONS ON FREE MOVEMENT ACROSS A landscape can threaten species survival—both plant and animal. Habitat fragmentation, usually a result of habitat loss, can weaken a species group by dividing it into isolated subpopulations. While the causes of habitat fragmentation are generally outside of a resource manager's sphere of influence (urbanization, agricultural development, tectonic movement, rise in sea level via climate change), popular conservation practices promote the use of corridors to mitigate the effects. Through creation of artificial corridors or maintenance of natural ones, dispersal of species between habitats can occur and the accompanying gene flow between subpopulations can extend species viability—supposedly.

The analysis highlights the effectiveness of land-made corridors over that of man-made ones.

Citing an increase in use of corridors for conservation purposes, "despite a lack of consensus on their efficacy," Gilbert-Norton et al. (2010) sought a practical overview of corridor success by scrutinizing the results of 20 years of corridor use in linking habitat patches.

Using a variety of data collection methods across a diverse set of corridor experiments, the study sought to answer the question: Do corridors increase movement between habitat patches for a diverse set of organisms across a wide range of ecosystems? The authors conclude that yes, creating and maintaining corridors are "ultimately worthwhile." The collation of data from 78 pertinent experiments from 35 studies indicated that movement between habitats is approximately 50% greater in patches connected by corridors than in patches without corridors.

The methods used to compare and contrast corridor experiments began with keyword searches of scientific and bibliographic databases, and continued with mathematical models reflecting hierarchical dependence. Many variables were considered for experiments deemed worthy of inclusion in the study: animal and plant corridors, controlled and uncontrolled distance between habitat fragments, and preexisting corridors versus manipulated ones. Types of corridors that are most effective and species most likely to use them are qualified throughout the study. For instance, the analysis highlights the effectiveness of land-made corridors over that of man-made ones.

The authors note that, although relevant data suggest that invertebrates and plants benefit from corridors, most manipulated corridors are created for terrestrial vertebrates, adding that general information on which particular species are most likely to benefit from corridors would be of great use to land managers and conservationists. Because pollination and seed dispersal are aided by avian and nonavian vertebrates and insect vectors, some evidence suggests that plants are more likely than animals to move through corridors. However, before findings can be generalized into practices, a more complete understanding of the relationship between connectivity and dispersal mechanisms is required.

The real-world applications of this analysis are clear: natural, preexisting corridors are more highly trafficked than experimental manipulations and the conservation of natural corridors seems generally more beneficial to habitats than the creation of manipulated ones.

The authors conclude by noting that while corridors promote movement between habitat patches, more long-term studies are required to determine whether that movement actually reduces population extinction.

Reference

Gilbert-Norton, L., K. H. Beard, R. Wilson, and J. R. Stevens. 2010. A meta-analytic review of corridor effectiveness. Conservation Biology 24(3):660–668.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Improving pest risk maps for management of invasive species

DESPITE THE URGENCY OF RESPONDING TO A BIOLOGICAL invasion, plant or animal, careful analysis of the situation and informed decision making will ultimately lead to a more effective solution. The pest risk map is a powerful tool for any resource manager faced with surveillance for invasive species because it tracks the arrival and spread of these species and illustrates their potential impacts across spatial and temporal scales.

Pest risk maps are prepared by various organizations, including the USDA Forest Service, which has its own pest risk mapping team. Depending on the type of pest, a team of experts is assembled that can include animal or plant pathologists, botanists, ecologists, and climatologists.

Though risk map development has evolved to include global environmental databases and computer-generated models of a species' geographic distribution, Venette et al. (2010) point to uncertainties surrounding the creation and interpretation of risk maps and recommend several improvements to current widespread methods.

Expounding on a 2007 meeting of the USDA Pest Risk Mapping Workgroup, the authors detail 10 recommendations for improving the accuracy and clarity of pest risk maps. At the top of the list is greater communication between map developers and stakeholders regarding methods for developing maps. With greater documentation of model development, land managers can more appropriately assess the given information. Thorough documentation of a map's rationale, comprehensive explanations of data-gathering procedures, and a clear statement of the map's intent by analysts will allow resource managers to better evaluate the model.

The workgroup's recommendations also call for better representation of uncertainty, a factor inherent in compiling all risk maps because of the vast complexity of ecological systems. In a study of risk maps of the nonnative woodwasp (*Sirex noctilio*), detected in the United States and Canada, Koch et al. (2009) explore how numeric assumptions that accompany uncertainties can impact the reliability of a risk map. Detailed consideration of uncertainty, the authors affirm, should be standard procedure.

Other methods for improving the effectiveness of pest risk maps are expanding the availability and accessibility of primary data, developing a best-practices guide and tool kit for modeling, detailing impacts, increasing international collaboration, incorporating climate change data, studying how human and biological dimensions interact, and providing training in pest risk modeling practice.

Venette et al. (2010) conclude that the quality of available data should be considered when analyzing the accuracy of any pest risk map. Unfortunately, the function of such a map is often constrained by a small set of available data coupled with the urgency of implementation. Another major conclusion is that risk maps can and should be assembled with greater ambition to include meteorological, economic, and historical information to address more elements related to invasion risk than just basic geographic reach. Perhaps the most potent conclusion is that the development of risk maps should be documented in greater detail so that resource managers can more aptly and effectively analyze their relevance and usefulness.

References

Koch, F. H., D. Yemshanov, D. W. McKenney, and W. D. Smith. 2009. Evaluating critical uncertainty thresholds in a spatial model of forest pest invasion risk. Risk Analysis 29(9):1227–1241.

Venette, R. C., D. J. Kriticos, R. D. Magarey, F. H. Koch, H. A. Richard, S. P. Worner, R. Gomez, N. Nadilla, D. W. McKenney, E. J. Dobesberger, D. Yemshanov, P. J. DeBarro, W. D. Hutchinson, G. Fowler, T. M. Kalaris, and J. Pedlar. 2010. Pest risk maps for invasive alien species: A roadmap for improvement. Bioscience 60(5):349–362.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Enhancing the uses of aerial photography in ecological management

A TRADEMARK OF TECHNOLOGY IS THAT IT CHANGES quickly, in the blink of an eye—or in this case, in the click of a camera's shutter. Aerial photography has been a staple of land assessment since the 1930s and, with the advent of satellite imagery in the 1970s and ongoing advances in digital photo analysis, its applications continue to multiply. In a survey of aerial photography characteristics, Morgan et al. (2010) describe the specific uses of applying digital analysis to traditional film photography to increase consistency, objectivity, and cost-effectiveness for applications to land management, in contrast to cheaper but often coarser satellite imagery.

Well-trained and seasoned interpreters of aerial photography, the authors say, are decreasing in number. A picture may be worth a thousand words, but without an informed interpreter, the potential for application of aerial photography to land management is all but lost. Enter digital photo analysis, made possible by scanning technology. Traditional aerial film photography may still be preferred over newer aerial digital photography because there is loss of spatial resolution with the latter. Though digital enhancement can mine a photograph for data sets beyond those available by simple visual examination, potential geometric (positional) displacements and radiometric (tonal or color) distortions abound in the process of taking and processing aerial photographs. Other factors are outside of the processor's influence—such as an unfocused lens, inappropriate flying height, or unfavorable weather conditions—and the quality of a film-based photograph ultimately depends on the quality of the camera.

The authors outline how eight primary characteristics of aerial photography are used in interpreting ecological features and, furthermore, how digital manipulation of aerial film photography can improve the accessibility of information. For those not trained in aerial photograph assessment, digital manipulation can be tantamount to a decoder ring. For instance, tone and color are used to identify soil composition and, by digitally manipulating the contrast, basic soil coverage images can become a major indicator of drainage rates. Likewise, size, shape, pattern, and shadow can be enhanced or manipulated to better identify foliage, and landscape use and structure.

Despite the challenges, Morgan et al. (2010) argue in conclusion that ecosystem research and management can be benefited greatly by using aerial photography to inventory specific foliage and even compile a history of topographical changes. With digital tools, the consistency and accuracy of aerial photography are advancing healthily. Traditional manual interpretation, subject to the interpreter's experience level, can now be improved upon by automated analysis programs.

Reference

Morgan, J. L., S. E. Gergel, and N. C. Coops. 2010. Aerial photography: A rapidly evolving tool for ecological management. Bioscience 60(1):47–59.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Taking it to the trees: A primer on the scope and purpose of environmental adult education

THOUGH ENVIRONMENTAL ADULT EDUCATION (EAE) IS A young field, academically speaking, any examination of the past can serve as a guidepost for the future. Starting with its birth as a unique field of study in the 1970s and proceeding to its more recent coherence as a tool for promoting sustainable living and enacting social change, Haugen (2009) documents environmental adult education as a movement that is both "growing up" and becoming more relevant than ever.

Haugen begins her analysis of the concepts and themes in environmental adult education with the first person to call for it: Lars Emmelin, now a professor at the Swedish Environmental Impact Assessment Centre. In a 1976 paper, Emmelin made a case for both formal and informal environmental adult education: workshops and seminars that would have as much potential to create genuine environmental change as community-oriented activities, such as taking a composting class at a local food co-op, participating in a guided park tour, or attending an environmental protest.

The legitimizing of the EAE movement continued into the 1980s with the publication of several more journal articles and case studies, finally reaching the international stage with the first Earth Summit in 1992. Five years later, environmental adult education, with its focus on the ethical ramifications of stewardship over basic cause-and-effect studies, was recognized by UNESCO (United Nations Educational, Scientific, and Cultural Organization) as a distinct field of practice, which goes beyond the focus placed on experiential learning about the environment used in traditional environmental education. Environmental adult education is, essentially, an ideological agreement between the environmental movement and adult education.

As environmentalism became prominent in a global context, EAE practitioners were now suited to address the sociopolitical factors that lead to widespread environmental destruction, a major breaking away from the traditional field of environmental education, which was "not meeting the needs of adult learners" and lacked a holistic view of how humans interact with nature. Thus, Haugen notes, "feminism" and other "indigenous, popular, and nonformal" education philosophies were used to shore up the foundations of environmental adult education in the late 1990s.

Through her historical literature review, Haugen (2009) notes that the basis of environmental adult education can be found earlier in human history. In ancient societies, communal living practices necessitated involvement with and respect for the biosphere, whereas today we may engage in responsible environmental behavior only when convenient or out of guilt. That is to say, environmentalism cannot simply be taught and learned: it must be lived. The author concludes that the constant goal of any environmental adult educator is to strengthen learners' sense of ecological responsibility, which perhaps has ebbed or disappeared altogether in modern society. Informed of their role, historically and ideologically, active environmental adult educators can more aptly clarify their goals and more passionately convert learners into activists.

In conclusion, environmental adult education is as much about the study of root causes of environmental problems as it is a way to gain the tools to offset them. Through experiential learning processes, a true and lasting appreciation for natural wonders is gained and the basic tenets of environmental stewardship are communicated, values that are both collective and individual.

Reference

Haugen, C. S. 2009. Adult learners and the environment in the last century: An historical analysis of environmental adult education literature. Electronic Green Journal 1(29):1–14.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Environmentalism cannot simply be taught and learned: it must be lived.

INTEGRATED SUMMARIES

Planning and collaboration are keys to successful fire management

WILDFIRES FREQUENTLY START AT THE WILDLAND-URBAN interface (WUI), where human development meets naturally occurring vegetation. Therefore, clearly defining and mapping these areas are crucial to fire suppression and human safety. Platt (2010) offers an evaluation of five models used in WUI mapping based on characteristics of the wildland-urban interface as outlined in the *Federal Register* (USDI 2001), comparing and contrasting their uses across four U.S. counties in Colorado, Florida, Washington, and Wisconsin.

Differences among the models can be subtle or pronounced depending upon characteristics of each WUI area. Methods for WUI mapping, detailed on the University of Wisconsin–Madison's Silvis Web site (UWM 2010), focus varyingly on three components—settlements or housing structures, suitable buffer around such settlements, and wildland vegetation—so choosing the correct method depends on accurately surveying the protected area. While one method is useful for mapping tracts of land with ample vegetation, another is suited to areas with numerous existing structures. Implementation differs even among users of the same method because of variations in buffer zones, which can range from 0.5 to 1.5 miles (0.8 to 2.4 km). Depending on one's goals for identifying the number of structures, potential fuel ignition sources, amount of vegetation, and highest priority areas for mitigation, managers and stakeholders must evaluate their area and decide which method is best. "No single mapping approach is unequivocally superior, and each has trade-offs that need to be fully understood for use in management," writes Platt (2010). For instance, a trade-off in a housing-oriented WUI may be inaccurate structure counts because of gaps in zoning data. Choosing the correct WUI method and accurately mapping an area could improve fire suppression planning, not to mention leading to increased allocations of federal funds to certain areas, Platt adds.

Goldstein and Butler (2010) describe the inner workings of the Fire Learning Network (FLN), an organization dedicated to improving the restoration of fire-dependent ecosystems nationwide. The result of five years of policy analysis and interviews, this research proposes a theory of collaborative planning in which land management and conservation can best be improved by a synergy among stakeholder-based collaborations and communities of practice in which private-sector and federal entities share information and advise each other about prescribed fire practices. The authors claim that a long-standing practice of stakeholders collaborating only with other stakeholders has blinded natural resource planners to the potential success of more inclusive approaches. Stakeholders aiming to effect a specific change in policy or regulation surrounding the complex issue of fire management can become entrenched in the advice of external advisors, but communities of practice should not be overlooked.

Organized around trading advice and expertise about a common issue, communities of practice have no explicit aim to solve the issues facing stakeholders, but can offer a fresh perspective nonetheless. In the Pacific Northwest, the Fire Learning Network has a presence in Washington and Oregon. The Northwest Fire Learning Network creates a flow of information among lumber companies, conservation and community organizations, private landowners, universities, fire departments, and state and federal government entities, educating the public along the way.

Goldstein and Butler (2010) found, using the Fire Learning Network as an example, that expertise in restoring ecosystems that depend on fire is best shared through collaborative planning. As in the Fire Learning Network, in collaboration among stakeholders (state and local governments) and communities of practice (regional networks), the potential for positive change is amplified. This approach nurtured expertise and expanded and sustained collaborative networks. While the progress made by the Fire Learning Network is highlighted extensively in the article, it is used as an example. "The power of the FLN is not found in the plans it produces, but in the way it disrupts old habits and fosters new routines and collaborative relationships," the authors surmise. In protected area management, not having enough cooks can spoil the broth.

References

Goldstein, B. E., and W. H. Butler. 2010. Expanding the scope and impact of collaborative planning. Journal of the American Planning Association 76(2):238–249.

Platt, R. V. 2010. The wildland-urban interface: Evaluating the definition effect. Journal of Forestry 108(1):9–15.

U.S. Department of Interior (USDI). 2001. Urban-wildland interface communities within vicinity of federal lands that are at high risk from wildfire. Federal Register 66(3):751–777.

University of Wisconsin–Madison (UWM). 2010. Wildland-urban interface maps, statistics, and data. Accessed 30 August 2010 from http://silvis.forest.wisc.edu/old/Library/WUILibrary.php.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

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Phenology and citizen science update their status

ONE ENVIRONMENTAL FIELD OF STUDY THAT HISTORICALLY has relied on laypeople or "citizen scientists" for data collection is now adapting to the ubiquity of global communications technology. Phenology, the study of the relationship between plant and animal life cycle stages and climate, is well poised to capitalize on the widespread availability of computer network, Internet, cell phone, and global positioning system (GPS) technologies for quick, easy, and integrated documentation of natural cycles.

Volunteers' or enthusiasts' notations of the date and location of first-arriving migratory birds, green-up of grasses, flowering and fruiting of plants, maximum abundance of migratory species, and insect emergence have contributed to biologists' understanding of species' life histories and ecosystem functions for centuries. The new game in town for phenologists is weighing, for example, a bird observation sent in by birdman221@yahoo.com and aggregating it with data from the 6 million bird migration cards written between 1881 and 1970 as part of the North American Bird Phenology Program. Historical records from this program have been incorporated into the USA National Phenology Network (NPN), founded in 2004 and sponsored by numerous governmental and nongovernmental organizations, including the National Science Foundation (NSF), U.S. Geological Survey, and National Park Service.

Already a cornerstone of phenology, the basic trust in data reported by citizen scientists can be improved with the addition of digital photographs and occasional confirmation of anomalous data, as demonstrated by the Cornell Lab of Ornithology's Project FeederWatch. This ongoing research Web site tracks the winter movements of North American bird populations as reported by the owners of bird feeders. Mayer (2010) writes that FeederWatch's use of new technologies makes participation more accessible and expedites the process of converting volunteer observations into usable data.

The scientific research community requires data collection standards and the National Phenology Network has developed "protocols for gathering observations," writes Mayer (2010). Preventive and corrective strategies built into the NPN data system ensure that the data it stores will meet research quality requirements. For example, a citizen scientist cannot mistakenly enter a future date or select a plant species foreign to the region. Similarly to FeederWatch, any questionable data are flagged and additional information is requested. With these back-end measures in place, and with clear instructions given to its participants to begin with, the National Phenology Network assumes that its "flock" of citizen scientists is flying straight.

An ambitious science program dedicated to collecting ecological and climatic observations and scheduled to begin in 2016 will include a citizen science component and plans to further help verify sightings. Known as the National Ecological Observatory Network (NEON) and funded by the National Science Foundation, this corporate program may use photos from cell phone cameras and GPS coordinates to confirm sightings by its citizen scientists. Its goals are to increase understanding of climate change, biodiversity, disease ecology, and invasive species and to forecast ecological change at continental scales.

Between ambition and practicality, however, there is money. The input of long-term, "legacy" data sets into publicly accessible databases is crucial for developing incisive and relevant conclusions in phenology, but "traditional funding sources, such as grants from the NSF or other government agencies and foundations, are given typically for no more than five years," according to Mayer (2010). One exception is Project FeederWatch, which requires a $15 annual fee from each participant and, according to its Web site, is run almost entirely on those funds.

The wide availability of new ways to engage the public in the scientific process can only be a boon to phenology, and some national parks may be able to incorporate nontraditional reporting means into scientific field activities such as bioblitzes and stimulate public interest and participation in park science and information sharing. Who knows, if Henry David Thoreau were alive today, he might be stalking Walden Pond with a wireless hotspot, "tweeting" from his iPhone about the first robin of spring.

References

Cornell Lab of Ornithology. 2010. Project FeederWatch. Accessed 1 September 2010 at http://birds.cornell.edu/pfw/.

Mayer, A. 2010. Phenology and citizen science. BioScience 60(3):172–175.

National Ecological Observatory Network (NEON). 2010. About NEON. Accessed 1 September 2010 at http://www.neoninc.org/about/overview.

USA National Phenology Network. 2010. USA National Phenology Network. Accessed 1 September 2010 from http://www.usanpn.org/about.

U.S. Geological Survey. 2010. North American Bird Phenology Program. Accessed 1 September 2010 at http://www.pwrc.usgs.gov/bpp/.

—Jonathan Nawn, Mindi Davis, and Jeff Selleck

Science Notes

Understanding lake drainage in northern Alaskan national parks

Impacts of a warming climate

By Amy Larsen

IN 2003, NATIONAL PARK SERVICE PILOT Kevin Fox flew over a lake in the vast Yukon–Charley Rivers National Preserve. Days earlier the lake had been teeming with life, but what Fox saw as he gazed down on the landscape looked more like a muddy lunar landscape than a lake (fig. 1, facing page). In just three days the lake had drained completely. This was the first of dozens of catastrophic lake drainages that have since been documented in Alaska's national parks.

NPS/AMY LARSEN

NPS/AMY LARSEN

Figure 1. Catastrophically drained lake in Yukon–Charley Rivers National Preserve.

Aerial photographs and satellite images allow network resource managers to look back in time to see how these lakes have changed over the past 50 years.

Drainage events such as this typically are brought on by the natural movement of a stream across its floodplain. If a lake is encountered during this lateral movement, the stream erodes the lake shoreline, the lake is breached, and lake water rapidly drains into the stream or a nearby lake. Recent drainage events, however, have shown no evidence of this type of drainage. Instead, many of the lakes appeared as if their "plug" had simply been pulled and the water drained away.

Understanding how and why these ecosystems are disappearing in this manner is important to park managers because shallow lakes are productive and support a diverse array of plants and animals. In turn, they are important to the people who hunt and trap subsistence resources such as moose, waterfowl, and furbearing mammals within the boundaries of Alaska's national parks. Thus, preserving these ecosystems is a concern for park managers.

Studies ensue

The Central Alaska and Arctic networks (fig. 2) of the Inventory and Monitoring Program began monitoring shallow lakes in 2003 in order to understand these important ecosystems and the changes that were occurring. One of the primary objectives is to detect changes in the number, area, and distribution of park lakes, and remote sensing is the most effective way to measure this type of lake change. Aerial photographs and satellite images allow network scientists to look back in time to see how these lakes have changed over the past 50 years (fig. 3, next page). Analysis of historical lake change conducted to date reveals that lake surface area has been reduced by as much as 28% across north-central Alaska (fig. 4, next page).

One of the most impacted national parks is Kobuk Valley, where lake area has declined by about 20% and 12 lakes have drained catastrophically over the past five years. Catastrophic lake drainage occurs very rapidly taking only a few days or weeks. Understanding the environmental conditions found in Kobuk Valley can help scientists and resource managers determine why this region is changing so quickly. Park scientists believe the changes here are due to regional geographic and soil conditions.

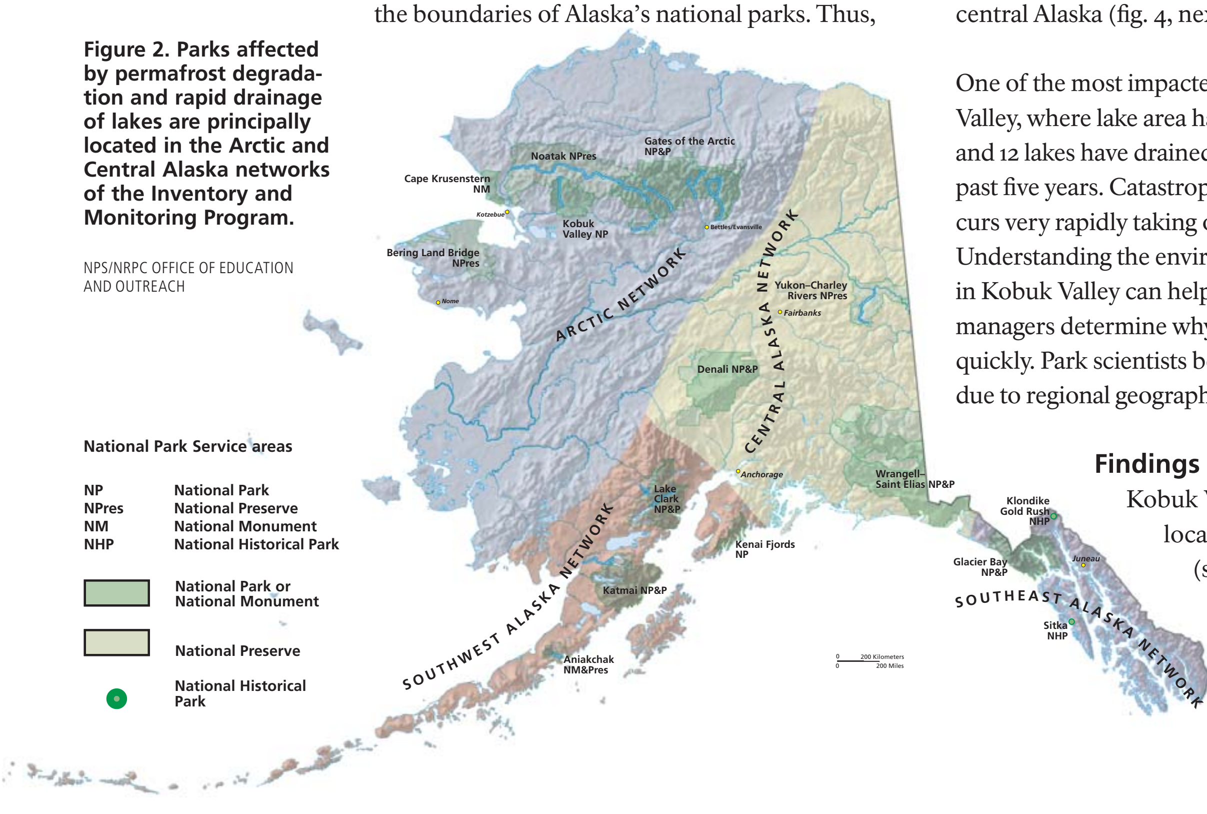

Figure 2. Parks affected by permafrost degradation and rapid drainage of lakes are principally located in the Arctic and Central Alaska networks of the Inventory and Monitoring Program.

NPS/NRPC OFFICE OF EDUCATION AND OUTREACH

Findings

Kobuk Valley National Park is located in northwestern Alaska (see fig. 2) on the southernmost edge of the continuous permafrost zone. Permafrost is peren-

Science Notes

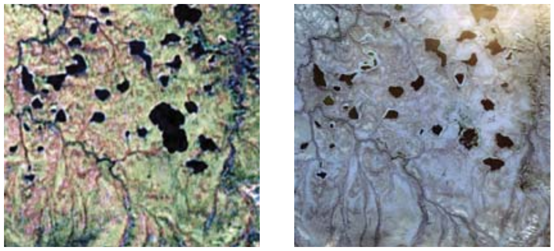

Figure 3. Remote sensing is used to track historical changes in lake surface area. These photographs show changes in surface area of the large lake over the past six years.

LEFT: 2003 LANDSAT THEMATIC MAPPER. MIDDLE: 2007 IKONOS. RIGHT: 2009 LOW ALTITUDE AERIAL PHOTO NPS/AMY LARSEN.

nially frozen ground that, when intact, prevents seepage of water, leaving it trapped near the soil surface or within depressions such as lakes. As permafrost melts, lake water is allowed to infiltrate the sediment underlying the lake and ultimately seeps out the lake bottom. Permafrost degradation surrounding lakes is common because soil temperatures tend to be warmer than in the surrounding upland terrain. The impacts of permafrost degradation are most severe in areas where the permafrost is ice rich; when ice-rich permafrost melts, the terrain subsides, creating new stream channels, and frequently results in catastrophic lake drainage. The ice content of permafrost varies greatly across northern Alaska and is high along the Nigeruk Plain in Kobuk Valley. Our aerial photography shows permafrost degradation in Kobuk Valley is concentrated in these ice-rich regions. Historically, annual average air temperature readings throughout the park have been well below freezing (20°F [−7°C]) and the permafrost has been stable; however, in the past 50 years average annual air temperature has increased 6°F (3.3°C). This temperature increase is likely the principal cause of permafrost degradation and the subsequent lake drainage.

Other soil characteristics, including thin organic layer, course soil particles, and fire, also affect the integrity of permafrost. Thick organic material common in other regions of northern Alaska protects permafrost by forming an insulating barrier that helps keep soil cold. In much of Kobuk Valley, however, the organic layer is thin and does not effectively protect permafrost. In addition, many of the lakes in the park lie between the two active sand dunes and are underlain by sand; therefore, when permafrost melts, water quickly infiltrates the sand and lake level drops. The southern portion of the park is occupied largely by boreal forest, where fire periodically removes the organic layer, reducing insulation of the permafrost. The vast majority of catastrophic drainage in the park has occurred

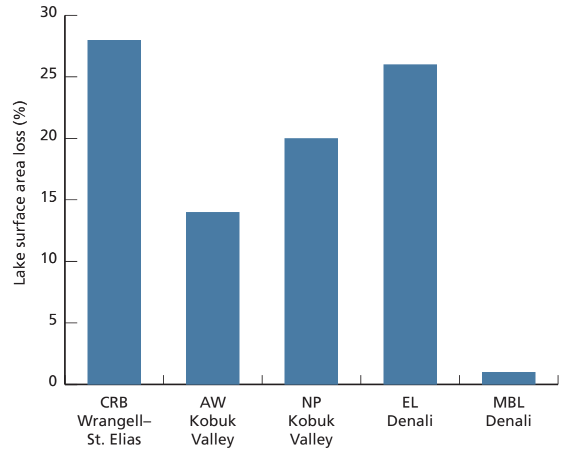

Figure 4. Change in lake surface area over the past 30–50 years in national parks located across north-central Alaska. CRB = Copper River Basin, AW = Ahnewetut Wetlands, NP = Nigeruk Plain, EL = Eolian Lowlands, MBL = Minchumina Basin Lowlands. Source: M. Necsoiu et al. 2009; Riordan et al. 2006; Verbyla 2007.

within the boreal forest zone. These geographic and soil characteristics contribute to the high degree of lake change observed in Kobuk Valley.

Information for managers

Field surveys planned for August 2010 will measure permafrost and soil characteristics in drained lake beds in Kobuk Valley to help park managers further understand the mechanisms contributing to lake drainage. Scientists studying the changes plan to model lake vulnerability in the park from the data gathered. This information will help managers track and forecast potential lake changes. These data, combined with other data on muskrat, moose, and beaver, will be used to make management decisions related to hunting, trapping, and fishing. At this time it is not feasible to mitigate the impacts of climate warming in these remote and otherwise pristine ecosystems. Educating the public is the strongest tool managers have to ameliorate the impacts of climate warming. Scientists are working to inform the public of the dramatic changes that are occurring in these remote regions of Alaska so they can affect legislation to reduce global emissions of gases known to contribute to global warming.

About the author

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Benthic habitat mapping in ocean and Great Lakes parks

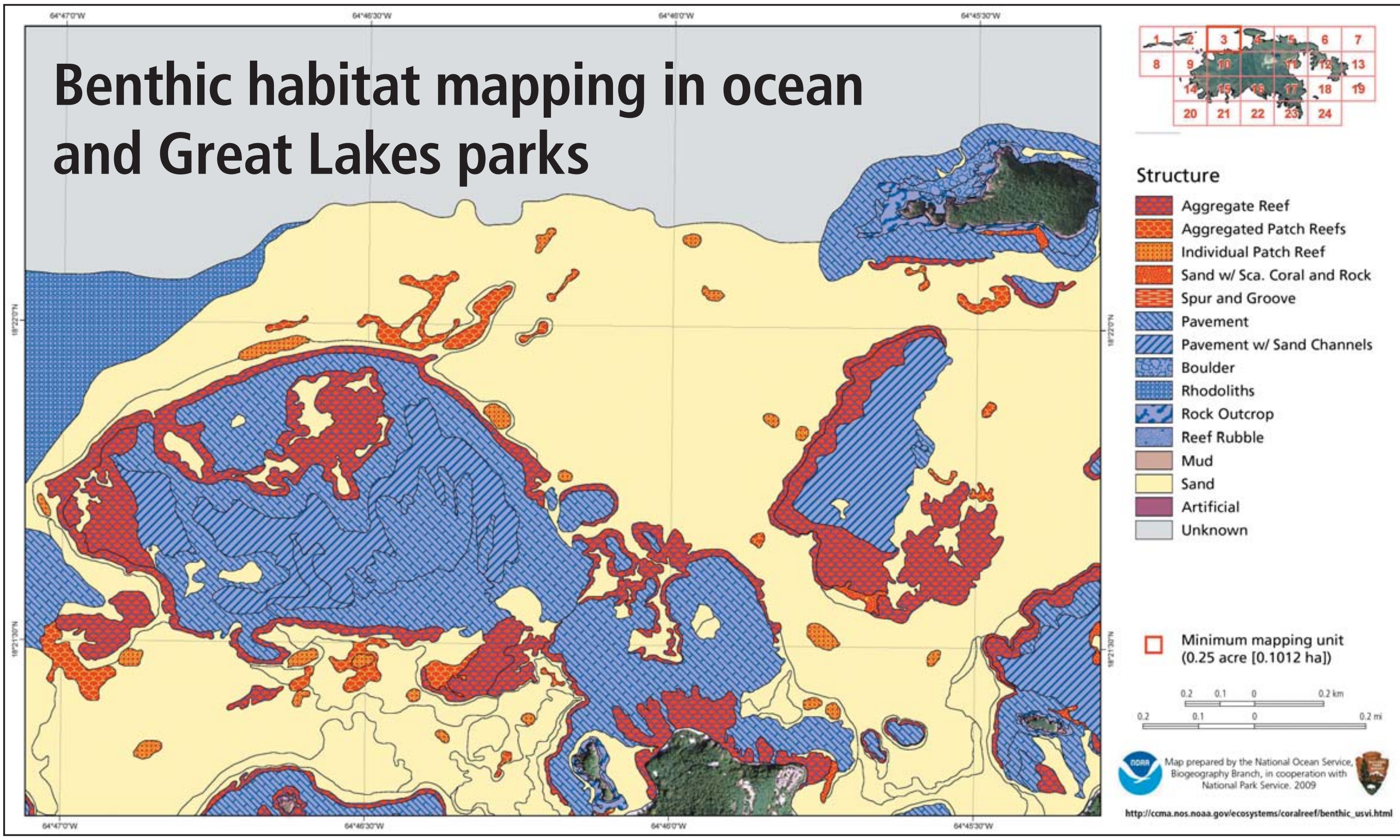

Figure 1. This benthic habitat map of Cinnamon Bay, Virgin Islands National Park, is based on aerial color photography and IKONOS satellite imagery. It was produced by the NOAA Center for Coastal Monitoring and Assessment (complete park map is available for downloading from http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic_usvi.html).

By Jeffrey N. Cross

MANAGERS OF 80 OCEAN AND GREAT LAKES units in the National Park System face increasing impacts from coastal development, land-based pollution, recreational use, nonnative species, and climate change. Park managers often have only general knowledge and a vague understanding of the nature, extent, and condition of submerged resources within their park's boundaries. Unlike their counterparts at terrestrial parks, managers of ocean and Great Lakes units cannot readily observe their resources. The most spectacular topography and habitat features are hidden from casual view and may only be detected by surveys that are technically complex, logistically difficult, and expensive, which is why submerged natural resources remain unmapped for the majority of our ocean and Great Lakes parks.

Spatial display and analysis is the most efficient and cost-effective way for park managers to use complex natural resource information. In 2008, the Natural Resource Program Center (NRPC) initiated a program to produce digital, geographically referenced data that can be used in geographic information systems (GIS) to create high-quality habitat maps that support resource assessments and management planning. Funded by the NPS Inventory and Monitoring Program, the Natural Resource Program Center partnered with the U.S. Geologic Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and several academic institutions to develop benthic habitat maps for six parks,[1] with several more under way or about to get started.[2] While the focus is on submerged natural resources, it can easily be extended to cultural resources. As Dave Conlin, director of the NPS Submerged Resources Center, says, "Submerged cultural resources are habitat for natural resources."

[1] Glacier Bay National Park and Preserve, Golden Gate National Recreation Area, Gulf Islands National Seashore, Sleeping Bear Dunes National Lakeshore, Virgin Islands Coral Reef National Monument, and Virgin Islands National Park

[2] Assateague Island and Point Reyes national seashores, Buck Island Reef National Monument, San Juan National Historic Site, and Salt River Bay National Historical Park and Ecological Preserve

Science Notes

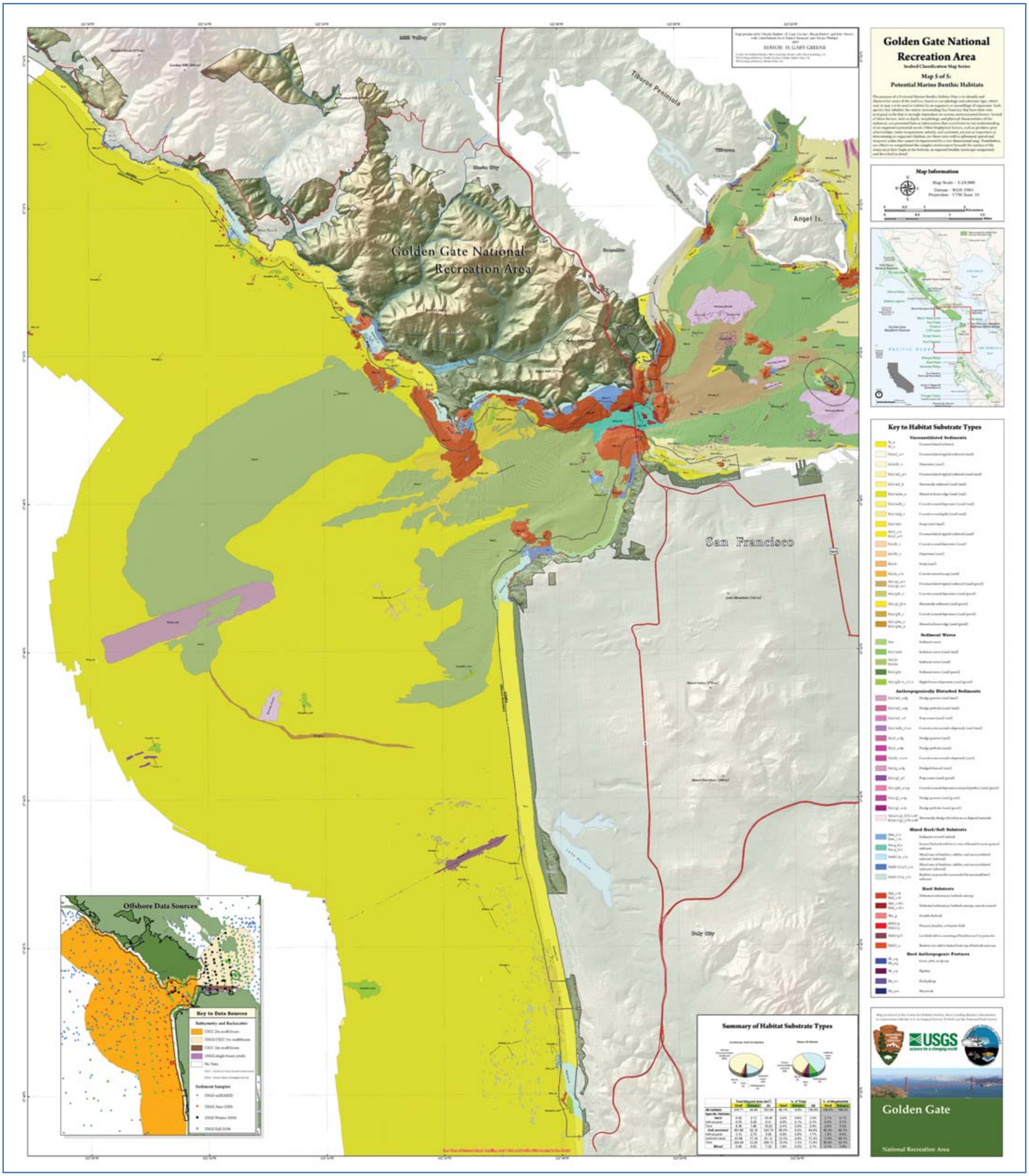

Figure 2. This benthic habitat map of Golden Gate National Recreation Area and vicinity is based on multibeam and side-scan acoustic data and sediment surveys. The map was produced by the U.S. Geological Survey and Moss Landing Marine Laboratories.

The most spectacular topography and habitat features are hidden from casual view and may only be detected by surveys that are technically complex, logistically difficult, and expensive, which is why submerged natural resources remain unmapped for the majority of our ocean and Great Lakes parks.

Mapping standards

Currently, no national standard for classifying ocean and coastal habitats is available for use. The primary challenge is to develop a classification standard that can support site-specific maps (high level of detail) and regional maps (lower level of detail). The Natural Resource Program Center is working with the NOAA Center for Coastal Monitoring and Science, NatureServe, and the Federal Geographic Data Committee to adopt a national classification, mapping, and validation standard based on the Coastal Marine Ecological Classification Standard developed by NOAA and NatureServe. A draft classification was submitted to the Federal Geographic Data Committee for review and consideration in early summer 2010.

Producing the maps

The steps to produce benthic habitat maps include data mining and acquisition, interpretation and mapping, validation and accuracy assessment, and GIS products and reports. Data for mapping are usually acquired by remote sensing and include visible imagery, acoustic data, laser light data, and bottom visualization.[3]

Satellite and aerial imagery are useful for studying ocean and coastal features. Satellites with multispectral sensors, such as Landsat (30 m resolution) and IKONOS (4 m resolution), can be used to map submerged resources in shallow (<20 m), clear waters (fig. 1, page 21).

Sonar systems (side-scan and multibeam) use sound produced and recorded by an array of transducers to generate high-resolution, three-dimensional images of the ocean floor. Side-scan systems are effective in shallow water because they can image wide areas from a short distance above the bottom. Multibeam systems are useful in deep water because of the wide bottom swath, although resolution decreases with increasing depth (fig. 2, facing page). Acoustic surveys return a depth value in addition to a reflection coefficient that is correlated to bottom properties. Using reflectivity correlations, bottom types can be classified in terms of "hardness" (e.g., mud, sand, rock).

Light detection and ranging (lidar) can be used in clear, shallow waters (1–10 m resolution). The light waves from a green laser are reflected from the bottom and the travel time is used to calculate depth. Lidar systems can be used over land as well as in the water to map the topography across the coastal zone.

Direct images of the bottom are necessary to validate habitat maps based on remotely sensed data. Bottom visualization systems include scuba divers, towed and dropped cameras, remotely operated vehicles, and submersibles. Bottom visualization can be augmented by shipboard sampling (e.g., sediment grabs).

Benthic habitat maps establish baselines for monitoring. As sea level rises and barrier islands are eroded by storms, as ocean temperatures rise and flora and fauna redistribute themselves, benthic habitat maps can be used to track changing conditions. Mapping products can also guide park managers as they assess post-incident damage (e.g., storms, ship groundings, oil spills) and inform post-incident mitigation and management decisions.

About the author

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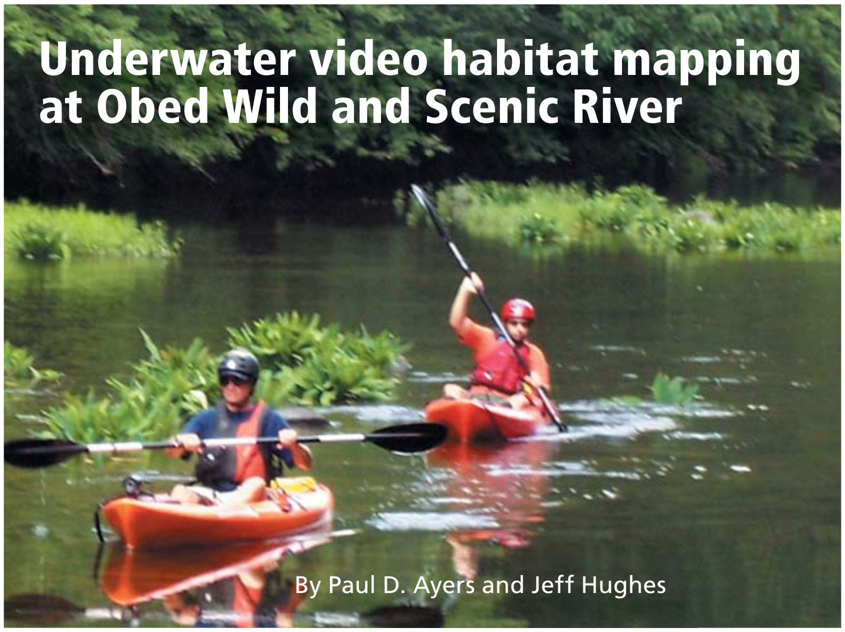
[3]Moses, C. S., A. Nayegandhi, R. Beavers, and J. Brock. A Service-wide benthic mapping program for national parks. USGS Open File Report. U.S. Geological Survey, Reston, Virginia, in press.

Science Notes

Underwater video habitat mapping at Obed Wild and Scenic River



UNIVERSITY OF TENNESSEE

By Paul D. Ayers and Jeff Hughes

Figure 1. Researcher Ayers and a graduate student map Clear Creek, Obed Wild and Scenic River, using the underwater video mapping system.

RESOURCE MANAGERS AT OBED WILD AND Scenic River are striving to understand the effects of growing human population on the park's watershed. As in much of the country, human population is increasing on the Cumberland Plateau of Tennessee, where the wild and scenic river is located. Managers are concerned that development associated with population growth may significantly alter the flow regime and water quality of portions of the Obed River, Daddy's Creek, and Clear Creek in the park. They have begun to study the potential impacts of development on park hydrology and water-related resources. Recently they initiated research to determine the location and amount of riverine habitat available for aquatic species in the park.

Paul D. Ayers, professor at University of Tennessee, Department of Biosystems Engineering and Soil Science, is leading the project and has surveyed the entire 45 miles (72 km) of Obed River, Clear Creek, and Daddy's Creek within the park (fig. 1). He is assembling the complete river system map in a Geographic Information System (GIS) format for use by the National Park Service (NPS) for general river management, determining areas of impact from development, and identifying resource values and habitat of endangered species. The federally listed endangered and threatened species under the scope of this research include three fishes (the spotfin chub [*Erimonax monachus*], blackside dace [*Phoxinus cumberlandensis*], and dusktail darter [*Etheostoma percnurum*]) and six mussels (the Cumberland elktoe [*Alasmidonta atropurpurea*], purple bean [*Villosa perpurpurea*], Cumberland bean [*Villosa trabalis*], Cumberlandian combshell [*Epioblasma brevidens*], tan riffleshell [*Epioblasma florentina walker*], and littlewing pearlymussel [*Pegias fibula*]).

Ayers developed the underwater video mapping system (UVMS) to examine submerged ecosystems and record their locations. The system incorporates three Ocean Systems, Inc., DropShot underwater video cameras; a Garmin 18 differentially corrected Global Positioning System (GPS) receiver; a Red Hen Systems, Inc., video mapping system (VMS) 200, which integrates GPS locations with video; three Sony digital video recorders; a pair of underwater laser pointers (20 mW, 635 nm); and a depth sonar transducer (fig. 2). Two DropShot underwater cameras are flush-mounted to the bottom and side of the kayak hull; the third camera is mounted to the bow to acquire above-water video (figs. 3 and 4). The GPS receiver is a 12-channel, high-performance unit that uses a system of satellites and ground-based stations to provide better location accuracy than satellites alone. The video recorders save the geo-referenced video locations from the VMS 200. The laser pointers, also flush-mounted to the kayak, produce two dots on the substrate to provide a scale to determine substrate size (see fig. 2). Sonar measures river depth.

Ayers has previously conducted UVMS research that used underwater technology on a canoe and outboard motor boat at Biscayne National Park (Florida), Cherokee National Forest (Tennessee), and in Molokai (Hawaii). The customized kayak UVMS apparatus used at Obed Wild and Scenic River, however, was more compact and, overall, the kayak protected sensitive equipment from harsh environmental conditions very effectively (see fig. 3). The kayak-based system proved its durability and navigational precision in shallow, narrow channels and swift water (see fig. 1).

Researchers analyzed video footage for substrate, river characteristics, river depth, and embeddedness of the substrate in developing maps of optimal habitat for the threatened and endangered fish and mussel species (fig. 5).

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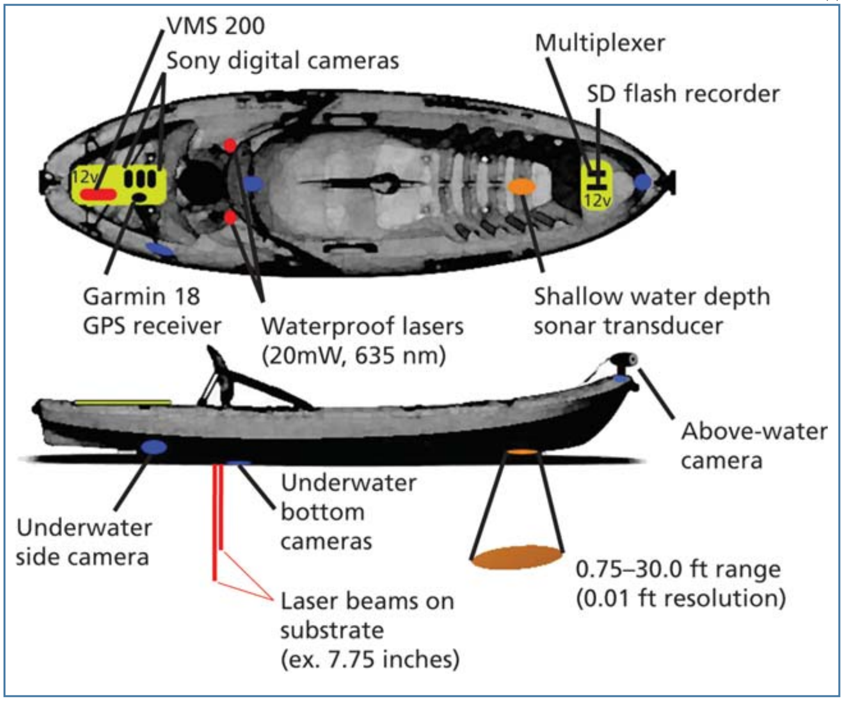

Figure 2. Schematic of the kayak-based underwater video mapping system.

Figure 3 (left). Underwater camera and laser pointers are embedded into the bottom of the kayak where they are well protected.

Figure 4 (above). The above-water camera in front of the kayak captures images of river characteristics.

NATIONAL PARK SERVICE

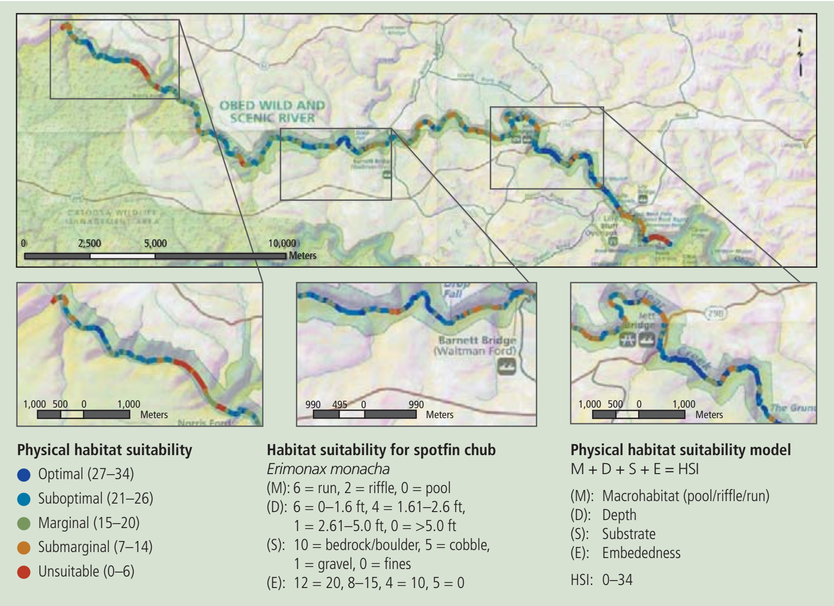

Figure 5. One of the maps produced from the research was this one of Clear Creek that shows the habitat suitability transitions for spotfin chub within Obed Wild and Scenic River.

Habitat mapping has become an effective tool contributing to aquatic conservation and management. Compared to traditional river surveying methodologies, the underwater video mapping system invites management awareness of habitat that is usually out of sight. It provides for management recommendations on a large scale but with zoom-in capabilities to assess microhabitat.

Acknowledgments

Collaborators for this and other NPS projects are Rebecca Schapansky (Obed Wild and Scenic River), Steve Bakaletz (Big South Fork National River and Recreation Area), and Matt Kulp (Great Smoky Mountains National Park). The NPS Water Resources Division, Natural Resource Program Center, funded the project and provided expertise on water rights issues.

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Science Notes

NPS PHOTO

Water right protects Great Sand Dunes National Park and Preserve

South Twin Lake, located near the remote southwestern corner of Great Sand Dunes National Park and Preserve, is an expression of the shallow unconfined aquifer.

By James Harte

ON 4 AUGUST 2008, WATER JUDGE O. JOHN Kuenhold signed a historic decree approving an in-place right to groundwater for Great Sand Dunes National Park and Preserve. The water right is the first of its kind in the state of Colorado and concludes more than a decade of work by the National Park Service, the state of Colorado, and the local community to protect water and water-dependent resources in the San Luis Valley.

Great Sand Dunes National Park and Preserve (Great Sand Dunes) is located in the San Luis Valley of south-central Colorado and has been threatened for years by proposals to export water to the Front Range of Colorado or to New Mexico. In 2000, with the support of the state, the Rio Grande Water Conservation District, and the local community, Congress passed the Great Sand Dunes National Park and Preserve Act. The act was unique because Congress specifically recognized that surface and groundwater systems on and underlying the Great Sand Dunes and adjacent lands were necessary to the preservation of resource values, including the unique pulse flow characteristics of Sand and Medano creeks. In addition, Congress directed the Secretary of the Interior to obtain and exercise water rights to fulfill the purposes of the park by maintaining groundwater levels, surface water levels, and streamflows on, across, and under the park.

To accomplish this, the U.S. Department of Justice, representing the Service, filed a water right ap-

NPS/WATER RESOURCES DIVISION, JAMES HARTE

Little Spring Creek, located west of the main dune complex in Great Sand Dunes National Park and Preserve, arises from the ground where the shallow unconfined aquifer intersects the ground surface.

NPS PHOTO

During spring snowmelt runoff and intense summer thunderstorms, Sand Creek flows west from the Sangre de Cristo Mountains, along the north side of the main dune complex, and may eventually make its way into San Luis Lake, near the western boundary of Great Sand Dunes National Park and Preserve.

plication in December 2004 to claim a right to all unappropriated (available) water in the unconfined aquifer (shallow water-table aquifer) beneath the park. Following a short trial, during which the court heard testimony from experts in hydrogeology, herpetology, and wetlands ecology, the judge signed the decree entitling the National Park Service to an absolute water right to appropriate in-place all unappropriated groundwater in the unconfined aquifer beneath the park. The water right entitles the Service to specific water levels at 10 monitoring wells located near the western boundary and allows the park to challenge any changed or expanded use of an existing water right and new rights junior to the park's.

Construction of the 10 groundwater monitoring wells was completed in October 2009. The wells will be outfitted with electronics to continuously measure, record, and report water table elevation in the shallow unconfined aquifer to the Colorado Division of Water Resources (CDWR). Following the first 10 years of data collection the court will revisit the 2008 decree and determine if the water table elevations listed in the decree are reasonable or if they will be adjusted to reflect the 10-year data record. The water table elevation data will be used by the CDWR to administer the park's in-place groundwater right.

With this water right, the streamflows, surface water, groundwater, and natural resource values at Great Sand Dunes National Park and Preserve will be protected for future generations.

About the author

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In Focus: Denali Park Road

An integrated study of road capacity at Denali National Park

By Laura M. Phillips, Philip Hooge, and Thomas Meier

Abstract

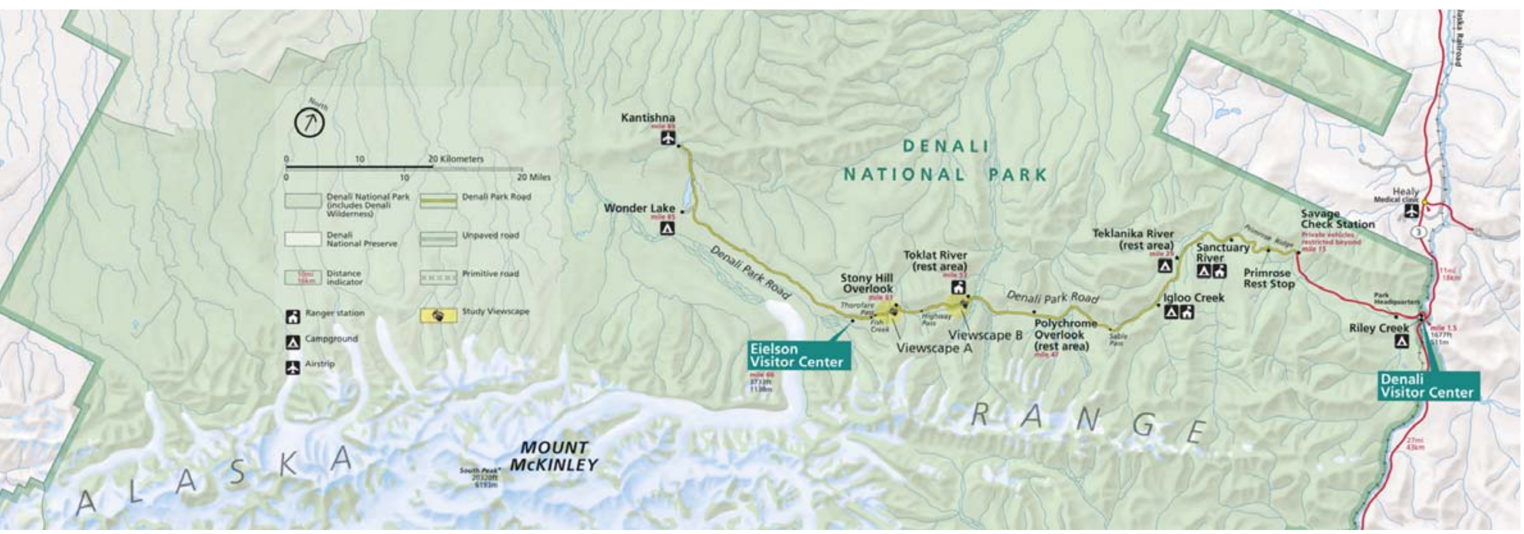
In 1986, managers at Denali National Park and Preserve in Alaska limited vehicle trips on the park road to 10,512 annually based on studies and observations that the number and behavior of vehicles may negatively affect wildlife behavior and the quality of the visitor experience. In 2006, vehicle use was approaching this limit and park managers began a process to comprehensively reevaluate the strategy for transporting people on the road. Managers enlisted an interdisciplinary team of scientists to conduct a series of studies over three years with the goal of assessing the effects of increased traffic volumes on important indicators of social and resource values and combining the results into a predictive traffic simulation model. The model enables park managers to integrate findings from wildlife behavior and visitor experience studies into planning documents and decisions that will guide transportation management in the park for years to come.

Key words: access, capacity, Denali National Park, resources, road, standards, visitor experience

AT MORE THAN 6 MILLION ACRES (2 MILLION HA) IN SIZE, Denali National Park and Preserve (Denali) in Alaska has but one road: a narrow, low-speed route that takes a sinuous path over dramatic terrain in a pristine land (fig. 1). Extending 91 miles (146 km) from the park entrance to the old mining community of Kantishna where it dead-ends, the road traverses boreal forests and subarctic tundra, crosses rolling mountainsides and sheer cliffs, and meanders through scenic vistas and prime wildlife viewing areas. The first 15 miles (24 km) of the road are paved, after which it transitions to gravel.

The Denali Park Road gives visitors of all abilities the opportunity to travel by vehicle through, and access to, a vast, rugged wilderness. As they travel the road, visitors have the opportunity to observe wildlife in their natural habitat and to enjoy outstanding scenery (fig. 2). Currently, most visitors access Denali via the Denali Park Road on a tour or shuttle bus operated by a concessioner that is regulated by the National Park Service (NPS). Tour bus offerings include an eight-hour trip called the Tundra Wilderness Tour, primarily billed as a wildlife viewing opportunity that travels to mile 53 or mile 66 on the Denali Park Road depending on weather conditions, and a three-hour trip called the Denali Natural History Tour, which focuses on cultural history and only travels to mile 17. Visitors may also ride the shuttle bus system, which is designed to provide general access into the park for visitors who do not desire a narrated tour. This bus system runs on a regular schedule to all major destinations along the park road, and provides access for viewing scenery and wildlife as well as transportation to visitor centers, campgrounds, and hiking locations. The road also provides circulation to public and administrative facilities and provides for reasonable access to private property. Private vehicle use is mainly limited to NPS staff living at field camps along the park road, Kantishna landowners accessing their

Figure 1. Denali National Park and Preserve's 6 million acres straddle the Alaska Range in the middle of the state. One low-speed, gravel road provides access to the interior of the park, winding its way through boreal forest and tundra. Visitors have the opportunity to view dramatic scenery and wildlife in their natural habitat along the road, but will not encounter many facilities or amenities along the way.



Park managers note that the transportation system for the Denali Park Road has never been comprehensively evaluated and that the question of whether Denali is providing the best system possible for all users should be answered.

NPS/JOHN HOURDOS

Figure 2. Buses transporting visitors on the road in Denali National Park stop to watch a caribou. Seeing large mammals along the road is a highlight of a trip to Denali for most visitors.

property or transporting guests to one of the three lodges located in the area, and visitors staying at the Teklanika campground at mile 28. While the current transportation system allows various user groups to access the park using the Denali Park Road, the number of trips allocated to each group is highly regulated and restricted. Park officials have always recognized that the unpaved road was not designed to be a high-volume public thoroughfare and had a limited capacity for accommodating park visitation.

Limits to road access

The Denali Park Road was completed to Kantishna in 1938 and is the only publicly accessible road in the national park. Initially, use of the road was limited because of low park visitation. Prior to 1957, when the Denali Highway was completed, connecting the park entrance to Alaska's Richardson Highway, visitors had to travel by train or plane to reach the park and park visitation rarely exceeded 7,000 people annually. Because visitors arrived without their own means of transportation, private concessioners provided tours along the park road using horses and cars. Completion of Alaska's Denali Highway gave motorists easier access to Denali National Park, and vehicle traffic on the Denali Park Road doubled as a result. To accommodate more private vehicles, the Denali Park Road was upgraded and widened in the 1960s. Opposition to the improvements was widespread. Adolph Murie, a prominent wildlife biologist, opposed the changes and stated that the "drastic rebuilding of the old road shows an obsessive regard for superhighway standards and a lack of appreciation for the spirit of this northern wilderness" (Murie 1965). Park managers were sympathetic to the public outcry, and the "wilderness feel" of a trip on the park road has been considered by management an intrinsic part of the visitor experience that should be maintained.

In 1971, the opening of another important Alaska highway—the George Parks Highway (Alaska Route 3)—greatly shortened the driving time between Alaska's main population centers of Anchorage and Fairbanks, and provided direct access to Denali National Park. Predicting another dramatic increase in automobile traffic to the park, officials closed most of the Denali Park Road to private vehicles and implemented a mandatory public transit system to provide public access beyond the Savage Check Station at mile 15 (fig. 3, next page). Private vehicles would be allowed access through a permitting system, and buses would transport visitors throughout the park, giving them access to park lodging, trailheads, and campgrounds. Initially, this mandatory bus system was free to the public and acted only as a means to shuttle visitors to destinations along the road. National Park Service director George Hartzog proclaimed, "we have reached the end of this cycle of more roads and more trails . . . and . . . have got to look to other means of access" (Norris 2006). The school buses that began transporting visitors into the park in 1972 remain an iconic symbol of the Denali Park Road today (see figs. 2 and 3).

Publication of the Denali General Management Plan (U.S. Department of Interior 1986) in 1986 confirmed the advantages of a limited-access transportation system for the park road in providing wildlife viewing opportunities while preserving wildlife and a high-quality visitor experience. The plan established a maximum limit of 10,512 vehicle trips per season beyond mile 15, the restricted section of the road. The decision to limit traffic was based on NPS studies, general observations, and public input that the number and type of vehicles on the Denali Park Road in 1984 were having negative impacts on wildlife behavior and the visitor experience (Singer and Beattie 1986). The vehicle limit was established using 1984 use levels as a base and allowing a maximum 20% increase in shuttle and tour bus traffic while decreas-

In Focus: Denali Park Road

NPS/LAURA PHILLIPS

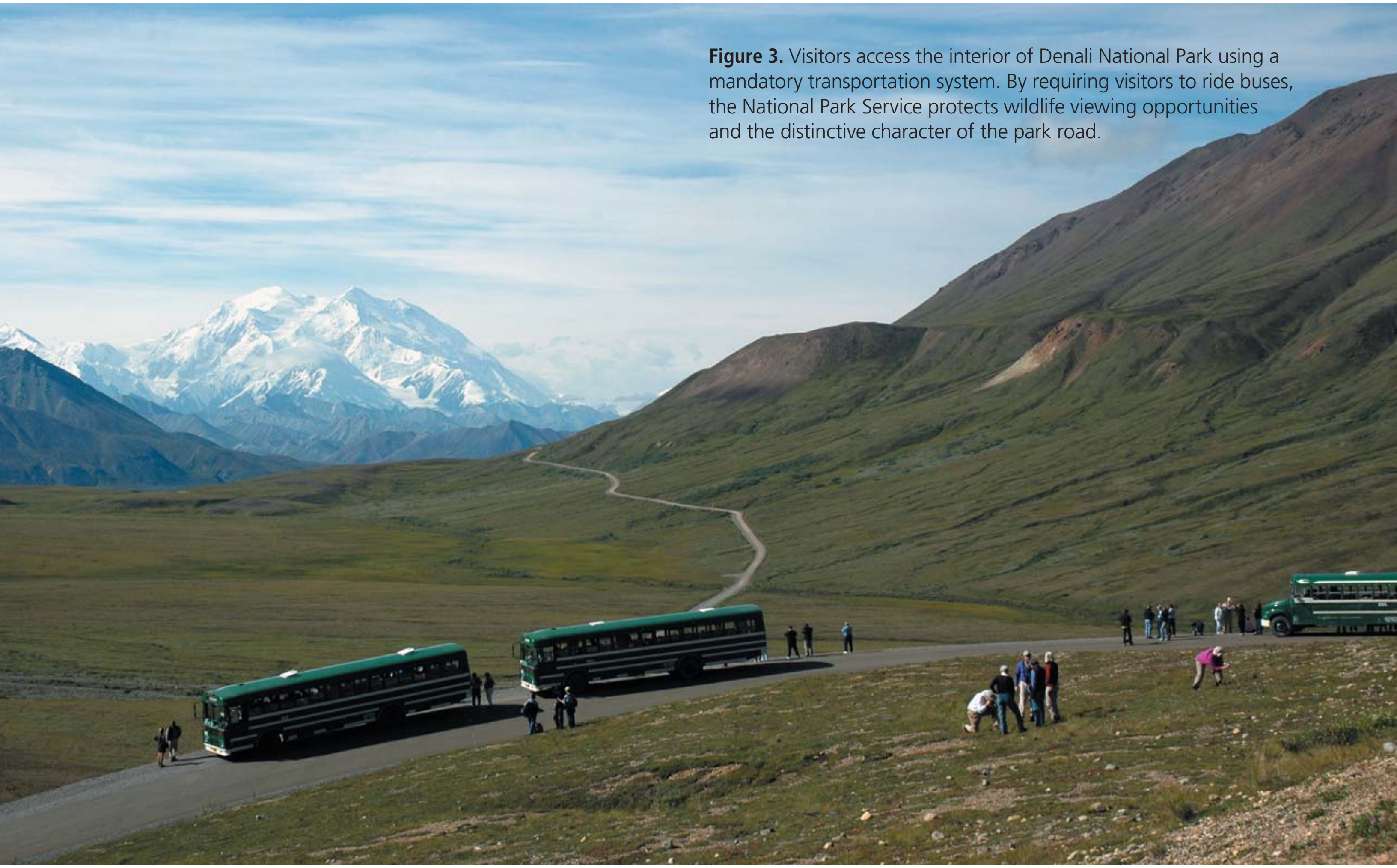


Figure 3. Visitors access the interior of Denali National Park using a mandatory transportation system. By requiring visitors to ride buses, the National Park Service protects wildlife viewing opportunities and the distinctive character of the park road.

ing private vehicles that were found to have a disproportionate impact on wildlife (Singer and Beattie 1986).

Park managers further described desired future conditions for the park road in the 1997 Entrance Area and Road Corridor Development Concept Plan (Entrance Area Plan; U.S. Department of Interior 1997) by defining management zones for the park. The gravel portions of the Denali Park Road were included in wildlife viewing subzones 1 and 2, the primary purposes of which include wildlife and scenery viewing. The plan also specified that visitor use would be proactively managed by applying the Visitor Experience and Resource Protection (VERP; National Park Service 1997) framework. Managers realized that providing a quality experience and protecting park resources required specific desired conditions and key impact indicators to be identified, and desired park conditions to be compared with existing ones.

The Entrance Area Plan also redefined the allocation of vehicle trips by user group on the Denali Park Road within the 10,512 limit. Only minor changes have been made by management to vehicle trip allocation since 1997. Currently, up to 30 Tundra Wilderness Tours, 23 Denali Natural History Tours, and 36 shuttle buses are allowed to travel the park road each day. During peak visitation in July, the park concessioner frequently runs a full allocation of tour buses with every seat filled.

Need for integrated study approach

When the mandatory transportation system in Denali was implemented in 1972, it was the only regulatory system for private vehicles and buses on roads in a U.S. national park. The National Park Service conducted a number of surveys to evaluate public attitudes toward restrictions placed on road access (Harrison 1975; Singer and Beattie 1986; Miller and Wright 1998). Generally, visitors have had favorable opinions of traffic limits, and listed protection of wildlife, enhancement of wildlife viewing opportunities, and reduction in traffic congestion on the road as factors contributing to their satisfaction with the policy. However, since those studies were completed, visitors and stakeholders have

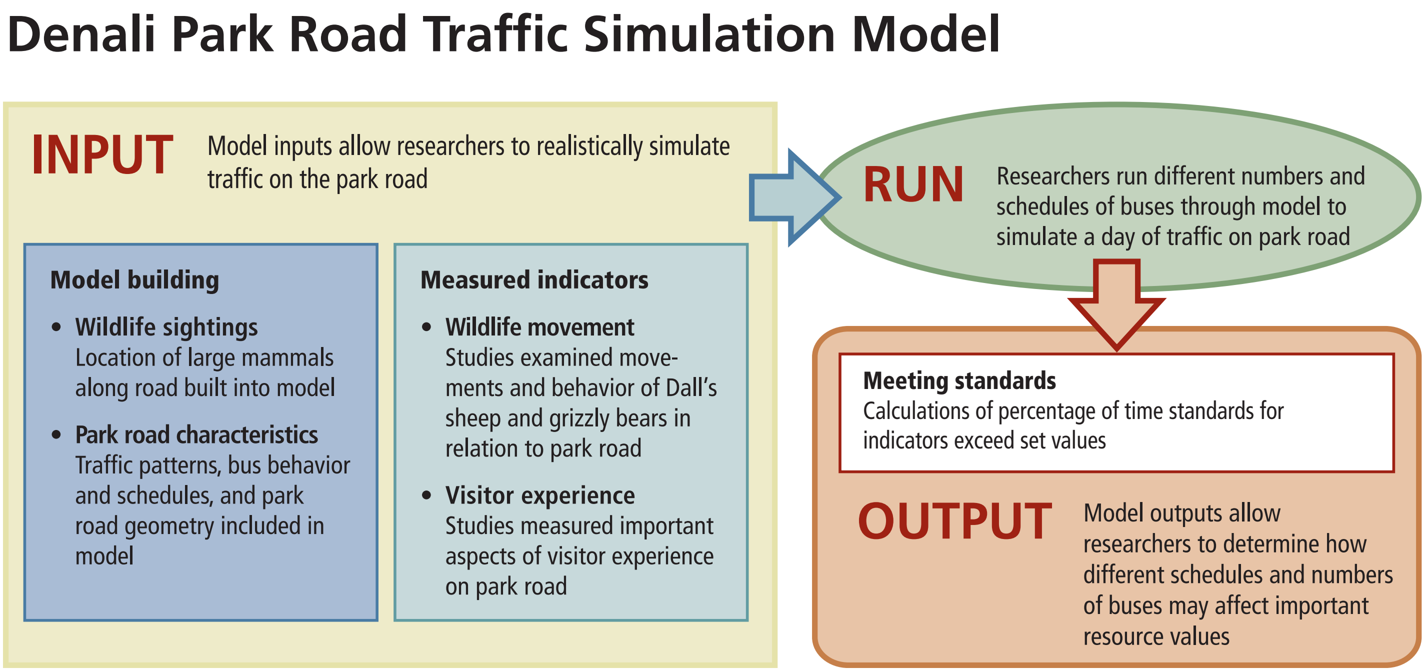


Figure 4. A simulation model integrates results from social and biological studies with traffic patterns to determine potential impacts of alternative transportation strategies on important visitor experience and wildlife resource indicators.

expressed concerns about the regulatory policy. They explained that the policy did not provide for growth in park visitation or flexibility to meet changing needs of visitors, bus operators, and park resources; others felt that it did not adequately protect park resources or provide adequate opportunities for visitors to choose park experiences that address their personal interests. Park managers note that the transportation system for the Denali Park Road has never been comprehensively evaluated and that the question of whether Denali is providing the best system possible for all users should be answered. Visitation at Denali is projected to increase and, along with it, the demand to travel the Denali Park Road. Managers also wonder whether changes in demographics and interests of visitors are being met by the current system.

These issues have biological, sociological, and physical elements that require better understanding. Thus, in 2006, more than 34 years after the first limits were imposed, managers decided to comprehensively reevaluate road use limits in relation to concerns for wildlife well-being and preservation of the high-quality experience associated with touring the park road. Managers understood the necessity of designing a series of interdisciplinary studies and integrating their results in order to define potential solutions to stakeholder concerns and to identify effects of various alternative transportation scenarios. They enlisted an interdisciplinary team of scientists to conduct three studies over three years. The goal of the research is to assess the effects of changes in traffic volume and patterns on important indicators of social and resource values by combining the results into a predictive model of detailed road traffic scenarios (fig. 4).

Three studies

One of these studies was aimed at defining important components of visitor experience. Investigators employed qualitative interviews and surveys of park road users to identify and measure experiential indicators and standards of quality in a more comprehensive fashion than in the past. As the following article on pages 33–41 by Robert Manning and Jeffrey Hallo explains, the standards for selected indicators could then be applied to predictive modeling to assess impacts on visitor experience of alternative management scenarios.

A second study investigated possible links between traffic on the Denali Park Road and the behavior of large mammals. The park road provides a unique opportunity for visitors to view wildlife by accessing remote areas where animals remain tolerant of some human disturbance. Though previous research had suggested possible negative effects of traffic on wildlife, it was based on observational studies that only considered wildlife movements within the road corridor and did not attempt to directly link

In Focus: Denali Park Road

traffic volume to wildlife behavior. Hence, investigators Laura Phillips, Richard Mace, and Thomas Meier designed a more comprehensive study of traffic-wildlife interactions to determine potential links between traffic numbers and wildlife movements. This research is described on pages 42–47.

Finally, Ted Morris, John Hourdos, Max Donath, and Laura Phillips looked at the logistical constraints associated with traffic patterns on the park road. Their article on pages 48–57 concludes this segment of *Park Science* focused on the Denali Park Road. This report describes development and application of a traffic simulation model to analyze the effects of current and increased traffic volume and changes in traffic patterns on visitor experience and wildlife protection. Park planners and managers are now using this model to test the efficacy of alternative management scenarios in protecting park wildlife and the quality of the visitor experience.

Conclusion

Understanding the relationships among experiential values, biological resources, and human use is vital to formulating and implementing management policy in national parks. While the VERP framework has been used to address capacity issues in many parks, few applications have employed an interdisciplinary program of research to devise and test alternative management approaches. The following articles outline our approach to evaluating a complex management issue and to testing multiple alternative solutions. The results of these integrated studies will inform development of a new vehicle management plan aimed at addressing increasing recreation demand while ensuring a high-quality experience for visitors, protecting resource values, and maintaining the unique character of the Denali Park Road.

Acknowledgments

Funding for this project was provided by the National Park Service. Many people worked to make this project a success, but we would like to acknowledge the critical support provided by Doyon/Aramark Joint Venture, especially John Kenny and Brian Hewitt, and staff at Denali National Park, including Paul Anderson, Guy Adema, Craig Brandt, and Bridget Borg. We would also like to thank our cooperators, John Hourdos, Ted Morris, and Max Donath at the University of Minnesota; Robert Manning and Jeff Hallo at the University of Vermont; and Rick Mace at the University of Montana.

References

Burson, S. L., J. L. Belant, K. A. Fortier, and W. C. Tomkiewicz. 2000. The effect of vehicle traffic on wildlife in Denali National Park. Arctic 53:146–151.

Harrison, G. S. 1975. The people and the park: Reactions to a system of public transportation in Mt. McKinley National Park, Alaska. Journal of Leisure Research 7:6–15.

Miller, C., and G. Wright. 1998. An assessment of visitor satisfaction with the public transportation services at Denali National Park & Preserve. Park Science 19(2):18–19.

Murie, A. 1965. Road building in Mount McKinley National Park. National Parks Magazine 39:4–8.

National Park Service. 1997. VERP: The Visitor Experience and Resource Protection (VERP) framework—A handbook for planners and managers. Denver Service Center, Denver, Colorado, USA.

Norris, F. 2006. Crown jewel of the North: An administrative history of Denali National Park and Preserve. Alaska Regional Office, National Park Service, Anchorage, Alaska, USA.

Singer, F. C., and J. B. Beattie. 1986. The controlled traffic system and associated wildlife responses in Denali National Park. Arctic 39:195–203.

Tracy, D. M. 1977. Reaction of wildlife to human activity along Mount McKinley National Park road. Thesis. University of Alaska, Fairbanks, USA.

U.S. Department of Interior. 1986. General Management Plan, Denali National Park and Preserve. National Park Service, Denali National Park, Alaska, USA.

U.S. Department of Interior. 1997. Entrance Area and Road Corridor Development Concept Plan, Denali National Park and Preserve. National Park Service, Denali National Park, Alaska, USA.

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PS

The Denali Park Road experience: Indicators and standards of quality

By Robert E. Manning and Jeffrey C. Hallo

Abstract

Contemporary frameworks for managing parks and outdoor recreation, like the National Park Service's (NPS) Visitor Experience and Resource Protection (VERP) framework, rely on indicators and standards of quality as empirical measures of management objectives or desired conditions. This study identified indicators and standards for the Denali Park Road experience based on data from 126 interviews and 707 questionnaires. Indicators that may be used to measure and manage this experience include number of buses seen along the road, number of buses at informal wildlife stops, waiting time to see wildlife at informal wildlife stops, number of buses and people at rest stops, and percentage chance of seeing a grizzly bear. Potential standards for these were then identified based on visitor evaluations of photos or narrative descriptions representing a range of conditions for each indicator variable. For example, visitors' mean acceptability ratings fall out of the acceptable range and into the unacceptable range when more than five buses are visible along the road. This value represents one possible standard for measuring and managing crowding on the Denali Park Road. In keeping with the VERP framework, findings from this program of research should be combined with other information to define and guide management of the visitor experience on the Denali Park Road. Indicators should be monitored and management actions taken to ensure that standards of quality are maintained. In this way, the carrying capacity of the Denali Park Road can be defined and managed. However, a more proactive approach is also possible by incorporating these indicators and standards into a simulation model that estimates the maximum number of vehicles that can be accommodated on the road without violating standards of quality.

Key words: carrying capacity, Denali National Park, norms, VERP (Visitor Experience and Resource Protection framework), visitor experience

CONTEMPORARY APPROACHES TO MANAGING PARKS and outdoor recreation—and carrying capacity in particular—rely on a foundation of formulating indicators and standards of quality. Visitor Experience and Resource Protection (VERP) (National Park Service 1997; Manning 2007) and Limits of Acceptable Change (LAC) (Stankey et al. 1985) are examples of this type of management/carrying capacity framework. In these frameworks, indicators and standards of quality are used as empirical measures of management objectives or desired conditions. Indicators of quality are measurable, manageable variables that serve as proxies for management objectives/desired conditions, and standards of quality define the minimum acceptable condition of indicator variables. Once indicators and standards of quality are formulated, indicator variables are monitored to determine the degree to which standards of quality are being maintained. If monitoring suggests that standards of quality are in danger of being violated, then carrying capacity has been reached and management practices must be applied. Management practices can range widely, including "hardening" park resources (e.g., paving trails, constructing tent platforms), reducing the impacts of visitors (e.g., encouraging visitors to stay on designated trails, substituting public transit for private automobiles), and limiting the amount of visitor use (e.g., limiting the length of stay, requiring a use permit) (Manning 2004; Manning 2007).

The study

This study was designed to support formulation of indicators and standards of quality for the visitor experience on the Denali Park Road (see fig. 1, page 28). We conducted the study in two phases. Phase 1 consisted of a series of qualitative interviews with Denali Park Road users to identify potential indicators of quality for the visitor experience. Interviewers asked a series of open-ended questions that encouraged respondents to provide narrative, contemplative answers about their experience on the Denali Park Road. Qualitative methods provide a depth of insight into recreation experiences and are particularly useful when little is known about the nature of experiences or what influences them. We conducted 126 interviews during the 2006 peak visitor use season (July–August), and two focus groups at one of the park lodges. Questions asked were intended to gather information to help understand the visitor experience on the park road and to inform development of indicators of quality. All interviews were recorded and transcribed verbatim. A content analysis of each interview was then performed by segmenting data into codes—simpler, general categories that can then be used to expand and develop new questions and levels of interpretation (Coffey and Atkinson 1996).

Phase 2 of the study consisted of a quantitative survey of Denali Park Road visitors to measure standards of quality for selected indicator variables. Research on standards of quality increasingly has focused on personal and social norms. Developed in the discipline of sociology, norms have attracted considerable attention as a theoretical construct and empirical framework in park and outdoor recreation research and management (see, for example, two double issues of *Leisure Sciences*, volume 18, numbers 1 and 2, and volume 24, numbers 3 and 4). In particular, normative theory has special application in helping to formulate standards of quality for the recreation experience. As applied in parks and outdoor recreation, norms are generally defined as standards that individuals and groups use for evaluating behavior and social and environmental conditions (Donnelly et al. 1992). If visitors have normative standards concerning relevant aspects of park and out-

In Focus: Denali Park Road

If monitoring suggests that standards of quality are in danger of being violated, then carrying capacity has been reached and management practices must be applied.

door recreation experiences, then such norms can be measured and used as a basis for helping to formulate standards of quality.

Application of normative theory and methods to help formulate visitor-based standards of quality in parks and outdoor recreation is most fully and recently described in Manning 2007 and 2009. Park and outdoor recreation visitors (or other survey respondents) are conventionally presented with a range of recreation-related impacts and asked to judge the acceptability of such conditions. Using these methods, the personal norms of individuals can be aggregated to test for the existence of social norms or the degree to which norms are shared across groups. Normative research in outdoor recreation has focused largely on the issue of crowding, but has also been expanded to include other relevant issues, such as ecological impacts to trails and campsites.

Normative research on standards of quality in parks and outdoor recreation has often used visual simulations to portray a range of resource and social impacts and resulting conditions (Manning et al. 1996; Manning and Freimund 2004; Manning 2007; Manning 2009). Visual research methods offer several potential advantages over conventional narrative/numerical questions to measure standards of quality. For example, visual methods can help "standardize" such research, focus more directly and exclusively on the treatment variables under study, offer a more elegant means of communicating variables that are difficult or awkward to describe in narrative/numerical terms, and can be used to represent conditions that are difficult to find in the field or that do not currently exist. Research suggests that visual research methods may be most appropriate in relatively high-use density contexts, may result in more valid or realistic estimates of visitor standards of quality in such applications, may meet generally accepted standards of validity, and may be methodologically robust (Manning and Freimund 2004).

We administered the phase 2 survey during the 2007 summer use season to the five major types of bus users on the Denali Park Road: (1) those who use the park's general shuttle bus system, (2) those who use special shuttle buses to access campgrounds, (3) those who use special buses to access the commercial lodges at Kantishna at the road's terminus, and (4 and 5) Tundra Wilderness Tour and Denali Natural History Tour participants—relatively short commercial tours. A response rate of 78% was attained and this yielded 707 completed questionnaires.

Study findings

Indicators of quality

We considered two questions from the 2006 interviews to be foundational to identifying potential indicators of quality for the Denali Park Road experience. In the first question, we asked respondents about the things they enjoyed most about their time on the Denali Park Road. The most frequently occurring responses related to "wildlife," "scenery or mountains," and "driver or information provided by driver" (table 1).

Other responses suggested the importance of specific landscape attributes, activities, and experience characteristics. For example, one respondent said, "We had wonderful weather so we were able to see Denali in all its glory." Another identified the significance of "social experience with others," in addition to the importance of the bus driver. Some respondents indicated the importance of "solitude or not too much traffic" and "using bus transportation."

A greater number of coded responses emerged from the second question about the things respondents enjoyed least about their time on the park road (table 2). The two most frequently occurring codes—"long ride or being on the bus" and "uncomfortable seats on the bus"—related to the schedule of the bus trip or the bus itself. Other experiential issues regarding the bus and its schedule emerged in less frequently occurring responses, such as "malfunctioning or dirty windows," "frequency or duration of stops," "buses too big," and "time to load and unload the bus."

Codes related to the built road environment emerged in response to this question. Several respondents expressed safety concerns related to the road, particularly regarding traveling through Polychrome Pass. Also, respondents suggested that the "condition of the road" or "dust" generated by vehicles detracted from their experience. Other responses indicated that "some of the outhouses weren't as nice as they could have been" or that there was a "lack of signs on the road."

Table 1. Things enjoyed most by visitors on the Denali Park Road

Category/Code	Frequency Indicated (n=126)
Wildlife	87
Scenery/mountains	83
Driver/information provided by the bus driver	49
Mount McKinley	14
Natural environment/landscape	8
Social experience with others	7
Solitude/not too much traffic on the road	6
Bus transportation	4
Hiking	3
Ride along the road	3
Wildflowers	2
Polychrome Pass	2
Driving on the road with a recreational vehicle	2
Rules on the bus intended to protect wildlife	1
Being able to get off the bus and walk around	1

We assigned codes for wildlife viewing and factors influencing that experience in response to the second question. Some responses indicated that "not seeing enough wildlife" or "wildlife being too far away" negatively affected their experience. For example, "We didn't see any moose, or sheep, or bear" and "we didn't see anything." One respondent reported an issue with a bus scaring away wildlife of interest.

We assigned other codes to responses related to whom respondents interacted with or what people experienced. Seeing "other buses or traffic" or "too many people at rest areas" impacted the experience of road users. For example, one respondent said, "I don't like all the buses. . . . I would like to have the road all to myself." For other respondents the least enjoyable aspects of their experience were their interactions with the "driver," the "behavior and actions of others on the bus," and "not seeing Mount McKinley." Also, we assigned codes of "poor value or too costly" and "bus not going far enough into the park" in the analysis.

Based on findings from the interviews conducted in phase 1, we included a more quantitative approach to identifying indicators of quality in the visitor survey administered in 2007. A series of 29 issues associated with the visitor experience on the Denali Park Road were included in the questionnaire, and respondents were asked to report the extent to which they considered these issues to be problems (table 3, next page). The three most problematic issues were "not seeing wildlife close to the road," "too many buses on the Denali Park Road," and "too few animals along the road."

Table 2. Things enjoyed least by visitors on the Denali Park Road

Category/Code	Frequency Indicated (n=126)
Long ride/being on the bus	28
Nothing	20
Uncomfortable seats on the bus	19
Didn't see enough wildlife/wildlife too far away	12
Safety concerns (e.g., driving through Polychrome Pass)	12
Dust	12
Condition of the road	10
Seeing buses/traffic	7
Frequency/duration of stops	6
Driver (e.g., couldn't hear, annoying, not informative)	5
Malfunctioning/dirty windows	4
Behavior and actions of other visitors on the bus	4
Lodge buses too big and with too many people	3
Too many people at rest areas	2
Lack of facilities	2
Tour didn't go far enough into park	2
Bathroom facilities along road were not very nice	2
Vehicles scaring wildlife away	1
Road was unpaved	1
Poor value/cost	1
Not seeing Mount McKinley	1
Lack of signs on road	1
Time to load and unload the bus	1

Standards of quality

The phase 2 visitor survey measured a range of standards of quality for five potential indicator variables: (1) number of buses on the Denali Park Road, (2) number of buses stopped at the same place to observe wildlife, (3) number of buses and people stopped at a rest area, (4) wait time at wildlife stops to see wildlife (as all buses/visitors take their "turn"), and (5) percentage chance of seeing a grizzly bear. These indicators were selected by researchers and Denali Park staff because they are measurable, manageable, and related to visitor use.

We addressed the first three of these variables through a series of photographic simulations to depict a range of use levels and associated impacts. For each series of photographs, respondents were asked a battery of evaluative questions. They were first asked to evaluate the acceptability of each of the study photographs (termed "acceptability"). Acceptability was measured using a nine-point Likert-type scale ranging from −4 ("very unacceptable") to 4 ("very acceptable"). Zero represented the middle of

In Focus: Denali Park Road

Table 3. Visitor perceptions of problems on the Denali Park Road

Parameter	Percentage of Respondents				N	Mean*
	Not a Problem (1*)	Small Problem (2*)	Big Problem (3*)	Don't Know		
Too many buses on the Denali Park Road	43.3	45.7	9.8	1.2	685	1.66
Too many private cars/recreational vehicles on the Denali Park Road	64.5	23.0	9.3	3.2	668	1.43
Not seeing enough wildlife	49.5	33.2	16.7	0.6	683	1.67
Not seeing enough wildlife close to the road	39.6	37.4	22.0	1.0	690	1.82
Too few animals along the road	45.1	34.4	18.9	1.6	683	1.73
Wildlife being scared away from the road by buses	57.8	22.2	9.1	10.9	615	1.45
Other buses blocking views	62.4	30.4	5.4	1.7	675	1.42
Too many buses at "wildlife stops"	53.7	36.3	7.3	2.7	652	1.52
Visitors not following rules for observing wildlife while on the bus	67.3	23.3	6.3	3.2	666	1.37
Bus drivers not providing enough time at "wildlife stops"	87.0	10.4	1.6	1.0	686	1.14
Dust generated by buses	48.3	36.8	13.2	1.6	676	1.64
Uncomfortable seating on buses	55.0	34.9	9.8	0.3	689	1.55
Too many people on buses	61.4	29.0	9.1	0.4	689	1.47
Bus noise along the road	63.0	29.3	5.8	1.9	677	1.42
Noisy people on the bus	65.5	27.0	7.3	0.3	687	1.42
Too many buses at rest stops	65.3	27.0	6.4	1.3	677	1.40
Buses being poorly maintained	82.7	11.8	1.8	3.7	659	1.16
Windows on buses not working properly	68.5	24.0	6.7	0.9	682	1.38
Windows on buses are dirty	62.6	28.6	8.3	0.4	685	1.45
Bus drivers not stopping when asked	92.6	5.1	1.2	1.2	677	1.08
Lack of interpretive information provided on the bus	86.6	10.3	2.2	0.9	680	1.15
Lack of visitor facilities (e.g., restrooms)	90.6	8.3	0.6	0.6	686	1.09
Degradation of the quality of the Denali Park Road	64.4	26.2	5.0	4.4	656	1.38
Degradation of the wilderness character of the Denali Park Road (e.g., by buildings and human presence)	70.1	21.1	5.9	2.9	662	1.34
Not having binoculars	68.5	16.3	13.5	1.6	669	1.44
Poor weather	71.8	19.0	7.8	1.5	670	1.35
Smoke from wildfires	89.2	3.1	0.9	6.9	636	1.05
Feeling unsafe traveling along the road	85.7	11.5	2.0	0.7	682	1.16
Brush along the road obscured view of wildlife	75.5	20.9	2.8	0.9	683	1.27

*Means are based on a scale of 1 ("not a problem") to 3 ("big problem"). "Don't know" responses are excluded from mean calculations.

this scale or the point of indifference. The second question in the series asked respondents to report the photograph that showed the number of buses they would prefer to see (termed "preference"). A third question asked visitors to report which photograph showed the condition that would be "so unacceptable that they would no longer use the Denali Park Road" (termed "displacement"). Further, respondents were given the opportunity to indicate that "none of the photographs are so unacceptable that I would no longer use the Denali Park Road." The fourth question asked visitors to report the photograph representing the highest level of visitor use they thought the National Park Service should allow, or the point at which the number of buses should be restricted (termed "management action"). Additionally, respondents were given the opportunity to report that none of the photographs showed a high enough level of use to restrict use or that use should not be restricted at all. The fifth question referred to existing conditions (termed "typically seen"), asking respondents to report the photograph that best represented the condition they "typically saw today" while traveling on the Denali Park Road.

NPS PHOTOS (7) BY WAYNE FREIMUND AND JEFFREY HALLO

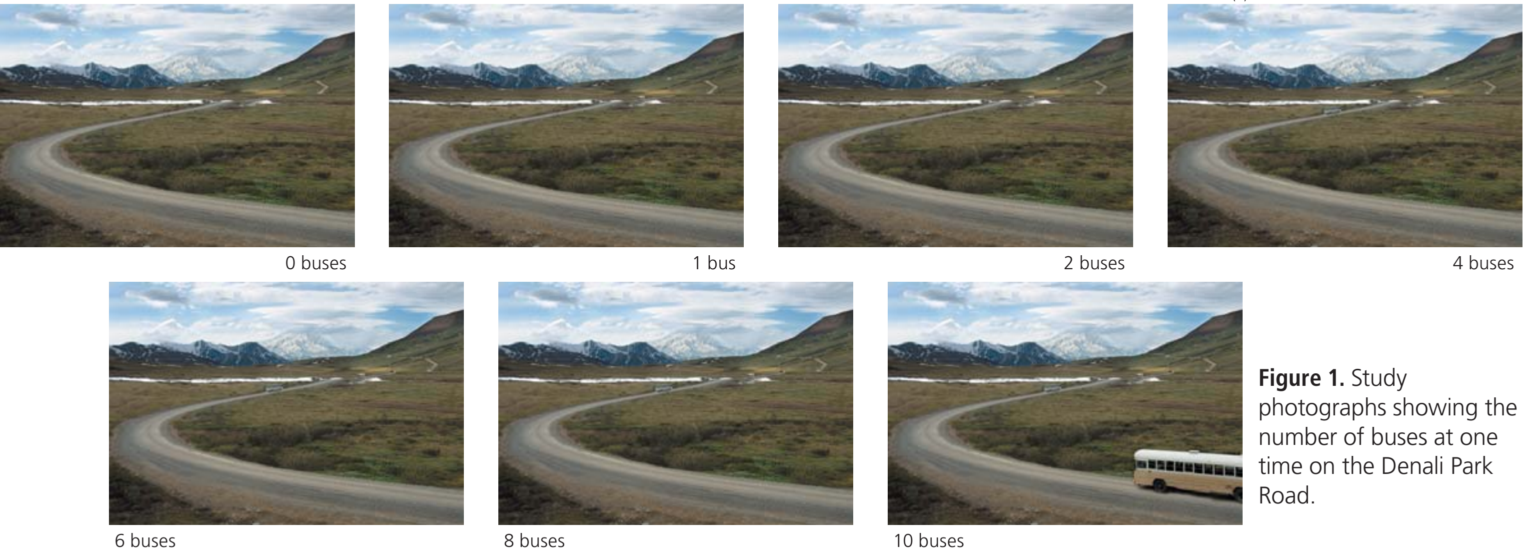

Figure 1. Study photographs showing the number of buses at one time on the Denali Park Road.

For the variables "wait time at wildlife stops to see wildlife" and "percentage chance of seeing a grizzly bear," a range of conditions was described numerically. We asked respondents to evaluate the acceptability of the numerical options, and we again measured acceptability using a nine-point Likert-type scale ranging from −4 ("very unacceptable") to 4 ("very acceptable").

We measured standards of quality for the number of buses on the Denali Park Road using a series of seven study photographs as shown in fig. 1. Figure 2 shows the social norm curve derived from the average acceptability ratings. These findings indicate that increasing numbers of buses are generally found to be increasingly unacceptable and that this pattern holds across all five types of bus users. For all respondents, mean acceptability ratings fall out of the acceptable range and into the unacceptable range at 5.5 buses. Findings for the other evaluative dimensions of preference, management action, displacement, and typically seen are summarized (along with the above findings on acceptability) in table 4.

Standards of quality for the number of buses stopped to observe wildlife on the Denali Park Road were measured using a series

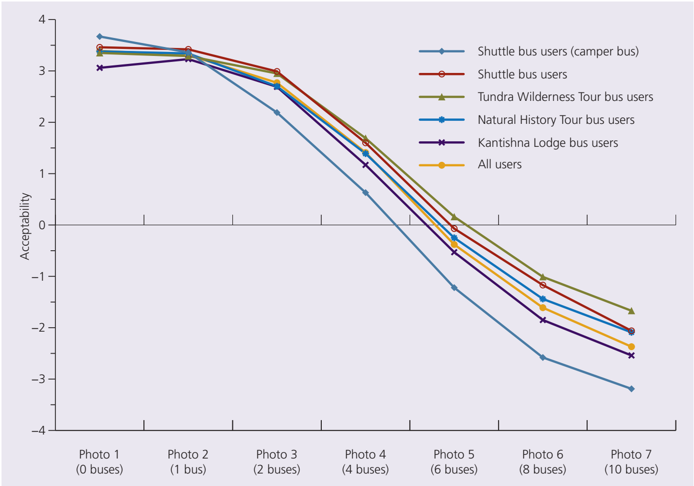

Figure 2. Social norm curve for the number of buses at one time on the Denali Park Road.

Table 4. Range of standards for the number of buses at one time by type of bus visitor

Evaluative Dimension	Camper Bus User	General Bus User	Tundra Wilderness Tour	Natural History Tour	Lodge Bus User	All Users
Acceptability	4.7	5.9	6.3	5.7	5.5	5.5
Preference	1.2	2.3	2.8	2.2	1.9	2.1
Management action	5.5	5.5	5.1	6.0	5.1	5.5
Displacement	7.2	8.1	8.2	7.7	7.6	7.8
Typically seen	2.6	3.5	4.2	3.5	4.1	3.6

In Focus: Denali Park Road

NPS PHOTOS (8) BY WAYNE FREIMUND AND JEFFREY HALLO

Figure 3. Study photographs showing the number of buses stopped to observe wildlife on the Denali Park Road.

of eight study photographs, as shown in fig. 3. Figure 4 shows the social norm curve derived from the average acceptability ratings. These findings reveal that increasing numbers of buses are generally found to be increasingly unacceptable. For all respondents, mean acceptability ratings fall out of the acceptable range and into the unacceptable range at 4.7 buses. Findings for the other dimensions of preference, management action, displacement, and typically seen are summarized (along with the above findings on acceptability) in table 5.

Standards of quality for the number of buses and people at a rest stop along the Denali Park Road were measured using a series of eight study photographs, as shown in fig. 5. Figure 6 shows the social norm curve derived from the average acceptability ratings. These findings indicate that increasing numbers of buses and people are generally found to be increasingly unacceptable. For all respondents, mean acceptability ratings fall out of the acceptable range and into the unacceptable range at 4.7 buses. Findings for the other dimensions of preference, management action, displacement, and typically seen are summarized (along with the above findings on acceptability) in table 6 (page 40).

We asked respondents to evaluate the acceptability of different waiting times to see wildlife when buses were stopped along the road. We presented them with a range between "no wait time" and a "15-minute wait." Figure 7 (page 40) shows the resulting social norm curve. Study findings suggest that longer wait times are found to be increasingly unacceptable, and that the mean acceptability rating falls out of the acceptability range and into the unacceptable range at 4.6 minutes.

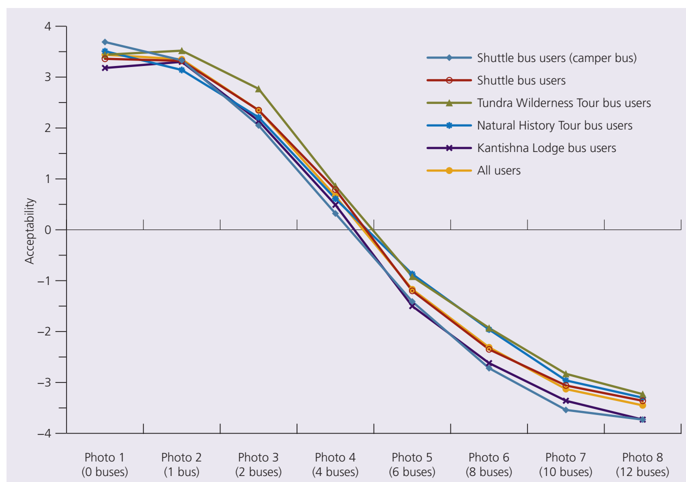

Figure 4. Social norm curve for the number of buses stopped to observe wildlife on the Denali Park Road.

We asked respondents to evaluate the acceptability of different percentage chances of seeing a grizzly bear along the Denali Park Road. Respondents were presented with a range between a "0% chance of seeing a grizzly bear" and a "100% chance of seeing a grizzly bear." Figure 8 (page 40) shows the resulting social norm curve. Study findings suggest that lower percentage chances of seeing a grizzly bear are found to be increasingly unacceptable, and that the mean acceptability rating falls out of the acceptability range and into the unacceptable range at a 20% chance of seeing a grizzly bear.

NPS PHOTOS (8) BY WAYNE FREIMUND AND JEFFREY HALLO

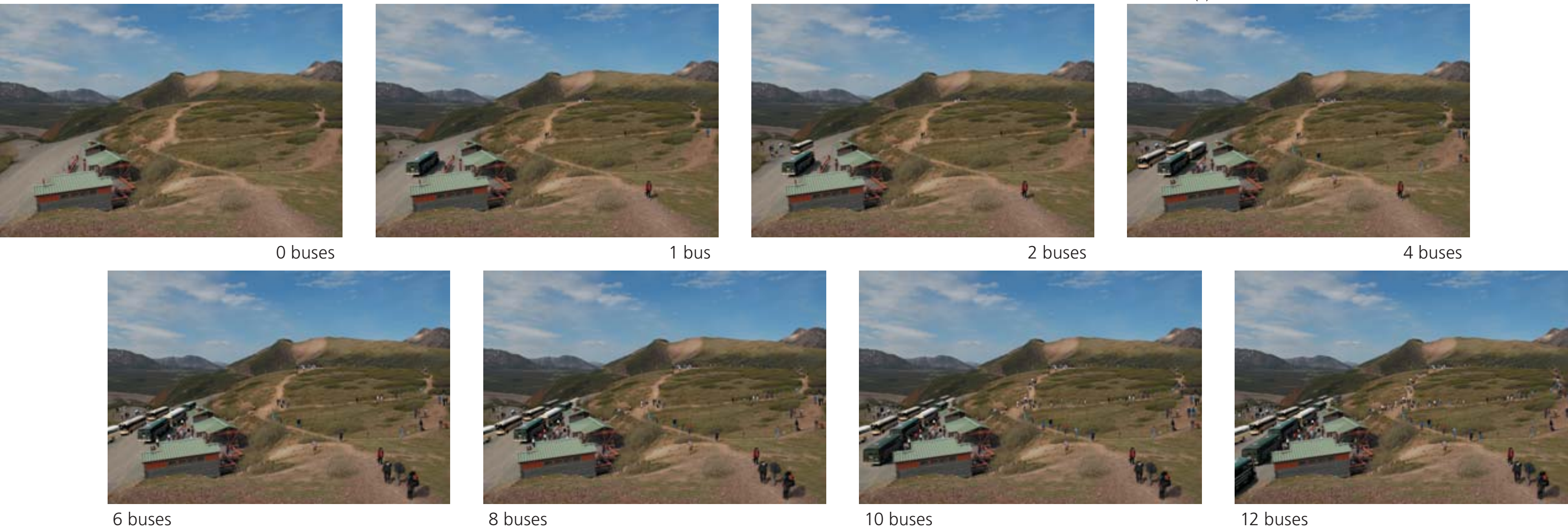

Figure 5. Study photographs showing the number of buses stopped at a rest stop along the Denali Park Road.

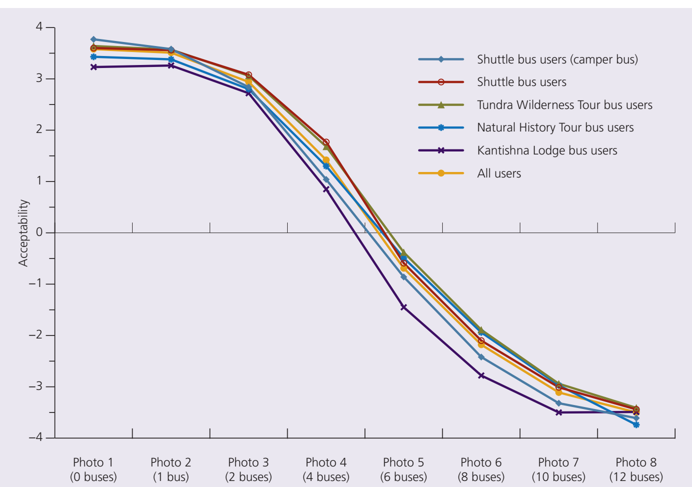

Figure 6. Social norm curve for the number of buses stopped at a rest area on the Denali Park Road.

We examined differences between mean responses among user groups for all the above questions. In general, differences among the values reported by the five types of bus users are not large, though camper and lodge bus users are often more sensitive to increasing use levels.

Conclusions

Phase 1 qualitative interviews identified a number of issues that affected the quality of the visitor experience. However, some of these issues do not meet the criteria for good indicators of quality because they are not readily measurable, they are beyond the control of park staff to manage, or they are not related to visitor use levels (Manning 2007). Examples include the quality of scenery, ability to see Mount McKinley, the physical condition of buses,

Table 5. Range of standards for the number of buses stopped to observe wildlife by type of bus visitor

Evaluative Dimension	Camper Bus User	General Bus User	Tundra Wilderness Tour	Natural History Tour	Lodge Bus User	All Users
Acceptability	4.4	4.8	5.0	4.8	4.5	4.7
Preference	1.2	1.5	2.1	1.5	1.7	1.6
Management action	5.2	5.3	5.8	6.2	5.4	5.5
Displacement	7.6	7.7	7.8	7.9	7.7	7.9
Typically seen	2.6	2.6	3.4	3.1	2.7	2.8

In Focus: Denali Park Road

Table 6. Range of standards for the number of buses at a rest stop by type of bus visitor

Evaluative Dimension	Camper Bus User	General Bus User	Tundra Wilderness Tour	Natural History Tour	Lodge Bus User	All Users
Acceptability	4.4	4.8	5.0	4.8	4.5	4.7
Preference	1.6	2.1	2.5	2.1	1.9	2.1
Management action	5.7	6.0	6.0	6.1	5.4	5.9
Displacement	7.8	7.7	8.0	8.4	7.4	7.8
Typically seen	3.5	3.7	3.9	3.0	3.5	3.6

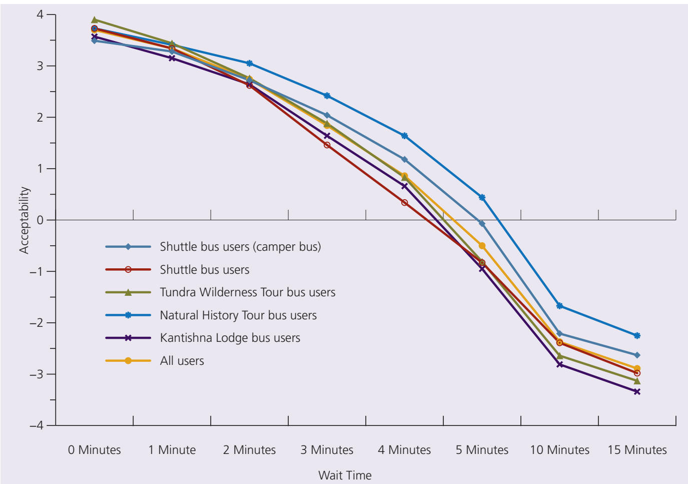

Figure 7. Social norm curve for the wait time to see wildlife on the Denali Park Road.

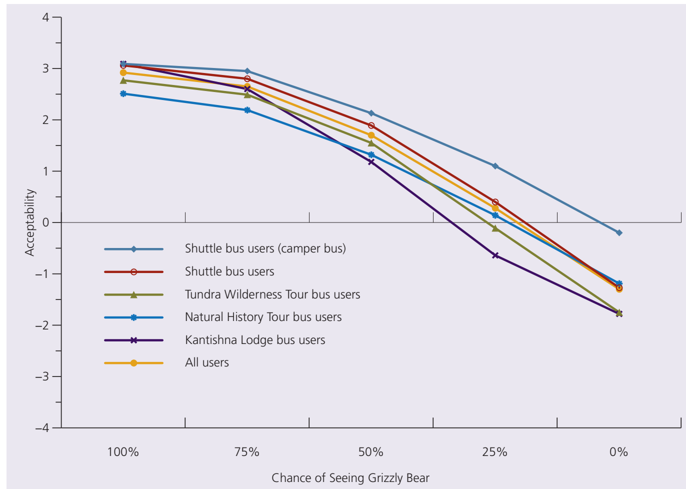

Figure 8. Social norm curve for the percentage chance of seeing a grizzly bear on the Denali Park Road.

the quality of bus drivers and their commentary, and the long bus ride needed to travel to the interior of the park.

However, several issues do constitute potentially important indicators of quality, and these include the number and type of wildlife seen (especially wildlife seen close to the road and especially grizzly bears), the number of buses seen along the road, the number of buses at informal "wildlife stops," waiting time to see wildlife at informal wildlife stops, and the number of buses and people at rest stops. For example, many of the comments in the interviews noted that seeing wildlife was one of the most enjoyable aspects of the trip along the Denali Park Road, while many other comments noted that not seeing much wildlife or that wildlife was too far from the road was the most disappointing element of the trip. Moreover, many responses noted that little traffic along the road contributed to the feeling of being in the "wilderness," while the number of buses and people seen along the road sometimes detracted from this sense. Most comments reflected support for the NPS limit on the number of buses that can use the road. Findings from the phase 2 quantitative visitor survey generally corroborated these conclusions.

Findings from the phase 2 visitor survey provide an empirical foundation to formulate standards of quality for several potential indicators of quality. Resulting data offer a range of potential standards of quality to be formulated. Generally, there was considerable agreement about these potential standards across the five major types of bus users, though Visitor Transportation System camper bus users and Kantishna Lodge bus users were often more sensitive to deteriorating conditions than were other types of bus users. There was a generally consistent relationship between what visitors experienced on the road and their evaluations of the study photographs. Generally, visitors saw more buses and people than they preferred, but fewer than they found minimally acceptable.

In keeping with the VERP framework, findings from this program of research should be combined with other information and used to formulate a series of indicators and standards of quality to define and guide management of the visitor experience on the Denali Park Road. Indicators should then be monitored and management actions taken to ensure that standards of quality are maintained. In this way, the carrying capacity of the Denali Park

Most comments reflected support for the NPS limit on the number of buses that can use the road.

Road can be defined and managed. However, a more proactive approach is also possible by incorporating these indicators and standards into a simulation model that estimates the maximum number of vehicles that can be accommodated on the road without violating standards of quality (Lawson et al. 2003). In this way, a numerical vehicle carrying capacity can be estimated, and this approach is described in the accompanying research report by Morris, Hourdos, Donath, and Phillips on pages 48–57.

As noted, study data present a continuum of potential standards of quality that range from "preference" to "displacement." Selection of a standard of quality within this continuum should be based on management objectives and desired conditions for the Denali Park Road and other considerations. Generally, a standard of quality associated with "preference" will result in a very high-quality visitor experience, but will probably result in some limitations on visitor use levels. A standard of quality associated with the other end of the continuum will allow more visitors to use the road, but will also result in a lower-quality visitor experience. Consideration should be given to applying more than one standard of quality based on either spatial or temporal zoning in order to create a range of visitor opportunities/experiences.

Acknowledgments

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References

Coffey, A., and P. Atkinson. 1996. Making sense of qualitative data. Sage, Thousand Oaks, California, USA.

Donnelly, M., J. Vaske, and B. Shelby. 1992. Measuring backcountry standards in visitor surveys. Defining wilderness quality: The role of standards in wilderness management—A workshop proceedings. USDA Forest Service General Technical Report PNW-305, 38–52. USDA Forest Service, Portland, Oregon, USA.

Lawson, S., R. Manning, W. Valliere, and B. Wang. 2003. Proactive monitoring and adaptive management of social carrying capacity in Acadia National Park: An application of computer simulation modeling. Journal of Environmental Management 68:305–313.

Manning, R. 2004. Recreation planning frameworks. Society and natural resources: A summary of knowledge. Modern Litho, Jefferson, Missouri, USA.

———. 2007. Parks and carrying capacity: Commons without tragedy. Island Press, Washington, D.C., USA.

———. 2009. Parks and people: Managing outdoor recreation at Acadia National Park. University Press of New England, Lebanon, New Hampshire, USA.

Manning, R. E., and W. A. Freimund. 2004. Use of visual research methods to measure standards of quality for parks and outdoor recreation. Journal of Leisure Research 36(4):557–579.

Manning, R. E., D. Lime, W. Freimund, and D. Pitt. 1996. Crowding norms at frontcountry sites: A visual approach to setting standards of quality. Leisure Sciences 18:39–59.

National Park Service. 1997. VERP: The visitor experience and resource protection (VERP) framework—A handbook for planners and managers. Denver Service Center, Denver, Colorado, USA.

Stankey, G. H., D. N. Cole, R. C. Lucas, M. E. Peterson, S. S. Frissell, and R. F. Washburne. 1985. The limits of acceptable change (LAC) system for wilderness planning. USDA Forest Service General Technical Report INT-176. USDA Forest Service, Ogden, Utah.

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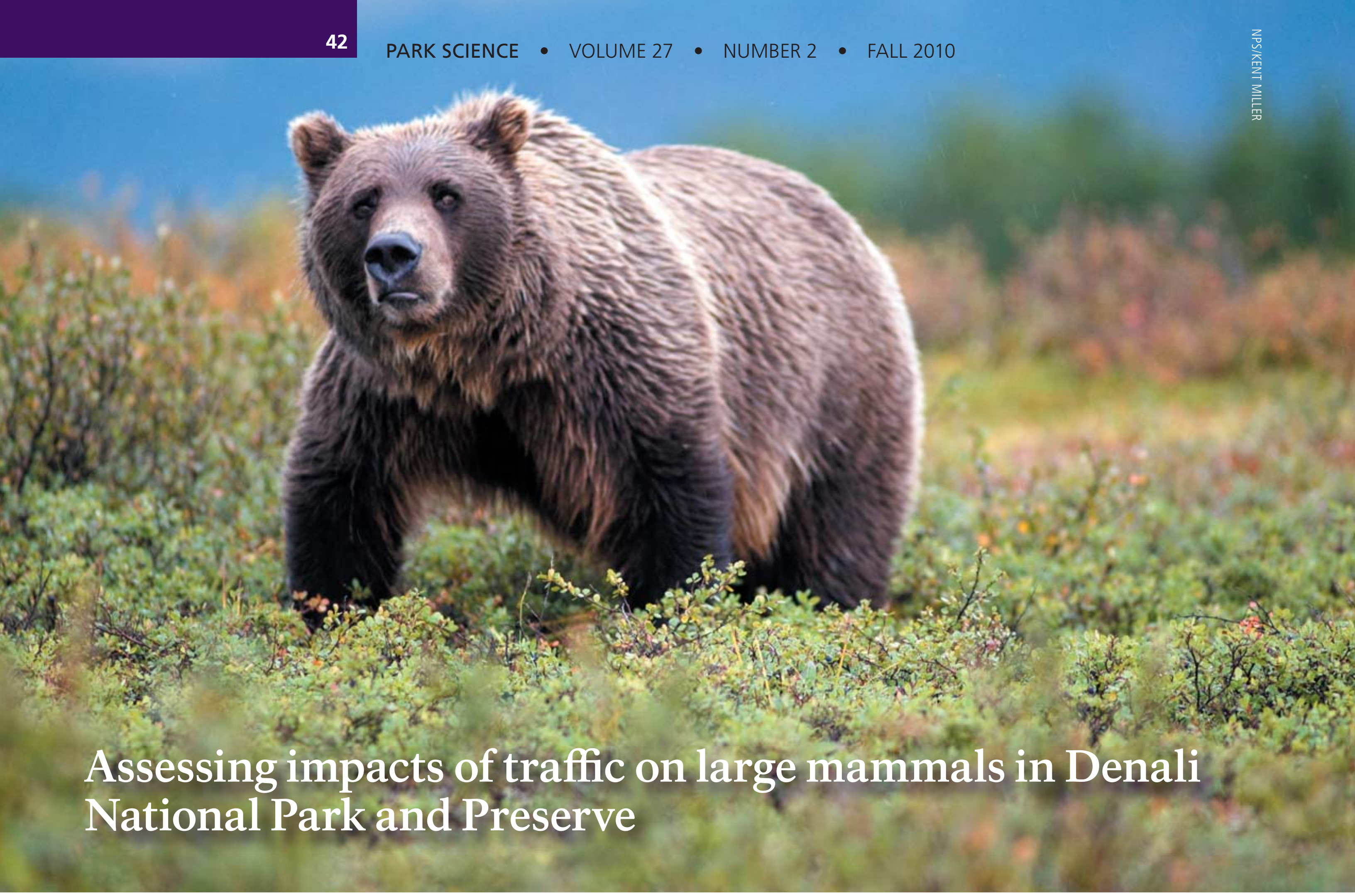

NPS/KENT MILLER

Assessing impacts of traffic on large mammals in Denali National Park and Preserve

By Laura M. Phillips, Richard Mace, and Thomas Meier

Figure 1. To assess potential impacts to wildlife from traffic patterns on the road in Denali National Park, managers analyzed fine-scale movement data from grizzly bears (above) and Dall's sheep (facing page, at top).

CREATED AS A WILDLIFE SANCTUARY IN 1917, Denali National Park (Denali) remains a spectacular place to view large mammals in their natural habitat. Shortly after the park was established, Superintendent Harry Karstens realized that one of the most urgent needs was "a main artery road through the upper passes" (Norris 2006). The National Park Service (NPS) envisioned a road that would allow visitors access to "the best possible views and vistas of the country" (Norris 2006). The Denali Park Road was completed in 1938 and provided a unique opportunity for visitors to view wildlife by accessing remote areas of open tundra, boreal forests, mountain vistas, and rugged terrain within the park. Little thought was given to the potential impacts that a road could have on the large mammals the park was established to conserve, although an unexpected benefit was apparent shortly after its construction. Easier access to the interior of the park and cabins built along the route allowed rangers to more successfully patrol the park and protect wildlife from poaching (Norris 2006). However, as visitation continued to increase, managers noticed that disturbance of the magnificent wildlife visitors expected to see from the park road was also increasing (Tracy 1977; Singer and Beattie 1986).

Because the Denali Park Road is the only means to reach the park interior, most potential resource impacts from visitation are confined to the road corridor. Today it is well established that with roads and vehicles comes environmental degradation, and as a result, environmental protection now plays a key role in transportation policy and decisions (Forman et al. 2003). As Denali managers began to reevaluate the park's system for transporting people on the Denali Park Road, they realized that determining potential impacts on wildlife from any changes that may be made to traffic volume and patterns on the road was a priority. Roads and vehicles may affect wildlife in many ways, including degrading the quality of adjacent habitat, restricting movements, and altering behavior (Trombulak and Frissell 2000; Forman et al. 2003). Previous wildlife studies in Denali suggested that traffic restricted the movements of Dall's sheep (*Ovis dalli*) as they traveled between winter and summer ranges (Dalle-Molle and Van Horn 1991), caused moose (*Alces alces*) to shift away from the road (Singer and Beattie 1986), and produced flight reactions in caribou (*Rangifer tarandus*) and grizzly bears (*Ursus arctos*) (Tracy 1977; Singer and Beattie 1986; Burson et al. 2000). While these studies pointed to possible impacts, they were limited to observations made within the road corridor and generally failed to comprehensively link negative effects with traffic patterns.

Abstract

In 2006, managers of Denali National Park and Preserve (Denali) implemented a number of integrated studies to comprehensively reevaluate the strategy for transporting people in the park. Given Denali's history as a world-class wildlife viewing park, managers realized that they should examine potential impacts on wildlife from any changes that may be made to traffic volume and patterns on the road. We used Global Positioning System (GPS) technology to study the fine-scale movement patterns of grizzly bears and Dall's sheep, as well as the distribution and abundance of other large mammals along the park road, to identify possible links between traffic volume and wildlife behavior. We documented 444 and 121 crossings of the Denali Park Road by GPS-collared grizzly bears (n=11) and Dall's sheep (n=17), respectively, during the study. Grizzly bears in this study were most active during the daylight hours and made most of their road crossings during periods of high traffic volume. Our study revealed that both grizzly bears and Dall's sheep in Denali responded negatively to increased traffic volumes by increasing their movement rates when approaching the road. Dall's sheep also shifted away from the road at higher traffic levels. Bus drivers recorded the locations of wildlife sightings along the road, which revealed areas with greater opportunities for viewing large mammals. The distribution and abundance of these sightings are important for visitor satisfaction and wildlife protection. Because access to the Denali Park Road is restricted, park managers have a level of control over vehicle use that is not available to many working to mitigate impacts of traffic on wildlife populations. Our study found evidence that vehicle numbers or patterns of vehicle behavior on the road affected wildlife distribution and movements; however, the magnitude of those effects did not appear to be great. Managers should carefully consider the potential to increase impacts on wildlife to unacceptable levels when analyzing transportation alternatives prior to implementing any changes.

Key words: Dall's sheep, Denali National Park and Preserve, Global Positioning System (GPS), grizzly bear, movement, roads, traffic, wildlife

NPS/JARED WITHERS

NPS/THOMAS MEIER

Figure 2. A wildlife biologist attaches a GPS collar to a grizzly bear in Denali National Park. GPS collars collected one location per hour from 15 May through 20 September 2006, and were programmed to automatically release from the animal after the study.

The objective of our research was to examine the movement and distribution of large animals relative to the Denali Park Road to assess potential correlations between traffic volume and patterns, and wildlife behavior (see fig. 1, page 28). To do this, we used Global Positioning System (GPS) technology to study the fine-scale movement patterns of Dall's sheep and grizzly bears (fig. 1, facing page), as well as the distribution and abundance of other large mammals along the park road. Results from this study would then be integrated with concurrent studies on visitor experience (see Manning and Hallo, pages 33–41) and traffic patterns to assess potential impacts of various alternative transportation strategies using a simulation model (see Morris et al., pages 48–57).

Methods

We captured grizzly bears from a helicopter using standard aerial darting techniques in May 2006 and Dall's sheep from a helicopter using net gunning techniques in March 2007. We fitted 20 bears and 20 sheep with GPS collars that collected one location per hour from 15 May through 20 September, when they were programmed to automatically release from each animal (fig. 2). We used location data from 17 bears (4 males and 13 females) and 18 sheep (7 males and 11 females) to examine movements and road crossing behavior in relation to vehicle numbers and traffic patterns. Two male bears were not used in analyses as they were the

In Focus: Denali Park Road

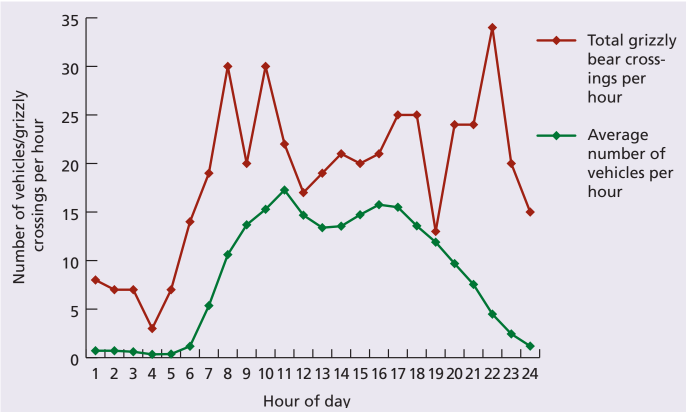

Figure 3. Grizzly bears crossed the Denali Park Road during all hours of the day, but crossings were more frequent in midday when most vehicles were on the road. That study bears crossed the road most frequently during periods of high traffic suggests that bears were not altering their activity patterns to avoid disturbance from the road.

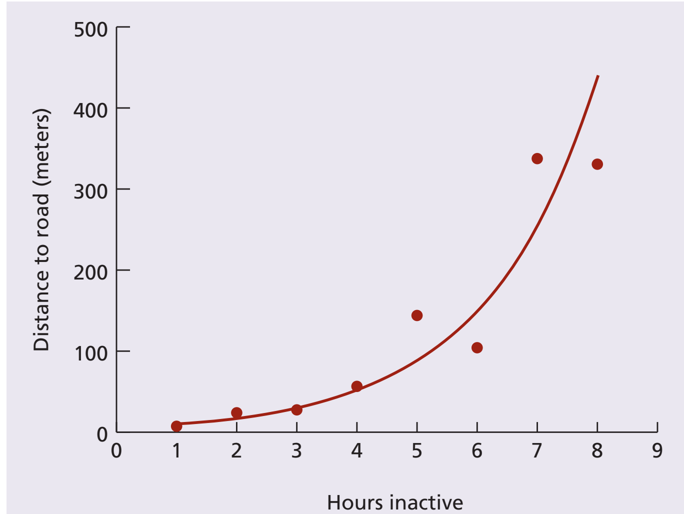

Figure 4. Grizzly bears were inactive (movement rates <10 meters/hour [33ft/hr]) for longer periods of time farther from the Denali Park Road, suggesting that they were less comfortable being either relatively stationary or asleep while near the road corridor.

dependent young of collared females and their movements were autocorrelated with those of their mother. One collar placed on a female bear was not retrieved from the field. Data from two collared Dall's sheep were not used in analyses because one animal died prior to the end of the study period and one GPS collar failed to provide any data.

We obtained hourly summaries of vehicle numbers by road section using traffic counters placed at six locations along the road. We collected information about the number and distribution of large mammals (grizzly bears, caribou, Dall's sheep, moose, and wolves [*Canis lupus*]) along the road from touch-panel interfaces installed in 20 buses. Bus drivers entered the species type observed when they stopped to view wildlife along the road. Data entered into the panels were geo-coded automatically by GPS Automatic Vehicle Locator units installed on each bus. Managers implemented a "quiet night" of minimal or no traffic as an experimental control during the summer seasons of 2007 and 2008. Traffic was limited to urgent or emergency travel from 10 p.m. on Sundays until 6 a.m. on Mondays to examine potential impacts on the number of wildlife viewing opportunities for visitors on morning trips into the park.

Roads and vehicles may affect wildlife in many ways, including degrading the quality of adjacent habitat, restricting movements, and altering behavior.

Main findings

Individual bears had home ranges at varying distances from the Denali Park Road. Eleven grizzly bears were classified as having home ranges that straddled the road. Of the six bears that did not cross the road, three had home ranges that were adjacent to the road but did not cross it and three had home ranges more than 3 km (2 mi) from the road. We documented 444 crossings of the Denali Park Road by bears whose ranges straddled the road. The number of crossings ranged from 2 to 136 among individuals. Grizzly bears crossed the road during all hours of the day, but made crossings more frequently during the period when most vehicles were on the road (fig. 3). Bears were inactive (movement rates <10 meters/hour [33 ft/hr]) mostly during hours of darkness. Bears spent longer periods of inactivity farther from the road (fig. 4). Bears moved faster when crossing the road than immediately before or after crossing. We noted some differential use of three general land types (tundra, mountain, river channel) between genders and seasons. In general, female grizzly bears made greater use of mountain habitats while male bears moved much more extensively throughout the tundra and river channel land types.

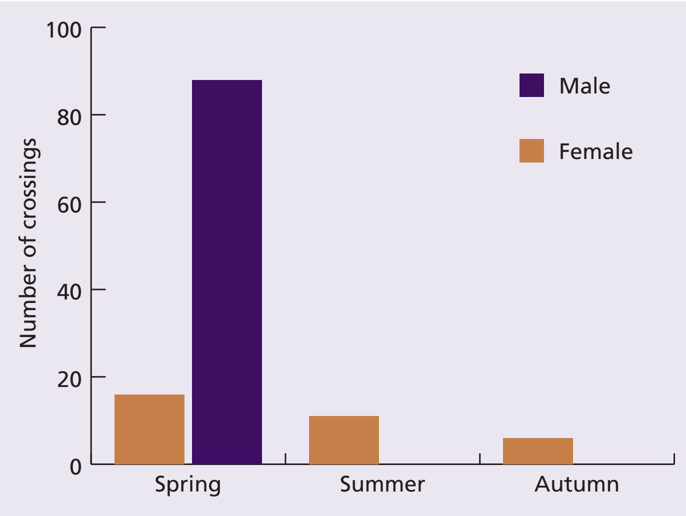

Figure 5. Both male and female Dall's sheep crossed the road during summer, but male sheep made more crossings than females and crossed only in spring. Forage is available at higher elevations later in summer in Denali National Park, so disturbance of sheep within the road corridor during spring may have a greater impact on them than during the remainder of the summer.

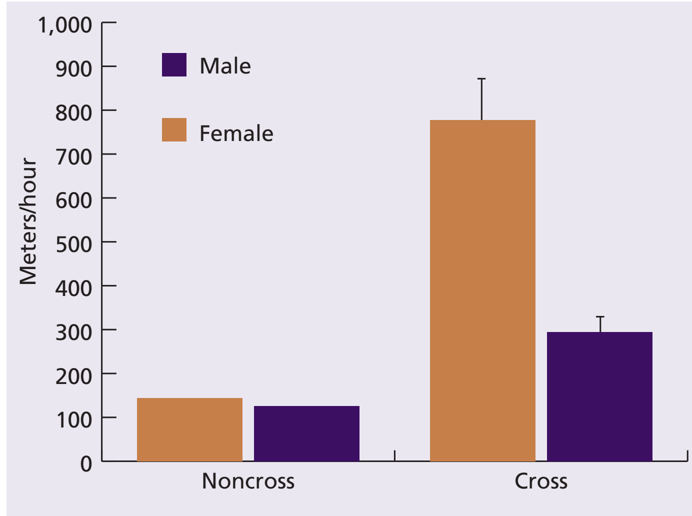

Figure 6. Dall's sheep moved at a faster rate as they crossed the road in Denali than the general movement rate. Increased movement speed of sheep while crossing suggests that they were wary of human activity along the road and used speed to minimize the duration of contact with humans.

We did not detect any changes in bear use of the land types [tundra, mountain, and river channel] when adjacent to, or while crossing, the road.

We did not detect any changes in bear use of the land types when adjacent to, or while crossing, the road. When bears did cross the road, they typically moved from the mountains on one side of the road to mountains on the opposite side.

We recorded 121 road crossings by Dall's sheep during the study. Both sexes crossed, but male sheep made more crossings than females (33 female, 88 male). Female sheep crossed the road 3 times on average (range = 1–8), while males crossed 12.6 times (range 0–51). Male sheep crossed the road only in the spring (15 May to 30 June), while females crossed throughout the study period (fig. 5). Like bears, Dall's sheep moved at a faster rate as they crossed the road compared with general movement rates, and movement rates increased with higher traffic levels (fig. 6). The distribution of sheep locations showed a shift away from the road as traffic volumes increased. The proportion of locations within 300 meters (984 ft) of the road declined from 22% at <10 vehicles/hour to 9% at >20 vehicles/hour.

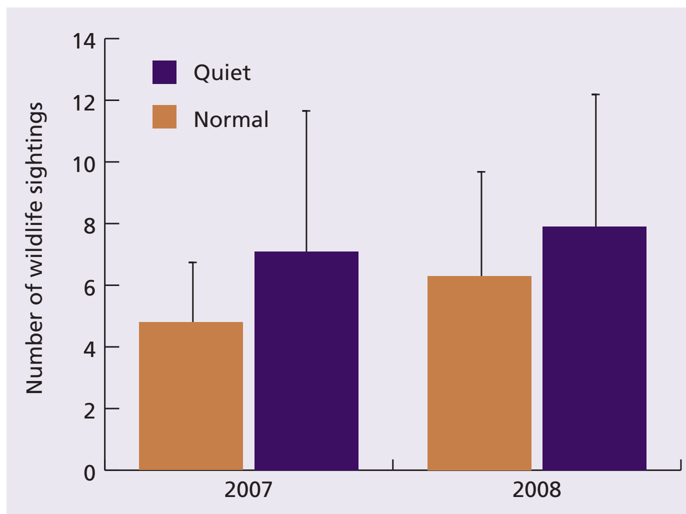

Figure 7. Bus drivers recorded a slight increase in the number of wildlife sightings on Monday mornings after nights of little or no traffic on the park road (quiet) compared to mornings after regular nighttime traffic levels (normal).

The highest number of bear, sheep, and caribou sightings recorded by bus drivers occurred between miles 32 and 45. Traffic levels were significantly lower on quiet nights than on regular nights along the entire length of road. We noted a slight increase

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in number of recorded wildlife sightings on Monday mornings after quiet nights compared with normal mornings, but the increase was not statistically significant (fig. 7).

Conclusions

To our knowledge this is the first telemetry study to investigate relationships between grizzly bears and vehicular traffic along a single unpaved road with relatively low traffic volumes in a national park setting. Conversely, most previous studies were conducted in nonpark environments either where bears were hunted legally or illegally or where other forms of human-caused mortality were prevalent (Waller and Servheen 2005; Graves et al. 2006). In most of these cases, biologists assume that bears are somewhat wary of human presence. In contrast, biologists generally assume that grizzly bears in Denali are habituated to, or have become tolerant of, human presence over time. The high number of bear sightings from buses shows that bears have not been completely displaced from the road corridor.

Wildlife may respond to human activity by changing the timing of their activities to minimize deleterious interactions (Forman et al. 2003; Yri 2006). Grizzly bears in this study were most active during the period of day when road traffic was heaviest. This pattern of relatively high activity during daylight hours is the norm for grizzly bears across their range (Hechtel 1985; Wenum 1998). That our study bears were most active and crossed the road mostly during periods of high traffic suggests that bears were not measurably altering their temporal patterns of activity to avoid human disturbance from the road.

We inferred some behavioral effects of road traffic from our telemetry data. We found that duration of time when bears were inactive was shortest nearest the road and increased as distance from the road increased. Furthermore, the longest bouts of inactivity occurred at more than 300 meters (984 ft) from the road during high traffic periods. These data suggest that bears were less comfortable being either relatively stationary or asleep while near the road corridor. Grizzly bears significantly increased their movement speed while crossing the Denali Park Road. This increase suggests that bears were cognizant of human activity along the road, and used speed to minimize the duration of contact with road traffic.

Our study revealed that Dall's sheep in Denali responded negatively to increased traffic volumes by increasing their movement rates when approaching the road and shifting away from the road at higher traffic levels. While many studies have investigated the potential for vehicles to affect sheep behavior and distribution, most have examined individual or group responses to the approach of individual vehicles, or general distribution of sheep relative to road corridors, rather than volume or patterns of traffic (Papouchis et al. 2001; Keller and Bender 2007). Our results reflected a threshold distance for response to disturbance by showing that sheep within 300 meters (984 ft) of the road shifted farther away at higher traffic volumes and that small increases in the number of vehicles on the road could have impacts on Dall's sheep movements. Movement of sheep away from the road corridor at higher traffic volumes may decrease the amount of habitat available for foraging. This may be most relevant to sheep during the spring season, when they most frequently cross the road and "green-up" has not yet occurred at higher elevations.

Managers at Denali may want to consider mitigating impacts on sheep by tailoring any traffic increases to avoid migration periods, or by scheduling bus departures to create quiet periods of low traffic on the road to protect wildlife crossing opportunities.

The potential restriction of movement by sheep because of traffic impediments may be of greater concern to park managers than is loss of habitat. Migratory movements of sheep from their winter range to summer use areas may be important to the health of sheep populations in Denali because seasonal range shifts allow them to take advantage of the most nutritious forage available. It also allows for connectivity among groups of sheep and has important implications for population viability (Nichols and Bunnel 1999; DeCesare and Pletscher 2006).

The tendency for large mammals to be observed more frequently on mornings after nighttime traffic levels were reduced suggests that vehicles on the park road may be impacting wildlife viewability. The locations of wildlife sightings recorded along the road reveal areas with greater opportunities for viewing large mammals. Distribution and abundance of these sightings are important for visitor satisfaction and wildlife protection.

Because access to the Denali Park Road is restricted, park managers have a level of control over vehicle use that is not available to many working to mitigate impacts of traffic on wildlife populations. Our study found evidence that vehicle numbers or patterns of vehicle behavior on the road affected wildlife distribution and movements; however, the magnitude of those effects did not appear to be great. Managers should carefully consider the potential to increase impacts on wildlife to unacceptable levels when analyzing transportation alternatives prior to implementing any changes. Managers at Denali may want to consider mitigating impacts on sheep by tailoring any traffic increases to avoid migration periods, or by scheduling bus departures to create quiet periods of low traffic on the road to protect wildlife crossing opportunities. By integrating standards for maintaining opportunities for wildlife crossings into a traffic simulation model, managers could possibly forecast how well alternative transportation scenarios meet these targets.

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References

Burson, S. L., J. L. Belant, K. A. Fortier, and W. C. Tomkiewicz. 2000. The effect of vehicle traffic on wildlife in Denali National Park. Arctic 53:146–151.

Dalle-Molle, J., and J. Van Horn. 1991. Observations of vehicle traffic interfering with migration of Dall's sheep (*Ovis dalli dalli*), in Denali National Park, Alaska. Canadian Field Naturalist 105:409–411.

DeCesare, N. J., and D. H. Pletscher. 2006. Movements, connectivity, and resource selection of Rocky Mountain bighorn sheep. Journal of Mammalogy 87:531–538.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road ecology, science and solutions. Island Press, Washington D.C., USA.

Graves, V. A., S. Farley, and C. Servheen. 2006. Frequency and distribution of highway crossings by Kenai Peninsula brown bears. Wildlife Society Bulletin 34:800–808.

Hechtel, J. L. 1985. Activity and food habits of barren ground grizzly bears in Arctic Alaska. Thesis. University of Montana, Missoula, USA.

Keller, B. J., and L. C. Bender. 2007. Bighorn sheep response to road-related disturbances in Rocky Mountain National Park, Colorado. Journal of Wildlife Management 71:2329–2337.

Nichols, L., and F. L. Bunnel. 1999. Natural history of thinhorn sheep. Pages 23–77 in R. Valdez and P. R. Krausman, editors. Mountain sheep of North America. University of Arizona Press, Tucson, USA.

Norris, F. 2006. Crown jewel of the North: An administrative history of Denali National Park and Preserve. Alaska Regional Office, National Park Service, Anchorage, USA.

Papouchis, C. M., F. J. Singer, and W. B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65:573–582.

Singer, F. C., and J. B. Beattie. 1986. The controlled traffic system and associated wildlife responses in Denali National Park. Arctic 39:195–203.

Tracy, D. M. 1977. Reaction of wildlife to human activity along Mount McKinley National Park road. Thesis, University of Alaska, Fairbanks, USA.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

Waller, J. S., and C. Servheen. 2005. Effects of transportation infrastructure on grizzly bears in northwestern Montana. Journal of Wildlife Management 69:985–1000.

Wenum, E. A. 1998. Activity patterns and time budgets of grizzly bears in the Swan Mountains of Montana. Thesis. Montana State University, Bozeman, USA.

Yri, I. M. 2006. Seasonal and diel variation in road avoidance behavior of female Scandinavian brown bears. Thesis. Norwegian University of Life Sciences, Aas, Norway.

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Modeling traffic patterns in Denali National Park and Preserve to evaluate effects on visitor experience and wildlife

By Ted Morris, John Hourdos, Max Donath, and Laura Phillips

Abstract

Historically, traffic on the Denali Park Road has been limited in order to protect wildlife and improve visitor experience. The Denali Park Road is one example of a park roadway facing increasing visitation and pressure to change or defend the current limits on traffic. To respond to such pressures, park and protected area managers need a greater understanding of the impacts of traffic volume and traffic patterns on the physical, biological, and social environment. This study developed a traffic simulation model of the Denali Park Road that predicts visitor experience and impacts on Dall's sheep for hypothesized road usage scenarios. The model incorporated crowding indicators at prescribed scenic areas and at wildlife stops along the road, as well as traffic levels at critical wildlife crossing locations. Violations of set standards for each of the indicators were then assessed for several scenarios that encompassed road usage beginning from a below-average condition to a condition well above the current mandated daily vehicle trip limit. Results from the model indicated that adherence to standards representing a higher-quality visitor experience may be difficult to maintain on the park road if more visitors—in more vehicles—are allowed on the park road.

Key words: Dall's sheep, Denali National Park and Preserve, scenic road, traffic microsimulation, visitor experience

FACED WITH INCREASING VISITATION AND PUBLIC USE in the road-accessible, remote areas of Denali National Park, land managers needed to develop a greater understanding of the impacts of traffic volume and patterns on the physical, biological, and social environment of the lands that the Denali Park Road traverses. Studies have explored the reactions of wildlife to increased vehicle volumes; however, these studies were mainly directed at understanding the impact of high-volume highway traffic (Langevelde and van Jaarsma 2004). Current research indicates that increased public visitation in remote public spaces creates unique traffic patterns and challenges, such as maintaining visitor satisfaction and safety and protecting wildlife and other natural resources. Denali National Park and Preserve (Denali) in Alaska exemplifies the challenges of managing a public space with high visitation and sensitive wildlife.

Most visitors experience the park by traveling the historical Denali Park Road, a restricted-access, mostly gravel road extending 90 miles (145 km) from the park entrance to the old mining district of Kantishna (see fig. 1, page 28). The road provides an almost wilderness experience and unparalleled wildlife viewing, and is the only road facility providing access to the interior of the park. The current mandatory transportation system consists of park-sponsored, regularly scheduled shuttles and ticket-reserved bus tours, both of which travel to several turnaround destinations within the restricted 75-mile portion of the park road.

The traffic simulation model incorporated seven separate destinations. Five of the seven turnaround destinations are provided by the shuttle service beyond the Savage Creek checkpoint at mile 15 where the restricted portion begins (refer to the map on page 28). Specifically, they are Polychrome Overlook rest area (mile 47), Toklat River rest area (mile 53), Fish Creek (mile 63), Wonder Lake (mile 85), and Kantishna (mile 89). The remaining two destinations are turnaround points for the bus tours: the shorter interpretive Denali Natural History Tour turns around at Primrose Rest Stop, located at mile 17, and the Tundra Wilderness Tour travels to Stony Hill Overlook located just before mile 62. In addition to shuttle bus and tour bus operations, scheduled one-way and round-trip bus service is provided for visitors staying at any of the three lodges located on the west end of the park road near Kantishna. The service is privately operated by the lodges themselves. Unlike either the tour or the lodge bus operations, the scheduled visitor shuttle service stops to pick up day hikers and campers at designated stops near campgrounds, or anywhere along the road. The general management plan (GMP) implemented by the National Park Service (NPS) in 1986 (NPS 1986) mandates a daily limit of 88 bus trips: 30 Tundra Wilderness Tours, 36 shuttle trips, and 22 Denali Natural History Tours. The lodge bus service is not included in these daily limits (though they do count toward the annual trip limit). The lodge buses provide about 12 trips per day throughout the summer (mid-June through the beginning of September). These trips are included in all the simulation scenarios.

The buses that encounter wildlife in view of the road stop frequently for several minutes to allow passengers to observe and photograph the animals. The buses also stop for extended periods (10 to 30 minutes) at several scenic rest stops, for example, Tekla nika River at mile 29, Polychrome Pass, and Stony Hill Overlook (particularly when Mount McKinley is in view; see cover photo and fig. 3, page 30). The round-trip travel time to Primrose Ridge (the shortest bus trip) averages three hours, while the average travel time to Kantishna and back is more than 11 hours. Two very popular routes, the shuttle service to Fish Creek (15 bus trips were scheduled daily during peak season in 2007) and the bus tour to Stony Hill Overlook (about 30 trips during peak season), have average round-trip travel times of 7.7 and 7.4 hours, respectively. Further details of the park road and the transportation system are described in the introductory article by Phillips, Hooge, and Meier on pages 28–32.

Recently, because of concerns that the mandatory transportation system was not meeting the needs of visitors, Denali park managers began an integrated study to examine the interactions among road use, quality of the visitor experience, and wildlife behavior. A traffic simulation model was needed to integrate logistical constraints and interactions among traffic, wildlife, and the visitor experience. Computer simulation modeling has been shown to serve as a valuable tool for managing visitor recreation use in a variety of public and protected area settings (Lawson et al. 2003; Cole 2005). Modeling informs park managers about the possible effects of future management options for the park road.

A traffic simulation model was needed to integrate logistical constraints and interactions among traffic, wildlife, and the visitor experience.

Traffic on the park road primarily comprises large buses that stop frequently for passengers to view wildlife. This driving behavior imposes modeling constraints that traditional traffic planning models cannot handle. The objective of this study was to develop an integrated simulation model capable of analyzing the effects of vehicle-specific driving behaviors, vehicle schedules, and wildlife sighting probabilities on visitor experience and resource protection. Park managers could then use the model proactively to evaluate the impacts of several alternative transportation management strategies on the ability to achieve visitor experience and wildlife resource standards.

Building the model

The model was implemented using traffic microsimulation software. Similar to other protected area capacity simulation approaches (Gimblett e-t al. 2001; Lawson et al. 2003; Cole 2005; Itami 2005; Morris et al. 2005), traffic microsimulation is a dynamic, stochastic (i.e., random), and discrete event-based simulation. Such an approach typically has been used to understand complex traffic systems and facilities in urban settings (Barcelo et al. 2005). Traffic microsimulation is an evolutionary departure from other simulation approaches since it requires that vehicle behaviors such as following, passing, merging, route choice, and other complex interactions be inherent characteristics of the simulation. Also, it provides an open architecture to modify and add other behaviors to individual vehicles. We used this methodology to define such complex interactions and behaviors on the park road.

First we constructed the geometry of the park road in the simulation model by referencing a Geographic Information System (GIS) layer of road information created by the National Park Service from U.S. Geological Survey transportation files. The road narrows to 1.5 lanes beyond the Teklanika River rest area at mile 29 (see map, page 28), so we coded passing provision rules into the simulation software. This is especially important when buses are ascending or descending mountain passes, where adequate room must be given to vehicles in the outside lane as a traffic safety measure. A limited number of road permits are issued to private vehicles, and because of the passing provisions, the travel behavior of the buses is affected by private vehicle traffic as well. Therefore, in order to consider the effect of private vehicles, approximately 50 private vehicle trip departures were randomly generated throughout the simulation period. The distribution and number of trip destinations for these vehicles were derived from the daily log entries from the Savage Check Station at mile 15 (see map, page 28).

We used records from approximately 4,000 trips made by 87 buses equipped with Global Positioning System (GPS) Automatic Vehicle Locators (AVLs) to examine driving rules, speed behavior, rest stop and designated stop (e.g., stops at scenic vistas and campgrounds) dwell times, and wildlife encounter stop dwell times of vehicles on the park road. We recorded a GPS location every 400 feet (112 m) and uploaded the data wirelessly to a central server during the time buses were parked in service lots. We aggregated GPS speed data for the different vehicle operators (tours, shuttle service, lodge buses, and private vehicles) into one-mile segments in order to estimate a mean speed profile of the road and a statistical distribution of the speed of each different vehicle operator type over the round-trip length of their route. This captures general speed behavior for specific operators. For example, we found that the Denali Natural History Tour drivers travel about 10 miles per hour (mph) slower, on average, than the other bus operators. We then estimated maximum attainable speed along different road sections by computing one standard deviation above the mean speed profile.[1] When the simulation model computes a desired vehicle speed that is greater than the maximum attainable speed at a given location along the road, the vehicle is set to travel at the maximum attainable speed (which was typically 0 to 10 mph less than the 35 mph speed

[1] The simulator requires a maximum attainable speed be assigned for a given road section. A standard deviation above the mean population of bus drivers is a logical representation of this parameter as it includes a large majority of the drivers. Drivers going faster than this are considered outliers.

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limit enforced by the park). Computation of the desired vehicle speed when it encounters other traffic in its lane is based on the vehicle-following model by Gipps (1981). Note that the profile speed reflects a driving speed pattern that results from a myriad of factors beyond the enforced speed limit (35 mph) of the park road, such as road geometry, scenic viewing opportunities, and road and traffic conditions.

A key component in building the model was understanding driver stop behavior, especially with respect to wildlife sightings along the road. We developed a data acquisition system to allow bus drivers to geo-reference stop information using touch-screen panels that interfaced with the AVL units. Data recorded on the panels provided information about type and location of wildlife sightings, hiker pick-up and drop-off locations, and dwell times at rest areas. Twenty buses were equipped with the touch-screen panels, which provided information for 5,697 stops made by drivers during the summer season.

We built stops for wildlife viewing into the model by creating "incidents" simulated at 79 prescribed locations and time frames that impeded vehicles as they traveled along the road. The incidents were derived by observing where vehicles stopped in clusters in time and space using the AVL data. We determined stop duration behavior using data from 2,771 logged wildlife stops. The trends indicated that the time a bus spent at a wildlife stop varied by order of arrival at the sighting location and by the species being observed. In particular, buses spent more time for grizzly bear encounters than for other species of large mammals, and buses that stopped at a wildlife sighting after the first bus had arrived spent more time at that location. We computed rest stop and other designated stop durations for the different bus operators and routes from 1,059 stops extracted from the AVL data during July (mid-peak season). We validated the model by creating a simulation experiment that duplicated the actual schedule departures for 61 buses, and then comparing their arrival times at the wildlife, campground, and rest stops. The results indicated a travel time difference of 4 to 20.2 minutes ($p < 0.01$, $T = -205.5$, $N = 158{,}719$) between the model and actual travel times. Bus trip times averaged 6.5 hours, with the shortest trips taking 3.1 hours, and the longest lasting more than 11 hours.

Traffic microsimulation is an evolutionary departure from other simulation approaches since it requires that vehicle behaviors such as following, passing, merging, route choice, and other complex interactions be inherent characteristics of the simulation.

To integrate the model with important indicators of visitor experience and resource protection, we incorporated standards established by concurrent interdisciplinary studies. A GPS study of Dall's sheep movements (see article by Phillips, Mace, and Meier, pages 42–47) and previous studies of sheep behavior in the park (Putera and Keay 1998; Dalle-Molle and Van Horn 1991) indicated that sheep may be sensitive to traffic volume when crossing the park road during seasonal migration. To ensure protection of crossing opportunities for sheep, park managers determined that a gap between vehicles that is longer than 10 minutes each hour should be maintained as a standard at three traditional migration corridors along the road. The simulation model incorporated three sheep crossing locations at miles 21.6, 37.6 (near Sable Pass), and 52.8 (Toklat River).

Another study (see article by Manning and Hallo, pages 33–41) was designed to evaluate indicators of quality for the visitor experience on the Denali Park Road. The investigators used visitor surveys to formulate standards for three crowding indicators: (1) number of buses in a viewscape, (2) number of buses at a rest area, and (3) number of buses at a wildlife stop. Park managers

Table 1. Standards for the number of buses present at one time and one location on the Denali Park Road for all crowding indicators

	Type of Stop			
Indicator	**Iconic Viewscape (A)**	**Alternative Viewscape (B)**	**Wildlife Stops**	**Polychrome Overlook Rest Stop**
Low-crowding (preference)	2.43	2.17	1.75	2.24
Medium-crowding (typically seen)	3.80	3.51	3.06	3.57
High-crowding (acceptable)	5.95	5.68	4.85	5.48

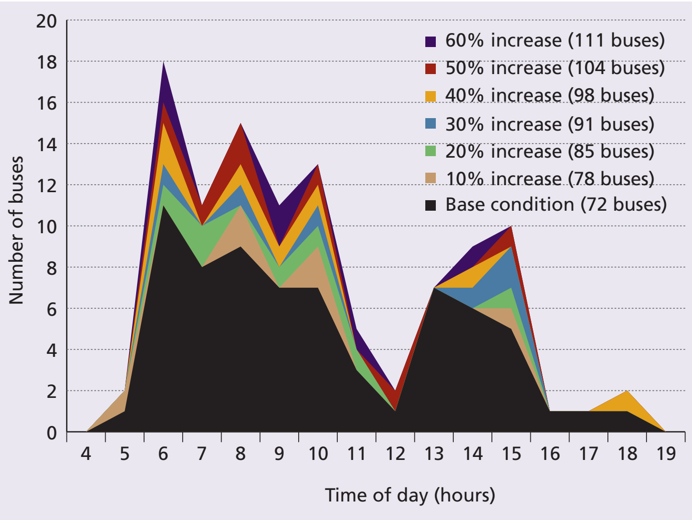


Figure 1. Bus schedules: We used seven traffic scenarios that represented a range of increases in road use in a microsimulation model of the Denali Park Road to identify possible impacts on important social norms and biological resources. In each scenario we increased the number of buses used in the model in proportion to a base schedule that is below the current traffic levels. Traffic on the park road is limited by the present GMP limit of 88 buses per day. Park managers are not considering a reduction in traffic volume as they revisit the traffic limits.

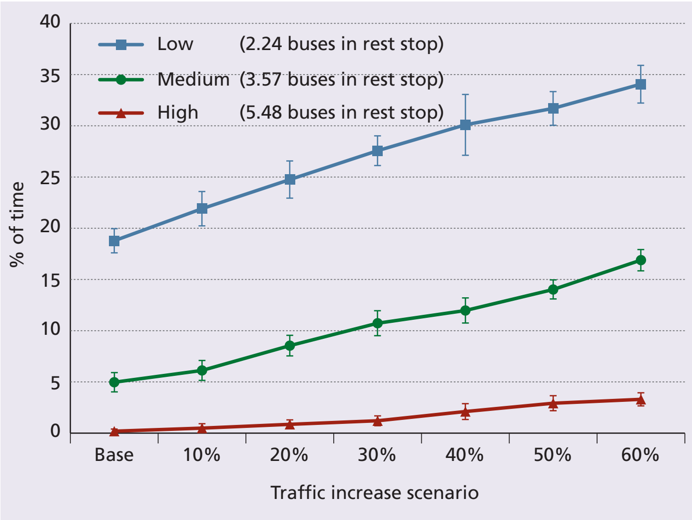


Figure 2. Rest stop crowding: The model forecasts (a) which crowding standards (low, medium, and high) at a rest area on the Denali Park Road would be exceeded more frequently from mid-morning (10 a.m.) until midafternoon (2 p.m.), and (b) a secondary sharp peak in the early evening (6–7 p.m.), as the number of vehicles on the road increased. For example, a traffic increase of 30% would result in the medium-crowding standard (i.e., normally experienced today) being violated around 11% of the time.

chose to analyze three levels of crowding, as indicated by the number of buses for a specified level of road use at a particular location. These crowding levels correspond to the traffic volume visitors would prefer (low), typically saw (medium), and found minimally acceptable (high) on the road (table 1). The set standards were computed using a weighted average based on the number surveyed of each visitor type during the season in order to balance differences among park users in a single set standard value (see article by Manning and Hallo, pages 33–41). We built tools to summarize and evaluate the ability of different transportation scenarios to meet road use levels within the traffic simulation model.

Evaluating transportation options

To evaluate potential impacts on the visitor experience and wildlife if traffic volume were to increase, park managers developed scheduling scenarios that amplified the park road usage patterns throughout the day by proportionally adding different bus routes and operators controlled by the daily limit specified in the general management plan (fig. 1). Park managers needed to understand how the indicators and set standards were affected by the logistical constraints of the current transportation system. The number of buses in base condition, a condition well below average traffic levels during the peak summer tourist season, was 29 fewer than the GMP limit of 88 shuttle and tour bus trips per day. The first three scenarios starting at the base condition represent a lower to more typical level of bus service below the GMP daily limit. Service at or near the GMP limit is represented by the 30% scenario. Note that it is not uncommon during the peak summer season for bus service to meet the daily GMP limit. Twelve scheduled lodge bus routes remained the same for all scenarios, since the National Park Service does not control day-to-day scheduling for these buses. For each condition, we executed 30 simulation experiments to benefit from the stochastic nature of the model. We then extracted performance measures from the simulation that project impacts on visitor experience and resource indicators by evaluating the degree of departure from set standards indicated in table 1. By examining change in violation rates for the three crowding standards of quality for viewscapes, wildlife, and rest stop crowding, we can assess the sensitivity of the standards to different levels of crowding modeled by the simulation experiments. This can indicate how the carrying capacity of the road is affected as use levels and standards of quality change from low to high (Lawson et al. 2003). The carrying capacity of the park road is defined by each of the four crowding indicator set standards (table 1) in addition to the sheep crossing gap time described previously.

In Focus: Denali Park Road

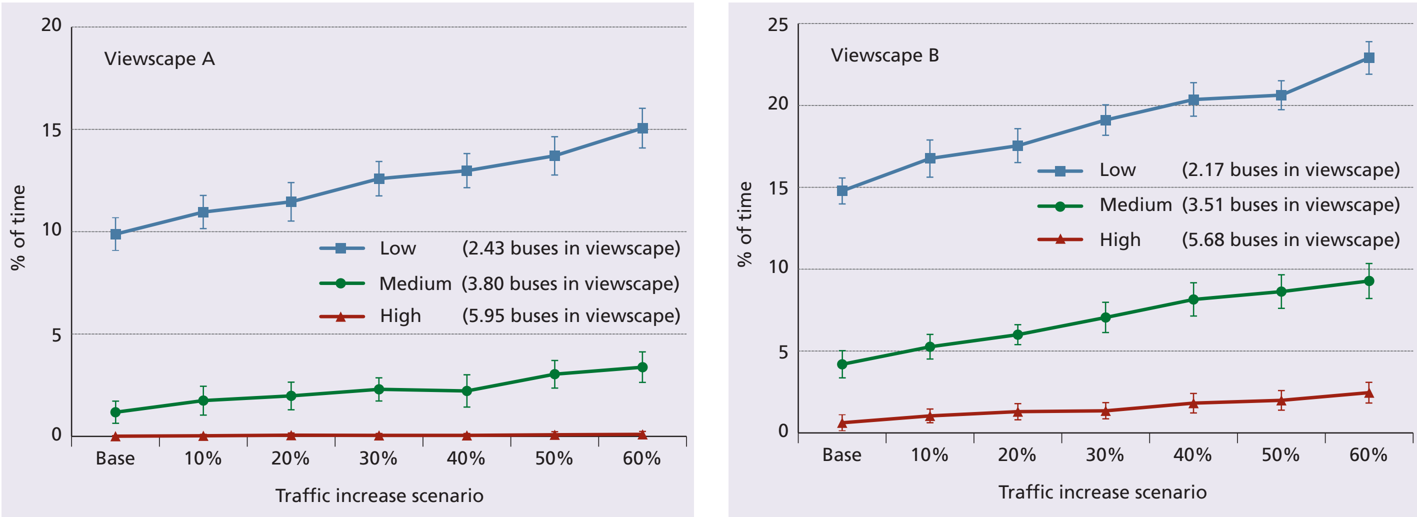


Figure 3. Viewscape crowding: The simulations produced violation levels for the medium- and high-crowding standards for Viewscape A, the iconic viewscape located at mile 62, just beyond the Stony Hill Overlook scenic rest stop and turnaround, that were less sensitive to increasing road use than those for Viewscape B, the "generic" viewscape located at mile 57, in part because more bus trips pass through Viewscape B than through Viewscape A.

We calculated maximum number of buses observed within a one-minute interval at rest areas to estimate the crowding levels and violation rates for the three standards. The low-crowding standard proved to be the most sensitive to increases in road use and was violated more frequently than the other standards. The low-crowding standard experienced an increase in frequency of violations from 18% at the low (i.e., base) road use level to 34% at the 60% increase scenario. In contrast the observed frequency of violations for the medium- (from 5% to 16%) and high-crowding standards (from <1% to 3%) increased at a much lower rate (fig. 2, previous page).

We evaluated crowding within two viewscapes on the road: Viewscape A, which represents an iconic view of the road just beyond mile 62 and Mount McKinley, and Viewscape B, which represents a generic scenic view of the road at mile 57 (see map on page 28), 3 miles beyond the Toklat rest area (fig. 3). As with the rest stop model outcomes, the low-crowding standard was the most sensitive (i.e., produced the greatest change in violations) to increased usage scenarios within viewscapes (a change in violation from 10% to 15% for Viewscape A and from 15% to 23% for Viewscape B). Fluctuations of this indicator over time can be examined and used by park managers to create bus schedules that reduce crowding during specific periods of the day. On average, the greatest simulated crowding impacts occur during two morning and evening peaks for Viewscape B and a more singular midday peak for Viewscape A. While the viewscapes are approximately 5 miles (8 km) apart, peak crowding occurs more than two hours apart, a pattern that could not be predicted without the simulation model (fig. 4).

For wildlife stops, the medium-crowding standard was most sensitive to the traffic increase scenarios relative to the base condition (i.e., increase in violation rate from 64% to 78%, 18% to 41%, and 3% to 12% for the low-, medium-, and high-crowding standard levels, respectively) (fig. 5). More than 80% of all wildlife stops occur within the first 50 miles (80 km) of the park road (about 600 stops). The variation of violation rates for the three set standard levels changes considerably with respect to time and location along the park road (fig. 6, page 55). This implies that management actions to respond to crowding at wildlife stops may need to be based on different standards that are specific to certain portions of the park road, or even to particular times of the day.

In order to assess potential impacts on wildlife, as represented by Dall's sheep, we examined temporal characteristics of road crossing opportunities of greater than 10 minutes without vehicle traffic and extracted them from the model for three locations along the road. Denali park managers ultimately wish to provide consistent crossing opportunities to sheep populations during the period when vehicles are traveling the park road. For example, at least one ample gap time is desired to accommodate sheep crossings for every hour of the day. Therefore, we studied the temporal variability of vehicle spacing and crossing opportunities by examining the amount of time during each hour of the day that was made up of gaps in traffic longer than 10 minutes. Gap times between vehicles that were greater than 10 minutes and that

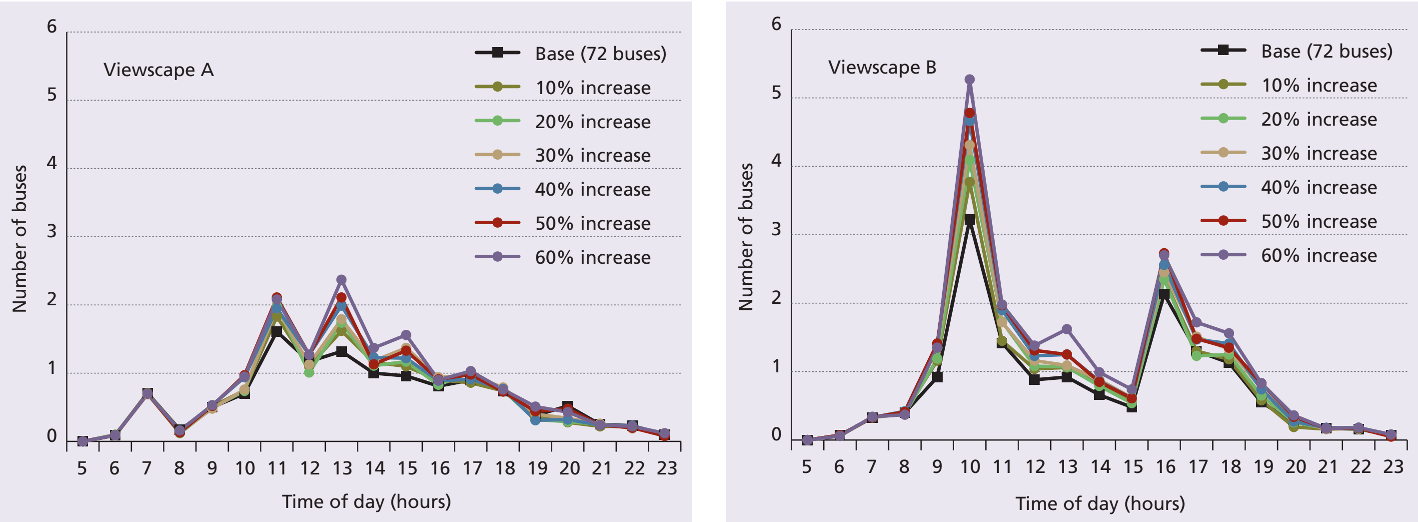


Figure 4. Viewscape crowding: Comparison of temporal trends between the iconic Viewscape A and Viewscape B indicates significantly different peaks in crowding that occurred several hours apart, even though the two viewscapes are only 5 miles (8 km) from each other on the park road.

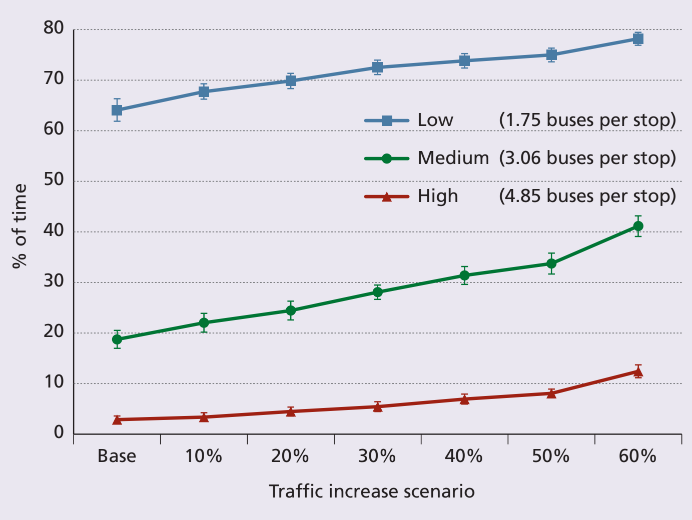


Figure 5. Crowding at wildlife stops: The medium-crowding ("typically saw") standard violation rate proved to be the most sensitive to the simulation traffic increase scenarios. For these scenarios, the largest increase in crowding occurred between mile 30 (1 mile west of the Teklanika River rest area) and mile 45 (2 miles east of the Polychrome rest area), where 24 of 79 wildlife "incidents" occurred in the simulation model. For example, even at the base condition, the high-crowding standard is violated nearly 3% of the time for number of buses at wildlife stops.

Buses spent more time for grizzly bear encounters than for other species of large mammals, and buses that stopped at a wildlife sighting after the first bus had arrived spent more time at that location.

In Focus: Denali Park Road

cross over a division between one hour and the next were divided between the hours. The model predicted that crossing opportunities would diminish specifically during morning hours, particularly at mile 37.6, the second crossing location encountered on the road. A similar circumstance occurs between noon and 2 p.m. for the farthest sheep crossing location. All sheep crossing locations lose crossing opportunities during various periods of the day for the 40%, 50%, and 60% increase cases—all greater than the daily GMP limits (fig. 7, page 56).

The temporal variations between the Dall's sheep crossing standard (fig. 7) and wildlife crowding standards (fig. 6) are similar, particularly between the first 30 miles of road and the first sheep crossing location, and between mile 54 (Toklat) and mile 66 (Eielson) and the last sheep crossing location (this can be visualized by turning the corresponding graphs in fig. 6 or 7 upside down). Intuitively, such a correlation between the two standards might be expected since both an increase in wildlife stop crowding and a reduction of the gap times between vehicles at the crossing locations result when the volume of traffic passing through these areas of the park road increases. Park management may wish to explore this relationship further since the implication is that if large variations in wildlife crowding standard violations can be reduced (e.g., "smoothing out" the peaks shown in fig. 6, next page), a more even distribution of sheep crossing opportunities in these two areas of the park road would also ensue during the period of the day when buses are operating.

Management application

We evaluated sensitivity of crowding indicators on the Denali Park Road by comparing the violation rates of three standards when traffic levels were increased incrementally starting from a low-use level in seven scheduling scenarios within a traffic simulation model. The resulting sensitivities for the three set standards for the four different Denali Park Road crowding indicators are nonlinear and differ significantly from each other. The violation rates of set standards varied significantly in time and space—especially for the high and medium standards. For example, the violation rate for the middle standard for wildlife stops was much more sensitive to increased traffic levels than the low and high standards. This is exemplified within a 24-mile (39 km) road section between Teklanika and Toklat. Therefore, the model results suggest that adherence to the more restrictive visitor experience standards may be difficult to maintain on the park road if more access were to be provided.

This study was a first step in evaluating traffic scenarios on the Denali Park Road. Managers are using the results to assist in creation of a range of alternatives for transportation systems on the road. An example being considered by park managers is a "loop" shuttle system that would allow visitors to leapfrog to destinations farther along the park road, instead of using a single route to similar destinations, as done in the current system. Yet another alternative would be to consolidate the different operators into a single, unified shuttle service, providing more route options to intermediate locations on the park road, such as Teklanika. Offering "express service," that is, not stopping for wildlife, is also being considered to provide visitors a more efficient means to reach destinations on the park road.

Denali park managers ultimately wish to provide consistent crossing opportunities to sheep populations during the period when vehicles are traveling the park road.

The simulation model will be used to explore the ability of the proposed alternatives to provide more opportunities for access to the road without compromising the visitor experience or behavior of Dall's sheep. We will alter the travel behavior of buses and other vehicles within the model to consider potential alternatives to assess the ability of new systems to meet crowding and wildlife protection standards. One example of such an alteration is to control the turnaround rest stop dwell times of the buses as a schedule adherence strategy for loop service. We will also explore effects of changing the route departure times for a desired level of service in order to reduce the violations of set standards for the current system as well as for the alternative transportation systems provided by the park. By examining temporal and spatial crowding trends, park managers will be able to forecast when and where the largest crowding impacts will occur and experimentally manipulate schedules within the model to mitigate the simulated impacts.

Additional data obtained from actual and simulated travel and stop behaviors of vehicles could provide valuable information for proactive management of park road access. For example, we could determine which vehicle behaviors may affect crowding and wildlife standards most often and recommend changes in operator behavior to address the problems. We will be building visualization tools to summarize this complex and multidimensional system to provide park managers with an enhanced ability

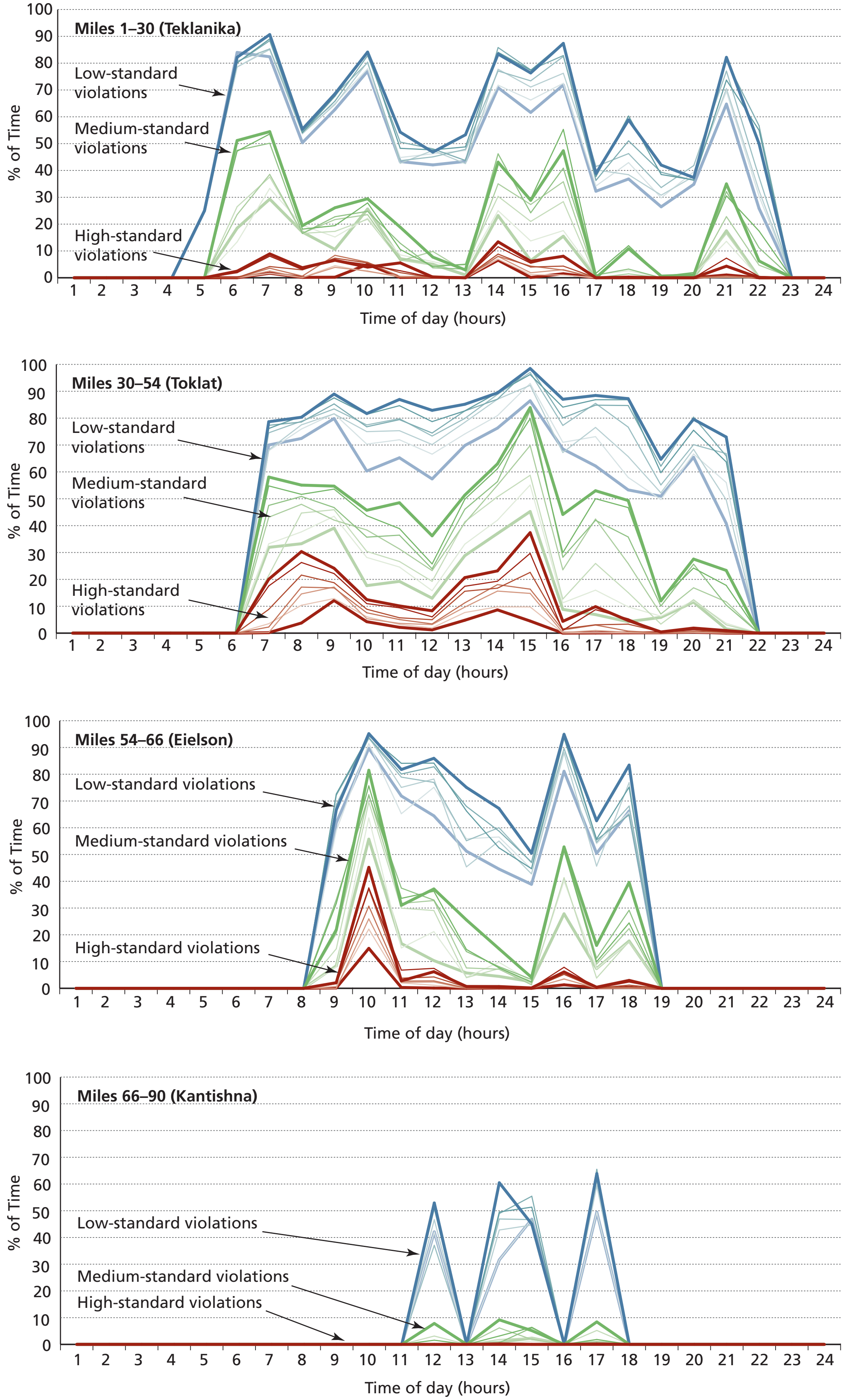


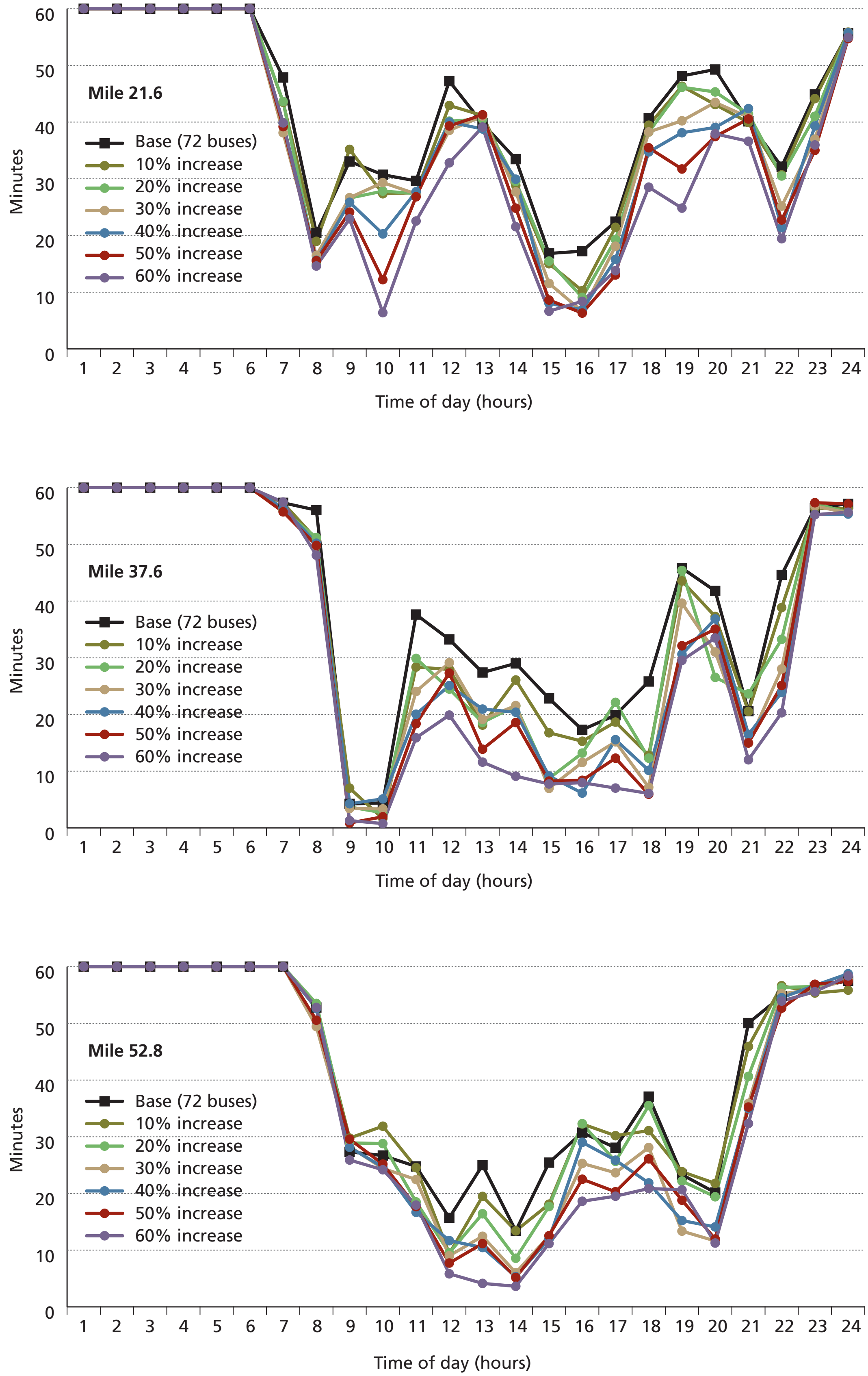
Figure 6. Temporal and spatial variation of crowding at wildlife stops along the park road: A crowding "shockwave" is observable by following the violation peaks in time starting from the beginning of the road in the morning hours (top graph), proceeding farther into the park, as more vehicles enter the park road. The family of curves in each of the three graphs represents the complete range of modeled traffic conditions.

Crowding standards violations
- Low-crowding standard
- Medium-crowding standard
- High-crowding standard

0%
10%
20%
30%
40%
50%
60%

In Focus: Denali Park Road

Figure 7. Road crossing opportunities for Dall's sheep: We estimated road crossing opportunities at different traffic levels by calculating the sum of >10-minute traffic gaps per hour at three historical migration corridors: (a) mile 21.6, (b) mile 37.6, and (c) mile 52.8. The 60% increase scenario showed a marked decrease in >10-minute gaps (hence sheep crossing opportunities) particularly in the afternoon and early evening hours at mile 37.6.



to make inferences about the causes and effects of modeled changes to indicators of visitor experience and wildlife resources on the park road.

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References

Barcelo J., E. Codina, J. Casas, J. L. Ferrer, and D. Garcia. 2005. Microscopic traffic simulation: A tool for the design, analysis, and evaluation of intelligent transport systems. Journal of Intelligent and Robotic Systems 41:173–203.

Cole, D. N. 2005. Computer simulation modeling of recreation use: Current status, case studies, and future directions. Technical Report RMRS-GTR-143. USDA Forest Service, Fort Collins, Colorado, USA.

Dalle-Molle, J., and J. Van Horn. 1991. Observations of vehicle traffic interfering with migration of Dall's sheep (*Ovis dalli dalli*), in Denali National Park, Alaska. Canadian Field Naturalist 105:409–411.

Gimblett, R., T. D. S. Cherry, and M. J. Meitner. 2001. The simulation and visualization of complex human-environment interactions. Landscape and Urban Planning 54:63–78.

Gipps, P. G. 1981. A behavioural car-following model for computer simulation. Transportation Research Part B: Methodological 15:2:105–111.

Itami, R. M. 2005. Port Campbell National Park, Australia: Predicting the effects of changes in park infrastructure and increasing use. Pages 57–59 *in* D. Cole, compiler. Computer simulation modeling of recreation use: Current status, case studies, and future directions. General Technical Report RMRS-GTR-143. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Langevelde, F., and C. F. van Jaarsma. 2004. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology 19:895–907.

Lawson, S. R., R. E. Manning, W. A. Valliere, and B. Wang. 2003. Proactive monitoring and adaptive management of social carrying capacity in Arches National Park: An application of computer simulation modeling. Journal of Environmental Management 68:305–313.

Morris, S., R. Gimblett, and K. Barnard. 2005. Probabilistic travel modeling using GPS. Pages 149–155 *in* A. Zerger and R. M. Argent, editors. MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, University of Arizona, Tucson, USA.

National Park Service (NPS). 1986. The Denali National Park and Preserve general management plan, land protection plan, wilderness suitability plan. D-96A. National Park Service, Denali National Park and Preserve, Denver, Colorado, USA.

Putera, J. A., and J. A. Keay. 1998. Effect of vehicle traffic on Dall sheep migration in Denali National Park, Alaska. Final report. U.S. Geological Survey, Biological Resources Division, Denali National Park, Alaska, USA.

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Science Feature

A 16th-century Spanish inscription in Grand Canyon?

A hypothesis

By Ray Kenny

Spanish conquistador

DRAWING BY FREDERIC REMINGTON; PHOTO COPYRIGHT CORBIS

THE AMAZING JOURNEY OF Francisco Vásquez de Coronado is well-known to historians as well as aficionados of the human history at Grand Canyon National Park, Arizona. A handful of Spaniards sent by Coronado from New Mexico first visited the Grand Canyon in September 1540. The story of the first visitation is told in many books and is based upon interpretations from George Parker Winship's 1892 translation of the accounts of Coronado's journey written by members of the expedition (De Coronado 1892). As told by Winship in an introduction to the account of Coronado's journey:

> It was perhaps on July 4th, 1540 that Coronado drew up his force in front of the first of the "Seven Cities," and after a sharp fight forced his way into the stronghold, the stone and adobe-built pueblo of Hawikuh, whose ruins can still be traced on a low hillock a few miles southwest of the village now occupied by the New Mexican Zuñi Indians. Here the Europeans camped for several weeks. . . . A small party was sent off toward the northwest, where another group of seven villages was found. . . . As a result of information found here [at the villages], another party journeyed *westward* until its progress was stopped by the Grand Cañon of the Colorado, then seen for the first time by Europeans.

Coronado had dispatched Don Pedro de Tovar to one of the seven villages with 17 horsemen and 3 or 4 foot soldiers. At the village, Tovar obtained information about a large river to the west. Tovar was not commissioned to go farther than the village and returned to Coronado with the information he had secured from the Native Americans. Upon learning about the news of a large river in the arid lands, Coronado dispatched Don Garcia Lopez de Cárdenas with 12 companions to go see this river. Cárdenas and his party returned to the Native American village loaded with provisions because they had to travel through a desert before reaching their destination, which the Native Americans said

> was more than twenty days' journey. After they had gone twenty days they came to the banks of the river. It seemed to be more than 3 or 4 leagues [a unit of distance equal to about 3 miles] in an air line across to the other bank of the stream which flowed between them.

The exact location where Cárdenas and his party first saw Grand Canyon, in the words of J. Donald Hughes (1978), "is not known." The location where Cárdenas and his men first laid eyes upon Grand Canyon was described in the account of Coronado's journey as

> elevated and full of low twisted pines, very cold, and lying open toward the north, so that, this being the warm season, no one could live there on account of the cold.

Most historians, based on this meager and ambiguous description, have surmised that Cárdenas arrived at the South Rim of Grand Canyon in the area between Moran Point and Desert View (e.g., Bartlett 1940) (fig. 1). Historians have reasoned that this area best fits the vague description and the area would have been along an old Native American trail. However, many areas along the south canyon rim have "low twisted pines" and have vistas that "open toward the north." Additionally, almost any route you take approaching the main canyon rim from the south results in traveling *up* in elevation. Furthermore, old Native American trails also led to *many* other locations along the entire length of the South Rim, including the western sections of the south canyon rim. In reality, the accounts of the exploration are too general with respect to distance, directions, and natural features to pinpoint what parts of the south canyon rim Cárdenas's men visited and explored. What we do know is that Cárdenas's men

> spent three days on this bank looking for a passage down to the river. It was impossible to descend, for after the three days Captain Melgosa and one Juan Galeras and another companion, made an attempt to go down at the least difficult place, and went down until those that were above were unable to keep sight of them. They returned . . . in the [late] afternoon, not having succeeded in reaching the bottom on account of the great difficulties which they found, because what seemed easy from above was not so, but instead very hard and difficult. They said they had been down about a third of the way and that the river seemed very large from the place which they reached.

Upon their return to the south canyon rim, the Native American guides convinced the party to travel no farther because of lack of water, and they returned to Coronado's camp.

Historical interpretation and reevaluation

So where was this enigmatic location where the Spaniards sought to find passage to the river? Where along the South Rim did the early Spanish explorers descend "about a third of the way" down off the rim? Without additional evidence beyond the vague description from the account of Coronado's journey, it may be a question without an answer. But is it possible that the Spanish explorers left a clue to mark their visitation site?

Examples of the Spaniards' presence in the New World in the form of inscriptions,

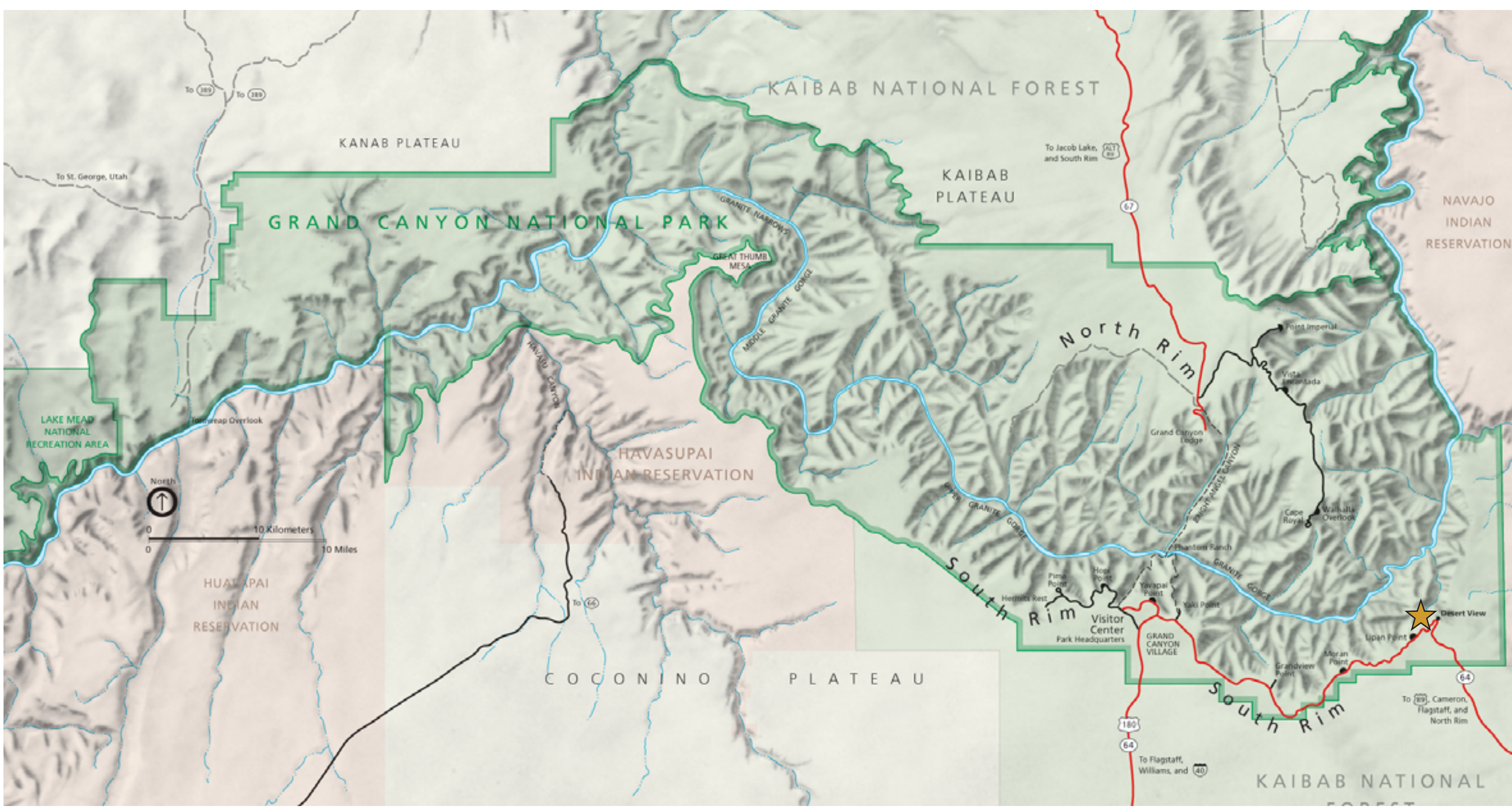

Figure 1. Grand Canyon National Park and surroundings. The gold star marks the historically accepted location where Spaniards first viewed Grand Canyon.

religious artifacts, and related influences can be found throughout the text describing the journey of Coronado, and as relics throughout southwestern North America. However, the small party that was sent to see the river traveled long distances, for 20 days, and was led over vast arid areas without much water. In reality, they may have been limited in their ability to adequately mark their passage. If indeed the Spaniards left some evidence of their passing, the inadequate and "open-ended" description of their journey (which could describe just about any place along the south canyon rim) would make searching for any evidence of their passing extremely difficult—indeed, it would be like looking for the proverbial needle in a haystack!

Although historians have suggested that the Spaniards first viewed the canyon near Desert View (based in part on known Native American travel routes), it seems equally reasonable to suggest that the Native Americans would *not* lead the Spaniards to the area near Desert View because they had established travel routes that led directly into the canyon and over to holy salt deposits and the sacred Sipapu (near the confluence of the Little Colorado River). Certainly, the Native Americans could easily have led the Spaniards to the river via several routes. Instead, as others have suggested, they may have been trying to take the Spaniards on a longer, more arduous journey with the hopes of convincing the foreigners to leave the area entirely. Hence, it seems equally plausible that the Native Americans led the Spaniards along routes that might lead them *far away* from their *most* sacred areas. Additionally, early Native American trails led to the far western reaches of present-day Grand Canyon, some 50 or more miles (>80 km) west of Desert View (fig. 1). Some of these old Native American trails (west of the present-day South Rim Village) descend into the canyon, have vistas of the river, are characterized by "low, twisted pines" along the rim, and open to the north and northwest.

Figure 2. The inscription in the Esplanade Sandstone is about 50 miles (80 km) west of Desert View in Grand Canyon National Park, Arizona. Perceptible weathering, a diminutive lichen colony growing inside some of the engraved letters, the Spanish- or Portuguese-derivative words, and a comparison with 16th-century Spanish calligraphy suggest that the inscription may have been carved by early Spanish explorers from the Coronado expedition in the year 1540. The scale marker is 13 cm (approximately 5 in.) in length.

One old trail, in particular, readily allows travel below the canyon rim down to the top of the Esplanade Sandstone (which is about one-third of the way down from the rim to the river). However, travel from the Esplanade Sandstone down to the river is only accomplished via a much less distinct trail. In contrast, the trails that descend from the south canyon rim near Desert View do not have any obvious impassable areas about one-third of the way down from the rim that would have stopped the Spanish explorers from making the journey to the Colorado River.

The inscription

In the 1990s while working on permitted research related to the geology of the area, I found an inscription (fig. 2) that may provide a clue to the location where the Spanish explorers first tried to descend to the Colorado River. Is the old, weathered, and worn inscription an engraving from the first Spanish explorers?

The inscription is carved into the Esplanade Sandstone at an awe-inspiring canyon ledge with an unobstructed view of the river and the North Rim. While there is not much detailed information from the original account of the descent, one thing seems clear: the three men who made the descent off the rim were able to *see* the river from the point at which they stopped (about a third of the way down from the South Rim). At the inscription site, there is a clear and unobstructed view of the river.

The inscription is not far from an old Native American trail that could have been used to lead the Spaniards all the way down to the river. The route is relatively easy to follow from the south canyon rim to the top of the Esplanade Sandstone (Supai Group), but the route from the Esplanade down to the Colorado River is not readily obvious and could easily have been overlooked by the three explorers (Captain Melgosa, Juan Galeras, and another companion). Indeed, an alternative route, one that does not lead to the Colorado River but instead leads to an old Native American dwelling or hunting site (now a ruin near a hidden spring) would likely have been the most obvious route for the men to follow. If the explorers continued on a northward trend toward the river, following what might appear to be the most direct route, they would have arrived at the prominent cliff that now bears the simple inscription. The cliff and the inscription are less than a mile (<1.6 km) beyond the old occupation site near the narrowest part of the sandstone promontory. (Note: the exact location of the inscription has been purposely omitted from this article.)

Although the inscription is worn from centuries of exposure, two Spanish- or Portuguese-derivative words are still visible:

MONTE VIDEO.

The exact "old Spanish" meaning of the words is unclear and may be lost to time, but "monte" could be translated as "mount" (as in mountain); "video" may be loosely translated as "seer" or "sighted" or possibly even "view." The location of the inscription does have a spectacular view of the topographically higher North Rim (perhaps interpreted as a mountain?).

Calligraphic considerations

The letters of the inscription appear to be written in an artistic and elegant style, which suggests that the inscriber(s) took great care and pride in making the inscription, and the style of lettering appears to resemble the block letter calligraphy of 16th-century Spanish writings (Brown 1921). Figure 3 shows a comparison of the

Figure 3. The "stone-cut" inscription is juxtaposed with an example of lettering from a 16th-century Spanish manuscript. The sample letters come from the writings of Francisco Lucas, a Spanish lettering master who penned the renowned Spanish manuscript "Arte de Escrevir" (around 1577). The block letter samples (lower left) are from Lucas's 16th-century Spanish roman lettering; the lowercase letter samples (lower right) are from Lucas's 16th-century Spanish round gothic style. The stone-cut inscription letters "N," "T," "E," "V," "I," and "D" all display slab-style serifs similar to the 16th-century Spanish roman lettering. Slab-style serifs refer to the small decorative strokes that cross the ends of letters, visually creating a "square" or "block-like" appearance. For example, this capital "T" does not have slab serifs, whereas this "T" does. The letter "m" in the stone-cut inscription seems similar to the lowercase letters of Lucas's 16th-century Spanish round gothic style, but was inscribed as a capital letter. The tops of the letters show a high degree of horizontal alignment, which may be a result of a guideline drawn (or etched) across the top prior to engraving. This was typically done during the early years of calligraphy to better align the letters.

"stone-cut" inscription in Grand Canyon with some of the writings of Francisco Lucas (a Spanish lettering master who penned the renowned Spanish manuscript "Arte de Escrevir" around 1577). One must take note that the 16th-century writing of Francisco Lucas was *not* incised in stone; in comparing the lettering of the stone-cut engraving to the writing of Lucas, allowances should be made for the different materials in which the letters were originally executed. Nevertheless, there are numerous similarities between the stone-cut inscription and the 16th-century Spanish calligraphy (fig. 3). In particular, consider the following style comparisons.

The letter "M" in the Grand Canyon inscription consists of a series of vertical strokes that converge at a horizontal guideline at the top of the letter. This style is similar to the 16th-century Spanish round Gothic letters, although the style of the stone-cut "M" more closely resembles a lowercase lettering style (fig. 3).

The letters "N," "T," "E," "V," "I," and "D" all display slab-style serifs and resemble 16th-century Spanish roman lettering (slab-style serifs refer to the small decorative strokes that cross the ends of letters, visually creating a "square" or "block-like" appearance; fig. 3). At the very least, engraving serifs takes patience, time, and attention to detail.

The letter "O" does appear to be slightly smaller than the other characters, which was also typical for this time period.

The tops of the letters (especially in the word "MONTE") show a high degree of horizontal alignment, which may be the result of a guideline drawn (or etched) across the top prior to engraving. This was typically done during the early years of calligraphy to better align the letters before engraving.

The Esplanade Sandstone near the inscription site is also soft enough to permit engraving with the steel weapons the Spaniards likely would have carried with them. Also, the explorers probably would have had the time to carve the inscription and return to the rim by late afternoon. I tested the "temporal" part of this theory and easily traveled (in late August and early September) from the rim to the inscription site and back up to the rim in a few hours.

This enigmatic inscription suggests that the intrepid Spaniard may have traveled to this point more than 470 years ago.

Inscription age

Does the inscription truly date from the 16th century? Again, this may be a question without an answer. Certainly, the ability to obtain weathering rates on exposed rock would be very useful for determining the age of the inscription. Unfortunately, obtaining accurate weathering rates for such a short span of geologic time is difficult at best. Successful research endeavors have mostly used independent proxy data to verify weathering rate estimates. For example, in the 1970s Peter Birkeland estimated the age of glacial deposits using lichen (*Rhizocarpon geographicum*) growth rates. However, the growth rate of lichens varies as a function of climate and microclimate, and studies that assume constant growth rates without correlating them with known weathering rates in the same geographic location are probably unreliable. Lichen cover at the inscription is minimal, which is consistent with an arid climate, making it hard to measure. Significantly, the error range associated with this dating method is greater than the maximum potential age estimate of the inscription.

More recently, cosmogenic (i.e., atmospheric exposure) age dating has been developed and successfully applied to geomorphically young surfaces. This technique relies on the measurement of cosmogenic nuclides (e.g., ^{36}Cl, ^{3}He, ^{10}Be) that build up in rock as soon as it is exposed at the surface. However, sandstone is not ideal for obtaining meaningful exposure dates, and the methodology is primarily used for material that has been exposed for a much longer time. Other quantitative measurement techniques, such as in situ weathering rinds and optically stimulated luminescence dating also require much longer exposure. As such, no attempt has been made to quantify the age of the inscription in Grand Canyon because established methodology is not applicable.

I have previously worked on research related to the biogeophysical and biogeochemical weathering of old inscriptions carved into sandstone (Kenny and Lancour 2001). I undertook the work on more than 200 inscriptions dating back to 1806 at Autograph Rock in Oklahoma in an effort to quantitatively determine the primary contributing factor leading to their weathering and degradation (Kenny 2000). (The site is part of the Santa Fe National Historic Trail and, like the letters at Grand Canyon, these are carved in sandstone.) The primary agent destroying the historical inscriptions was lichen. The microclimatic zones along the 30-foot-high (10 m) outcrop at Autograph Rock were variable, resulting in some inscriptions—those with more lichen cover—showing greater weathering, and others of comparable age—though with less lichen cover—appearing fresh and surprisingly unaltered.

Admittedly the climate in Oklahoma is different from that of northern Arizona, but the percentage of lichen cover may still be the primary factor leading to enhanced disintegration of sandstone. Lichen is a symbiotic relationship between fungi and algae, and the fungal component of lichen bears root-like rhizines, the hypha that anchor fungi to the surface and subsurface. The rhizines penetrate into sandstone interstices (tiny openings between the sand grains and the cement holding them together) and gradually pry apart (i.e., physically weather) the rock substrate. Disintegration of the substrate is also accomplished chemically by an increase in (phenolic) acidity in the microenvironment generated by the lichen. The rate at which physical and chemical disintegration can proceed depends in large part on the sustained availability of water or moisture: the more arid the climate (or microclimate), the slower the disintegration or weathering rate.

The inscription at Grand Canyon (1) is fully exposed to the elements—that is, no vegetation or rock outcrop provides any shade or microclimate; (2) is in a semiarid to arid climate; and (3) has only minor lichen growth in only a few of the inscription depressions. In spite of the area's natural aridity and the inscription's minimal to nonexistent lichen cover, the inscription does exhibit some degree of enhanced weathering (e.g., the "DEO" in "VIDEO"). While the climate has likely varied over the last few centuries, with both drier and wetter intervals (Cook et al. 2004), environmental conditions at the inscription location are conducive to a relatively slow disintegration or weathering rate. This might result in a sandstone inscription that is legible, even after several hundred years.

Other historical figures

Historians have established that the Spanish priest Francisco Tomas Hermenegildo Garces roamed extensively in Arizona in the years 1768–1781 (Coues 1900). In 1776, he traveled along what is now referred to as the Hualapai Trail and visited the Village of Supai in what is today western Grand Canyon. Father Garces commented and reflected on countless observations in his extensive diary, including the natural "barrier which nature had fixed," but *no* mention is made of an entrada into Grand Canyon aside from the one into the Village of Supai. Though it is possible that Father Garces did venture into the Grand Canyon at other locations, it becomes problematic to suggest that he made the inscription without so much as one historical reference to support this supposition.

It is also possible that the inscription was carved during the 1800s by an unknown traveler or travelers who descended from the South Rim into the canyon proper—perhaps led by one of the early Grand Canyon pioneers or guides. If this were the case, the architect of the inscription may be lost to history. But it begs the question, why would such a traveler inscribe a Spanish- or Portuguese-derivative phrase? Furthermore, I find it especially curious that of all the known inscriptions in Grand Canyon, this is the *only* Spanish- or Portuguese-derivative inscription yet to be found.

Summation

The "MONTE VIDEO" inscription in the Esplanade Sandstone in Grand Canyon is clearly worn from centuries of subaerial exposure to an arid to semiarid climate. The elegant and meticulous lettering arguably resembles the surviving examples of 16th-century Spanish calligraphy. The remote location of the inscription is near one of several old routes that could have been used by the Native American guides to escort the Spaniards to Grand Canyon and down toward the Colorado River. The scant description of the site where the Spanish first saw Grand Canyon could be applied equally to any number of South Rim locations and is not unique to the Desert View area, which some historians have suggested was the most likely descent location. The argument and preliminary evidence presented here suggest that the area near Desert View may *not* have been where the Spaniards first laid eyes upon Grand Canyon. Rather, the Native Americans may have led the Spaniards to a south canyon rim area far from the Desert View area trails that led into the canyon and down to their most sacred sites.

So is this weather-worn and elegant inscription carved in sandstone an engraving from Captain Melgosa, Juan Galeras, or the unknown companion? Did the three ancient Spaniards leave a clue to their labors, stand at this daunting point, and gaze out into the abyss for the last time before leaving the canyon forever? We may never know for sure, but this enigmatic inscription suggests that the intrepid Spaniards may have traveled to this point more than 470 years ago.

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References

Anderson, M. F. 1998. Living at the edge: Explorers, exploiters, and settlers of the Grand Canyon Region. Grand Canyon Association, Grand Canyon, Arizona, USA.

Babbitt, B. 1978. Grand Canyon: An anthology. Northland Press, Flagstaff, Arizona, USA.

Bartlett, K. 1940. How Don Pedro de Tovar discovered the Hopi and Don Garcia Lopez de Cárdenas saw the Grand Canyon, with notes upon their probable route. Plateau (12):37–45.

Brown, F. C. 1921. The Project Gutenberg e-book of letters and lettering: A treatise with 200 examples. Bates and Guild, Boston, Massachusetts, USA. http://www.gutenberg.org/files/20590/20590-h/20590-h.htm.

Cook, E. R., C. A. Woodhouse, C. M. Eakin, D. M. Meko, and D. W. Stahle. 2004. Long-term aridity changes in the western United States. Science 306(5698):1015–1018.

Coues, E. 1900. On the trail of a Spanish pioneer: The diary and itinerary of Francisco Garces. Francis P. Harper, New York, New York, USA.

De Coronado, F. 1892. The journey of Coronado, 1540–1542, from the city of Mexico to the Grand Cañon of the Colorado and the Buffalo Plains of Texas, Kansas, and Nebraska. Translated by G. P. Winship. Reprinted 2007 by Kessinger, Whitefish, Montana, USA.

Hughes, J. D. 1978. In the house of stone and light. Grand Canyon Natural History Association, Grand Canyon, Arizona, USA.

Kenny, R. 2000. The geology of Autograph Rock. Unpublished Resource Management Report. National Park Service, Grand Canyon National Park, Arizona, USA.

Kenny, R., and H. Lancour. 2001. Petrography and permeability of the Mesa Rica Sandstone at Autograph Rock, Oklahoma. Abstract. Geological Society of America, 53rd Rocky Mountain Section Meeting, 29 April–2 May 2001, Albuquerque, New Mexico, USA.

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Research Reports

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Will whitebark pine not fade away?

Insight from Crater Lake National Park (2003–2009)

Figure 1. A grove of whitebark pine trees is being decimated by blister rust and mountain pine beetles at the North Junction area of Crater Lake National Park, Oregon, 2007.

By Michael Murray

REGARDED AS A HARDY STALWART OF HIGH-ELEVATION forests on the Pacific Coast and in Rocky Mountain ranges, whitebark pine (*Pinus albicaulis*) is a prominent feature in 10 western national parks (fig. 1). The picturesque, weather-beaten form of timberline veterans is captured on the pages of calendars, postcards, guides, and photo albums of visitors who come to national parks and forests to enjoy the breathtaking mountain scenery. Many sites where whitebark pine resides are too climatically harsh for other tree species. Thus, whitebark pine forests thrive where otherwise only meadow, talus, or other sparse natural communities would. Showy wildflowers such as heart-leafed arnica (*Arnica cordifolia*) and verdant tufts of smooth woodrush (*Luzula hitchcockii*) prefer the filtered sunlight afforded by groves of whitebark pine. This pine species also stabilizes soil on steep slopes and shades patches of snow, providing continuous flow of meltwater well into summer. As the producer of the largest tree seeds in the subalpine zone, whitebark pine supports more than two dozen species of foraging mammals and birds, including grizzly bear (*Ursus arctos horribilis*) and Clark's nutcracker (*Nucifraga columbiana*). The value of whitebark pine to wildlife simply cannot be overstated.

Unfortunately, populations of whitebark pine are increasingly threatened and their numbers are dwindling. The nonnative blister rust disease (caused by the fungus *Cronartium ribicola*) has crept across its natural range since it was first introduced in western North America in 1910. Natural resistance to blister rust among whitebark pine may be lower than 1% (Hoff et al. 1994). Ongoing epidemics of the native mountain pine beetle (*Dendroctonus ponderosae*) appear unprecedented in extent (Sharik et al. 2010) in addition to common stress from fire, dwarf mistletoe (*Arceuthobium* spp.), and ips beetles (*Ips* spp).

Abstract

Populations of whitebark pine (*Pinus albicaulis*) are under threat from nonnative blister rust disease (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*), and climatic change throughout most of its range. Whitebark pine provides habitat for dozens of high-mountain plant and animal species and is a uniquely picturesque tree for thousands of visitors in the Pacific Northwest and Rocky Mountains every year. Crater Lake National Park, Oregon, supports the most extensive lakeside population of this species known. Findings acquired through annual monitoring indicate that healthy whitebark pine trees are declining by about 1% annually since 2003. Combined with a nearly one-third reduction in whitebark pine since the estimated spread of blister rust to Crater Lake in the 1930s, a continued downward trajectory indicates a significant loss of the species. Measures to protect and restore whitebark pine can include developing blister rust resistance, outplanting disease-resistant seedlings, and applying beetle deterrents.

Key words: blister rust, climate change, Crater Lake National Park, forest health, monitoring, mountain pine beetle, whitebark pine

Crater Lake National Park, Oregon, is home to the most extensive lakeside population of whitebark pine known. Some of the oldest trees in the park garnish the margins of the 33-mile-long (53 km) Rim Drive and Rim Village, enjoyed by nearly 500,000 visitors every year. By the late 1990s an accumulation of dead trees, such as those on the summit of Wizard Island in the middle of Crater Lake, had piqued the curiosity of park staff, visitors, and media. A subsequent survey revealed that most whitebark pine stands were infected with blister rust (Murray and Rasmussen 2003). In 2003, I initiated a long-term monitoring program to track mortality in whitebark pine at Crater Lake National Park. This is among the first established monitoring programs aimed specifically at whitebark pine in the National Park System.

Study methods

I monitored trees associated with a set of seven permanent sampling plots. At the time of installation (2003), the plots supported a total of 474 whitebark pine trees. I predetermined the general vicinity of each plot to represent the whitebark pine communities present in the park. I decided on the location of each plot based on field reconnaissance, and then chose each plot's center location based on its appearance as typical for the vicinity and community type. In relation to other tree species, whitebark pine comprised at least 75% of the plots by cover, number, and volume. Plots were circular, encompassing 300 square meters (0.7 ac). I geo-referenced each plot with a GPS (global positioning system).

Within each plot we mapped all trees regardless of species for ease of relocation in subsequent years. Aluminum identification tags were affixed to trees to provide additional reference. For all live and dead standing trees I recorded a unique alphanumeric identifier, species, diameter at breast height (in 2003 and 2007), and overall status (healthy, sick, dead). I also noted instances of physical damage that resulted in dead foliage.

Trees classified as sick were affected by disease, insects, or physical impacts. Trees that had died since the previous year's survey were labelled recently dead. For each sick tree, I documented the cause and magnitude of the affliction. Where white pine blister rust was found, I recorded the status (active or inactive) and location (distance from ground and main stem) of each canker, plus the percentage of crown killed. I noted blister rust cankers as active when one or more symptoms were present, such as resinous, fungal fruiting structures, and yellow- to orange-colored bark. Trees with inactive blister rust cankers were classified as healthy. Cankers were noted as occurring on either branches or stems. Using binoculars, I examined every tree for cones. Lack of staffing precluded monitoring in 2008.

Findings

Overall, we see evidence of a gradual decline (8%) in the number of healthy whitebark pine trees taller than 1.37 m (4.5 ft) (fig. 2). Despite witnessing a slight increase in 2005, I documented progressively lower numbers of healthy trees all other years. By 2009, sick and dead trees increased 3.7% and 4.5%, respectively.

Sixteen trees perished during the five-year study, equating to 5.4% of all trees (fig. 3, next page). The most common malady was mountain pine beetle, which affected most trees that died. This was indicative of a park-wide outbreak. Dwarf mistletoe (*A. cya-*

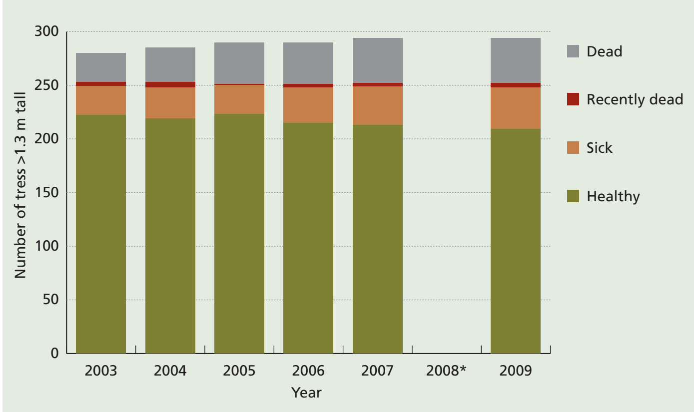

Figure 2. Healthy whitebark pine trees have declined 8% overall since 2003. *No sampling was conducted in 2008.

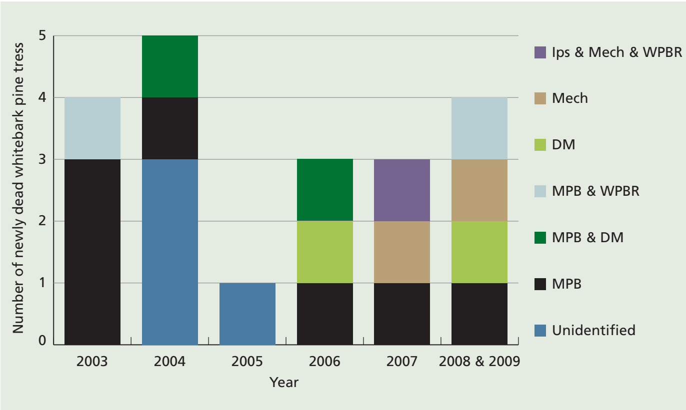

Figure 3. Mountain pine beetle (MPB) is the leading cause of tree mortality. Other causes of death: Ips (ips beetle), Mech (mechanical), WPBR (white pine blister rust), and DM (dwarf mistletoe).

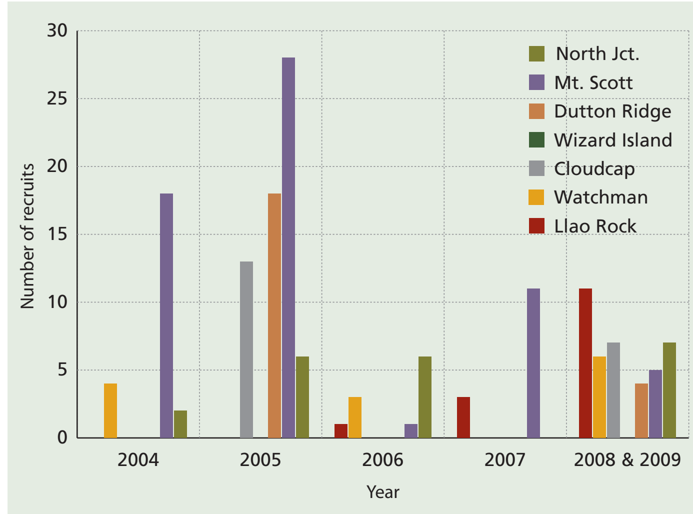

Figure 4. Nearly half of all recruited trees were observed in 2005.

nocarpum) was restricted to Wizard Island where nearly all trees had multiple infections, resulting in a severely impacted stand. Blister rust was associated with only three tree deaths observed.

I recorded 130 new recruits from 2004 to 2009. Recruits were not tallied in 2003 because this was the initial survey year. Thus, we could not determine which seedlings were new and which preceded 2003 (without destructive sampling). Curiously, half of all regeneration occurred in 2005, which preceded the best cone crops of the study (2005 and 2006). All plots exhibited regeneration except on Wizard Island (fig. 4). Mount Scott was the only location that generated recruits every year.

Discussion

These findings indicate that healthy whitebark pine trees above breast height have declined overall about 1% every year since 2003. Combined with a nearly one-third reduction in whitebark pine since the estimated arrival of blister rust in the park in the 1930s (Murray and Rasmussen 2003), a continued downward trajectory indicates a significant loss in park whitebark pine.

Prior to 2003, blister rust was believed to be the leading cause of death in the park. However, this study reveals that mountain pine beetle is now the leading mortality agent. This native insect has been a subtle yet persistent force of change during the past seven years—which would not have been well understood without this monitoring effort. Crater Lake's infestation resembles mortality at Yellowstone National Park (Wyoming, Montana, and Idaho), which has seen about 10% of trees succumb to the current beetle outbreak (D. Reinhart, personal communication). Yellowstone lags in rust-caused death, but this also appears to be rising. Although Glacier National Park, Montana, was affected by mountain pine beetle in the 1930s and again in the 1970s and 1980s, research in 2001 determined blister rust to be the leading cause of death for whitebark pine, with 44% mortality, 78% of trees infected, and 26% crown loss (Kendall and Keane 2001). Glacier had largely escaped infestation by mountain pine beetle over the last couple of decades, but this is changing. Dawn LaFleur, integrated pest management biologist at Glacier National Park, estimates that of the 4,450 acres (1,802 ha) of beetle-killed pine total in the park (USDA Forest Service unpublished flight data 2008–2009), 3 acres (1.2 ha) consists of whitebark pine. Logan and others (2010) suggest the current eruption of beetles throughout most of whitebark pine's range is a result of global warming.

Mountain pine beetle is now the leading mortality agent.

In the face of these challenges, maintaining whitebark pine will require our fervent attention well into the future. As noted earlier, a small percentage of trees may be naturally resistant to blister rust. By collecting (fig. 5) and propagating their seeds and outplanting the resulting seedlings, we can enhance the numbers of young pine that will survive the deadly disease. A beetle pheromone is also showing success in thwarting attacks by mountain pine beetle. Resource managers at Crater Lake National Park have stapled small packets of this synthetic deterrent, known as verbenone on the stems of culturally significant and potentially disease-

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Figure 5. The author collects cones at Rim Village to propagate and test this parent tree for disease resistance.

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Figure 6. Blister rust fruiting bodies threaten the tree (left), and a packet of verbenone (right) is used to repel mountain pine beetles.

resistant trees (fig. 6). Careful introduction of fire can also benefit whitebark pine by reducing competing tree species and opening up sites for enhanced regeneration. Guidance and awareness are increasing (Aubry et al. 2008; Schoettle and Sniezko 2007) with several additional national parks already implementing these measures. Collaborators with the National Park Service include the forest services of the United States and British Columbia, the U.S. Geological Survey, Parks Canada, universities, and the Whitebark Pine Ecosystem Foundation (www.whitebarkfound.org). Research and monitoring will continue to play critical roles in steering management and gauging success.

References

Aubry, C., D. Goheen, R. Shoal, T. Ohlson, T. Lorenz, A. Bower, C. Mehmel, and R. A. Sniezko. 2008. Whitebark pine restoration strategy for the Pacific Northwest 2009–2013. Region 6 report. USDA Forest Service, Pacific Northwest Region, Portland, Oregon, USA. Available online: http://www.fs.fed.us/r6/genetics/publications/detail/pub802.

Hoff, R. J., S. K. Hagle, and R. G. Krebill. 1994. Genetic consequences and research challenges of blister rust in whitebark pine forests. Pages 118–126 *in* W. C. Schmidt and F. Holtmeier, compilers. Proceedings—International workshop on subalpine stone pines and their environment: The status of our knowledge. General Technical Report INT-GTR-309. USDA Forest Service, Intermountain Research Station, Ogden, Utah.

Kendall, K. C., and R. Keane. 2001. Whitebark pine decline: Infection, mortality, and population trend. Pages 221–242 *in* D. F. Tomback, S. F. Arno, and R. E. Keane, editors. Whitebark pine communities: Ecology and restoration. Island Press, Washington, D.C.

Logan, J. A., W. M. Macfarlane, and L. Willcox. 2010. Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem. Ecological Applications 20:895–902.

Murray, M. P., and M. C. Rasmussen. 2003. Non-native blister rust disease on whitebark pine at Crater Lake National Park. Northwest Science 77:87–91. Available online: http://www.vetmed.wsu.edu/org_nws/NWSci%20journal%20articles/2003%20files/2003%20Vol%2077.htm.

Schoettle, A. W., and R. A. Sniezko. 2007. Proactive intervention to sustain high-elevation pine ecosystems threatened by white pine blister rust. Journal of Forest Research 12:327–336.

Sharik, T. L., W. Adair, F. A. Baker, M. Battaglia, E. J. Comfort, A. W. D'Amato, C. Delong, R. J. DeRose, M. J. Ducey, M. Harmon, L. Levy, J. A. Logan, J. O'Brien, B. J. Palik, S. D. Roberts, P. C. Rogers, D. J. Shinneman, T. Spies, S. L. Taylor, C. Woodall, and A. Youngblood. 2010. Emerging themes in the ecology and management of North American forests. Article ID 964360. International Journal of Forestry Research 2010. Available online: http://www.treesearch.fs.fed.us/pubs/34665.

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Whitebark pine restoration under way at Crater Lake

Preemptive strike against blister rust based on disease-resistant seedlings

By Laura E. Hudson and Elena Karnaugh Thomas

RESOURCE MANAGERS AT CRATER LAKE National Park in Oregon are fighting the die-off of whitebark pine (*Pinus albicaulis*) from blister rust fungal infection (*Cronartium ribicola*) through a series of experimental restorations. The project is a major part of the Whitebark Pine Conservation Program at the park and relies on collecting cones from apparently disease-resistant whitebark pines to obtain seeds for use in propagation studies. Disease resistance is a qualitative measure based on amount of blister rust infection apparent on a tree historically and at the time of seed collection. Infections are generally in the form of dead branches with old canker swelling, active cankers, or flagging (dead needles on the end of a branch).

Seeds collected from these disease-resistant parent trees in 2005 and 2006 were processed and sown at the USDA Forest Service's Dorena Genetic Research Center, Oregon. A subgroup of these seedlings is involved in a five-year blister rust assay; they were inoculated with blister rust in a separate, specially designated greenhouse in fall 2008, and final assessment of resistance will be available in 2013. Two other subgroups of the seedlings were returned to Crater Lake for (1) the Rim Village restoration project of a former parking lot, and (2) the Horse Trail project, involving an experimental rust-resistant endophyte study. The latter is to look at long-term success of seedlings that were inoculated with a

This experimental inoculation is intended to determine whether endophytes also can increase disease resistance in whitebark pine seedlings.

potential blister rust–resistant endophyte, and compare them with a control group. (An endophyte is a fungus that lives inside a plant, in a parasitic or mutualistic relationship.)

Figure 1. Whitebark pine restoration at Crater Lake Rim Village involved bringing in boulders to the former parking area, drilling holes in the compacted soil, and scattering woody debris. These microhabitat manipulations help protect the seedlings from exposure to high winds and heavy snowpack.

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Prior to planting our first-ever disease-resistant whitebark pine seedlings from Dorena, we had to review the restoration history of the former parking lot at the Crater Lake Rim Village. The century-old parking area was removed and relocated in 2006 during a major rehabilitation of the historical cafeteria and gift shop area. In 2007, a contractor replanted the site with native grass and wildflower seeds, and many older hemlock tree transplants. Success with the transplanted trees was minimal. This provided us with an opportunity to test restoration methods for planting whitebark pine seedlings that naturally occur alongside hemlocks. The timing was significant since the rust infestation was increasing dramatically on trees near the former parking lot. However, to improve restoration success, we decided to create microsite enhancements for each cluster of two to four seedlings. The park road crew assisted us by bringing in large boulders to the former parking area in fall 2008 (fig. 1). The following summer, an equipment operator assisted us by drilling more than 150 holes into the heavily compacted soil using a backhoe and auger. We also brought in woody debris and needle/duff litter from nearby sites to further establish the microhabitat. In mid-September 2009, we planted 331 whitebark pine seedlings, representing 16 disease-resistant parent trees from Crater Lake, in the former parking lot. We watered these seedlings on a regular basis until the first snowfall in early October (fig. 2). In summer we plan to monitor these seedlings for survival, herbivory, and disease.

NPS/ELENA THOMAS

Figure 2 (above). Seasonal plant technician Janelle Cossey waters endophyte-inoculated and untreated (control) whitebark pine seedlings along the Horse Trail experimental restoration site.

NPS/ELENA THOMAS

Figure 3 (right). Professor George Newcombe and vegetation ecologist Laura Hudson inoculate whitebark pine seedlings with endophytic fungus at the Dorena Genetic Research Center.

The second planting (Horse Trail study area) involved the experimental endophytic-inoculation study comprising 200 seedlings from five disease-resistant parent trees. Studies have shown endophytic fungi (i.e., those living within a plant) increase resistance of western white pine (*Pinus monticola*) to white pine blister rust; this experimental inoculation is intended to determine whether endophytes also can increase disease resistance in whitebark pine seedlings. We obtained the endophytic fungus (*Myrothecium roridum*) for the study's inoculant from needles collected from 10 apparently disease-resistant whitebark pine trees around Rim Village in summer 2008. George Newcombe, professor of forest pathology and plant symbiosis at the University of Idaho, cultured the inoculant in his lab. For the experimental planting, we treated 100 seedlings with the endophytic fungal culture and, as a control, left 100 seedlings untreated. Treatment consisted of pulling the seedlings from their planting tubes. Half of these were then dipped briefly in the fungal solution and the other half (the control seedlings) in distilled water (fig. 3). All seedlings were returned to their original tubes. We planted the surviving 192 endophytic study seedlings south of Rim Village in a more natural environment and away from the public to minimize disturbance to these treated seedlings. After initial planting, we measured seedling height. We plan to evaluate the seedlings annually for survival, growth (height), endophyte communities, blister rust symptoms and other diseases, and herbivory. Professor Newcombe plans to return to the park this summer to confirm successful inoculation of the trees. This is done through a process of limited sampling and surface sterilization of treated trees to isolate the inoculant.

In addition to these two planting projects, we will continue to monitor the status of disease-resistant parent trees in the park as de facto permanent plots. This will allow us to determine and assess the older trees' resistance to blister rust in conjunction with monitoring the survivability of their progeny at the Rim Village and Horse Trail planting sites. Our first-year planting results should be available for reporting at the end of the 2010 growing season.

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Canadian national parks as islands: Investigating the role of landscape pattern and human population in species loss

By Yolanda F. Wiersma and Christa Simonson

Abstract

Recent analyses of mammal species loss in protected areas around the world suggest that habitat loss and human population density outside of park boundaries may be better predictors of species loss and biodiversity patterns than absolute area of parks themselves. In North American parks, there have been conflicting studies about the relative impact of habitat versus human population density on the loss of mammals. These differences may be due to scale effects, as past studies in Canadian national parks have not examined the effect of spatial scale on species loss since the time of widespread European settlement. Here, we build on previous work and look at the effects of habitat area and human population density in buffer regions that are 10, 25, 50, and 100 km (6.2, 15.5, 31.1, and 62.1 mi) outside of the boundaries of 24 national parks in Canada on the loss of disturbance-sensitive mammals. We also examine whether the relative importance of predictors is correlated with species body size. As in previous work, we find that the amount of effective habitat area is a more significant predictor than human population density and that scale effects are not significant, at least for the scales and species examined.

Key words: biogeography, extirpations, GIS, habitat, human populations, land cover, land use, mammals, minimum reserve area, protected areas, spatial scaling

THE CANADIAN NATIONAL PARKS SYSTEM HAS MANY similarities to its U.S. counterpart. The two systems' histories parallel each other closely; the first American national park was established at Yellowstone in 1872; Banff National Park (initially Rocky Mountain National Park) in the Alberta Rockies was established just 13 years later. The early parks on both sides of the border emphasized preservation of "sublime" landscapes, were biased to the western half of the continent, and put an emphasis on tourism and recreation values (Runte 1987; McNamee 2009). Before the advent of the automobile and mass tourism, Canadian and American parks were set up as recreation havens for the rich, with visitors often arriving by train and staying in luxury accommodations. This has led the early parks to be characterized as "islands of civilization in a sea of wilderness" (see description in McNamee 2009). Despite some of the conflicts inherent in the "doctrine of usefulness" that governed early park management in both countries, park managers quickly recognized the potential for national parks to conserve wilderness (Runte 1987; McNamee 2009). Both countries introduced legislation (the Dominion Forest Reserves and Parks Act in Canada in 1911 and the U.S. National Park Service [Organic] Act in 1916) that included language about the preservation of the parks as unimpaired for future generations. As western North America continued to develop, and human settlement and resource extraction increased, the importance of this legislation became more evident. Toward the second half of the 20th century the parks slowly shifted to become "islands of wilderness in a sea of civilization" (see summary in McNamee 2009).

This phenomenon is not unique to North America. A recent global survey of protected areas effectiveness (Gaston et al. 2008; Mcdonald et al. 2008) suggests that not all protected areas are adequately maintained and that there is a need to understand what factors contribute to successful and unsuccessful conservation. As well, Gaston et al. (2008) suggest that a key knowledge gap lies in the interactions of populations of species within and outside of protected areas boundaries. In short, we recognize that parks are becoming (or have already become) islands of wilderness, but it is not always clear what the effects of this pattern are. Where it has been shown that parks are not doing an adequate job of conserving species within their boundaries, there is uncertainty as to exactly what factors are responsible.

Recent studies from protected areas around the world have focused on these islands of wilderness and examined the effects of landscape pattern and composition on species persistence within and surrounding a protected area. There are two schools of thought on what is contributing to reduced park effectiveness worldwide: the first suggests that changes in landscape pattern or available habitat outside of park boundaries are the most important factor; the second suggests that human population density is the key factor. Arguments for the "habitat" hypothesis point out that habitat loss outside of boundaries creates habitat "islands," and island biogeography theory suggests that isolated habitats (even large ones) have a higher chance of species loss through local extirpations and a reduced chance of colonization of new species. In Canada, Wiersma et al. (2004) showed that habitat loss outside of parks was an important predictor of species loss within national parks. The "human population" hypothesis suggests that increased human population densities outside the boundaries of protected areas are responsible for negative ecological effects within park boundaries, for example by contributing directly to species losses within a park through hunting and poaching, or indirectly via habitat change, increased road density, or disruption by noise or pollution. Parks and Harcourt (2002) showed that human population density was a significant predictor of large-mammal extinction in 13 U.S. national parks. In reality, it is likely that both habitat insularization and human population density contribute to species losses, and that these factors are, in many cases, correlated. However, the magnitude of the effect of habitat insularization versus human population density may be different for different species types, and in different protected areas. Some of these potential differences are discussed in this article.

In Canada, Wiersma et al. (2004) evaluated the contribution of effective habitat area and human population density to mammalian species losses within 24 national parks and in a 50 km (31.1 mi) buffer zone outside of each park. Wiersma et al. (2004) initially chose a 50 km (31.1 mi) buffer zone because it matched a distance chosen in a similar study in the United States (Parks and Harcourt 2002), and represented a reasonable distance within which park managers could potentially collaboratively manage with adjacent landowners and land managers. Wiersma et al. (2004) found that for disturbance-sensitive mammals (those not normally associated with areas of high human density), species loss since the time of widespread European settlement was best predicted by a model that measured the effective habitat area of the park and within a 50 km (31.1 mi) buffer zone outside of the park boundary. Effective habitat area was measured by subtracting human-built infrastructure (with appropriate buffer widths to capture zones of impact) and non-habitat (high-elevation rock and ice, agricultural and urban land cover) from the total area of each park and the total area of a 50 km (31.1 mi) buffer zone around each park. The addition of data on human population density in the 50 km (31.1 mi) buffer zone did not add any significant explanatory power for predicting species losses (see table 2 in Wiersma et al. 2004). Thus Wiersma et al. (2004) concluded that, in Canada at least, habitat change outside of park boundaries was a more important threat to the ecological integrity of the national parks than were changes in human population density.

In contrast, Parks and Harcourt (2002) analyzed human population density in 50 and 100 km (31.1 and 62.1 mi) buffer zones around 13 U.S. parks, while Wiersma et al. (2004) looked at human population density and effective habitat area only in 50 km (31.1 mi) buffer zones around Canadian parks. Parks and Harcourt (2002) focused on extinction and extirpation of large mammals, while Wiersma et al. (2004) looked at extirpation of all disturbance-sensitive mammals, regardless of size. The studies by Parks and Harcourt (2002) and by Wiersma et al. (2004) differed in their findings, but also in some of the parameters analyzed (table 1), including, most importantly, the type and number of species analyzed, as well as the historical reference point. To better compare with the American work, we wanted to test whether human population densities and effective habitat area at different extents beyond park boundaries are significant predictors of loss of disturbance-sensitive mammals since widespread European settlement, and if these effects were different when we compared large and small mammals.

Here, we repeat the analysis carried out by Wiersma et al. (2004), but expand on their work to look at effective habitat area and population size outside the same 24 national parks (fig. 1, next page) at distances of 10, 25, 50, and 100 km (6.2, 15.5, 31.1, and 62.1 mi). We examine these effects on the loss of disturbance-sensitive mammal species (as defined previously by our colleagues Glenn and Nudds 1989) from these parks since before widespread European settlement. Thus, our data represent both recent and less recent losses while other studies in North America (e.g., Parks and Harcourt 2002) have only examined relatively recent losses of species since time of park establishment and do not capture those species that became extirpated from a region well before a park was put in place. We also test for scale-dependencies for species losses by average body size. Body size and home range are known to correlate strongly (Lindstedt et al. 1986; Swihart et al. 1988), and thus we predict that effective habitat area within the smallest distance from park boundary (10 km [6.2 mi]) will be the best predictor for loss of small species from the parks, as they will be less likely to move large distances outside of a park. Similarly, we expect that effective habitat areas within the largest distance (100 km [62.1 mi]) will be the best predictor for loss of large species, which have larger home ranges and thus may use larger areas outside of park boundaries. Across all disturbance-sensitive mammals, we predict that we will see patterns of explanatory variables similar to those in the original work (i.e., effective habitat will be a more important predictor than human population density).

Table 1. Summary of data analysis in Parks and Harcourt (2002) and this study

Attribute Analyzed	Parks and Harcourt (2002)	This Study
Number of parks	13	24
Mean park size (±s.d.)	2,497 km^2 (±2,576 km^2) (964 ±995 mi^2)	3,466 km^2 (±9,337 km^2) (1,338 ±3,605 mi^2)
Width of buffer zones outside park	50 km (31.1 mi) and 100 km (62.1 mi)	10, 25, 50, and 100 km (6.2, 15.5, 31.1, and 62.1 mi)
Number of species examined	8	79
Taxonomic attributes of species examined	Orders Carnivora and Artiodactyla	All disturbance-sensitive mammals
Body size attributes	~2–500 kg (4.4–1,102 lb)	~2.5–500 kg (0.006–1,102 lb)
Temporal reference point for species loss	Time since park establishment (1872–1923)	Prior to widespread European settlement (~1750)
Geographic region and general habitat types	Western U.S.; desert, Rocky Mountains, Cascade Range, Sierra Nevada	Across Canada, excluding the far north; boreal, temperate, and mixed-wood forest, grasslands, Rocky Mountains

Figure 1. Map of the 24 Canadian national parks studied in the modeling investigation.

Methods

Park data

We used data from the same 24 parks south of the 60th parallel as analyzed by Wiersma et al. (2004). We excluded parks composed of island archipelagoes. For each park, we created four buffer regions, at distances of 10, 25, 50, and 100 km (6.2, 15.5, 31.1, and 62.1 mi).

Mammal data

We took historical mammal species composition (prior to widespread European settlement) for each of 24 national parks from Wiersma and Nudds (2001). The accuracy of historical estimates is never fully known, and may contribute to errors in inferring species extirpations. However, we are reasonably confident about the data used, based on a sensitivity analysis carried out to test for the probability of committing statistical errors of omission and commission with respect to detecting extinctions from parks (Habib et al. 2003). We used updated mammal occurrence records from Parks Canada's Biotics Web explorer (available at www.pc.gc.ca/apps/bos/BOSFieldSelection_E.asp?oqqc=aqs) to document the number of disturbance-sensitive mammal (DSM) species that had gone missing from each park ("species loss"). We also partitioned the mammal data according to average body size (obtained from Banfield 1974) into "large" (> 100 kg [221 lb] average body size) and "small" (< 20 kg [44 lb] average body size) and documented the net change in number of species of each of these two size classes.

Population and visitor data

Human population data were based on the 2001 national census from Statistics Canada. We used the GeoSuite database from Statistics Canada to overlay boundaries for census divisions with the buffer zones outside of park boundaries. We recorded the total population of the census division that overlapped with each buffer zone. We obtained visitor data for each park from Parks Canada for the 2006–2007 visitor season, which are available at www.pc.gc.ca/docs/pc/rpts/attend/table1_e.asp.

GIS analysis of spatial data

We followed the same protocols for measuring land use and land cover as did Wiersma et al. (2004), except that analysis was carried out in ArcGIS (ESRI, version 9.2, Redlands, California). National Topographic Series digital maps were obtained and the "footprint" of human-built infrastructure within each park and in each of the buffer zones outside of the park boundaries was measured by buffering linear features to account for avoidance distances, which is the distance by which certain species preferentially stay away from linear features (Jalkotzy et al. 1997). Buffers around linear features were the same as in Wiersma et al. (2004) (highways: 200 m [219 yd], paved roads and railways: 100 m [109 yd]; limited use roads: 50 km [31.1 mi], trails: 50 m [55 yd]) and were based on published road-avoidance distances for mam-

A key knowledge gap lies in the interactions of populations of species within and outside of protected areas boundaries…. We recognize that parks are becoming … islands of wilderness, but it is not always clear what the effects of this pattern are.

Table 2. Quasi log-likelihood and Akaike Information Criterion (QAIC$_c$) for the six best regression models for loss of disturbance-sensitive mammals in 24 Canadian national parks

Model	Log-likelihood	K	QAIC$_c$	Δ_i	w_i
EHA10	–14.863	4	39.831	0	0.19
EHA25	–14.936	4	39.976	0.15	0.18
EHA50	–14.974	4	40.054	0.22	0.17
EHA100	–15.744	4	41.893	1.76	0.08
EHAPark	–15.968	4	42.042	2.21	0.06
EHA10 + Visitors	–14.810	5	42.954	3.12	0.04

Notes: K equals the number of parameters plus an intercept and error term, and an additional value for the overdispersion parameter. Delta$_i$ (Δ_i) is the difference between model QAIC$_c$ and lowest QAIC$_c$ value. Δ_i values < 2 are considered credible best models. Weights (w_i) are a measure of the weight of evidence in favor of that particular model over all others. EHA: effective habitat area; EHAPark: effective habitat area in the park; EHA*xx*: effective habitat area *xx* km outside of park boundary. Variables are log-transformed.

mals (Jalkotzy et al. 1997). We also overlaid Advanced Very High Resolution Radiometer (AVHRR) satellite data for those land covers identified by Wiersma et al. (2004) as "non-habitat" (bare rock, ice and snow, agricultural cropland, agricultural rangeland, and large bodies of water). These cover types are not suitable habitat for any of the species included in the analysis. The total human footprint and non-habitat areas were then overlaid and subtracted from the total park area and total buffer areas to get effective habitat area within each park and within each buffer region outside of the parks, respectively.

Statistical analysis

As with the study by Wiersma et al. (2004), we constructed a series of models to explain species losses. We based possible models on the suite of models tested by Wiersma et al. (2004), and for comparison added models that used effective habitat area and human population at different spatial extents. Generalized linear models were built to explain species loss, and net change in small vs. large mammals. Statistical analysis was conducted using the R statistical package (v. 2.7.0). Models were evaluated using the corrected Akaike's Information Criterion (AIC$_c$; Burnham and Anderson 2002) because of the low ratio of sample size to model parameters ($n/K = 24/4$). Variables were log-transformed to achieve normality. Some models suffered from overdispersion (sample variance exceeds model variance, often due to nonindependent samples); these models were evaluated using QAIC$_c$, which accounts for overdispersion (Burnham and Anderson 2002). Models with lowest AIC$_c$ or QAIC$_c$ are considered the best model to predict those data; however, the magnitude of difference between the model with the lowest AIC$_c$ or QAIC$_c$ and competing models is important for making inferences. We calculated Δ_i (delta-*i*) as the difference between each model's AIC$_c$ (or QAIC$_c$) and the minimum (smallest) AIC$_c$ (or QAIC$_c$) value. Models with $\Delta_i < 2$ are strongly supported by the data, and those with $\Delta_i = 2–4$ are somewhat supported by the data (Burnham and Anderson 2002). Akaike weights (w_i) were also calculated; these provide a measure of the weight of evidence in favor of one model over others (White 2001).

Results

For loss of all disturbance-sensitive mammals, the effective habitat area outside the park was the best model ($\Delta_i < 2$); the QAIC$_c$ could not discriminate between effective habitat at 10, 25, 50 km (6.2, 15.5, 31.1 mi) outside of the park boundary (all three models had $\Delta_i < 0.25$ and w_i approximately equal (table 2). Effective habitat area within 100 km (62.1 mi) of the park boundary and within the park itself was also strongly supported ($\Delta_i < 2$), although this distance had lower weight of evidence ($w_i = 0.08$) than the top three models. Population was not a factor in any of the top models. The top model with population at any distance outside park boundaries as a predictor had a weighting of 0.008 and $\Delta_i = 6.2$, indicating it was a highly unlikely model to explain the data. The median human population density in the 10 km (6.2 mi) buffer zone outside the park was 1.29 persons/km^2 (5.53 persons/mi^2), and only 8 of the 24 parks were in areas of human population density higher than the Canadian average of 3.3 persons/km^2 (8.46 persons/mi^2). Within both the 50 km (31.1 mi) and 100 km (62.1 mi) buffer outside parks, the median human population density was close to the Canadian average of 3.3 persons/km^2 (8.46 persons/mi^2), and 12 parks had equal or higher human population density than the Canadian average within 50 km (31.1 mi) and 100 km (62.1 mi) of their boundaries.

Results when analysis was restricted to net change in small or large mammals only did not show any major differences. Models with a single predictor of effective habitat area were all plausible ($\Delta_i < 1$) and all had similar weightings (w_i = 0.12–0.14 for small mammals and w_i = 0.10–0.11 for large mammals). The order of the top models did not fit the predicted pattern (i.e., effective habitat area within the 10 km [6.2 mi] buffer was not the best predictor for net change in small mammal richness, and effective habitat area within the larger buffer distances was not the best predictor for large mammals). Parameter weightings across all models suggest that effective habitat area is a more important predictor in all cases than either visitor or human population densities, and that effective habitat area within 100 km (62.1 mi) of the park boundary was less important of a predictor than effective habitat within parks and within 50 km (31.1 km) or less of the park boundary (table 3).

Discussion

Overall, our results from this study yield conclusions similar to the earlier work of Wiersma et al. (2004), which suggested that effective habitat area within and outside of park boundaries was a more significant predictor of losses of disturbance-sensitive mammals in national parks since widespread European settlement than was human population density outside of protected areas. The earlier work did not examine scale effects; our work here suggests that models are not particularly sensitive to the spatial extent at which effective habitat area outside park boundaries is measured. The parameter weightings (see table 3) show that effective habitat area within 100 km (62.1 mi) of the park boundaries is not as important a predictor as the effective habitat area within the other buffer regions. This suggests that the effect of habitat loss outside of park boundaries on species loss within the parks is more important within 50 km (31.1 mi) of the park, and the effect of habitat loss on species loss within the parks becomes diminished as distances approach (and likely exceed) 100 km (62.1 mi) from the park boundary. Effective habitat area within the park boundaries is the most important predictor for net change in large and small disturbance-sensitive mammals. This fits the hypothesis for loss of small mammals from parks, which are predicted to be less affected by habitat loss outside of the park boundaries given their smaller home ranges. However, the result is counterintuitive for large mammals given that they generally have larger home ranges and might be expected to be more prone to regularly use habitat outside of park boundaries.

A number of additional studies since Wiersma et al. (2004) from around the world have found effects of human population densities on protected areas (Luck 2007; Rondinini et al. 2006; Mcdonald et al. 2008); these have focused on correlations between human population density and areas of high biodiversity or conservation value, and not on species losses per se. Moreover, they have focused on studies around the world; outside of North America patterns of human land use and activity in rural areas outside of protected areas might be different than in the developed world. It also appears that there are some differences between human population density patterns outside Canadian national parks and those in the U.S. parks analyzed by Parks and Harcourt (2002). Median human density in the 50 km (31.1 mi)

Table 3. Parameter weightings based on Akaike weights (w_i)[1] for each model for change in disturbance-sensitive mammals (DSM) in 24 Canadian national parks

	Parameter Weightings (w_i)			
Parameter	**Loss of DSM**	**Net Change DSM**	**Net Change Small DSM**	**Net Change Large DSM**
EHAPark	0.2559	0.3448	0.3568	0.4430
EHA10	0.2461	0.2189	0.2135	0.2321
EHA25	0.2619	0.2161	0.2170	0.2102
EHA50	0.2179	0.2147	0.2142	0.2134
EHA100	0.1208	0.1912	0.1575	0.2053
Visitors	0.1714	0.1680	0.1701	0.2636
Pop10	0.0093	0.0091	0.0095	0.0415
Pop25	0.0067	0.0074	0.0080	0.0203
Pop50	0.0067	0.0069	0.0074	0.0184
Pop100	0.0049	0.0059	0.0063	0.0190

[1]After Burnham and Anderson 2002.

Notes: Higher values indicate higher relative support for inclusion of a parameter in the model. EHA: effective habitat area; EHAPark: effective habitat area in the park; EHA*xx*: effective habitat area *xx* km outside of park boundary; Pop*xx*: human population density *xx* km outside of park boundary.

buffer around Canadian parks (3.45 persons/km² [8.85 persons/mi²]) was much lower than the human population density in the 50 km (31.1 mi) zone outside 8 of the 13 U.S. parks (table 4). Quite a few parks in Canada are surrounded by non-habitat (e.g., agricultural areas or high amounts of forested areas that have been harvested) but low population density. Figure 2a (next page) shows an aerial image of Riding Mountain National Park in Manitoba, which has very little habitat outside its boundaries, but human population density within all four buffer zones that is lower than the Canadian average. Figure 2b (next page) shows the Rocky Mountain parks in British Columbia and Alberta, and is centered on Glacier. This is an interesting area to compare with Rocky Mountain National Park in Colorado. Both are in similar ecoregions. Rocky Mountain has a human population density of 30.76 and 50.87 persons/km² (78.87 and 130.43 persons/mi²) in the 50 and 100 km (31.1 and 62.1 mi) buffer regions, respectively, and is 1,075 km² (415 mi²) in size (Parks and Harcourt 2002). In contrast, Glacier (Canada) has 0.79 and 0.58 persons/km² (2.02 and 1.49 persons/mi²) in the two buffer regions, and is 1,358 km² (524 mi²) in size. In addition, while protected areas have been found to be "attractors" for human populations in Africa and Latin America (Wittenmyer et al. 2008) and in many tropical countries (Mcdonald et al. 2008), rural areas outside North American parks are largely experiencing declines in human population. The only North American study to show an effect of human population density (Parks and Harcourt 2002) examined loss of large (> 5 kg [11 lb]) members of the orders Carnivora and Artiodactyla since park establishment. Our results suggest that, even for large mammals, effective habitat in parks and within 50 km (31.1 mi) of park boundaries is a more important predictor than human population density, even though we saw a pattern, as Parks and Harcourt (2004) did, of approximately half the parks having equivalent or higher human population density than the national average within 50 km (31.1 mi) of the park boundary. Thus, the lack of significance of human population density in our study may be due to pattern of human population. It is possible that human populations outside Canadian parks are more clumped than outside U.S. parks, and hence have a lower impact on habitat reduction. However, we do not have sufficient data to assess this. It is more likely that the difference between our findings here and in Wiersma et al. (2004) and those of Parks and Harcourt (2002) may continue to be due to the timescale for measuring species loss. For loss of a broader suite of disturbance-sensitive mammals since the time of widespread European settlement, effective habitat area still appears to be a better predictor than human population density. Thus, park managers concerned about species loss from their parks as the parks become islands of wilderness would do well to work with adjacent landowners and land managers to increase total habitat as much as possible, whether that be through creation of "stepping-stone" parks, formally designated habitat corridors, habitat restoration, or changes in resource management practices (e.g., forest harvest patterns), to maximize habitat connectivity with 50 km (31.1 mi) of the protected area boundaries. Further initiatives might involve conservation stewardship agreements with private landowners to facilitate habitat conservation.

Table 4. Human population density (persons/km²) in the 50 and 100 km zones outside 13 U.S. and 24 Canadian national parks

Park Name	Ecoregion Division[1]	Human Population Density in 50 km Buffer[2]	Human Population Density in 100 km Buffer[2]
Bryce Canyon	Temperate Desert Mountains	0.57	1.29
Crater Lake	Marine Mountains	1.17	8.04
Glacier	Temperate Steppe Mountains	3.88	2.85
Grand Canyon	Tropical/Subtropical Desert	1.06	7.89
Lassen Volcanic	Mediterranean Mountains	2.87	9.95
Mesa Verde	Tropical/Subtropical Desert	5.64	4.00
Mount Rainier	Marine Mountains	45.33	69.80
Olympic	Marine Mountains	23.47	92.92
Rocky Mountain	Temperate Steppe Mountains	30.76	50.87
Sequoia–Kings Canyon	Mediterranean Mountains	15.89	19.71
Yellowstone	Temperate Steppe Mountains	0.92	2.70
Yosemite	Mediterranean Mountains	4.73	24.93
Zion	Temperate Desert Mountains	4.21	1.82
U.S. median		**4.21**	**8.04**
Banff	Temperate Steppe Mountains	1.17	12.01
Cape Breton Highlands	Warm Continental	9.33	13.42
Elk Island	Prairie	80.00	28.00
Forillon	Subarctic	4.19	3.23
Fundy	Warm Continental	20.04	15.93
Glacier	Temperate Steppe Mountains	0.79	0.58
Grasslands	Temperate Steppe	0.41	0.78
Gros Morne	Subarctic Mountains	3.39	2.36
Jasper	Temperate Steppe Mountains	0.39	0.40
Kejimkujik	Warm Continental	5.59	10.52
Kootenay	Temperate Steppe Mountains	1.82	1.57
Kouchibouguac	Warm Continental	11.19	13.10
La Mauricie	Warm Continental	20.53	19.10
Mount Revelstoke	Temperate Steppe Mountains	0.68	1.86
Pacific Rim	Marine Mountains	3.97	28.71
Point Pelee	Warm Continental	22.56	14.39
Prince Albert	Prairie/Subarctic	4.86	2.15
Prince Edward Island	Warm Continental	53.67	84.80
Pukaskwa	Subarctic	0.58	0.63
Riding Mountain	Prairie	2.16	2.75
Terra Nova	Subarctic	3.51	3.32
Waterton Lakes	Temperate Steppe Mountains	2.64	5.86
Wood Buffalo	Subarctic	0.09	0.07
Yoho	Temperate Steppe Mountains	0.85	0.81
Canadian median		**3.45**	**3.28**

[1]After Bailey (1989).

[2]U.S. data are from Parks and Harcourt (2002).

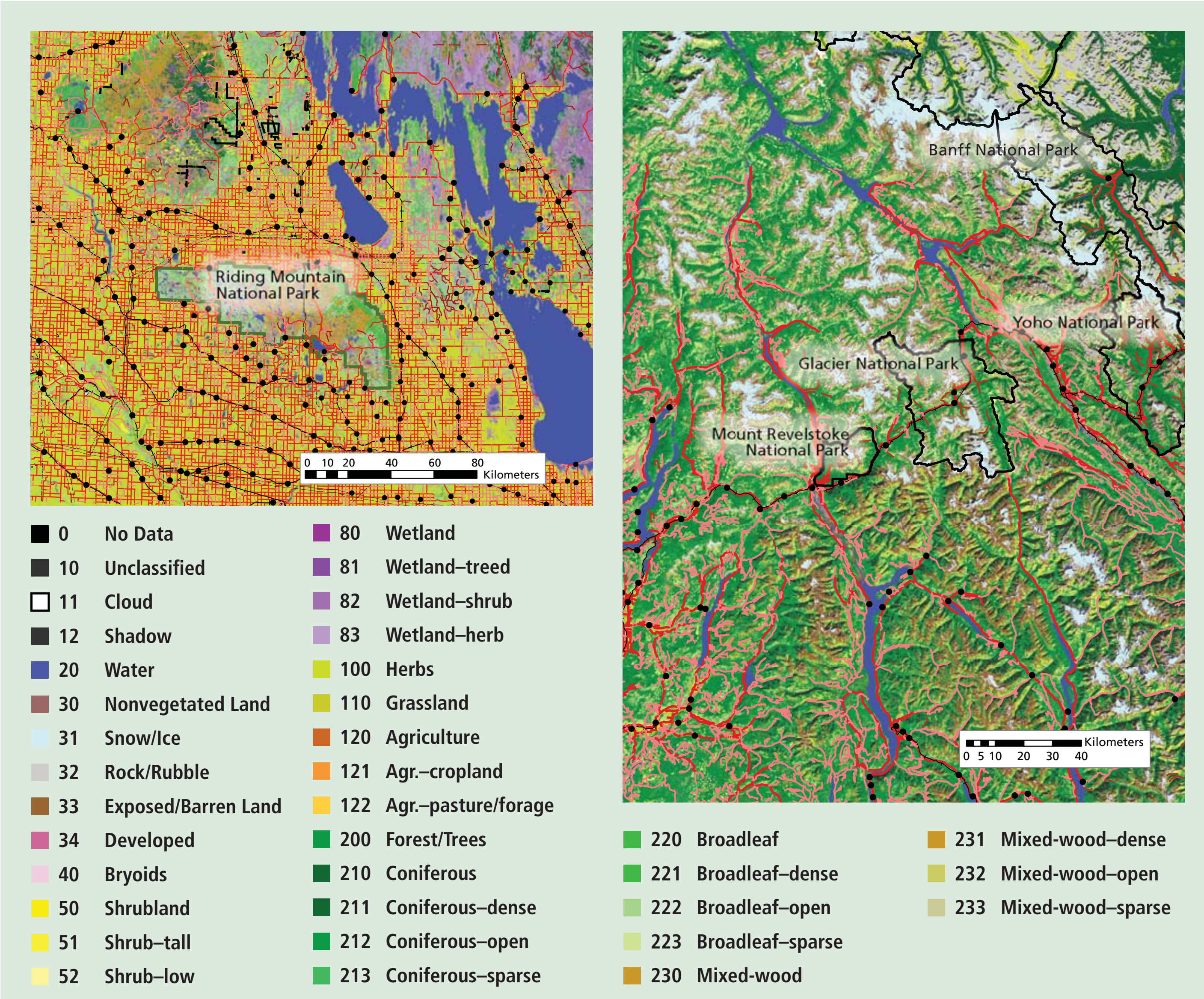

Figure 2a (above, left). Aerial image of Riding Mountain National Park (dark green outline) in Manitoba (area 3,091 km^2 [1,193 mi^2]) showing an area approximately 50 km (31.1 mi) outside the park. Human population density in this area is approximately 2.16 persons/km^2 (5.54 persons/mi^2). Black dots indicate built-up areas. Red and pink lines denote roads. Black lines with cross-hatching are railroads. (Note the high level of agricultural land outside the park boundary in contrast to the forested area within the park.) **Figure 2b (above, right).** Aerial image of the Rocky Mountain parks in Canada, centered on Glacier National Park (black outline) in British Columbia (area 1,358 km^2 [524 mi^2]) and showing an area approximately 50 km (31.1 mi) outside the park. Human population density in this area is approximately 0.79 person/km^2 (2.02 persons/mi^2). Dots indicate built-up areas. (Note the high level of high-elevation rock and ice [i.e., non-habitat] within and around these parks.)

The total amount of effective habitat area in the parks and within 50 km (31.1 mi) of park boundaries does not explain all of the variation in species loss in Canada's national parks. Future work examining factors affecting species loss within protected areas should examine the spatial configuration of the habitat patches outside of protected areas as well as the quality of the intervening habitat; such an analysis could explain more of the variation in species loss than current models. Most of the habitat around the Canadian parks is dominated by boreal, mixed-wood, or temperate forests, as well as grassland and tundra. Whether similar patterns of species loss and habitat change would be seen in U.S. parks surrounded by quite different habitat (e.g., deserts, subtropics) is unknown. However, given the well-known effects of habitat loss, it is quite likely that parks in the southern United States would exhibit a similar pattern, as has been demonstrated by this work. Application of the methods outlined here across all

Park managers concerned about species loss … would do well to work with adjacent landowners and land managers to increase total habitat as much as possible.

or part of the U.S. National Park System could be useful to test the significance of habitat loss vs. human population density in other habitat types.

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References

Bailey, R. G. 1989. Explanatory supplement to ecoregions map of the continents. Environmental Conservation 16:307–309.

Banfield, A. W. F. 1974. The mammals of Canada. University of Toronto Press, Toronto, Ontario, Canada.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Second edition. Springer Science, New York, New York, USA.

Gaston, K. J., S. F. Jackson, L. Cantú-Salazar, and G. Cruz-Piñón. 2008. The ecological performance of protected areas. Annual Review of Ecology, Evolution, and Systematics 39:93–113.

Glenn, S. M., and T. D. Nudds. 1989. Insular biogeography of mammals in Canadian parks. Journal of Biogeography 16:261–268.

Habib, L. D., Y. F. Wiersma, and T. D. Nudds. 2003. Effects of sampling bias on estimates of historical species richness and faunal relaxation of mammals in Canadian national parks. Journal of Biogeography 30:375–380.

Jalkotzy, M. G., P. I. Ross, and M. D. Nasserden. 1997. The effects of linear developments on wildlife: A review of selected scientific literature. Arc Wildlife Services Ltd., Calgary, Alberta, Canada.

Lindstedt, S. L., B. J. Miller, and S. W. Buskirk. 1986. Home range, time, and body size in mammals. Ecology 67:413–418.

Luck, G. W. 2007. A review of the relationships between human population density and biodiversity. Biological Reviews 82:607–645.

Mcdonald, R. I., P. Kareiva, and R. T. T. Forman. 2008. The implications of current and future urbanization for global protected areas and biodiversity conservation. Biological Conservation 141:1695–1703.

McNamee, K. 2009. From wild places to endangered spaces: A history of Canada's national parks. Pages 24–54 in P. Dearden and R. Rollins, editors. Parks and protected areas in Canada: Planning and management. Third edition. Oxford University Press, Don Mills, Ontario, Canada.

Parks, S. A., and A. H. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in U.S. protected areas. Conservation Biology 16:800–808.

Rondinini, C., F. Chiozza, and L. Boitani. 2006. High human density in the irreplaceable sites for African vertebrates conservation. Biological Conservation 133:358–363.

Runte, A. 1987. National parks: The American experience. Third edition. University of Nebraska Press, Lincoln, USA.

Swihart, R. K., N. A. Slade, and B. J. Bergstrom. 1988. Relating body size to the rate of home range use in mammals. Ecology 69:393–399.

White, G. C. 2001. Statistical models: Keys to understanding the natural world. Pages 35–56 *in* T. M. Shenk and A. B. Franklin, editors. Modeling in natural resource management: Development, interpretation, and application. Island Press, Washington, D.C., USA.

Wiersma, Y. F., and T. D. Nudds. 2001. Comparison of methods to estimate historic species richness of mammals for tests of faunal relaxation in Canadian parks. Journal of Biogeography 28:447–452.

Wiersma, Y. F., T. D. Nudds, and D. H. Rivard. 2004. Models to distinguish effects of landscape patterns and human population pressures associated with species loss in Canadian national parks. Landscape Ecology 19:773–786.

Wittenmyer G., P. Elsen, W. T. Bean, A. C. O. Burton, and J. S. Brashares. 2008. Accelerated human population growth at protected area edges. Science 321:123–126.

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Bears and humans: How Canadian park managers are dealing with grizzly bear populations in a northern landscape

By Ramona Maraj

Abstract
This study investigated the effects of human land use on grizzly bear (*Ursus arctos* L.) habitat and populations in the Kluane region of southwestern Yukon, Canada. Previous studies in the region identify grizzlies as the species most at risk from cumulative impacts of human activity. The goals of this project were to identify the effects of cumulative human activities on grizzly habitat and populations, and to provide recommendations on human-use management with respect to the conservation of grizzlies and their habitat. To examine the influence habitat and mortality had on grizzly bear productivity and survival, I compared the explanatory power of empirical habitat models based on grizzly bear telemetry relocations or forage availability against expert-opinion models. Empirical habitat models were best for explaining reproductive and survival rates to predict population status for grizzly bears in Kluane. Survival and productivity of grizzly bears decreased on the periphery of the protected area adjacent to highways. While productivity in the areas adjacent to highways was relatively high, mortality was also high. These areas, therefore, were acting like attractive sinks. Reducing human-caused mortality on the park periphery and developing a transboundary management strategy will be necessary to conserve grizzly bears in Kluane.

Key words: cumulative impacts, expert opinion, grizzly bear, Kluane, park, resource selection, source-sink dynamics, transboundary management

The grizzly bear's perspective: No national park is an island

GRIZZLY BEARS (*URSUS ARCTOS* L.) HAVE AN ECOLOGICAL role that makes them useful focal species for evaluating the effectiveness of protected areas (Gibeau et al. 1996; Noss et al. 1996; Paquet et al. 1996). Landscapes that sustain viable populations of grizzly bears are often ones where natural vegetation predominates, where native species are still found, and where historical ecological processes still operate (Noss et al. 1996; Carroll et al. 2001). As an apex predator, grizzly bears are one of the first species to be lost from an area as a result of land development (Noss et al. 1996; Woodroffe 2000). Grizzly bears are particularly sensitive to the impacts of human activities because generally they have relatively few young, range over large areas, and occur at low population densities (Gibeau et al. 1996; Mattson et al. 1996b; Paquet et al. 1996; Russell et al. 1998; Purvis et al. 2000). Consequently, grizzly bears have been considered indicators of the health or integrity of an ecosystem. They are also prone to direct conflict with people. The combination of these biological traits interacting with people's affinity to develop and use grizzly bear habitat usually results in compromised bear populations and habitat (Banff Bow Valley Study 1996; Woodroffe 2000; Mattson and Merrill 2002).

In 1976, in an effort to protect grizzly bears and other wildlife species, the Canadian government designated a portion of southwestern Yukon Territory as a national park. This region, designated as Kluane National Park and Reserve (Kluane), adjoined Glacier Bay National Park in the Alaska panhandle, Wrangell–St. Elias National Park in Alaska, and later Tatshenshini-Alsek Park in British Columbia to form the world's largest international protected area and world heritage site (fig. 1)[1]. Since the designation of Kluane, the area has been described as one of the last remaining strongholds for grizzly bear populations in North America (Herrero et al. 1993). Kluane has also been described as an important grizzly bear "source" population for the surrounding area (Jingfors 1990). Grizzlies have shown regional movements south into Tatshenshini-Alsek Park, east into the Aishihik region, and north into the Kluane Wildlife Sanctuary. In the first two years of the most recent grizzly bear population study in Kluane (McCann 1998), 21% and 36%, respectively, of the tracked bears made out-of-park movements (McCann 1998). Hence Kluane plays an important ecological role for the surrounding area (Jingfors 1990; Hegmann 1995).

While the bear population in Kluane is thought to act like a source population, previous studies in the region singled out grizzly bears as the species most at risk of being affected by cumulative impacts (Hegmann 1995). Increasing town site development in communities neighboring the park; mining, hunting, forestry, and agriculture pressure outside of the park; landfills in nearby towns that attract bears; and air traffic are all potential threats to the ecological integrity of Kluane (Hegmann 1995; Danby and Slocombe 2005). Further, although the park area is more than 22,000 km^2 (8,492 mi^2), only 4,000 km^2 (1,544 mi^2) (18%) is vegetated (Environment Canada 1987). The remainder is rock and ice field. The vegetated portion of the park is a thin belt, confined on the west by the St. Elias Icefields, the largest nonpolar ice field in the world, and on the east by the Alaska and Haines highways. Four towns and several small, summer-use aboriginal villages are situated along the highways and consequently border Kluane (fig. 2). There are also numerous rural residential dwellings, summer homes, and other infrastructure along both highways. The distance between the highways and the ice field is approximately 55 km (34 mi) at its widest and averages 35 km (22 mi) (Environment Canada 1987). The dimensions of the greenbelt cannot easily contain the multiannual home range of a female grizzly (McCann 1998), so bears are highly reliant on the surrounding area to meet

[1] There are some differences among the parks in terms of the protection afforded to bears. For instance, hunting of bears is permitted in Tatshenshini-Alsek Park and under state sport and federal subsistence hunting regulations in different areas of Wrangell–St. Elias National Park and Preserve and in Glacier Bay National Preserve. Hunting of grizzlies is prohibited in Glacier Bay National Park and Kluane National Park.

Figure 1. Kluane National Park and Reserve, located in the southwestern corner of Yukon, Canada, is part of the world's largest protected area complex.

Figure 2. Haines Junction and the Alaska and Haines highways border Kluane National Park, as revealed in this satellite image. While Haines Junction is the main town bordering the park, it is only one of four towns and several summer-use villages along the park perimeter.

some of their life requisites. However, when bears have made out-of-park movements, they were subject to various sources of direct mortality, principally hunting and management kills (e.g., bears shot in defense of life and property). Rates of mortality have been high, exceeding the growth rate for the population (McCann 1998; Yukon Territorial Government 2003).

Building a model to represent Kluane's bear ecology

In light of the pressures on grizzly bears in and around Kluane, an essential approach to promoting effective conservation is identifying which landscape features are inherently attractive to the species and how that attraction is modified by the presence of humans (Clark et al. 1996; Nielsen 2005). Expert-opinion models, such as habitat effectiveness and security area models originally developed for grizzly bear management in Greater Yellowstone and Yellowstone National Park, are relatively inexpensive approaches identifying important habitat and estimating the impacts of human land use on grizzly bear habitat (USDA Forest Service 1990; Purves and Doering 1998; Gibeau 2000). However, these models have been criticized for not performing as well as empirical habitat models, and because of lack of statistical rigor they are viewed as unreliable (Nielsen et al. 2003; Stenhouse et al. 2003).

Resource selection function modeling (Manly et al. 2002) is a more statistically robust approach than expert-opinion methods for examining the distribution of wildlife in relation to landscape characteristics. The distribution of most organisms relates to the distribution of patches of habitat. Patches occur at different scales and are encompassed by a landscape matrix in which the species is absent or occurs at much lower densities (Paquet et al. 1996; Boyce et al. 2003). Disturbance by humans can displace organisms from preferred or frequently used habitat patches (Paquet et al. 1996; Woodroffe 2000). Disturbances may include concentrations of people in space and time, the physical alteration of an area, or some combination of these effects (Paquet et al. 1996).

For an empirical habitat model to be useful it is necessary to show how an animal's habitat selection might affect its survival or reproductive success (Boyce and McDonald 1999; Naves et al. 2003). Models based solely on habitat attributes cannot consistently and accurately estimate species' population responses (Mitchell and Powell 2003); however, if habitat models are specific to births and deaths, changes in the availability of resources

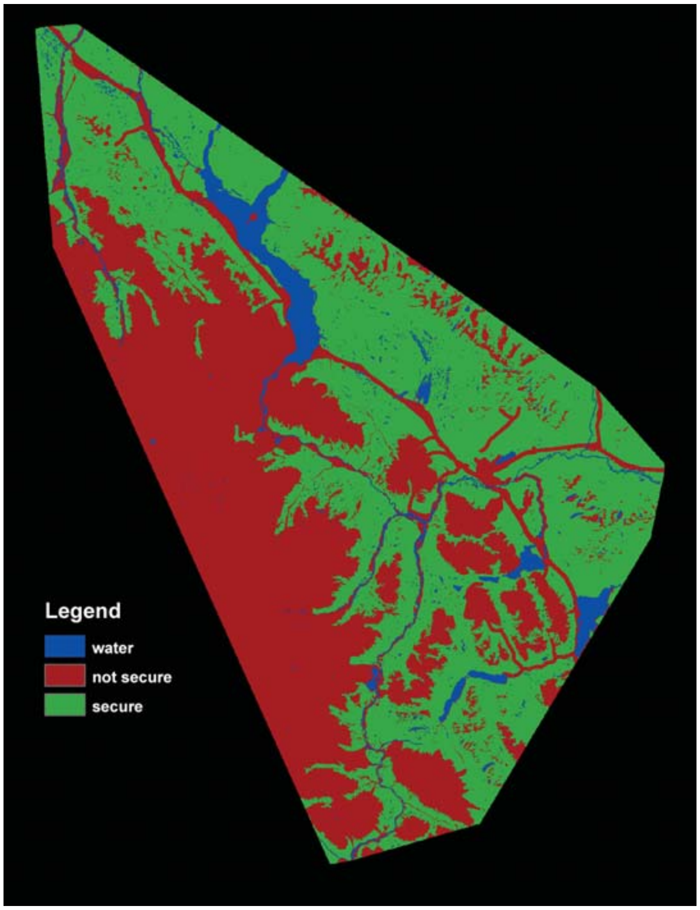

Figure 3. Expert-opinion maps, such as this security area map, were created using vegetation cover data. This study revealed that expert-opinion maps did not perform as well as occupancy and mortality risk maps.

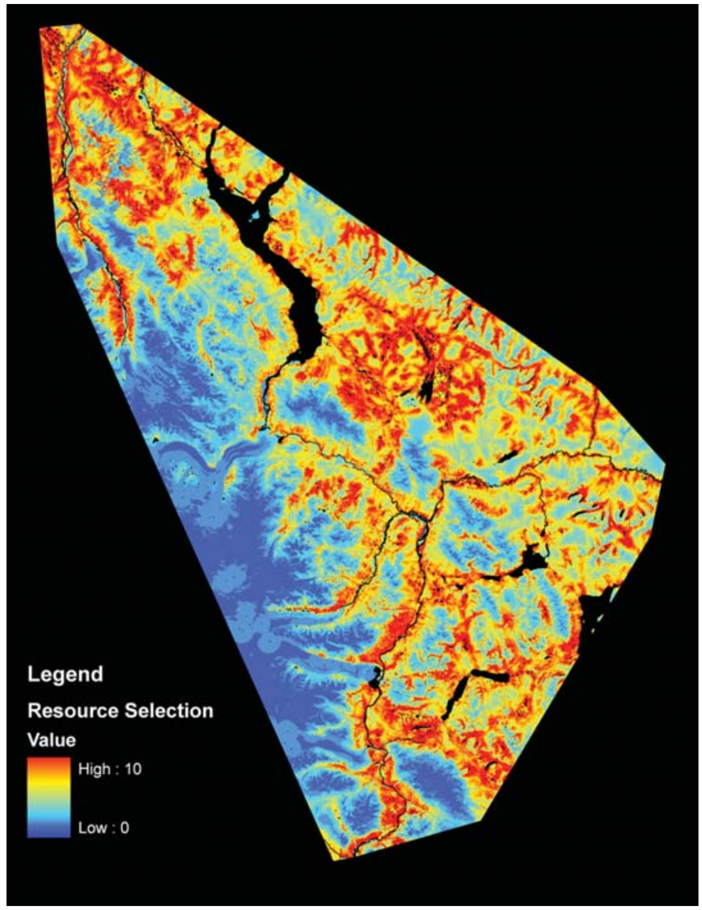

Figure 4. Telemetry relocations were used in a resource selection function to calculate the relative probability of occupancy for a grizzly bear in a given area.

that affect these processes may correlate with population responses (Naves et al. 2003). That is, as factors that increase the number of cubs that are born or live become prevalent, reproductive and survival rates for bears should concurrently increase (McLellan 1994). I evaluated this concept by assessing the effectiveness of occupancy (i.e., where bears use habitat) and mortality risk (i.e., where bears die) models for explaining productivity and survival rates, respectively. I appraised empirical habitat models, forage distribution models, and expert-opinion models with respect to reproductive and annual adult survival rates. Empirical habitat models described the relative probability distributions for family groups, adult females including family groups, adult males, and mortality locations. Expert-opinion models included habitat effectiveness and security models (fig. 3) and used the model parameters originally developed by experts researching bears in Yellowstone National Park. Habitat effectiveness describes the area's ability to support bears given the quality of the habitat and the extent of human disturbance. Security models describe the amount of area available to a female grizzly where she will be relatively secure from encounters with humans but can still meet her energy requirements. (See Maraj [2007] for full details of methods.)

To build empirical occupancy or habitat models, I used 3,941 aerial VHF telemetry relocations for 69 bears collared in the period 1989 to 2004. I used a resource selection function to model habitat selection by grizzly bears (Manly et al. 2002; fig. 4). This method employed telemetry locations for family groups and adult females, and a number of random coordinates, representing available habitat, to model the chance of a grizzly bear being at a given location as a function of a set of variables. Variables related to forage productivity, security from humans, terrain, and distribution of other bears. I recategorized the values produced by the resource selection function into two classes. The top 50% of the values represented habitat that had a high chance of being occupied by a grizzly bear, or high-quality habitat. The remainder of the values represented low-quality habitat.

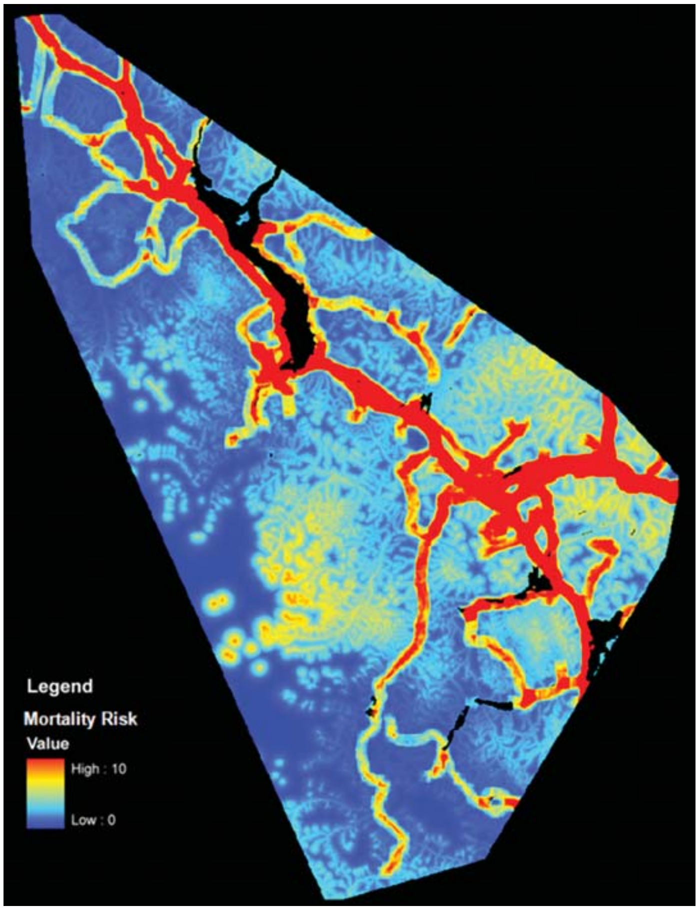

Figure 5. Kill locations were used in a resource selection function to calculate the relative probability of human-caused mortality for a grizzly bear in a given area.

Grizzly bears are particularly sensitive to the impacts of human activities because generally they have relatively few young, range over large areas, and occur at low population densities.

I built the mortality risk models using reported kill site data (fig. 5). From 1983 to 2004 the Yukon Territorial Government and Kluane tracked mortalities (hunting and nonhunting) and translocations through wildlife-in-conflict and year-end reports, by way of the Yukon Biological Submission process. Mortalities included dead bears and bears translocated so far that they could be considered removed from the population. Legal hunter kills were also included in the mortality data set. Nonhunt mortalities included management-related kills (translocations were considered management-related kills), defense kills, accidental kills, and poaching. Natural mortalities were not considered. I used a resource selection function model to explore the relationship between grizzly bear mortalities and possible variables. Variables, in this case, were elevation, distance to water, infrastructure density, distance to primary roads, distance to other linear features, and distance to landfills. As with the occupancy model, I recategorized the values produced by the resource selection function for mortality risk into two classes: the top 50% of the values represented high-mortality-risk areas and the remainder of the values represented low-mortality-risk areas.

I also developed an expert-opinion model. I calculated the proportion of each bear's home range that was scored as secure habitat and that had 80% or greater habitat effectiveness (Gibeau 1998; Purves and Doering 1998; Gibeau et al. 2001). For habitat effectiveness analysis I created a map of habitat values based on rankings of forage availability within land cover classes without human activity, then overlaid this map with a human disturbance layer. Habitat values up to given distances from a human disturbance feature were multiplied by values specified by expert opinion. The output map reflected the ability of the landscape to support grizzly bears in light of human disturbance (habitat effectiveness). For the security area analysis, I used the realized habitat map to identify suitable patches for foraging. All habitat patches that were large enough to meet the minimum average daily foraging radius for a female grizzly bear (Gibeau et al. 2001) were deemed secure.

I mapped the home range for each female bear and calculated the proportion of each bear's home range that was classified as high-quality habitat, high mortality risk, effective habitat, and secure habitat. I could then model the number of cubs and cub survival, and adult survival rates with the amount of high-quality and high-risk-mortality habitat in each female's home range. The number of cubs accompanying an adult female was recorded each year. If the cubs-of-year (those less than a year old) or yearlings were not seen with the adult female on two subsequent and consecutive flights, they were presumed dead. Yearlings were presumed dead if they did not emerge from the den with their mother. If the cubs were two years or older but were not accompanying the adult female, they were presumed dead or dispersed.[2]

These explanatory models for habitat-related productivity and survival rates were then used to predict productivity and survival

[2] Generally, grizzlies in Kluane do not disperse until two years of age, so cubs-of-year and yearlings that were not relocated were always assumed dead. While most two-year-olds dispersed from their mother, in some cases they died. The uncertainty as to whether a two-year-old had dispersed or died did not affect my survival estimates, as animals whose fates were unknown were coded the same way.

In light of the pressures on grizzly bears in and around Kluane, an essential approach to promoting effective conservation is identifying which landscape features are inherently attractive to the species and how that attraction is modified by the presence of humans.

rates in bear management units (BMUs) throughout the study area. BMUs aerially encompassed enough area of a watershed to support the multiannual home range of a female grizzly bear (fig. 6). Population status for each BMU, or the index for impact of human activities on the bear population, was classified as source-like, refuge-like, attractive sink-like, and sink-like (Naves et al. 2003).[3] Habitats where local reproductive success is greater than local mortality support source-like populations, characterized by an excess of individuals, who must disperse outside their natal patch to find a place to settle and breed. Areas that have scarce food resources but low risk of human-caused mortality are refuge-like, allowing for population persistence. The finite growth rate in refuge-type habitat would be close to one. Habitats where reproductive success and human-caused mortality are high, and result in a finite growth rate of less than one, are attractive sink-like. Poor habitats, where local reproductive success is lower than local mortality, are sink-like. Populations in sink habitats inevitably spiral to extinction without immigration from other areas.

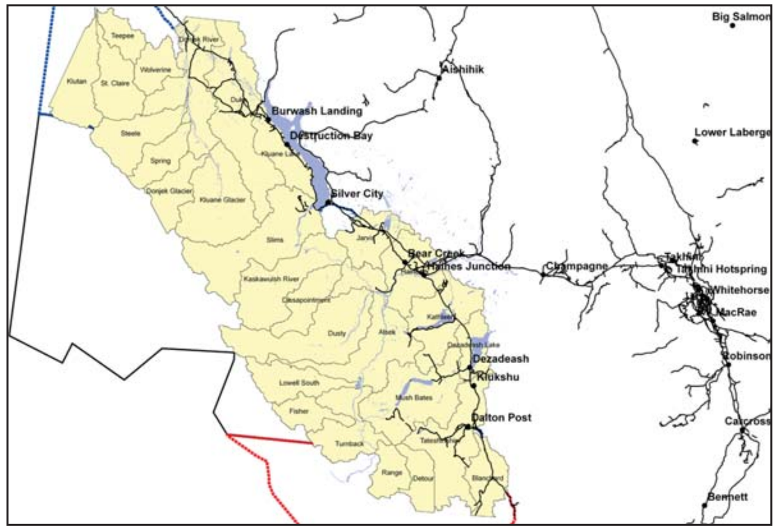

Figure 6. Shown here, bear management units (BMUs) for Kluane encompass watershed in which female grizzlies can have a multiannual home range.

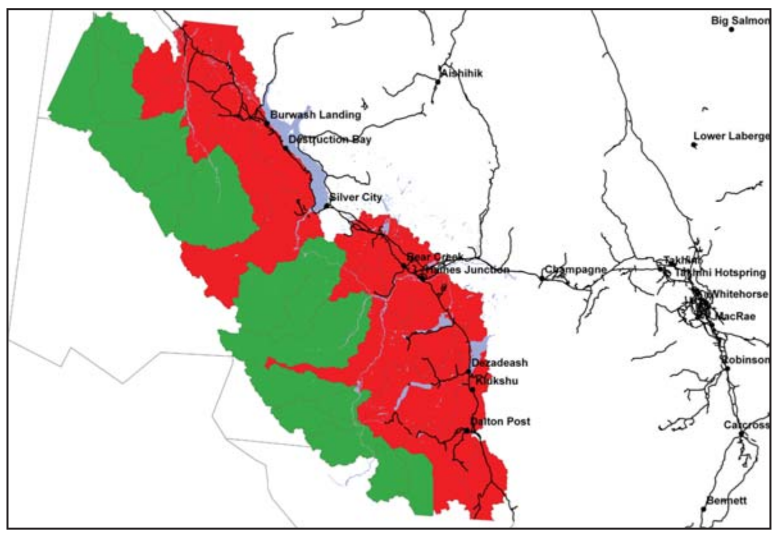

Figure 7. By considering the habitat-based mortality rates and productivity rates in each bear management unit, the ability of a BMU to retain a female can be assessed. Eleven BMUs (red) in the Kluane region area act like attractive sinks. The remaining BMUs are source-like habitat (green).

The impacts of human activity on bears

Though habitat-based methods for assessing impacts of human activities on grizzly bears are relatively inexpensive, their utility is limited if they do not express the relationship of habitat to demographic processes (Van Horne 1983; O'Neil and Carey 1984; Hobbs and Hanley 1990; Garshelis 2000; Tyre et al. 2001). I appraised empirical habitat models and expert-opinion models with respect to reproductive and annual adult survival rates.

I found that empirical habitat models were substantially better than expert-opinion models for explaining the observations of cub productivity and adult survival rates. In the case of Kluane, expert-opinion models indicated that only two BMUs had reduced potential for bears to survive as a result of human activities, whereas empirical habitat models showed that 11 BMUs had lost this potential (fig. 7). Notably, this expert-opinion model has been employed throughout North America in places such as Yellowstone National Park (USDA Forest Service 1990), Jasper National

[3] *Like* is used at the end of each habitat condition to represent the hypothetical state of the area without explicit consideration of demographic features.

Table 1. Potential landscape- and watershed-level recommendations

Area/Type of BMU	Recommendations	Options to Achieve Recommendations
Landscape		
	• Develop linkage zones between watersheds and protected areas	• Designate corridors between watersheds as places where low-impact or no activity can occur
Attractive sink-like (watershed)		
	• Reduce access, particularly in high-quality bear habitat • Reduce the availability of bear attractants • Reduce human-caused mortality through excessive harvest	• Limit development of new trails and roads • Close trails and roads • Reroute trails and roads into low-impact areas • Use seasonal road closures • Use guided access only • Prohibit activities that produce bear attractants (e.g., backcountry camping) • Allow activities but regulate attractants (e.g., mandatory storage of bear attractants in bear-proof receptacles) • Develop education programs about attractants • Implement quotas on resident harvest
Source-like (watershed)		
	• Protect these watersheds by limiting human activities	• Limit development of trails and roads • Designate as off-limits to human activity • Allow some low-impact activities and use seasonal closures when there is high potential for bear-human conflict • Allow some low-impact activities and implement human use quotas • Regulate activities to reduce bear attractants and chances of encountering bears (e.g., location of camping, management of garbage and food)

Note: This table outlines some of the management options available to reduce human-caused bear mortality. Options are generally listed in order of intensity, and are not exclusive. Options may be used in combination, or one option may be applied in one watershed while another option may be applied in another watershed. Options for attractive sink-like watersheds recognize that development has already occurred in these watersheds. Options for source-like watersheds recognize that development in these areas is currently very limited.

Park (Purves and Doering 1998), and Banff National Park (Gibeau 2000), and the results in these regions may also underrepresent the conservation concern.

Using the results of the empirical habitat models, I looked at how well each BMU in Kluane sustained adult female grizzly bears (see fig. 7). While productivity in the BMUs adjacent to the highways was relatively high, so was mortality. These areas, therefore, acted as attractive sinks. The attractive sink-like areas were effectively regions that could support viable populations of bears but, because of human activity, were unable to. Rather, bears came into these areas, attracted by the high-quality forage, and subsequently were killed by people. The primary reason for the high mortality rates was the high amount of access, either by foot or by motorized vehicle, penetrating important grizzly bear habitat. These areas probably relied on the adjacent source areas to sustain a population. Source-like areas were found in the northern and southern interior of Kluane and abutted the St. Elias Icefields.

These findings were corroborated by information from management agencies on mortality rates (Yukon Territorial Government 2003). McCann (1998) found that the resident Kluane population was declining at approximately 3% per year, and most attractive sink-like BMUs bordered or partially contained Yukon Territorial Government game management subunits where the management threshold rate for bear mortality (2% for females and 6% for males) was exceeded (Yukon Territorial Government 2003). Human-caused mortality in these regions was split equally between hunting and management kills (McCann 1998). For these areas, conservation of a grizzly bear population will require management actions to reduce mortality rates, including a combination of reduced harvest, reduced access, reduced bear attractants, and limiting or otherwise mitigating the effects of development in high-occupancy bear habitats (table 1). Many recommendations to reduce bear mortality were implemented in the national park over the course of the study, so the key area for management will be the regions bordering Kluane.

Source-like areas have high productivity and high survival. Attractive sinks may rely on source-like BMUs to sustain bear populations (Doak 1995). The dual role of source-like BMUs in producing individuals for recruitment within and supplying emigrants to other BMUs substantiates a priority need for protecting these areas (Knight et al. 1988; Doak 1995). Furthermore, with the high prevalence of attractive sink-like BMUs, management actions should be taken to reduce potential degradation of source-like BMUs. Management actions for preventing impacts on these BMUs would be similar to those for attractive sinks, though the current distance of these areas from human habitation offers de facto protection to bears (table 1).

Large carnivores ... are generally not specialized, and pristine conditions are not needed for their continued survival.... the principal factor affecting their abundance is security from human conflict.

In addition to protecting source-like BMUs, the connectivity between source and attractive sink-like BMUs should be a key management concern (Noss 1991). Breaks in connectivity would impede repopulating sink-like BMUs. Kluane's terrain is rugged, and valley bottoms, used by people for recreation, are also likely the primary travel routes for wildlife. This highlights the need for a land-use planning process in the region.

The outlook for Kluane grizzly bears

For this study I examined the cumulative impacts of human activity on grizzly bear habitat and populations in a northern ecosystem containing a protected-area complex. Cumulative impacts are disturbances where the combined effect of more than one human activity on the landscape often has a greater (multiplicative) negative impact than the additive impacts of each activity alone. Global conservation priorities primarily emphasize areas with the highest species richness or areas with species in imminent risk of extinction (Myers et al. 2000). Areas such as Kluane are usually of low concern to conservationists because the public and agencies commonly associate northern terrestrial environments with pristine wilderness (e.g., Ricketts et al. 1999). Though the footprint for human land use is smaller in the north than in southern environments, the latent global extinction risk for places like Kluane is high—some argue as high as that of severely disturbed wildlife habitats in Southeast Asia (Cardillo et al. 2006). With the increasing prevalence of tourism quotas and outright moratoriums on human use in southern parks (e.g., areas closed to public use in Yellowstone National Park), increased demand for a remote wilderness experience, and increased economic development in the north, northern terrestrial ecosystems—including protected areas—are increasingly prone to human-wildlife land use conflicts. Unfortunately, northern ecosystems have less capacity than southern ecosystems to withstand impacts from human land use (Rohde 1992; Cardillo et al. 2006). The paucity of biodiversity and biomass compared with ecosystems south of the 60th parallel means that Yukon ecosystems have poor ecological resilience (Rapoport 1982; Stevens 1989; Peterson et al. 1998). Given the current and emerging human land-use pressures in the north, without proactive attention wildlife populations of species such as grizzly bears will likely experience unsustainable rates of human-caused mortality and habitat loss.

Conservation of large carnivores and conservation of other elements of biodiversity are linked (Linnell et al. 2000; Carroll et al. 2001). In many ecosystems, protecting large carnivores facilitates preservation of other organisms (Noss et al. 1996; Linnell et al. 2000; Carroll et al. 2001). However, the causes of decline for each are not necessarily the same (Woodroffe 2000; Treves and Karanth 2003). Most terrestrial species have experienced population declines because of human-caused habitat change (Brooks et al. 2002). Large carnivores, however, are generally not specialized, and pristine conditions are not needed for their continued survival (Woodroffe 2001). While habitat loss has been cited as a fundamental concern for preserving some bear populations (Mattson and Merrill 2002; Ross 2002), the principal factor affecting their abundance is security from human conflict (Woodroffe 2001; Treves and Karanth 2003). Direct mortality appears to be the primary force driving grizzly bear populations to the brink of extirpation (Mattson et al. 1996b; Linnell et al. 2000; Woodroffe 2001; Benn and Herrero 2002). Roads and other linear access features are often a factor for high rates of human-caused bear mortality because they provide access for hunters, poachers, and others into regions where bears reside (McLellan and Shackleton 1988; Nielsen et al. 2004). Societal tolerance for property damage is often low (Sillero-Zubiri and Laurenson 2001), and fear of human injury or mortality is often high (Kellert et al. 1996; Bath 1998; Røskaft et al. 2003). As such, coexistence may require that there are tracts of land with little to no human access and limited human activity. Valley closures to human activity have become a common tool for grizzly bear conservation in many regions, including Yellowstone and Banff national parks, and restrictions on human access and activity have been successfully applied in places such as Denali National Park.

The Canadian and U.S. national park systems are a primary means of protecting large carnivores in North America; however, most of the protected areas that comprise the systems have not been designed to sustain populations of wide-ranging species (Newmark 1985; Mattson et al. 1996a). Many protected areas, particularly in mountainous regions, do not encompass enough area to provide for the lifetime home range requirements of a minimum viable population of grizzly bears (Weaver et al. 1996; Woodroffe and Ginsberg 1998). Most mountainous national parks are overwhelmingly composed of uninhabitable rock and ice (Banff Bow Valley Study 1996). Protected areas are often designed without linkages to other wildlife populations (Noss et al. 1996). Population status, particularly where bears experience high rates of human-caused mortality, becomes highly precarious with increasing geographical isolation from surrounding populations (Doak 1995). Kluane is unlike most mountain parks: it is contiguous to three other parks, forming the world's largest protected area complex. The approximately 4,000 km² (1,544 mi²) of green-belt in Kluane, which appears inadequate for maintaining a viable bear population, may rely heavily on influxes of bears from these adjacent areas (e.g., Glacier Bay National Park, Alaska). If high mortality rates continue unabated and there is no means to increase the land base for protection of bears, the key may be to focus on corridors and the surrounding source populations. Consequently, interagency dialogue will be a prominent part of grizzly bear conservation for protected areas in this region.

Although the concepts of limiting or reducing human activity in important grizzly bear habitat and keeping corridors traversable for bears appear logical and straightforward, perhaps the most challenging steps will be implementation of new management prescriptions to achieve security for grizzly bears. Humans are not generally accepting of land-use policies that restrict individual liberties (Rutherford and Clark 2005), particularly when economic gains are sacrificed. In the end, grizzly bears may prove to be the ultimate challenge for whether humans can coexist with nature (Kellert et al. 1996). The difficulty of coexisting with large carnivores is less about the carnivores than about societal values and perceptions (Primm and Clark 1996). Grizzly bears are relatively easy to manage; managing people in cooperative ways that give grizzly bear populations reprieve is much more challenging.

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References

Banff Bow Valley Study. 1996. Banff Bow Valley: At the crossroads. Technical report of the Banff Bow Valley Task Force. Prepared for the Honourable Sheila Copps, Minister of Canadian Heritage, Ottawa, Ontario, Canada.

Bath, A. J. 1998. The role of human dimensions in wildlife resource research in wildlife management. Ursus 10:349–355.

Benn, B., and S. Herrero. 2002. Grizzly bear mortality and human access in Banff and Yoho national parks, 1971–98. Ursus 13:213–221.

Boyce, M. S., and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology and Evolution 14:268–272.

Boyce, M. S., M. Turner, J. Fryxell, and P. Turchin. 2003. Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. Ecoscience 10:421–431.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat loss and extinction in the hot spots of biodiversity. Conservation Biology 16:909–923.

Cardillo, M., G. M. Mace, J. L. Gittleman, and A. Purvis. 2006. Latent extinction risk and the future battlegrounds of mammal conservation. Proceedings of the National Academy of Sciences of the United States of America 103:4157–4161.

Carroll, C., R. F. Noss, and P. C. Paquet. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. Ecological Applications 11:961–980.

Clark, T. W., P. C. Paquet, and A. P. Curlee. 1996. Large carnivore conservation in the Rocky Mountains of the United States and Canada. Conservation Biology 10:936–939.

Danby, R. K., and D. S. Slocombe. 2005. Regional ecology, ecosystem geography, and transboundary protected areas in the St. Elias Mountains. Ecological Applications 15:405–422.

Doak, D. F. 1995. Source-sink models and the problem of habitat degradation: General models and applications to the Yellowstone grizzly bear. Conservation Biology 9:1370–1379.

Environment Canada. 1987. Kluane National Park Reserve resource description and analysis. Two volumes. Natural Resource Conservation Section, Environment Canada, Parks, Prairie and Northern Region, Winnipeg, Manitoba, Canada.

Garshelis, D. L. 2000. Delusions in habitat evaluation: Measuring use, selection, and importance. Pages 111–164 *in* L. Boitani and T. K. Fuller, editors. Research techniques in animal ecology: Controversies and consequences. Columbia University Press, New York, New York, USA.

Gibeau, M. S. 1998. Grizzly bear habitat effectiveness model for Banff, Yoho, and Kootenay National Parks, Canada. Ursus 10:235–241.

_______. 2000. A conservation biology approach to management of grizzly bears in Banff National Park, Alberta. Dissertation. Resources and the Environment Program, University of Calgary, Alberta, Canada.

Gibeau, M., S. Herrero, J. Kansas, and B. Benn. 1996. Grizzly bear population and habitat status in Banff National Park. Chapter 6 *in* J. Green, C. Pacas, L. Cornwell, and S. Bayley, editors. Ecological Outlooks Project: A cumulative effects assessment and future outlook of the Banff Bow Valley. Prepared for the Banff Bow Valley Study. Department of Canadian Heritage, Ottawa, Ontario, Canada.

Gibeau, M., S. Herrero, B. N. McLellan, and J. G. Woods. 2001. Managing for grizzly bear security areas in Banff National Park and the central Canadian Rocky Mountains. Ursus 12:121–130.

Hegmann, G. 1995. A cumulative effects assessment of proposed projects in Kluane National Park Reserve, Yukon Territory. Thesis. University of Calgary, Alberta, Canada.

Herrero, S., A. Holcroft Weerstra, R. M. Roth, and L. Wiggins. 1993. The conservation significance of bears and their habitat in the Tatshenshini River Valley. Canadian Wildlife Federation, Ottawa, Ontario, Canada.

Hobbs, N. T., and T. A. Hanley. 1990. Habitat evaluation: Do use/availability data reflect carrying capacity? Journal of Wildlife Management 54:515–522.

Jingfors, K. 1990. Some important wildlife use areas in the Champagne-Aishihik traditional band area. Kent Jingfors Consulting Ltd., Whitehorse, Yukon Territory, Canada.

Kellert, S. R., M. Black, C. R. Rush, and A. J. Bath. 1996. Human culture and large carnivore conservation in North America. Conservation Biology 10:977–990.

Knight, R. R., B. M. Blanchard, and L. E. Eberhardt 1988. Mortality patterns and population sinks for Yellowstone grizzly bears, 1973–85. Wildlife Society Bulletin 16:121–125.

Linnell, J. D. C., J. E. Swenson, and R. Andersen. 2000. Conservation of biodiversity in Scandinavian boreal forests: Large carnivores as flagships, umbrellas, indicators, or keystones? Biodiversity and Conservation 9:857–868.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: Statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht, Netherlands.

Maraj, R. 2007. Evaluating the ecological consequences of human land use on grizzly bears in the Southwest Yukon, Canada. Dissertation. Faculty of Environmental Design, University of Calgary, Alberta, Canada.

Mattson, D. J., S. Herrero, R. G. Wright, and C. M. Pease. 1996a. Designing and managing protected areas for grizzly bears: How much is enough? Pages 133–163 *in* R. G. Wright, editor. National parks and protected areas: Their role in environmental protection. Blackwell Science, Cambridge, Massachusetts, USA.

_______. 1996b. Science and management of Rocky Mountain grizzly bears. Conservation Biology 10:1013–1025.

Mattson, D. J., and T. Merrill. 2002. Extirpations of grizzly bears in the contiguous United States, 1850–2000. Conservation Biology 16:1123–1136.

McCann, R. K. 1998. Kluane National Park Grizzly Bear Research Project: Interim report to accompany the project review, October 21 and 22, 1998. Draft. Centre for Applied Conservation Biology, University of British Columbia, Vancouver, Canada.

McLellan, B. N. 1994. Density dependent population regulation of brown bears. Pages 15–24 *in* M. Taylor, editor. Density dependent population regulation in black, brown, and polar bears. Ninth International Conference on Bear Research and Management, 23–28 February 1992, Missoula, Montana. Monograph Series No. 3. International Association for Bear Research and Management. Prepared for publication by U.S. National Park Service, Yellowstone National Park, Wyoming, USA.

McLellan, B. N., and D. M. Shackleton. 1988. Grizzly bears and resource extraction: Effects of roads on behavior, habitat use and demography. Journal of Applied Ecology 25:451–460.

Mitchell, M. S., and R. A. Powell. 2003. Linking fitness landscapes with the behavior and distribution of animals. Pages 93–124 *in* J. A. Bissonette and I. Storch, editors. Landscape ecology and restoration management: Linking theory with practice. Island Press, Washington, D.C., USA.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hot spots for conservation priorities. Nature 403:853–858.

Naves, J., T. Wiegand, E. Revilla, and M. Delibes. 2003. Endangered species constrained by natural and human factors: The case of brown bears in northern Spain. Conservation Biology 17:1276–1289.

Newmark, W. D. 1985. Legal and biotic boundaries of western North American national parks: A problem of congruence. Biological Conservation 33:197–208.

Nielsen, S. E. 2005. Habitat ecology, conservation, and projected population viability of grizzly bears (*Ursus arctos* L.) in west-central Alberta, Canada. Dissertation. Environmental Biology and Ecology, Department of Biological Sciences, University of Alberta, Edmonton, Canada.

Nielsen, S. E., M. S. Boyce, and G. B. Stenhouse. 2003. Development and testing of phenologically driven grizzly bear habitat models. Ecoscience 10:1–10.

Nielsen, S. E., S. Herrero, M. S. Boyce, B. Benn, R. D. Mace, M. L. Gibeau, and S. Jevons. 2004. Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation 120:101–113.

Noss, R. F. 1991. Landscape connectivity: Different functions at different scales. Pages 27–39 *in* W. E. Hudson, editor. Landscape linkages and biodiversity. Island Press, Washington, D.C., USA.

Noss, R. F., H. B. Quigley, M. G. Hornocker, T. Merrill, and P. C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology 10:949–963.

O'Neil, L. J., and A. B. Carey. 1984. When habitats fail as predictors. Pages 207–209 *in* J. Verner, M. Morrison, and C. J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, USA.

Paquet, P. C., J. Wierzchowski, and C. Callaghan. 1996. Effects of human activity on gray wolves in the Bow River Valley, Banff National Park, Alberta. Chapter 7 *in* J. Green, C. Pacas, L. Cornwell, and S. Bayley, editors. Ecological Outlooks Project: A cumulative effects assessment and future outlook of the Banff Bow Valley. Prepared for the Banff Bow Valley Study. Department of Canadian Heritage, Ottawa, Ontario, Canada.

Peterson, G., C. R. Allen, and C. S. Holling. 1998. Ecological resilience, biodiversity, and scale. Ecosystems 1:6–18.

Primm, S. A., and T. W. Clark. 1996. Making sense of the policy process for carnivore conservation. Conservation Biology 10:1036–1045.

Purves, H., and C. Doering. 1998. Grizzly bear habitat effectiveness: Assessing cumulative effects of human use in Jasper National Park. ESRI International User Conference proceedings, San Diego, California, USA.

Purvis, A., J. L. Gittleman, G. Cowlishaw, and G. M. Mace. 2000. Predicting extinction risk in declining species. Proceedings of the Royal Society B: Biological Sciences 267:1947–1952.

Rapoport, E. H. 1982. Areography: Geographical strategies of species. Pergamon Press, New York, New York, USA.

Ricketts, T. H., E. Dinerstein, D. M. Olson, C. J. Loucks, W. Eichbaum, D. Della Sala, K. Kavanagh, P. Hedao, P. T. Hurley, K. M. Carney, R. Abell, and S. Walters. 1999. Terrestrial ecoregions of North America: A conservation assessment. Island Press, Washington, D.C., USA.

Rohde, K. 1992. Latitudinal gradients in species diversity: The search for the primary cause. Oikos 65:514–527.

Røskaft, E., T. Bjerke, B. Kaltenborn, J. D. C. Linnell, and R. Andersen. 2003. Patterns of self-reported fear towards large carnivores among the Norwegian public. Evolution and Human Behavior 24:184–198.

Ross, P. I. 2002. Updated COSEWIC status report on the grizzly bear *Ursus arctos* in Canada. Pages 1–91 *in* COSEWIC Assessment and Update Status Report on the Grizzly Bear *Ursus arctos* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario, Canada.

Russell, G. J., T. M. Brooks, M. M. McKinney, and C. G. Anderson. 1998. Present and future taxonomic selectivity in bird and mammal extinctions. Conservation Biology 12:1365–1376.

Rutherford, M. B., and T. W. Clark. 2005. Coexisting with large carnivores: Lessons from Greater Yellowstone. Pages 271–276 *in* T. W. Clark, M. B. Rutherford, and D. Casey, editors. Coexisting with large carnivores: Lessons from Greater Yellowstone. Island Press, Washington, D. C., USA.

Sillero-Zubiri, C., and M. K. Laurenson. 2001. Interactions between carnivores and local communities: Conflict or coexistence? Pages 282–312 *in* J. L. Gittleman, S. M. Funk, D. W. MacDonald, and R. K. Wayne, editors. Carnivore conservation. Conservation Biology (No. 5). Cambridge University Press, Cambridge, UK.

Stenhouse, G., J. Dugas, J. Boulanger, D. Hobson, and H. Purves. 2003. Grizzly bear cumulative effects assessment model review for the Regional Carnivore Management Group. Foothills Model Forest, Hinton, Alberta, Canada.

Stevens, G. C. 1989. The latitudinal gradients in geographical range: How so many species coexist in the tropics. American Naturalist 133:240–256.

Treves, A., and K. U. Karanth. 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conservation Biology 17:1491–1499.

Tyre, A. J., H. P. Possingham, and D. B. Lindenmayer. 2001. Inferring process from pattern: Can territory occupancy provide information about life history parameters? Ecological Applications 11:1722–1737.

USDA Forest Service. 1990. CEM—A model for assessing effects on grizzly bears. U.S. Department of Agriculture Forest Service, Missoula, Montana, USA.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893–901.

Weaver, J. L., P. C. Paquet, and L. F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology 10:964–976.

Woodroffe, R. 2000. Predators and people: Using human densities to interpret declines of large carnivores. Animal Conservation 3:165–173.

________. 2001. Strategies for carnivore conservation: Lessons from contemporary extinctions. Pages 61–92 *in* J. L. Gittleman, S. M. Funk, D. W. MacDonald, and R. K. Wayne, editors. Carnivore conservation. Conservation Biology (No. 5). Cambridge University Press, Cambridge, UK.

Woodroffe, R., and J. R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126–2128.

Yukon Territorial Government. 2003. Unpublished data. Department of Environment, Whitehorse, Yukon Territory, Canada.

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