Spring 2009 • Volume 26 • Number 1 www.nature.nps.gov/ParkScience

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

RESEARCH OF THE CANON NATIONAL PARKS SCIENCE SCHOLARS PROGRAM

Contributions to protected area conservation

- Biological sciences
- Physical sciences
- Social / cultural sciences
- Technology innovation

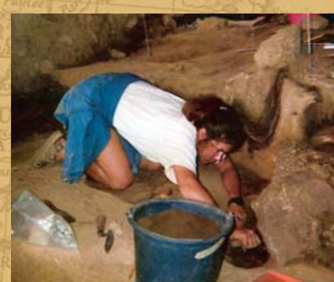












PARKScience

Integrating Research and Resource Management in the National Parks

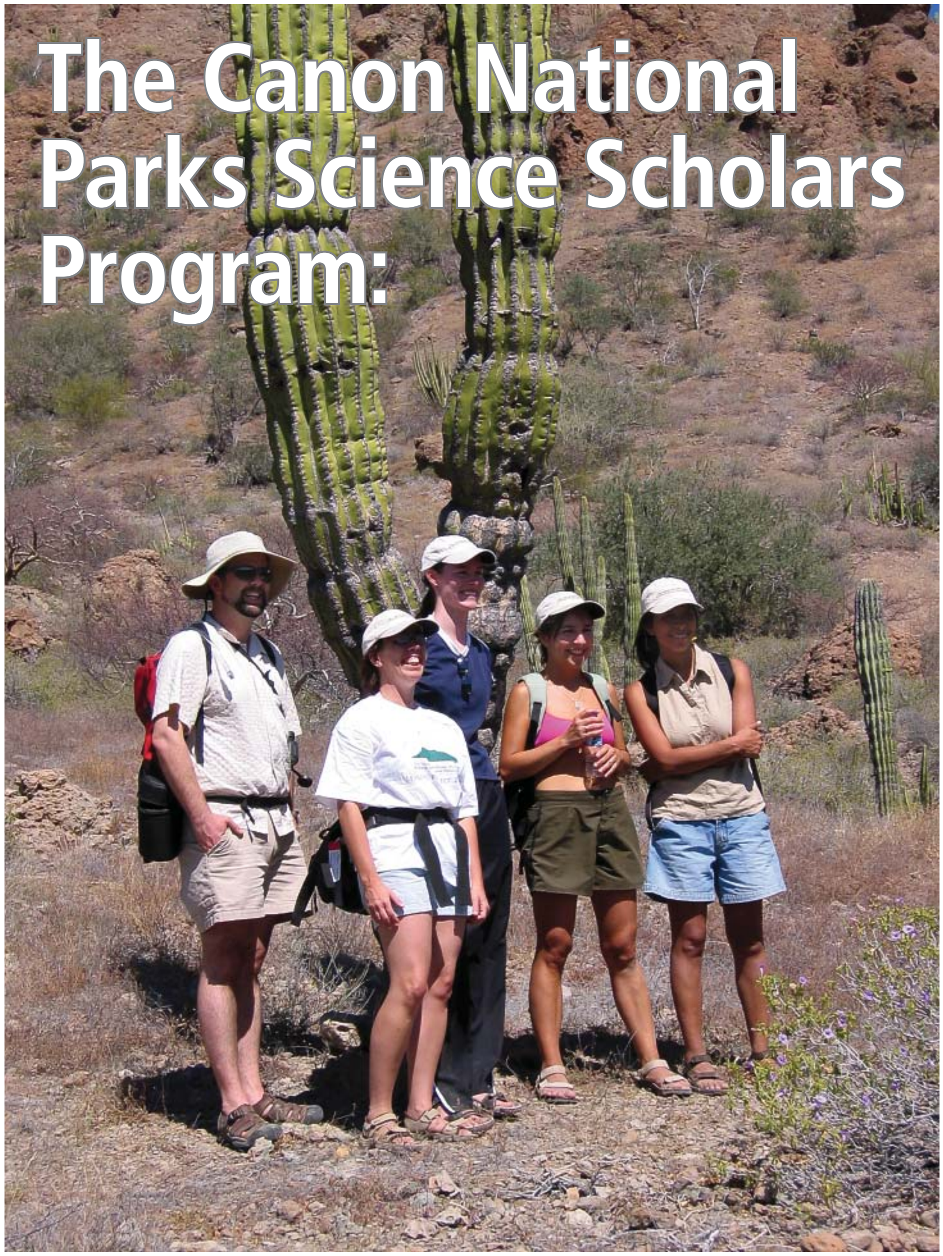
Volume 26 • Number 1 • Spring 2009
www.nature.nps.gov/ParkScience
ISSN 0735–9462

Published by
U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Lakewood, Colorado

Editorial office
Jeff Selleck
National Park Service
NRPC/OEO
P.O. Box 25287
Denver, CO 80225-0287

E-mail: jeff_selleck@nps.gov
Phone: 303-969-2147
Fax: 303-987-6704

From the Guest Editors



The Canon National Parks Science Scholars Program:

COURTESY OF THE CANON NATIONAL PARKS SCIENCE SCHOLARS PROGRAM

A legacy of science for national parks

AN URGENT NEED THROUGHOUT THE AMERICAS and the world is to better understand how to preserve the natural and cultural resources of national parks for future generations. Hence, educating and preparing the next generation of conservation scientists is a vital responsibility. These scientists will learn, discover, invent, and create solutions to preserve national parks in the 21st century. In 1997, Canon U.S.A., Inc., the National Park Service (NPS), and the American Association for the

Advancement of Science (AAAS) collaborated and created the Canon National Parks Science Scholars Program to help address these important challenges. Canon generously supported this program for more than a decade. The program awarded scholarships to more than 75 doctoral students who conducted research in more than 90 national parks throughout the Americas. Today, program alumni work in academia, the private sector (including nongovernmental organizations), and government. This theme issue of *Park Science* highlights the research activities of selected Canon Scholars and the difference they are making in science and conservation.

About the program

The program's mission was "to encourage the best and brightest graduate students in all relevant disciplines to conduct research important to the future of national parks, expand scientific knowledge concerning conservation and sustainability and share this knowledge broadly, develop future world leaders in science and conservation, demonstrate *kyosei* [coming together for the common good] in an innovative partnership, and help preserve the national parks of the 21st century." Originally, the program awarded scholarships to doctoral students studying in national parks in the United States. Beginning in 2002, the program expanded to include students in all countries of the Americas—Canada, United States of America, Mexico, and countries in Central and South America and the Caribbean.

Because much of the science important to national parks crosses traditional academic disciplines, scholarships covered four broad categories: (1) biological sciences, (2) physical sciences, (3) social/cultural sciences, and (4) technology innovation in support of conservation. The program awarded eight scholarships each year—four to students studying at universities in the United States and four to students studying at universities in other countries throughout the Americas. A significant portion of each student's research had to be in, or directly relevant to, a national park in the country in which he or she had citizenship. AAAS organized and led the annual international scientific review panels that selected the winners, administered the scholarship funds, and participated in program activities.

Each scholar received funding to support his or her doctoral research and complete a dissertation within three years. The total award amount for each scholar—$75,000 beginning in 1997, increased to $80,000 over the period of the program—went toward tuition, books, fieldwork expenses (including research assistants), equipment and supplies needed to complete the research project, laboratory expenses, travel to field sites and scientific meetings, and a student stipend. In addition to their scholarships, Canon Scholars participated in intensive science retreats held over the years at Yellowstone National Park, Wyoming; Williamsburg, Virginia; Washington, D.C.; Vieques, Puerto Rico; Bay of Loreto National Marine Park, Mexico; Waterton-Glacier International Peace Park, Canada; and Grand Canyon National Park, Arizona.

About this issue

The purpose of this issue of *Park Science* is to assemble examples of the scientific research through which Canon Scholars are making a difference in the future of national parks. Four guest editors prepared this special edition: Jean McKendry, the program's coordinator; Andrew Bunn, a Canon Scholar in 2001; Patricia Illoldi-Rangel, a Canon Scholar in 2002; and Gary Machlis, the program's director. Program alumni contributed to several sections of this issue; 12 alumni authored research articles. The research articles are organized around the four program categories and reflect the broad diversity of research in which Canon Scholars are engaged. Guest editors Bunn and Illoldi-Rangel summarized selected peer-reviewed articles (see Information Crossfile department) published elsewhere. Elizabeth Brusati, a Canon Scholar in 2001, also contributed to Information Crossfile. Alice Wondrak-Biel, a Canon Scholar in 1999, reviewed the book *Yellowstone denied: The life of Gustavus Cheyney Doane*.

The biological and physical science articles illustrate the opportunities that national parks provide to make fundamental contributions

MASTHEAD (CONT'D FROM PAGE 2)

Park Science is a research and resource management bulletin of the U.S. National Park Service. It serves a broad audience of national park and protected area managers and scientists and provides public outreach. Published twice a year in spring and fall with occasional supplementary issues, *Park Science* reports the implications of recent and ongoing natural and social science and related cultural research for park planning, management, and policy. Thematic issues that explore a topic in depth are published occasionally. 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. The publication is funded by the Associate Director for Natural Resource Stewardship and Science through the Natural Resource Preservation Program.

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.

Facts and views expressed in *Park Science* are the responsibility of the authors and do not necessarily reflect opinions or policies of the National Park Service. Mention of trade names or commercial products does not constitute an endorsement or recommendation by the National Park Service.

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, key word searching, an archive 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

Lundquist, J., and J. Roche. 2009. Climate change and water supply in western national parks. Park Science 26(1):31–34.

Printed on recycled paper.

FROM THE GUEST EDITORS (CONT'D)

to science. They also highlight the stresses that parks face in a changing world. The articles from these two sections cover a breadth of scientific disciplines that would never be brought together at traditional scientific conferences.

The articles in the social/cultural sciences emphasize the importance of people in the preservation and management of national parks. While research on park visitors has become more common, equally significant is research that focuses on park employees, partners, and local residents (present and past). The articles in this section exemplify these topics.

The articles about technology innovation in support of conservation illustrate how contemporary park research and management activities can substantially benefit from scientific advances in technology fields not traditionally associated with national parks.

Conclusion

For more than a decade, the Canon National Parks Science Scholars Program encouraged graduate students to conduct research important to the future of national parks. Many Canon Scholars are now teaching and mentoring a new generation of conservation scientists. The program's legacy is significant yet not fully realized. The need to expand the role of science in national parks continues, and we hope that support for additional national parks science scholars will continue in the future. This special issue of *Park Science* illustrates the diversity of scientific talent that is both needed and available to meet the equally diverse challenges of park management and conservation now and in the future.

The guest editors thank Michael Soukup, former associate director, Natural Resource Stewardship and Science, National Park Service (retired), and Shirley Malcom, director, Education and Human Resources Programs, American Association for the Advancement of Science, for their extraordinary commitment to the success of the Canon Scholars and training the next generation of conservation scientists. We also express our gratitude to the Canon U.S.A., Inc., executives and employees who so enthusiastically supported the program.

—Jean E. McKendry, Andrew G. Bunn, Patricia Illoldi-Rangel, and Gary E. Machlis

Jean E. McKendry *is principal scientist in the College of Natural Resources at the University of Idaho and can be reached at jeanm@uidaho.edu.* ***Andrew G. Bunn*** *is assistant professor in the Department of Environmental Sciences, Huxley College, Western Washington University, and can be reached at andrew.bunn@wwu.edu.* ***Patricia Illoldi-Rangel*** *is a postdoctoral student in the Biocultural and Biodiversity Lab, University of Texas at Austin, and professor in the Faculty of Sciences, National Autonomous University of Mexico, and can be reached at pilloldi@ibunam2.ibiologia.unam.mx.* ***Gary E. Machlis*** *is professor of conservation in the College of Natural Resources at the University of Idaho and visiting senior scientist for the National Park Service and can be reached at gmachlis@uidaho.edu.*

Contents

COURTESY OF VICTOR BONITO

DAVID TATIN

NPS/JAMES ROCHE

DEPARTMENTS

From the Guest Editors 2

In This Issue 7

Information Crossfile 8
Journal articles summarized by Canon Scholars about the work of their Canon Scholar colleagues

Book Review 12
Yellowstone denied: The life of Gustavus Cheyney Doane

ON THE COVER

The photo mosaic samples the more than 75 men and women who have undertaken research projects in national parks and protected areas over the past 10 years with the support of the Canon National Parks Science Scholars Program. This issue of *Park Science* summarizes a selection of their discoveries in the areas of biological, physical, social, and cultural sciences, as well as technology innovation.

PHOTOS: COURTESY OF THE CANON NATIONAL PARKS SCIENCE SCHOLARS PROGRAM. *MAP:* LIBRARY OF CONGRESS, GEOGRAPHY AND MAP DIVISION

RESEARCH REPORTS

Biological Sciences

Science for parks / parks for science: Conservation-based research in national parks 14
Author uses his research on invasive species to highlight the importance of parks to science.
By Andrew V. Suarez

The rock and ice problem in national parks: An opportunity for monitoring climate change impacts 17
Research examines opportunities to study the effects of climate change on the physical, floral, and faunal components of alpine systems.
By Andrew G. Bunn

1,000 feet above a coral reef: A seascape approach to designing marine protected areas 22
Investigators apply terrestrial landscape ecology principles to managing coral reef ecosystems.
By Rikki Grober-Dunsmore, Victor Bonito, and Thomas Frazer

Management strategies for keystone bird species: The Magellanic woodpecker in Nahuel Huapi National Park, Argentina 27
A flagship species helps guide ecosystem management in the forests of southern Argentina and Chile.
By Valeria Ojeda

Physical Sciences

Climate change and water supply in western national parks 31
Authors describe the impacts of warming temperatures on precipitation regimes in the western United States.
By Jessica Lundquist and James Roche

Mercury in snow at Acadia National Park reveals watershed dynamics 35
Research examines deposition in snow in Acadia's forested watersheds.
By Sarah J. Nelson

Organic pollutant distribution in Canadian mountain parks 39
Scientists identify contaminant "hot spots" in Canadian mountain parks.
By Gillian Daly and Frank Wania

DAVID SNYDER

42

COURTESY OF EMILY BROWN

46

COURTESY OF RENATA SOUSA-LIMA

59

FUTURE ISSUES

Summer 2009
Research Reports, State-of-the-Science, Case Studies, Restoration Journal, Features, Profile, At Your Service, and more

Fall 2009
Theme issue: Soundscapes research and management in the National Park System

Spring 2010
Now accepting articles, news, updates, and photographs. Contributor's deadline: November 15, 2009. Visit http://www.nature.nps.gov/ParkScience/ for author guidelines or contact the editor at jeff_selleck@nps.gov or 303-969-2147 to discuss proposals.

PARK SCIENCE ONLINE
www.nature.nps.gov/ParkScience/

- Multimedia files and full tabular data for selected articles
- Complete catalog of back issues
- Key word searching
- Author guidelines
- Editorial style guide
- Share comments on articles
- Manage your subscription

Social / Cultural Sciences

Building an NPS training program in interpretation through distance learning 42
Designed to meet professional competencies, a new distance learning program reaches interpreters, volunteers, concessioners, and other employees.
By Elizabeth R. Barrie and Katie L. Bliss

Musical instruments in the pre-Hispanic Southwest 46
Museum collections from National Park System sites facilitate an understanding of the social and physical contexts of music in pre-Hispanic cultures.
By Emily Brown

Societal dynamics in grizzly bear conservation: Vulnerabilities of the ecosystem-based management approach 50
Author analyzes the human dimensions of bear management in Canada, specifically the need to integrate conservation goals with effective collaborative processes for successful planning and management.
By Douglas Clark

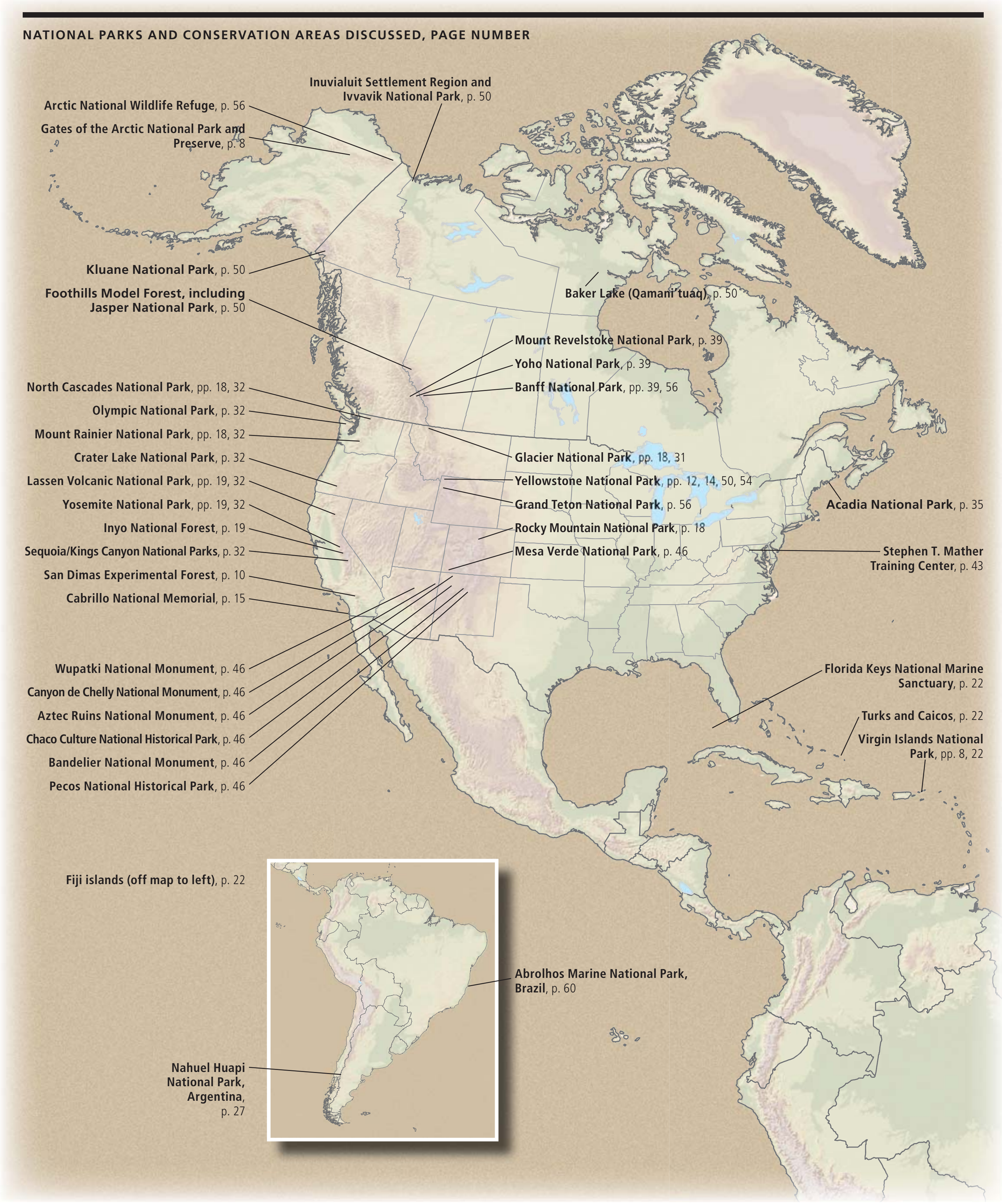
Technology Innovation

Linking wildlife populations with ecosystem change: State-of-the-art satellite ecology for national park science 54
Combined GPS and satellite imagery provide new ways to monitor ecosystem dynamics at geomorphologically large scales.
By Mark Hebblewhite

Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park 59
Using passive acoustic technology, researchers record the movements of whales, assess the impacts of noise from boat tours, and help refine tourism management.
By Renata S. Sousa-Lima and Christopher W. Clark

In This Issue

NATIONAL PARKS AND CONSERVATION AREAS DISCUSSED, PAGE NUMBER



Information Crossfile

(Journal article summaries prepared by Canon Scholars about the work of their Canon Scholar colleagues.)

BY ANDREW BUNN

Andrew Bunn *was a 2001 Canon Scholar from Montana State University, Bozeman. He is an assistant professor in the Department of Environmental Sciences at Western Washington University.*

The importance of research archives in national parks

MANY NATIONAL PARKS CONTAIN detailed records of historical land uses and events. Dedicated historians and archivists compile and archive these records, which helps further the National Park Service's mission. However, one area in Park Service records to which researchers may not have systematic access is the early scientific research done in and around parks. Martin Wilmking and Jens Ibendorf present a short journal article that details the rediscovery of experimental plots used to test theories of tree-line advance in what is now Gates of the Arctic National Park (Alaska). Wilmking and Ibendorf describe their search for Bob Marshall's ecological research plots established in the 1930s. Marshall sowed white spruce (*Picea glauca*) seeds in these plots north of the current latitudinal tree line. Using field notes and personal communications with others interested in Marshall's scientific legacy, Wilmking's team rediscovered Marshall's plots, though the trees are no longer living. The plots contain living trees planted by Sam and Billie Wright in 1968, when the plots were last visited.

Wilmking and Ibendorf's article gives an account of the search for the plots and measurements of the trees as well as a short explanation of tree-line advance theories in Marshall's time and our own. The explanation is interesting in its own right. However, even more striking is the article's description of a small but fascinating piece of historical research that Wilmking re-created by reading journals and biographies and through interactions with primary sources. Long-term research is consistently identified as a major lacuna or gap in understanding ecological changes; easy access to historical research and experiments is critical. Indeed, in this case, both documents and natural resources served as valuable archives. The national parks have a real opportunity for making these documents accessible to today's scientists.

Reference

Wilmking, M., and J. Ibendorf. 2004. An early tree-line experiment by a wilderness advocate: Bob Marshall's legacy in the Brooks Range, Alaska. Arctic 57:106–113.

Martin Wilmking *was a 2000 Canon Scholar from the University of Alaska, Fairbanks. He is a research group leader at University Greifswald in Germany and an affiliate research professor in the Forest Sciences Department of the University of Alaska, Fairbanks.*

■ ■ ■

Can marine reserves enhance fishery yield?

WITH MANY FISHERIES UNDER MOUNTING PRESSURE, the use of marine reserves as a strategy for enhancing fishery yields is becoming more popular. However, empirical data on the effectiveness of this strategy are rare, as is often the case with fishery data. This lack of data leads scientists and managers to rely on modeling to determine the efficacy of marine reserves in enhancing commercially harvested fish populations. A recent paper by Crow White and Bruce Kendall in *Oikos* describes two influential fishery science papers that come to different conclusions regarding the use of marine reserves—whether the reserves provide "equivalence at best" or "potentially improved" yield—and provide a third model analysis suggesting that reserves can substantially benefit yield in fisheries with post-dispersal density dependence, where crowding tends to increase deaths and decrease births after dispersal.

Simply put, all models are not created equal; understanding a model's assumptions and what questions a particular model is good at asking is very difficult for the uninitiated.

For managers, this journal article emphasizes a classic dilemma in understanding and applying modeling studies. Simply put, all models are not created equal; understanding a model's assumptions and what questions a particular model is good at asking is very difficult for the uninitiated. Furthermore, inventorying and monitoring underwater resources are hard for marine reserves managers. One of the few tools available to them is the judicious use of models. The progress made by White and Kendall in better understanding the links between management of protected areas and resource extraction helps push the field forward.

Reference

White, C., and B. E. Kendall. 2007. A reassessment of equivalence in yield from marine reserves and traditional fisheries management. Oikos 116:2039–2043.

__Crow White__ was a 2005 Canon Scholar from the University of California, Santa Barbara. He is a postdoctoral research fellow with the Marine Science Institute in the Department of Ecology, Evolution, and Marine Biology at the University of California, Santa Barbara.

▪ ▪ ▪

BY ELIZABETH BRUSATI

__Elizabeth Brusati__ was a 2001 Canon Scholar from the University of California, Davis. She is a project manager with the California Invasive Plant Council.

How far should a marine protected area extend to provide refuge for fish near coral reefs?

MARINE PROTECTED AREAS PROVIDE a safe place for fish and invertebrates to reproduce without fishing pressure. To design boundaries, managers need to understand how fish respond to habitat patches at the landscape scale. In Virgin Islands National Park (U.S. Virgin Islands), researchers found that reserves must include habitat patches that extend at least 1 kilometer (0.6 mi) away from the reefs.

Habitat diversity is often used to determine reserve boundaries. However, because coral-reef fish vary so much in their habitat requirements, diversity cannot always predict how many fish or which species will use an area. Types of habitat, specifically sea grass, may be more important. *Thalassia testudinum* was the most common species of sea grass in the study area. Sea grass serves as a nursery for juvenile fish and invertebrates. In this study, researchers counted the number of fish in and out of sea-grass patches, classifying them by feeding preference, degree of mobility, and age. The 118 species observed included grunts, groupers, and snappers. Measuring the coverage of sea grass patches with simple geographic information system (GIS) tools and habitat maps provided a good prediction of where the most reef fish would occur. Harvested fish species occurred more often within sea grass patches than outside of those areas. Reefs surrounded by large expanses of sea grass had the most species of fish, although even modest amounts of sea grass made a difference.

Measuring the coverage of sea grass patches with simple . . . GIS tools and habitat maps provided a good prediction of where the most reef fish would occur.

Many species living near the U.S. Virgin Islands are overfished. The correct placement of reserve boundaries is essential in maintaining populations. While sea grass is not the only factor that makes a good reserve, these results show that fish must be able to move among sea grass patches in order to keep populations healthy.

Reference

Grober-Dunsmore, R., T. K. Frazer, W. J. Lindberg, and J. Beets. 2007. Reef fish and habitat relationships in a Caribbean seascape: The importance of reef context. Coral Reefs 26:201–216.

__Rikki Grober-Dunsmore__ was a 2002 Canon Scholar from the University of Florida. She is an associate professor at the Institute for Applied Sciences at the University of the South Pacific in Fiji, South Pacific Islands.

▪ ▪ ▪

Effects of increased nitrogen deposition in wilderness areas

URBANIZATION IN THE SOUTHWEST and associated air pollution from cities such as Los Angeles, Phoenix, and Denver have led to atmospheric nitrogen deposition in adjacent ecosystems and elevated nitrate levels in stream networks. Few studies have examined the added impact of disturbance, specifically fire, on hydrologic and biogeochemical processes against this background of elevated atmospheric deposition in southern California. Understanding the extent to which fire may reduce nitrate concentrations and improve water quality in these semiarid areas is important, particularly because prescribed fire is often used as a management tool in such fire-influenced ecosystems.

The authors investigated the effects of fire on nitrate levels in streams in chaparral ecosystems within the San Dimas Experimental Forest, located 40 kilometers (25 mi) northwest of Los Angeles. This site allowed comparisons of nitrate concentrations in an unburned area (control) with concentrations in a prescribed-burn area over a 15-year period. Fire was expected to improve water quality by releasing accumulated nitrogen and reducing nitrate levels in streams. However, the results of this study indicate that such a response did not occur in this ecosystem. After an initial, dramatic increase in the export of nitrogen immediately following the burn, the concentration of nitrates remained higher for a period of seven years in the burned area compared with the unburned area. This postfire behavior differed from response in other ecosystems, e.g., mesic or humid areas, where nitrate levels decline more rapidly and remain low for a longer period following a fire. The authors conclude that prescribed fire in chaparral ecosystems is not effective in ameliorating high nitrogen deposition rates from nearby urban areas and suggest that reducing nitrogen emissions at the source is needed to protect ecosystems from atmospheric pollution, particularly watersheds and streams in wilderness areas.

Reference

Meixner, T., M. E. Fenn, P. Wohlgemuth, M. Oxford, and P. Riggan. 2006. N saturation symptoms in chaparral catchments are not reversed by prescribed fire. Environmental Science and Technology 40:2887–2894.

Thomas Meixner *was a 1997 Canon Scholar from the University of Arizona. He is an associate professor of hydrochemistry in the Department of Hydrology and Water Resources at the University of Arizona.*

■ ■ ■

BY ELIZABETH BRUSATI AND PATRICIA ILLOLDI-RANGEL

Elizabeth Brusati *was introduced on page 9.*

Patricia Illoldi-Rangel *was a 2002 Canon Scholar from the National Autonomous University of Mexico. She is a professor in the Faculty of Sciences at the National Autonomous University of Mexico and a postdoctoral fellow with the Biodiversity and Biocultural Conservation Laboratory at the University of Texas at Austin.*

Ecological traps: Implications for the conservation of animal populations

ACCORDING TO THE ECOLOGICAL THEORY of source-sink dynamics, animals first fill up "sources"—habitat that allows good survival and reproduction—then move into "sinks," less productive habitat. Movement from sources to sinks results in stable populations over time. However, an "ecological trap" can attract animals to lower-quality habitat first, causing the population to decline, even to the point of extinction. Habitats modified by human activities are the most likely to contain ecological traps, but pristine areas may also house them. Many case studies, mostly on birds, have proposed that traps include linear habitat corridors, artificial wetlands, and the entire prairie pothole region of the U.S. Midwest. A specific example is Cooper's hawks (*Accipiter cooperii*) selecting Tucson, Arizona, as a nesting site even though the hawks contract the fatal disease trichomoniasis from eating pigeons there. The inability of organisms to adapt, either behaviorally or evolutionarily, seems to be the most important characteristic leading to their vulnerability to ecological traps. Because of this, ecological traps present a substantial management challenge. Managers are unlikely to be certain of the location, size, and implications of a suspected trap.

If traps do exist, then several questions confront managers: Where are the traps? Which species are most vulnerable? What measures can be used to identify a trap? How can managers incorporate this information into conservation planning? Often traps are found where rapid human-caused changes have occurred. More subtle changes include the expansion of invasive plants that provide poor habitat. Vulnerable species include those that must make quick assessments of habitat quality such as birds arriving on nesting grounds. Species that show little variation in habitat preferences are also at risk. Additionally, gene flow among some populations prevents local adaptation.

Because human-caused landscape changes are now commonplace, managers must take into account the possibility of ecological traps when managing animal population or planning conservation strategies. Any attempt to conserve animal populations, particularly in changing landscapes, may be severely complicated by the presence of ecological traps. Managers might consider solutions that improve habitat quality or discourage animals from settling in poor patches.

Reference

Battin, J. 2004. When good animals love bad habitats: Ecological traps and the conservation of animal populations. Conservation Biology 18:1482–1491.

James Battin was a 2000 Canon Scholar from Northern Arizona University. He works for the National Marine Fisheries Service in a postdoctoral research position at the Northwest Fisheries Science Center in Washington.

▪ ▪ ▪

Alternative approaches to reserve design

SCIENTISTS AND THE PUBLIC HAVE CRITICIZED the establishment of reserves as not promoting the persistence of species, ecosystems, and ecological processes representative of biological diversity. Gonzales et al. (2003) demonstrate the application of newer approaches to systematic reserve design, which could help stakeholders simultaneously maximize ecological, societal, and industrial goals. The authors created example-reserve designs using the simulated annealing algorithm of SITES 1.0 and then contrasted them with a proposed multi-stakeholder process for British Columbia's central coast. Without increasing land area or timber volume, the strategic approach used reserve designs that included greater portions of key conservation elements such as parts of ecosystems or habitats identified by stakeholders.

The example designs are a work in progress and do not represent final results. The approaches shown are scientifically repeatable and allow modifications as new information is obtained. Simulations can be conducted rapidly, to facilitate workshop formats, or compiled in a manner to prioritize conservation planning units. The authors strongly recommend that strategic approaches to reserve design be used both to provide focus and to catalyze planning discussions. These tools should encourage planning teams to review and modify proposed designs based on theory, natural history information, and local and traditional knowledge. Applying such tools in cases that involve complex sets of biological, social, economic, and political goals and constraints should make planning processes more explicit, repeatable, and defensible.

These tools should encourage planning teams to review and modify proposed designs based on theory, natural history information, and local and traditional knowledge.

Reference

Gonzales, E. K., P. Arcese, R. Schulz, and F. L. Bunnell. 2003. Strategic reserve design in the central coast of British Columbia: Integrating ecological and industrial goals. Canadian Journal of Forest Resources 33:2129–2140.

Emily K. Gonzales was a 2004 Canon Scholar from the University of British Columbia in Canada. She works as an ecosystem scientist/park ecologist at St. Lawrence Islands National Park in Mallorytown, Ontario.

The role of genetics in understanding landscape-level ecological processes

SPATIAL AND TEMPORAL LANDSCAPE PATTERNS across ecosystems have long been known to influence biological processes, but these processes often operate at scales that are difficult to study. The use of alternative methods like genetic markers can become a useful aid in the study of such patterns in ecology. Researchers can use a landscape-genetics approach to test hypotheses, as the authors did with the Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*). They employed microsatellite DNA variation in a complex stream network in the Great Basin region of the western United States. Their analyses reflected patterns of dispersal, population stability, and local effective population sizes. In addition, the authors found that trout populations presumed to have greater proportions of migratory individuals or to originate from physically connected, large, or high-quality habitats had higher genetic variability and lower genetic differentiation than other populations. However, the opposite pattern was found in populations thought to contain largely nonmigratory individuals, suggesting behavioral isolation. Estimated effective sizes were small, and the authors identified significant and severe genetic bottlenecks in several populations that were isolated, recently founded, or that inhabited intermittent streams. Their results show the importance of grounding genetic inferences in ecological hypotheses and predictions, but also demonstrate that genetic patterns can reveal processes that may be quite unexpected.

Reference

Neville, H. M., J. B. Dunham, and M. M. Peacock. 2006. Landscape attributes and life history variability shape genetic populations in a stream network. Landscape Ecology 21:901–916.

Helen M. Neville was a 1999 Canon Scholar from the University of Nevada, Reno. She is a research scientist with Trout Unlimited in Boise, Idaho.

Book Review

Yellowstone denied: The life of Gustavus Cheyney Doane

By Kim Allen Scott
University of Oklahoma Press, 2007
305 pages
ISBN 0806138009

Reviewed by Alice Wondrak Biel, *Devils Tower, Wyoming, author of* Do (not) feed the bears: The fitful history of wildlife and tourists in Yellowstone. *Alice Wondrak Biel was a 1999 Canon Scholar from the University of Colorado–Boulder. She is working with the NPS Intermountain Region Inventory and Monitoring Program as a writer-editor and can be reached at Alice_Wondrak_Biel@nps.gov.*

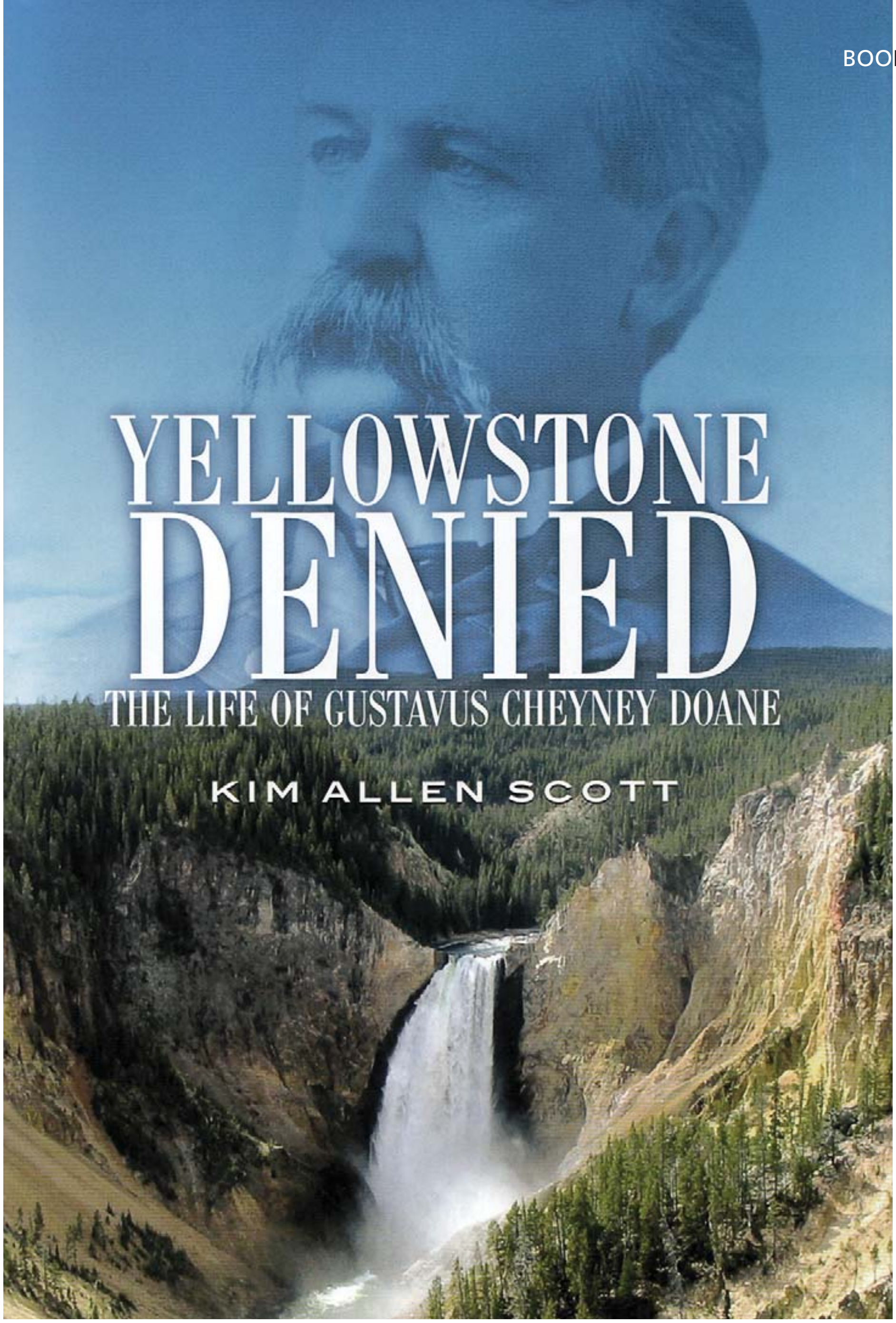
KIM ALLEN SCOTT'S *Yellowstone denied: The life of Gustavus Cheyney Doane* is a gem: an engaging, informative account of a man who has largely escaped popular notice and was devastated because of it. Doane, best known for his participation in the Washburn-Langford-Doane expedition into Yellowstone in 1870, was a career U.S. Cavalryman consumed by a single-minded pursuit of fame in the waning days of American exploration. Coupled with an uncanny knack for being in the wrong place at the wrong time and an unbecoming sense of entitlement, Doane's thirst for recognition had profound negative effects on both his professional and personal lives.

A string of failures

Scott describes Doane's career as "star-crossed" (p. 263), clearly an apt term. After a largely obscure Civil War career—in which his carefully cultivated connections ultimately got him placed with a brigade whose primary activities seemed to be mutiny and plunder—his biography is a litany of missed opportunities. In business he was an unsuccessful carpetbagger and inventor; his attempts to persuade the army to purchase and produce his innovative tent design failed largely because of bad timing and unreliable partnerships. His effort to play a significant role in the U.S. Army's Nez Perce campaign was foiled by natural disaster in the form of a ruinous hailstorm. He was appointed the nominal leader of an Arctic expedition, only to have it end in failure and its sponsor exposed as a crook and embezzler. On that expedition, Doane displayed the same Ahab-like determination that had earlier contributed to the equally miserable failure of an ill-advised midwinter reconnaissance down the Snake River. Doane spent the last days of his military career tramping around Arizona as part of the army's Apache campaign.

Successes

Doane did enjoy two great successes in life: a well-written and well-received report on the Yellowstone expedition of 1870, and his marriage to Mary Lee Hunter, his second wife. Doane was tapped to serve as army escort on the Washburn expedition because of his polished writing skills and his loyalty to Major E. M. Baker, perpetrator of a Piegan Indian massacre in which Doane participated. While acting as the Washburn party's scribe, in an irony worthy of Greek tragedy Doane battled a thumb infection that made the act of holding a pencil excruciatingly painful. "In the middle of the opportunity of his life, his thumb threatened to rob him of the ability to record his experiences" (p. 76). Doane's perseverance paid off, however; as Scott attests, "The accolades that Doane received on his [Yellowstone] report marked the high-water point of his life" (p. 83). The success of his report awakened in Doane a desire to forever be remembered



COPYRIGHT UNIVERSITY OF OKLAHOMA PRESS

in connection with Yellowstone National Park, and he devoted substantial amounts of time and resources to achieving that goal. Most of all, he coveted, but was never granted, the park's superintendency. Throughout these efforts, he was supported by Mary, in whom he found lasting companionship and loyalty.

Yellowstone finally realized

This book, largely informed by archival documents, could have been dry, but is not. Scott has written a hugely engaging account with a little something for everyone interested in Yellowstone history, military history, or American frontier history. *Yellowstone denied* is also an excellent book for those who understand the pull that Yellowstone country can exert on the soul. Perhaps this is why, even with full knowledge that Doane never became superintendent of Yellowstone and that he was an unpleasant person, readers may find themselves rooting for him to succeed in his quest, or at least to achieve the widely recognized association with the park that he so desperately craved.

If the book has a shortcoming, it is that the author sometimes gets a bit ahead of his narrative, characterizing Doane as self-aggrandizing and hungry for glory before fully allowing him, through his letters and other documents, to reveal those traits himself. This leaves the reader, early on, to wonder if the author is not being a bit harsh, although in time it becomes clear that Scott is right about Doane. Doane's papers and actions are themselves lively, revealing, and transparent enough to reveal his true character without the author's assistance. However, this is a minor quibble with a very good book a very long time in the making. Scott's epilogue recounts how, long after Doane's 1892 death from influenza, even the writing of his biography was stalled and thwarted because of personalities. In the 1930s, Mary Doane provided her husband's papers to then–Montana State College professor Merrill Burlingame, for purposes of writing Doane's biography. By 1944, Burlingame had rather obstinately refused to produce a manuscript that satisfied his publisher and given up on the project. He subsequently declined to allow any other prospective biographers to access Doane's materials, and then parceled the documents out to different repositories over a number of decades. Burlingame eventually donated the remainder of Doane's papers to Montana State University in the early 1990s, and other remnants have arrived at the university in piecemeal fashion since then. One is left wondering what Doane would have thought of this book, or if he would have simply sighed in relief and satisfaction that his story was finally told at all, his name linked, in its title, forever with that of Yellowstone.

PS

Biological Sciences

COURTESY OF ANDREW SUAREZ

Science for parks / parks for science:
Conservation-based research in national parks

By Andrew V. Suarez

“The use of national parks for the advancement of scientific knowledge is . . . explicit in basic legislation. National Parks, preserved as natural comparatively self-contained ecosystems, have immense and increasing value to civilization as laboratories for serious basic research. Few areas remain in the world today where the process of nature may be studied in a comparatively pure natural situation.” (from Wagner and Kay 1993)

IN ADDITION TO PROVIDING VISITORS with the opportunity to appreciate natural scenery and wildlife, national parks have a long history of scientific research, dating back to the establishment of Yellowstone National Park (Wyoming, Montana, Idaho) in 1872 (Sellars 1997). National parks historically offered unique opportunities for scientists because their ecosystems are largely unmodified relative to the surrounding landscapes. However, national parks are also important to the conservation sciences as we become more aware that they are not “islands” but interact substantially with surrounding environments. The longevity of these invaluable resources will depend heavily on management recommendations and restoration efforts guided in turn by scientific efforts.

Human activities have greatly modified natural ecosystems and threatened biodiversity. One principal mechanism for these threats is the spread of invasive species, characterized by the establishment of species in environments outside of their native range. Their impact is usually measured by the elimination of native species through direct interactions (for example, competition, parasitism, and predation) or indirectly through cascading mechanisms resulting from the loss of keystone species, mutualists, or nutrient availability (Parker et al. 1999; Mack et al. 2000). While national park units are among our most pristine remaining natural resources, they are by no means immune to invasion by nonnative species. In fact, they are increasingly taking a central role as resources for the study of biological invasions.

A change in the type of research conducted within U.S. national parks is reflected in publications of park-based research over three periods (1968–1975, 1985–1987, and 2000–2001). The proportion of journal articles reporting inventories or describing species remained consistent; however, the proportion of articles reporting research that focused on subjects relating to conservation and restoration increased (fig. 1). National parks worldwide have also become increasingly important in research on biological invasions. An online search for “national parks” and “invasion” in the citation database Web of Science® found more than 650 publications, 225 of which were published since 2005.

Conducting research in national parks

National parks are often perceived as closed to scientists, despite the unique opportunities for research they offer. This perception stems largely from National Park Service regulations regarding collections and research. However, these regulations, in the form of applications, annual reports, and the deposition of vouchers in public museums, can facilitate future research and should not be viewed as a hindrance.

One example highlighting the benefits of this process is the Investigator's Annual Report (IAR). This reporting system provides a permanent record of research and scientific information in national parks and is accessible via a search engine on the NPS Web site (http://science.nature.nps.gov/research/ac/ResearchIndex). Investigator's annual reports from all units of the National Park System are compiled to help inform scientists of the parks' collective research activities. This increases the value of research conducted in national parks as well as the importance of these lands as a scientific resource to other researchers, and scientific progress at large. By making these reports available, the National Park Service promotes communication and collaboration among scientists working both within and outside the National Park System. The compilation of investigator's annual reports (and other materials such as voucher specimens) also produces a chronological account of research conducted. These records allow for a careful reconstruction of the park's environmental history and can be used to provide the foundation for current or future work (see Woodroffe and Ginsberg 1998).

This process is illustrated by my own research on invasive ants and lizard communities in Cabrillo National Monument (California). By coordinating research and sampling the same sites, researchers from different agencies and universities were able to link the absence of coastal horned lizards (*Phrynosoma coronatum*) in the monument to the presence of the invasive Argentine ant (*Linepithema humile*). This collaboration, initiated in part by interactions between the researchers and the monument's chief of Natural Resource Science, contributed to the examination of ant invasions as a possible reason for horned lizard decline throughout southern California (Fisher et al. 2002; Suarez and Case 2002).

This early, positive experience in the National Park System continues to shape my research today. After examining the consequences of Argentine ant invasion in southern California, I became interested in the success mechanisms for invasive ants. Most hypotheses for the success of invasive species stem from differences in biology between native and introduced populations (Kolar and Lodge 2001). Subsequently, my research has concentrated on examining the biology of Argentine ants in their native range (Tillberg et al. 2007). Some of my best study sites for examining Argentine ants under natural conditions in their native range have been under the supervision of the Asociación de Parques Nacionales en Argentina (fig. 2).

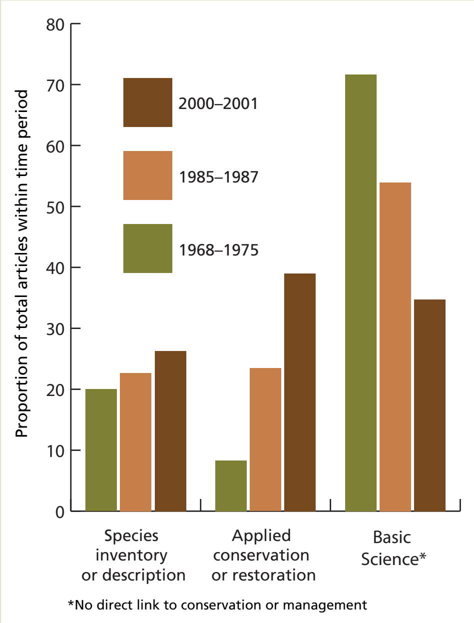


Figure 1. Categories of published studies of biological research conducted in U.S. national parks over three periods. Publication source: JSTOR database (Andrew Mellon Foundation) for 1968–1975; BIOSIS database (Biological Abstracts, Inc.) for 2000–2001 and 1985–1987.

Conclusions

Contrary to historical views that the purpose of national parks in research is primarily to study natural or healthy ecosystems, researchers now also use parks to examine the mechanisms of species loss and decline. Rather than viewing parks merely as large, isolated islands, researchers now consider and study parks as dynamic reserves that interact with their surroundings. Parks are ideal for research because of the quality of historical information and regulations that promote communication and collaboration among scientists and agencies.

The role of the National Park Service as stewards or protectors of this nation's natural resources is more important than ever. The National Park System is a cornerstone in a multiagency reserve system including state parks, Bureau of Land Management areas, national forests, wildlife areas, and other public lands. The amount of land for preserving biodiversity, ecosystem function, and the services they provide (Costanza et al. 1997; Pimentel et al. 1997) is decreasing; science is the common language that will tie together the separate pieces of this national reserve system.

COURTESY OF NEIL TSUTSUI

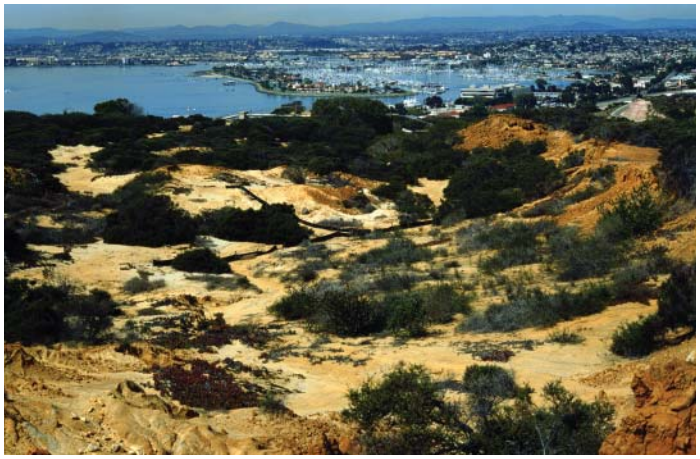


Figure 2. Research on the invasive Argentine ant has benefited from cross-continental comparisons of its biology in its introduced range (Cabrillo National Monument, USA, above) and its native range (Parque Nacional El Palmar, Argentina, page 14). The Argentine ant is able to monopolize plant-based resources in introduced populations while being primarily predatory in its native range. This change in trophic biology may allow Argentine ants to attain higher worker densities in introduced populations (where they displace other ants) relative to their native range where they coexist with other ants in species-rich communities.

Moreover, it has been suggested that park effectiveness in tropical reserves is correlated with basic management activities, indicating that even modest increases in funding might directly increase the ability of park managers to protect biodiversity. The ability to conserve biodiversity and ecosystem function will also improve with increased scientific research.

How do we turn the mantra "science for parks/parks for science" into a reality? The National Park Service and its collaborators can start by focusing on the next generation of scientists, providing opportunities that promote graduate-student research in parks. Positive experiences with the National Park Service early in a career can lead to long-term relationships between national parks and scientists. The value of public lands in science for parks and parks for science will become more apparent as science conducted in national parks continues to benefit both parks and scientists.

Acknowledgments

Samantha Weber and Terry DiMattio at Cabrillo National Monument (USA) and Paula Cichero, Fernanda Menvielle, Gabrielle Lepera, and Silvia Fabri from the Asociación de Parques Nacionales (Argentina) facilitated my own research within national parks. Gary Machlis and Sandy Watson provided valuable discussion, support, and encouragement throughout my tenure as a Canon National Parks Science Scholar. This work was made possible by financial support from the Canon National Parks Science Scholars Program and the National Science Foundation.

Literature cited

Bruner, A. G., R. E. Gullison, R.E. Rice, and G. A. B. da Fonseca. 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291:125–128.

Costanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. vanden Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253–260.

Fisher, R. N., A. V. Suarez, and T. J. Case. 2002. Spatial patterns in the abundance of the coastal horned lizard. Conservation Biology 16:205–215.

Kolar, C. S., and D. M. Lodge. 2001. Progress in invasion biology: Predicting invaders. Trends in Ecology and Evolution 16:199–204.

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. Ecological Applications 10:689–710.

Parker, I. M., D. Simberloff, W. M. Lonsdale, K. Goodell, M. Wonham, P. M. Kareiva, M. H. Williamson, B. Von Holle, P. B. Moyle, J. E. Byers, and L. Goldwasser. 1999. Impact: Toward a framework for understanding the ecological effects of invaders. Biological Invasions 1:3–19.

Pimentel, D., C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff. 1997. Economic and environmental benefits of biodiversity. Bioscience 47:747–757.

Sellars, R. W. 1997. Preserving nature in the national parks. Yale University Press, New Haven, Connecticut, USA.

Suarez, A. V., and T. J. Case. 2002. Bottom-up effects on the persistence of a specialist predator: Ant invasions and coastal horned lizards. Ecological Applications 12:291–298.

Tillberg, C. V., D. A. Holway, E. G. LeBrun, and A. V. Suarez. 2007. Trophic ecology of invasive Argentine ants in their native and introduced ranges. Proceedings of the National Academy of Sciences 104:20,856–20,861.

Wagner, F. H., and C. E. Kay. 1993. "Natural" or "healthy" ecosystems: Are U.S. national parks providing them? Pages 257–270 *in* M. J. McDonnell and S. T. A. Pickett, editors. Humans as components of ecosystems. Springer-Verlag, New York, New York, USA.

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

About the author

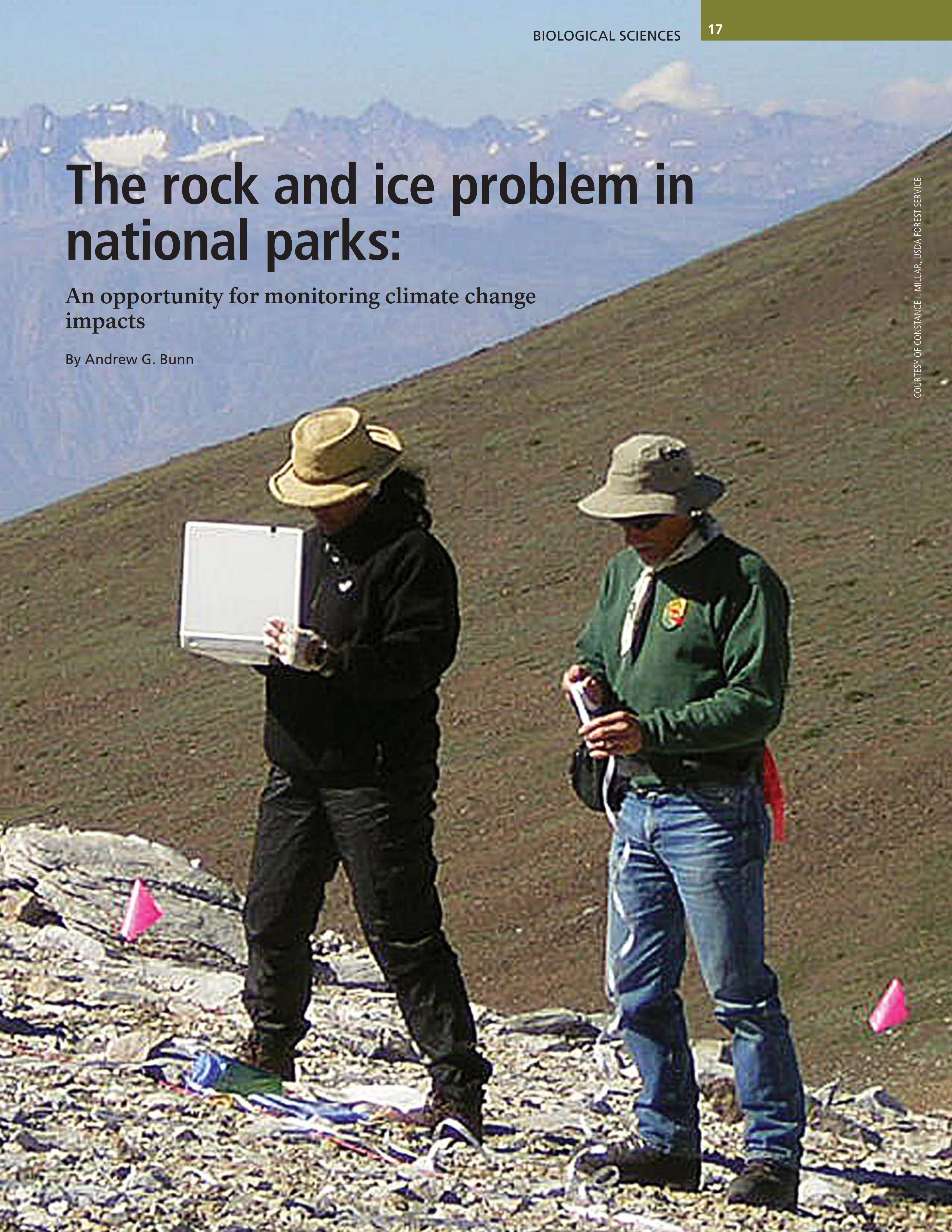
Andrew V. Suarez *was a 1997 Canon Scholar. He completed his dissertation, "Causes and consequences of biological invasions: The Argentine ant in southern California," at the University of California, San Diego, in 2000. He is an assistant professor in the Department of Entomology and the Department of Animal Biology at the University of Illinois, Urbana-Champaign, and can be reached at avsuarez@life.uiuc.edu.*

PS

The rock and ice problem in national parks:

An opportunity for monitoring climate change impacts

By Andrew G. Bunn



COURTESY OF CONSTANCE I. MILLAR, USDA FOREST SERVICE

IN 1979, ALFRED RUNTE ADVANCED THE WORTHLESS-LANDS THESIS (Runte 1979). This loosely posits that the National Park System comprises lands with low economic, and subsequently low ecological, value. The concept is controversial in some respects, but many alpine researchers have acknowledged the "rock and ice problem" in national parks. Certainly, scenic alpine vistas are overrepresented in national park units compared with low-elevation areas with higher primary production, species diversity and richness, and complex ecosystem structure. The National Park Service has a unique chance to use the rock and ice problem as an advantage in understanding climate change, which might be the greatest challenge scientists and society have ever faced (Speth 2005).

The fundamental physics of an enhanced greenhouse effect due to fossil fuel combustion is well understood, and Earth is warming (IPCC 2007). Considerable uncertainty exists regarding the impacts of climate change, but high latitudes and high elevations are thought to be leading indicators of future trends. The suite of high-elevation lands protected by the National Park Service is ideal in terms of documenting and monitoring the physical, floral, and faunal impacts of climate change. Indeed, the network of alpine lands managed by the Park Service in the mountainous western United States spans maritime-to-arid ecosystems over a dozen degrees of latitude (fig. 1). The web grows even farther if we consider alpine park units in Hawaii, Alaska, and the eastern United States. It is a network that has no other analog and offers unparalleled opportunities for global change monitoring.

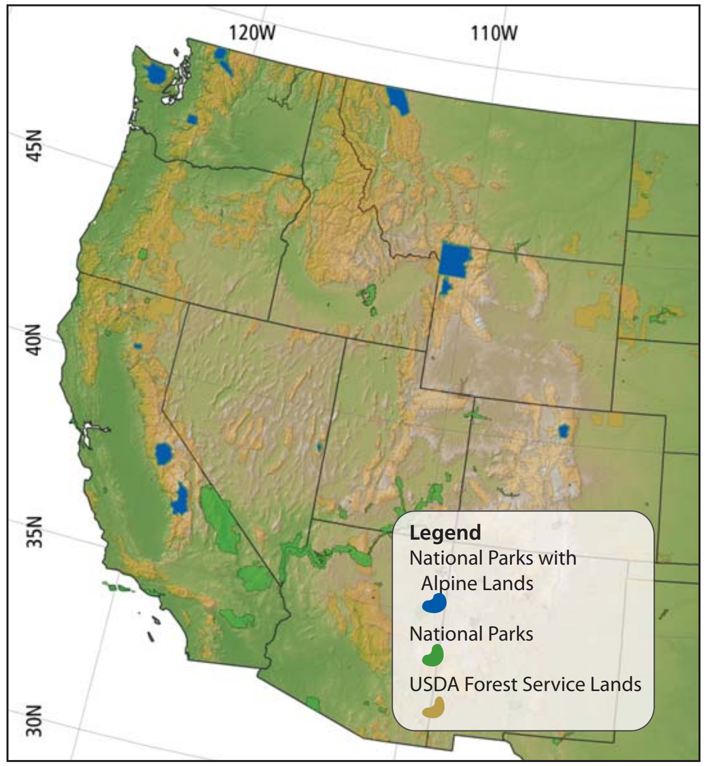


Figure 1. National Park System units in the western conterminous United States contain extensive alpine areas and span maritime-to-arid ecosystems over a dozen degrees of latitude. As part of a suite of high-elevation, protected areas, extensive alpine sites adjacent to park boundaries are managed by the USDA Forest Service and other agencies.

PROJECTION: ALBERS EQUAL AREA CONIC, NAD 83. *DATA SOURCES:* USDA FOREST SERVICE, NATIONAL PARK SERVICE, ESRI, U.S. NATIONAL ATLAS. *CARTOGRAPHER:* JACOB TULLY, WESTERN WASHINGTON UNIVERSITY, GEOGRAPHY DEPARTMENT.

Physical attributes

Glaciers present ideal opportunities to directly measure climate change impacts on alpine areas. Many of the relatively small glaciers in national parks have experienced widespread changes. Some have been measured and photographed over time, yielding aerial estimates of retreat, and some have had more formal studies of mass balance. The retreat of glaciers has been documented with repeat photography most famously in Glacier National Park (Montana) (Key et al. 2002) and also through aerial estimates of glacial ice changes in other national parks, including Kings Canyon (California), Rocky Mountain (Colorado), North Cascades (Washington), and Mount Rainier (Washington) (Fountain 2007; Hoffman et al. 2007).

Although rarer than ice glaciers, rock glaciers provide an intriguing and often overlooked opportunity for climate monitoring. Although their geologic origins are a matter of debate (Whalley and Martin 1992), rock glaciers are essentially fields of underground ice that are covered by rock. The extent of rock glaciers in national park units is poorly known, but they are thought to be retreating like ice glaciers and are critical water supplies for high-elevation ecosystems in summer (Millar and Westfall 2008).

Other physical attributes of national parks can be monitored for climate change (see Lundquist and Roche, page 31 this issue), but glacier retreat is a charismatic phenomenon that has captured the imagination of the public. Nevertheless, the National Park Service does not have a systematic glacial monitoring program in place that integrates observations across the National Park System. Although mass balance of glaciers would be of great scientific value, a monitoring program for aerial extent of glaciers in the alpine areas of national parks would be a logical start; protocols exist for incorporating glacier monitoring into management (Fountain et al. 1997).

One particularly appealing method of monitoring faunal changes is to make better use of historical zoological surveys that exist in many park units.

Flora

Several avenues exist for monitoring climate change using alpine flora in national parks, where growth is typically limited by climate. The two most promising lines of monitoring the response of alpine vegetation to climate change are expansion in woody vegetation at alpine tree line and community composition of herbaceous growth.

Alpine tree-line expansion and contraction can be monitored at temporal scales ranging from centuries to decades (Bunn et al. 2005; Graumlich et al. 2005). The spatial patterns of tree line can be complex (see, for example, Alftine and Malanson 2004). Further, changes in tree line have the potential to greatly transform the alpine land surface, as can be observed from historical repeat photography (Klasner and Fagre 2002) and future predicted changes of conifer distribution under climate change (Schrag et al. 2008). The ways that tree lines are likely to change across national parks in the West involve complex series of feedbacks, including seed dispersal, snow dynamics, and spatial patterns brought about by modifications of microclimate in and along the boundaries of low-growing prostrate growth forms (e.g., krumholtz) (Malanson et al. 2007).

The longevity and slow growth of subalpine conifers lead to lags in climate-driven, tree-line changes; monitoring of herbaceous plants in alpine areas might yield better measures of how alpine changes are occurring in time scales more relevant to land managers (years to decades). One mechanism is to work within the international Global Observation Research Initiative in Alpine Environments (GLORIA) project (Grabherr et al. 2000; see http://www.gloria.ac.at). GLORIA is a network of long-term alpine observatories where scientists collect vegetation and temperature data specifically to discern climate-related pressures on high-elevation ecosystems (fig. 2). More than 40 GLORIA sites are operating on conical mountaintops worldwide, with another 50 in various stages of planning. The sites use simple survey methods and have low maintenance costs; vegetation response is monitored every 5 to 10 years. Several installations are planned in park units and national forests throughout the western United States.

Fauna

Animals that live in alpine areas of national parks are of intense interest to park managers and visitors. They also have the potential to be seriously impacted by predicted climate changes. For instance, American pikas (*Ochotona princeps*) are under threat from climate change; the Center for Biological Diversity (San Francisco, California) has filed petitions to list the species as endangered under the Federal Endangered Species Act and the California Endangered Species Act. Monitoring of alpine fauna has tremendous promise for documenting and understanding climate-induced changes to parks. One particularly appealing method of monitoring faunal changes is to make better use of historical zoological surveys that exist in many park units.

The most comprehensive historical zoological survey in the alpine areas of national parks was the work of Joseph Grinnell in the early 20th century (Grinnell and Storer 1924). Grinnell systematically surveyed the alpine areas that are now Yosemite and Lassen Volcanic national parks (California) as well as several other alpine

COURTESY OF CONSTANCE I. MILLAR, USDA FOREST SERVICE

Figure 2. More than 40 long-term, alpine observatories—part of the international Global Observation Research Initiative in Alpine Environments (GLORIA) project—record vegetation and temperature data in high-elevation ecosystems. The GLORIA installation pictured here and on page 17 is in the White Mountains of California in the Inyo National Forest.

The suite of high-elevation lands protected by the National Park Service is ideal in terms of documenting and monitoring the physical, floral, and faunal impacts of climate change.

areas in California. His famous attention to detail has made a resurvey of those areas possible (Moritz 2007; see http://mvz.berkeley.edu/Grinnell). The Grinnell Resurvey Project has noted extensive habitat and community changes of alpine mammals coincident with warming temperatures. Similar work is possible in other units of the National Park System. The study of historical changes to fauna can take advantage of a wealth of physiological studies. For instance, hibernating small mammals are directly affected by climate change because body temperatures during torpor are strongly influenced by exterior temperature. A prime example of this is the golden-mantled ground squirrels (*Spermophilus lateralis*) in the White Mountains of California, which show delayed entrance into hibernation with increasing temperatures (Frank 2007).

Conclusion

Climate change in the coming decades will impact national parks, and managers must be prepared to anticipate and adapt to those changes (Stephenson et al. 2006). In addition to GLORIA (described above), other routes for institutional assistance are available to the National Park Service for alpine monitoring, such as the Western Mountain Initiative (Stephenson et al. 2006; see http://www.cfr.washington.edu/research.fme/wmi) and the National Phenology Network (Betancourt et al. 2007; see http://www.usanpn.org). The National Park Service has an opportunity to better document and understand climate change–related impacts on national parks through its Inventory and Monitoring (I&M) Program. Park-specific management issues make Service-wide integration of standardized I&M Program priorities difficult, but the relatively low diversity, structural complexity, and human uses of alpine areas offer the potential for these places to help implement standardized inventorying and monitoring throughout parks in the western United States. Efforts under way to implement systematic monitoring such as those described by Manier et al. (2006) should be strongly encouraged.

The National Park Service controls a globally unique network of alpine lands that span an impressive array of latitudes and longitudes. Approaching alpine monitoring in terms of physical, floral, and faunal components makes logical and logistical sense for setting up low-cost, simple, and flexible schemes. The Service has a chance to foster better understanding of the impacts of climate on alpine systems. Indeed, the time is ripe to turn the "rock and ice problem" into the "rock and ice opportunity."

Acknowledgments

I am indebted to the Canon National Parks Science Scholars Program for support during my years as a PhD student and to my graduate advisor, Lisa Graumlich, who encouraged me to apply. I gratefully acknowledge support from the National Science Foundation (awards 0732477, 0612341, and 0629172) for research into climate change at high elevations and latitudes.

References

Alftine, K. J., and G. P. Malanson. 2004. Directional positive feedback and pattern at an alpine tree line. Journal of Vegetation Science 15:3–12.

Betancourt, J. L., M. D. Schwartz, D. D. Breshears, D. R. Cayan, M. D. Dettinger, D. W. Inouye, E. Post, and B. C. Reed. 2007. Implementing a U.S. national phenology network. Eos, Transactions, American Geophysical Union 86:539.

Bunn, A. G., L. A. Waggoner, and L. J. Graumlich. 2005. Topographic mediation of growth in high elevation foxtail pine (*Pinus balfouriana* Grev. et Balf.) forests in Sierra Nevada, USA. Global Ecology and Biogeography 14:103–114.

Fountain, A. G. 2007. A century of glacier change in the American West. Fall Meeting Supplement, Abstract GC32A-06. Eos, Transactions, American Geophysical Union 88:52.

Fountain, A. G., R. M. Krimmel, and D. C. Trabant. 1997. A strategy for monitoring glaciers. Circular 1132, U.S. Geological Survey, Reston, Virginia, USA.

Frank, C. L. 2007. Effects of recent climate change on facultative and spontaneous torpor in alpine habitats. Fall Meeting Supplement, Abstract GC33B-02. Eos, Transactions, American Geophysical Union 88:52.

Grabherr, G., M. Gottfried, and H. Pauli. 2000. GLORIA: A global observation research initiative in alpine environments. Mountain Research and Development 20:190–192.

Graumlich, L. G., L. A. Waggoner, and A. G. Bunn. 2005. Detecting change at alpine treeline: Coupling paleoecology with contemporary studies. Pages 405–412 *in* U. Huber, H. Bugmann, and M. Reasoner, editors. Global change and mountain regions: An overview of current knowledge. Advances in Global Change Research, Volume 23. Springer, Dordrecht, the Netherlands.

Grinnell, J., and T. I. Storer. 1924. Animal life in the Yosemite: An account of the mammals, birds, reptiles, and amphibians in a cross-section of the Sierra Nevada. University of California Press. http://www.nps.gov/history/history/online_books/grinnell (accessed 28 March 2008).

Hoffman, M. J., A. G. Fountain, and J. M. Achuff. 2007. Twentieth-century variations in area of cirque glaciers and glacierets, Rocky Mountain National Park, Rocky Mountains, Colorado. Annals of Glaciology 46:349–354.

IPCC. 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, editors. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Key, C. H., D. B. Fagre, and R. K. Menicke. 2002. Glacier retreat in Glacier National Park, Montana. Pages J365–J381 *in* R. S. Williams Jr. and J. G. Ferrigno, editors. Satellite image atlas of glaciers of the world, glaciers of North America—Glaciers of the Western United States. Chapter J. U.S. Geological Survey Professional Paper 1386-J. U.S. Government Printing Office, Washington D.C., USA.

Klasner, F. L., and D. B. Fagre. 2002. A half century of change in alpine treeline patterns at Glacier National Park, Montana, U.S.A. Arctic, Antarctic, and Alpine Research 34:49–56.

Malanson, G. P., D. R. Butler, D. B. Fagre, S. J. Walsh, D. F. Tomback, L. D. Daniels, L. M. Resler, W. K. Smith, D. J. Weiss, D. L. Peterson, A. G. Bunn, C. A. Hiemstra, D. Liptzin, P. S. Bourgeron, Z. Shen, and C. I. Millar. 2007. Alpine treeline of western North America: Linking organism-to-landscape dynamics. Physical Geography 28:378–396.

Manier, D. J., M. Bivin, B. Bowman, M. Britten, D. Clow, C. Copass Thompson, D. Fagre, J. Gross, J. Holmquist, L. Kurth, J. Lundquist, D. Manier, A. Miller, M. Murray, D. Patten, L. Rachowicz, J. Riedel, D. Sarr, J. Schmidt-Gengenbach, B. Schweiger, T. Seastedt, B. Stottlemyer, K. Tonnessen, H. Van Miegroet, E. Wenk, and M. Williams. 2006. Proceedings of the National Park Service Alpine Monitoring Workshop, 20–23 September 2005. Rocky Mountain Inventory and Monitoring Group, National Park Service Fort Collins, Colorado, USA.

Millar, C. I., and R. D. Westfall. 2008. Rock glaciers and related periglacial landforms in the Sierra Nevada, CA, USA: Inventory, distribution and climatic relationships. Quaternary International 188(1):90–104.

Moritz, C. 2007. A re-survey of the historic Grinnell-Storer vertebrate transect in Yosemite National Park, California. Sierra Nevada Network Inventory and Monitoring Program, Sequoia and Kings Canyon National Parks, Three Rivers, California, USA.

Runte, A. 1979. National parks: The American experience. University of Nebraska Press, Lincoln, Nebraska, USA.

Schrag, A. M., A. G. Bunn, and L. J. Graumlich. 2008. Influence of bioclimatic variables on tree-line conifer distribution in the Greater Yellowstone Ecosystem: Implications for species of special concern. Journal of Biogeography 35:698–710.

Speth, J. G. 2005. The single greatest threat: The United States and global climate disruption. Harvard International Review 27:18–22.

Stephenson, N., D. Peterson, D. Fagre, C. Allen, D. McKenzie, J. Baron, and K. O'Brien. 2006. Response of western mountain ecosystems to climatic variability and change: The Western Mountain Initiative. Park Science 24(1):24–29.

Whalley, W. B., and H. E. Martin. 1992. Rock glaciers: II models and mechanisms. Progress in Physical Geography 16:127–186.

About the author

Andrew G. Bunn *was a 2001 Canon Scholar from Montana State University, Bozeman. He completed his dissertation, "Temporal and spatial patterns at alpine treeline in the Sierra Nevada USA: Implications for global change," in 2004. Dr. Bunn is an assistant professor in the Department of Environmental Sciences, Huxley College, Western Washington University, and can be reached at andrew.bunn@wwu.edu.*

1,000 feet above a coral reef:

A seascape approach to designing marine protected areas

By Rikki Grober-Dunsmore, Victor Bonito, and Thomas Frazer

FROM THE VANTAGE OF AN OPEN-COCKPIT AIRPLANE, the colors of the water below shift from light green to aqua blue to rich cobalt. These color changes signify the different patches of habitat that lie beneath the surface: sea grass beds, shallow reefs, halos of sand, and deep channels. From 300 m (1,000 ft) above, this habitat mosaic hints at the connectedness of the coral reef ecosystem. Habitat patches of varying shapes and sizes are linked to one another by movement of fish, nutrients, and energy flows, creating patterns of connectivity across spatial scales from the reef patch to the barrier reef. Because the elements of coral reef ecosystems are interconnected, managing them as a whole, rather than as a series of disconnected parts, makes sense. Landscape ecology is ideally suited for addressing real-world problems, from designing migration corridors for elephants in Africa to creating networks of protected areas for giant otters in the Peruvian rain forest. By using a "seascape" perspective, scientists and managers can address concerns at a scale appropriate to resource management needs in coral reef ecosystems (Forman 1995).

Such a bird's-eye or seascape perspective will be critical for designing marine protected areas (MPAs) (fig. 1), which have grown increasingly popular as ecosystem-based tools for improving fisheries management and protecting biodiversity. Effectiveness is contingent on understanding key ecological patterns and processes at appropriate spatial scales, and may depend upon maintaining critical linkages among essential habitat patches to conserve reef fish communities. Unfortunately, how the design of any particular MPA will influence its effectiveness, especially in highly complex and dynamic coral reef ecosystems, is unclear. Coral reefs exist as heterogeneous ecosystems consisting of various habitat patches that can differ markedly in their spatial arrangement and composition. Evidence is increasing for the importance of maintaining habitat linkages that support key ecosystem processes, which in turn sustain viable reef fish populations. A failure to consider and maintain functional habitat linkages that affect important ecological processes in the design of protected areas is likely to result in undesirable changes in community structure and possibly the loss of key species. Consequently, while reef habitat may be essential to reef fish production, different MPA designs—size, shape, and proximity to habitat types—may produce different results. For example, movement of fishes may be more likely outside the boundaries of MPAs given certain arrangements of habitat types (see Chapman and Kramer 2000). Thus, a key to future success in protecting reef habitat and fisheries is quantifying how alternative design options will impact a desired outcome. Simply setting aside areas based on jurisdictional or political motivations may not be sufficient.

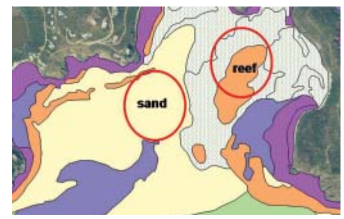


Figure 1. In this study we used benthic habitat maps, created by the NOAA Biogeography Team for the U.S. Virgin Islands, from which we calculated landscape-scale metrics of the seascape spatial patterning for each study reef. In the Ikonos aerial imagery (above, left) and classified benthic habitat maps (above, right), each color represents a different habitat type: pink = bedrock, orange = reef, purple = gorgonian plain, yellow = sand, white = sea grass. Given aerial imagery and habitat classification capability, this information can be used to design more effective MPAs.

Seascape patterns and reef fish in the Caribbean

We present here a brief overview of some of our recent work in which we applied terrestrial landscape ecology principles to the issue of MPA design and management in coral reef ecosystems. Our objectives are to (1) demonstrate the benefits of a landscape ecology approach in coral reef ecosystems and (2) examine the utility of large-scale benthic habitat maps for tracking fish movement in order to predict the structure and spatial patterns of reef fish assemblage as proxies for selecting priority conservation sites. Our research to date has spanned the globe, with specific work carried out in both the Caribbean and South Pacific, including study sites in the Florida Keys, Turks and Caicos islands, U.S. Virgin Islands (Grober-Dunsmore et al. 2007; Grober-Dunsmore et al. 2008), and Fiji islands.

In the Caribbean, we conducted fish censuses (fig. 2) at reefs in the U.S. Virgin Islands, the Florida Keys National Marine Sanctuary, and the Turks and Caicos islands. Using a Geographic Information System (GIS), we spatially analyzed various reef fish parameters derived from these data. We tested hypotheses to investigate how well different landscape metrics predict reef fish assemblage structure and examined the importance of habitat linkages. General landscape metrics such as habitat diversity and patch density were not predictors of reef fish assemblage structure. However, as expected, reef context (the spatial pattern of surrounding habitat patches) was a strong predictor of reef fish assemblage structure. Specific relationships were functionally consistent with the ecology of the fishes of interest. For example, reefs with large amounts of sea grass nearby harbored the greatest numbers of fishes, particularly mobile invertebrate feeders and exploited fishes such as grunts and snappers. Species richness for the entire fish community and within these latter groups of fishes was also strongly associated with reef context (fig. 3). We detected fish-habitat relationships as far as 1 kilometer (0.6 mi) from study reefs, suggesting that fish movements result in habitat encounter rates that may influence their patterns of distribution. Consequently, functional habitat connectivity of habitat patches appears important in structuring reef fish assemblages, and suggests that landscape-scale metrics may provide insights useful to managers designing MPAs.

COURTESY OF VICTOR BONITO

Figure 2. Scientist Rikki Grober-Dunsmore conducts a reef fish census.

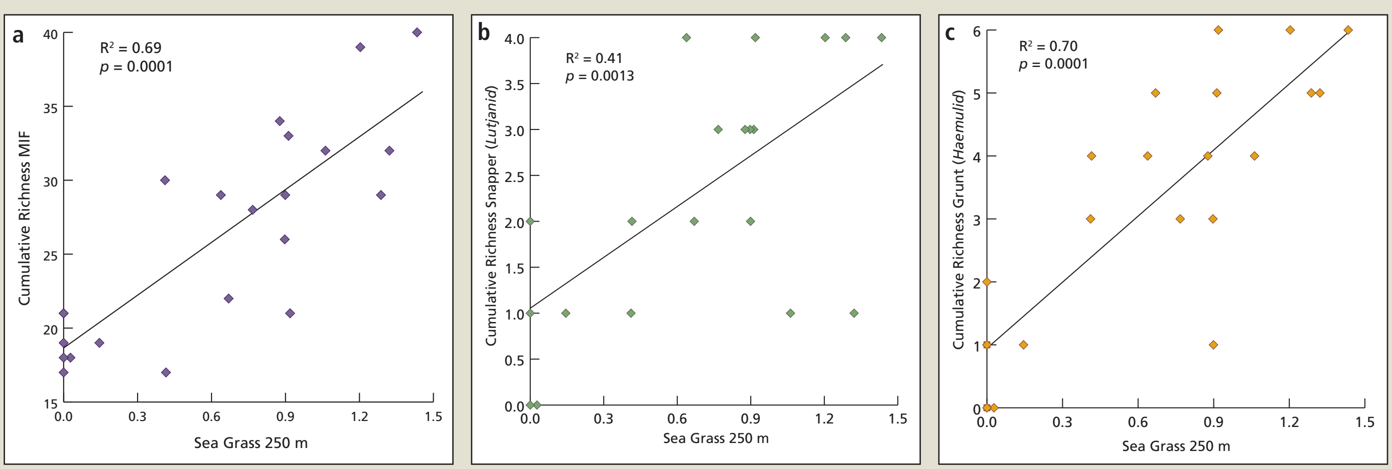
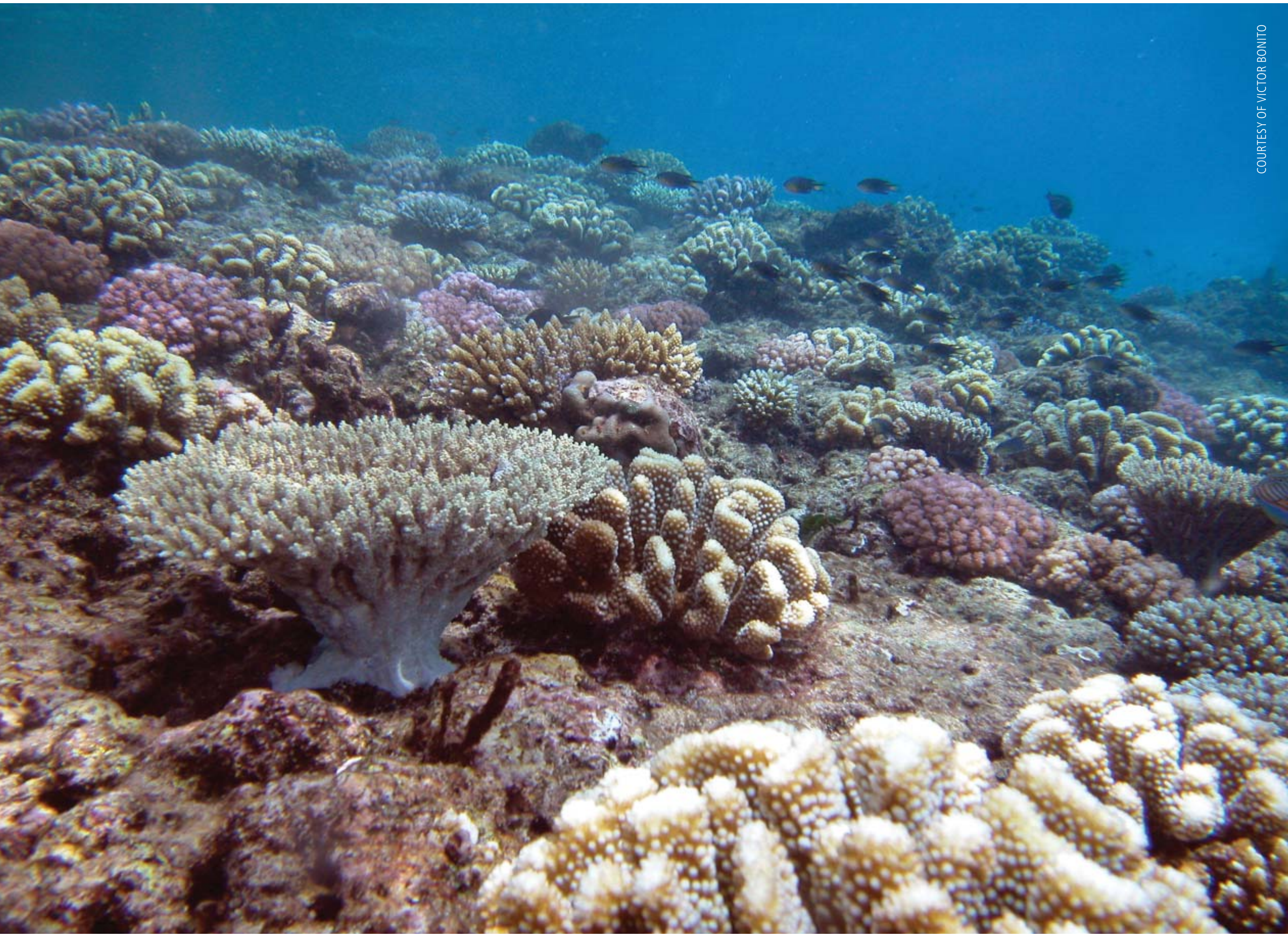


Figure 3. The graphs show the relationship of cumulative species richness to spatial extent of sea grass and reveal that species richness is strongly associated with reef context. In 2002, we sampled (a) mobile invertebrate feeders (MIFs), (b) snapper (lutjanids), and (c) grunt (haemulids) within 22 study reefs in St. John, U.S. Virgin Islands. The x-axis is spatial extent of sea grass, $\log_{10}$ (x+1) transformed. *Source:* Grober-Dunsmore et al. 2007.



COURTESY OF VICTOR BONITO

Figure 4. At the coral reef community in Fiji, South Pacific Islands, we asked the question: "Does the location and surrounding seascape of a particular MPA influence whether reef fishes will remain within the boundaries of an MPA or move outside and be susceptible to fishing mortality?" Research findings from acoustic tagging revealed that fishes moved consistently across MPA boundaries within a continuous reef patch. While periodic excursions outside the reef patch occurred, it appears that the underlying seascape can influence reef fish movements.

Measuring reef fish movement in Fiji

To build on these findings and better understand how seascape features influence reef fish distribution, movement patterns, and ultimately MPA effectiveness, our scientific team traveled to the Coral Coast of Vitu Levu in Fiji (fig. 4). Here we asked the question "Does the location and surrounding seascape of a particular MPA influence whether reef fishes will remain within the boundaries of an MPA or move outside and be susceptible to fishing mortality?" To date, most research has focused on describing patterns of fish assemblage structure given variation in landscape structure (Kendall et al. 2003; Dorenbosch et al. 2007; Grober-Dunsmore et al. 2007, 2008), rather than on identifying and quantifying key ecological mechanisms that underlie the observed patterns. By using high-tech acoustic tagging technologies, we were able to track the movements of targeted reef fishes using a landscape ecology approach to improve our understanding of the linkages among habitat types.

COURTESY OF VICTOR BONITO

Figure 5. Fijian fishers Betty and Teresia (left and right, respectively, with author Rikki Grober-Dunsmore in the center) teach scientists about the movement patterns and behaviors of targeted reef fishes in their local village of Votua, along the southern coast of Fiji.

COURTESY OF THATCHER KAI DUNSMORE

Figure 6. By inserting an acoustic pinger into fish such as *Lethrinus harak*, we were able to track the movement patterns of reef fishes inside and outside the MPA. The pinger sends a beeping signal to a receiver.

In collaboration with local communities (fig. 5), we evaluated whether Lethrinids (bottom-feeding fishes) captured at common village fishing areas were part of the same population as those intended for conservation within the adjacent MPA. Our team caught Lethrinids in the channel and shallow back reef (i.e., "reef flat habitat") within and outside the MPA, which we implanted with acoustic tags that allowed us to track their movements for up to five months. Fishes tagged from disparate habitats (fig. 6) exhibited different temporal and spatial diurnal patterns of movement. Fishes tagged in the channel were detected predictably inside the channel during the day, but at night left the channel and were detected on adjacent reef flat habitat not within the MPA (fig. 7). Fishes tagged on the reef flat moved primarily during the night within reef flat habitat, and were detected periodically in the channel. These fishes crossed MPA boundaries, moving freely across the continuous fringing reef flat habitat and traveling distances up to 1 kilometer (0.6 mi). Although the entire home range of Lethrinids does not appear to be incorporated within the present MPA design, the MPA may afford considerable protection of Lethrinids because fishing pressure occurs almost exclusively during the day. Fishes generally left the MPA during the night, when fishing rarely occurs. Consequently, fishes may derive "temporal refugia" from fishing pressure because they remain inside the MPA during the periods when fishing generally occurs. Comprehensive diurnal habitat requirements may be met with minor adjustments in MPA boundaries. Finally, fishes that reside primarily outside the MPA may be afforded benefits by the MPA because they appear to use the reef flat area for foraging.

COURTESY OF RIKKI GROBER-DUNSMORE

Figure 7. A seascape perspective (aerial image) of Votua Reef along the Coral Coast of Fiji shows the deep-channel and back-reef flat habitat in which we tracked reef fish to determine how various habitat features inhibit or facilitate movement.

Summary

Increasingly, marine scientists are adopting a seascape approach to examine coral reef ecosystem patterns and processes across spatial scales in order to address pressing resource management concerns such as conserving essential fish habitat and designing MPA networks (Friedlander et al. 2007; Grober-Dunsmore et al. 2007; Pittman et al. 2007). Our work over the past several years confirms that landscape ecology can also assist in understanding interactions between movement behavior and the spatial patterning of the seascape, ultimately leading to more ecologically meaningful MPA designs. Ongoing spatial planning efforts around the world (e.g., Australia, New Zealand, California, and Hawaii) are using a seascape perspective to better manage and conserve coral reef ecosystems.

A failure to consider and maintain functional habitat linkages that affect important ecological processes in the design of protected areas is likely to result in undesirable changes in community structure and possibly the loss of key species.

Acknowledgments

Funding for this work was provided by the Canon National Parks Science Scholars Program (award to Rikki Grober-Dunsmore) and the Biological Resources Discipline of the U.S. Geological Survey. Logistical support was provided by Virgin Islands National Park with field assistance from Jason Hale, Thomas Kelly, Sherri Caseau, and Iuri Herzfeld. In the U.S. Virgin Islands, special thanks are owed to Rafe Boulon and Caroline Rogers at Virgin Islands National Park. In the Florida Keys the support of the Florida Keys National Marine Sanctuary, in particular Billy Causey and Brian Keller, is greatly appreciated. Field support in the Florida Keys and Turks and Caicos was provided by Duncan Vaughn and the School for Field Studies. In Fiji the University of the South Pacific's Institute of Marine Sciences facilitated our research. In particular, Bill Aalbersberg, James Comley, and Tawake Aliferiti assisted in countless ways. Votua village deserves particular recognition, especially the field support crew of Team Kabatia. Thank you all.

References

Chapman, M. R., and D. L. Kramer. 2000. Movements of fishes within and among fringing coral reefs in Barbados. Environmental Biology of Fishes 57:11–24.

Dorenbosch, M., W. C. E. P. Verberk, I. Nagelkerken, and G. van der Velde. 2007. Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs. Marine Ecology Progress Series 334:103–116.

Forman, R. T. 1995. Land mosaics: The ecology of landscapes and regions. Cambridge University Press, New York, New York, USA.

Friedlander, A. M., E. K. Brown, and M. E. Monaco. 2007. Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii. Ecological Applications 17(3):715–730.

Grober-Dunsmore, R., T. K. Frazer, J. P. Beets, W. J. Lindberg, P. Zwick, and N. Funicelli. 2008. Influence of landscape structure on reef fish assemblages. Landscape Ecology 23:37–53.

Grober-Dunsmore, R., T. K. Frazer, W. J. Lindberg, and J. Beets. 2007. Reef fish and habitat relationships in a Caribbean seascape: The importance of reef context. Coral Reefs 26:201–216.

Kendall, M. S., J. Christensen, and Z. Hillis-Starr. 2003. Multi-scale data used to analyze the spatial distribution of French grunts, *Haemulon flavolineatum*, relative to hard and soft bottom in a benthic landscape. Environmental Biology of Fishes 66:19–26.

Pittman, S. J., J. D. Christensen, C. Caldow, C. Menza, and M. E. Monaco. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. Ecological Modelling 204:9–21.

About the authors

Rikki Grober-Dunsmore *was a 2002 Canon Scholar from the University of Florida. She completed her dissertation, "Application of landscape ecology principles to the design and management of marine protected areas in coral reef ecosystems," in 2004. Dr. Grober-Dunsmore is an associate professor at the Institute for Applied Sciences at the University of the South Pacific in Fiji, South Pacific Islands. She can be reached at dunsmore_l@usp.ac.fj.*

Victor Bonito *is founder of Reef Explorer Fiji, working as a coral reef ecologist developing research and educational programs to improve success of marine conservation efforts.*

Thomas Frazer *is associate director of the School of Forest Resources and Conservation, University of Florida, and oversees the school's Fisheries and Aquatic Sciences Program. Dr. Frazer's area of interest and expertise is the ecology of oceanic and coastal marine systems.*

PS

VALERIA OJEDA

Management strategies for keystone bird species:

The Magellanic woodpecker in Nahuel Huapi National Park, Argentina

By Valeria Ojeda

DAVID TATIN

FOREST LOSS AND FRAGMENTATION are affecting the temperate forests of southern South America at an increasing rate (Armesto et al. 1998). A large portion (about 30 million acres [12 million ha]) of these *Nothofagus* species–dominated forests includes several national parks in Chile and Argentina (fig. 1). Most of these protected areas lack management plans or have old plans under reevaluation in light of new biological information and theoretical framework changes, as focus shifts from single-species management to ecosystem management. For this task, resource managers need information on the biology of species that (1) are threatened, (2) are indicators of particular forest conditions, (3) are highly appealing ("flagship"), (4) generate key habitat structures or resources ("keystone"), or (5) require large territories such that their protection ensures the preservation of many other organisms ("umbrella").

Some species display several of these characteristics, and knowledge of such species is of major importance in park planning and management. The Magellanic woodpecker (*Campephilus magel-*

Figure 1. Magellanic woodpeckers rely heavily on *Nothofagus*, or southern beech, forests of southern Chile and Argentina, making little use of tree species in other genera. Two *Nothofagus* species are dominant in Nahuel Huapi National Park: *N. dobeyi*, a large, evergreen form found in wetter areas and valleys that grows to a height of 148 ft (45 m); and the deciduous *N. pumilio*, which adopts a shrub form at upper tree line, but attains heights of 100 ft (30 m) on moderate slopes.

[Its] role as a keystone species in creating cavity habitat for other species was suspected. . . . but the most basic information on its natural history was lacking.

lanicus) represents a good model species to demonstrate the role of ecosystem management in park planning. My dissertation research (2000–2006) was based at Nahuel Huapi National Park, Argentina (fig. 2), but applicable to forest management within and adjacent to preserves in northwestern Patagonia and elsewhere.

Figure 2. Situated in the foothills of the Andes Mountains, Nahuel Huapi National Park (reddish rectangle) is located in northwestern Patagonia, southern South America.

The ecological roles of the Magellanic woodpecker

Several woodpecker species decreased in number in the 20th century because of loss of forest habitat worldwide (Winkler and Christie 2002). The forests of southern Chile and Argentina hold three woodpecker species, two of which are small to medium in size—*Colaptes pitius* (length: 13 inches [33 cm]) and *Picoides lignarius* (7 inches [18 cm])—and show no obvious population decline or range retraction. The Magellanic woodpecker, in contrast, is a large (18 inches [46 cm]) species renowned for its sexual dimorphism; that is, the differences in form between males and females (fig. 3). It is the third largest member of its genus after ivory-billed woodpeckers (*C. principalis* and *C. imperialis*). Its large size compared with other neotropical woodpeckers and its typical behavior—moving year-round in noisy family groups—have made this woodpecker very conspicuous and charismatic.

Magellanic woodpecker populations are declining in several parts of their range, so this species appears to be an excellent indicator of ecosystem response to decreasing old-growth forest habitat. However, empirical information on habitat relations was extremely limited when I began my research. In particular, preliminary observations on the structures required for nesting, roosting, and foraging indicated that standing dead trees (the "key" resource for several woodpecker species in the world) may not alone be able to support viable populations of Magellanic woodpeckers. Their role as a keystone species in creating cavity habitat for other species was suspected but undocumented. The Magellanic woodpecker looked attractive as a multirole species, but the most basic information on its natural history was lacking.

The Magellanic woodpecker . . . represents a good model species to demonstrate the role of ecosystem management in park planning.

The main objectives of my research were to (1) describe the most relevant traits of the nesting biology and social behavior of the Magellanic woodpecker, (2) explore cavity tree and cavity site selection in pristine forests, and (3) assess the ecological role of this woodpecker through the construction of cavities potentially used by other species.

Methods

I conducted a mid-term (1998–2006) study of the woodpeckers' reproductive biology and social behavior based on about 40 nests (Ojeda 2004; Ojeda and Chazarreta 2006), and studied nesting habitat selection in old-growth continuous forest (2003–2005) based on 160 cavities (Ojeda 2006). I studied the habitat selection process at three levels: (1) the forest patch surrounding the cavity (0.10-acre [0.04-ha] circular plots), (2) trees used for cavity location, and (3) the portion of the tree where cavities were excavated. At each level I recorded variables such as tree height and diameter at breast height; presence/absence of fruiting bodies of wood-rotting fungi; number of saplings and stumps (<10 feet [3 m] high) in the plots; and distance from a plot to the closest building, trail, road, forest opening, and water body. I recorded architecture and morphometrics data (e.g., vertical and horizontal diameter of the cavity entrance, compass orientation, vertical depth) for more than 100 cavities, as well as excavation dynamics, use patterns, and causes of cavity loss. I studied other species' use of Magellanic woodpecker cavities by inspecting cavities in the trees and by monitoring cavity entrances from ground blinds or hides. Small video cameras mounted on poles were inserted into the cavities at various times throughout the year.

Figure 3. As with other species of *Campephilus*, Magellanic woodpeckers have black plumage, a strong crest, a pale wing patch (white, in this case), and a specialized bill and tail. Males (right) have a scarlet head and neck while females (left) have a black head with curled crest and a dull red base of the bill. Because it is the only large woodpecker in its range, misidentification in the field is impossible. These powerful woodpeckers excavate a new nesting cavity every year, mostly in partially decayed parts of living trees (as shown in the image at right).

Main findings

At the landscape scale, cavities were frequently clustered; the cavities in some of these clusters were maintained as roosts by family groups throughout the year. I was able to confirm eight bird and one mammal species as secondary users of Magellanic woodpecker cavities. Most users were midsize to large species that adopted abandoned woodpecker cavities; these species were also found nesting or roosting in other natural holes, which were abundant at the study sites. I recorded circumstantial evidence of direct competition for woodpecker cavities only among some secondary users (e.g., pygmy owl and parrot species) and between these secondary users and the woodpeckers.

Magellanic woodpeckers were rather nonselective regarding the site surrounding the cavity tree; the selection hierarchy was instead strongly biased toward the cavity tree itself. The woodpeckers excavated cavities mostly in live trees 16–20 inches (40–50 cm) in diameter at breast height (with a minimum threshold of about 12 inches [30 cm]) and greater than 170 years in age (with an average of about 200 years). Suitable portions of boles for cavity excavation were those devoid of branches with a diameter greater than or equal to 12 inches (30 cm) and rarely greater than 16 inches (40 cm), which indicated an optimum diameter. In general, cavity trees had distinctive heart rot decay, but nevertheless in a tree live enough to persist in the environment for years. Although alive, these trees exhibited the phenomenon of vigor decline significantly more than their neighbors of the same age class, as shown by the suppression of radial growth during the last decades. The minimum threshold diameter at breast height recorded for cavity trees (12 inches [30 cm]) was strikingly similar to the values reported by other authors for geographic extremes of the species' distribution and for different forest types, suggesting that cavity excavation size may be a constraint for the species.

Conclusions

The incompatibility between the conservation of Magellanic woodpeckers and current trends of widespread exploitation of *Nothofagus* forests is among the most important conclusion of the present study. The harvesting systems used in timber operations today would impoverish forest habitat for this woodpecker and for other cavity nesters, mainly through rot reduction at the managed sites. Heart rot is characteristic of unmanaged native forests and was a greater factor in the tree selection made by Magellanic woodpeckers than any other habitat feature measured in this study. Much more data are needed in order to determine the actual ecological roles of this woodpecker, mostly with regard to potential obligate users of its cavities in forests with low availability of natural holes.

The Magellanic woodpecker did not prove sensitive to intermediate levels of human presence (e.g., closeness to trekking trails or car access roads) or to moderate exploitative practices (e.g., < 50% firewood removal and occasional selective cutting) in their territories. The tolerance and charismatic nature of this species make it an ideal tool for the development of profitable alternative forest activities such as ecotourism, recreation, and biodiversity prospecting, both within and outside of protected areas. This reflects the claim of many international visitors that the Magellanic woodpecker is a flagship and probably a keystone species of the forests of southern Argentina and Chile.

Acknowledgments

This research was supported by the Canon National Parks Science Scholars Program and CONICET-Argentina. Idea Wild and Birders' Exchange provided equipment fundamental to this study. The Universidad Nacional del Comahue provided constant support to these studies in different ways and at different stages.

References

Armesto, J., R. Rozzi, C. Smith Ramírez, and M. Kalin Arroyo. 1998. Conservation targets in South American temperate forests. Science 282:1271–1272.

Ojeda, V. 2004. Breeding biology and social behaviour of Magellanic woodpeckers (*Campephilus magellanicus*) in Argentine Patagonia. European Journal of Wildlife Research 50:18–24.

Ojeda, V. 2006. Nesting habitat selection and reproductive biology of Magellanic woodpeckers *Campephilus magellanicus* (Aves, Picidae) in northwestern Patagonia, Argentina. Dissertation. Universidad Nacional del Comahue, Bariloche, Argentina.

Ojeda, V., and M. L. Chazarreta. 2006. Provisioning of Magellanic woodpecker (*Campephilus magellanicus*) nestlings with vertebrate prey. Wilson Journal of Ornithology 118:251–254.

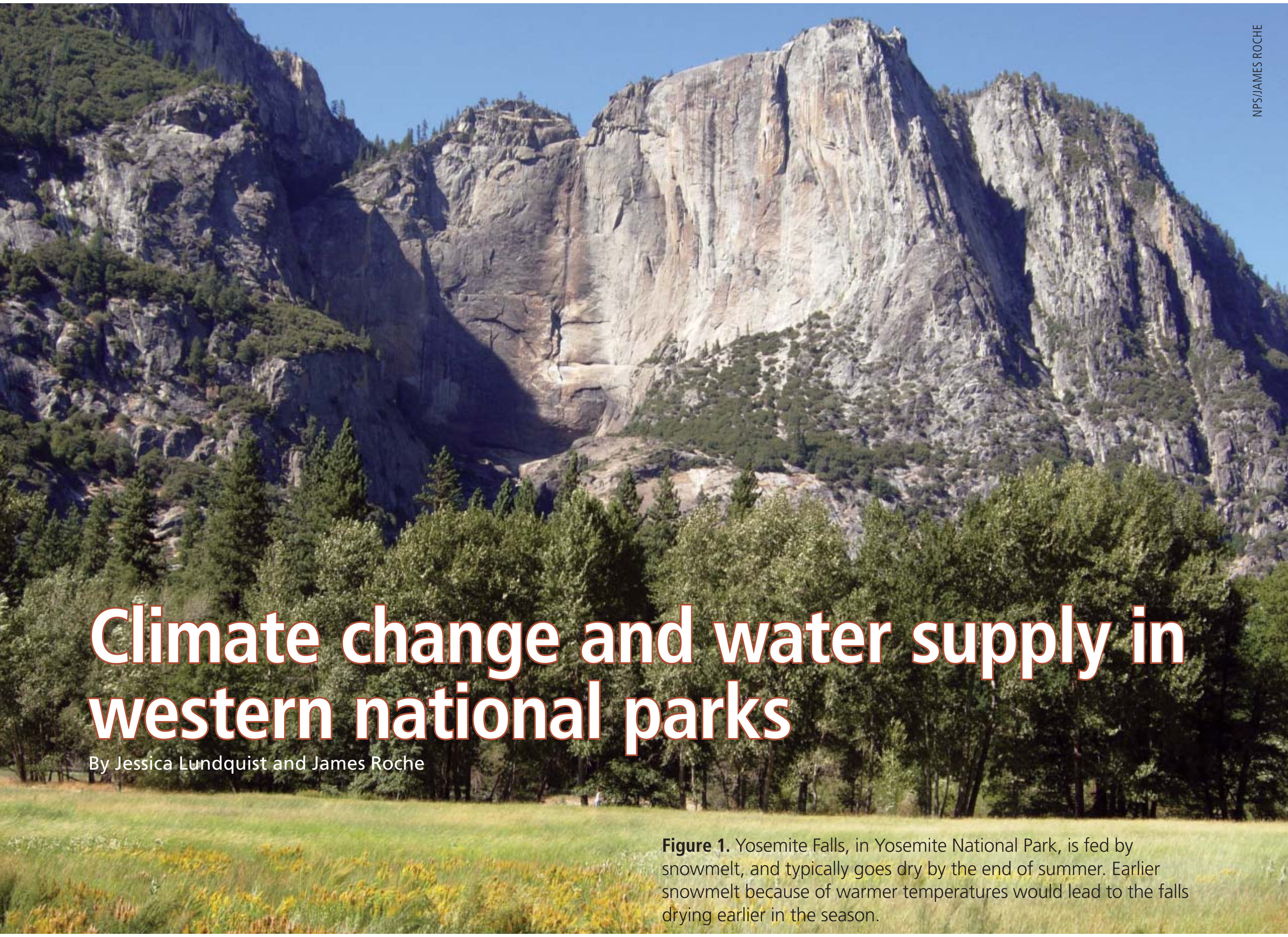
Winkler, H., and D. A. Christie. 2002. Family Picidae (woodpeckers). Pages 296–555 *in* J. Del Hoyo, A. Elliott, and J. Sargatal, editors. Handbook of the birds of the world. Volume 7: Jacamars to woodpeckers. Lynx Edicions, Barcelona, Spain.

About the author

Valeria Ojeda *(photo) was a 2003 Canon Scholar from the Universidad Nacional del Comahue in Bariloche, Argentina. She completed her dissertation, "Nesting habitat selection and reproductive biology of Magellanic woodpeckers* Campephilus magellanicus *(Aves, Picidae) in northwestern Patagonia, Argentina," in 2006. Dr. Ojeda is a wildlife biologist with CONICET (Concejo Nacional de Investigaciones Científicas y Técnicas) and the Universidad Nacional del Comahue in Bariloche, Argentina. She can be reached at campephilus@bariloche.com.ar.*

PS

Physical Sciences



Climate change and water supply in western national parks

By Jessica Lundquist and James Roche

Figure 1. Yosemite Falls, in Yosemite National Park, is fed by snowmelt, and typically goes dry by the end of summer. Earlier snowmelt because of warmer temperatures would lead to the falls drying earlier in the season.

OVER THE PAST 50–60 YEARS, warming temperatures across the western United States have resulted in greater proportions of precipitation falling as rain rather than snow (Knowles et al. 2006) and in earlier snowmelt and streamflow (Mote et al. 2005; Stewart et al. 2005). The years 2004 and 2007 marked two of the earliest spring melts on record (Pagano et al. 2004), and 2007 was one of the driest years on record in California. Glaciers are disappearing across the West, and Glacier National Park (Montana) may cease to live up to its name as early as 2030 (Myrna et al. 2003). Annual precipitation amounts in the western United States have not changed significantly, and predictions of precipitation are uncertain (Dettinger 2005, 2006). However, even without changes in total precipitation amounts, warming temperatures and corresponding shifts from solid to liquid precipitation have profound implications for park water supplies and park management.

Glaciers have provided a buffer against low flows in dry, warm summers, and their absence could result in perennial rivers becoming ephemeral streams. Streams that are already ephemeral, such as Yosemite Falls, will likely become drier on average earlier in summer.

Temperature changes will have the greatest influence in mountain parks with a Mediterranean climate such as Yosemite (California), Sequoia and Kings Canyon (California), Lassen Volcanic (California), Crater Lake (Oregon), Mount Rainier (Washington), Olympic (Washington), and North Cascades (Washington) national parks, where nearly all precipitation falls in winter, and where ecosystems and humans depend on snowmelt for water supplies throughout summer. Earlier snowmelt and a greater proportion of rain result in more water flowing into rivers in winter when it is a hazard, and less into rivers in summer when it is a resource.

Too much water in winter: Warming and flood management

Warmer temperatures increase the elevation where falling snow melts and becomes rain, thus increasing the contributing area for a given storm and the likelihood of flooding (White et al. 2002; Lundquist et al. 2008). Mountain ranges lining the Pacific coast are most at risk from "atmospheric river" or "pineapple express" storms, when winds transfer a narrow jet of warm, moisture-rich air from near Hawaii to the U.S. West Coast (Ralph et al. 2004; Ralph et al. 2006; Neiman et al. 2008). This type of storm caused floods that closed Yosemite Valley in Yosemite National Park in January 1997 and May 2005, and floods that drastically damaged roads in Mount Rainier and North Cascades national parks in November 2006. Rivers with a large proportion of total contributing area near the mean elevation of the winter 0°C (32°F) isotherm are most sensitive to increased flood risks because these areas will become unfrozen and contribute to flood runoff as temperatures warm (Bales et al. 2006).

Too little water in summer: Warming and drought management

In addition to too much water in winter, too little water in summer is a danger. Warmer temperatures will subject park water supplies to less reliable late summer streamflow. Not only will snow melt earlier (Stewart et al. 2005), but glacial meltwater will soon disappear in many western national parks (Myrna et al. 2003). Historically, glaciers have provided a buffer against low flows in dry, warm summers, and their absence could result in perennial rivers becoming ephemeral streams. Streams that are already ephemeral, such as Yosemite Falls, will likely become drier on average earlier in summer (fig. 1, previous page).

NPS/JAMES ROCHE

Figure 2. Run-of-the-river water supplies, as pictured here on the South Fork of the Merced River near Wawona in Yosemite National Park, are particularly vulnerable to earlier melting of snowpack.

These shifts in water timing will probably have large impacts on regional ecosystems (Stephenson et al. 2006), resulting in rapid, threshold-type responses (Burkett et al. 2005). For example, earlier drying of ephemeral streams will lead to lower water tables in meadows. Once groundwater level drops below a critical depth, vegetation will change from mesic (wet meadow) to xeric (dryland) (Loheide and Gorelick 2007).

Park water supplies that depend on snow- or glacier-fed surface runoff—for example, in Tuolumne Meadows and on the South Fork of the Merced River near Wawona in Yosemite National Park (fig. 2)—will need management plans that consider the increased likelihood of late summer water shortages. Few sources other than surface water are available, given the lack of deep alluvial basins in many developed areas such as Wawona. This lack makes groundwater extraction for public water supplies infeasible (Borchers 1996). Management of these systems will require careful stream gauging and discharge monitoring to accurately quantify low flows and implement water rationing or other management actions.

Park management strategies

Regardless of world action plans to mitigate climate change, temperatures are likely to continue rising for the foreseeable future (Intergovernmental Panel on Climate Change 2007). Park management can best adapt to climate change by understanding which areas are likely to be most affected by warming temperatures and why. For example, Lundquist and Flint (2006) dem-

Park management can best adapt to climate change by understanding which areas are likely to be most affected by warming temperatures and why.

onstrated that at midlatitudes, such as in the Sierra Nevada and Colorado Rockies, high-elevation, north-facing basins are much less sensitive to warming temperatures than their south-facing counterparts. Melt onset is delayed longer in the shadiest basins in years with early melt onset than in years with average melt timing, resulting in nonlinear differences between subbasins that are not captured by standard modeling techniques (Lundquist and Flint 2006). Also, temperatures in different locations in complex terrain respond differently to variations in atmospheric circulation. For example, because of decadal weakening of westerly winds over central California, the eastern slope of the Sierra Nevada has been warming significantly less than the western slope (Lundquist and Cayan 2007). Managers can take advantage of spatial patterns to determine which park areas would benefit most from restoration or enhanced protection.

As snowmelt becomes a less reliable source of water in late summer, summer precipitation will become increasingly important in controlling late summer soil moisture and minimum flows in mountain streams. Hamlet et al. (2007a, b) found that modeled late-season soil moisture depends more on summer precipitation than on temperature or the spring snowpack. These studies also found that in many areas of the western United States, summer precipitation has been increasing in recent decades. For example, one large thunderstorm in late summer 2007 was sufficient to keep water levels in Wawona from falling below critical rationing levels. Thus, further monitoring and research should be devoted to understanding and predicting summer precipitation, which most often falls as spatially variable thunderstorms at high elevations (fig. 3).

Conclusions

Adapting to climate change will require careful, spatially distributed monitoring to understand how different areas will respond. Parks managers will need to be prepared for the increasing likelihood of both floods and drought; this will require flexible management plans that can adapt as baselines change and new information is gleaned.

COURTESY OF JESSICA LUNDQUIST

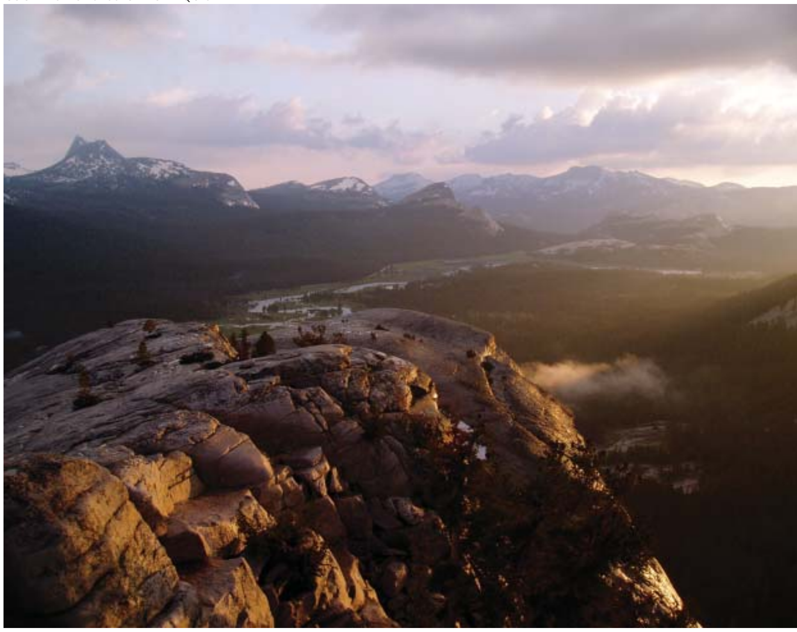


Figure 3. Summer thunderstorms, as seen here in Tuolumne Meadows, Yosemite, California, will become increasingly important in providing late summer moisture to the western mountains and their national parks.

Acknowledgments

We would like to thank the Canon National Parks Science Scholars Program for its support of this work. We would also like to thank the dedicated and professional staff of the Resource Management and Science and Wilderness divisions of Yosemite National Park, particularly Joe Meyer, Mark Butler, and Niki Nicholas, for their encouragement and support of our hydroclimate-related park research. Thanks also to Brian Huggett, Heidi Roop, Josh Baccei, Sam Luthy, Steve Loheide, Dan Cayan, Mike Dettinger, Julia Dettinger, Jim Wells, Larry Riddle, John Shupe, Josh Wyrick, and Fred Lott, who helped with fieldwork.

References

Bales, R. C., N. P. Molotch, T. H. Painter, M. D. Dettinger, R. Rice, and J. Dozier. 2006. Mountain hydrology of the western United States. Water Resources Research 42, W08432, DOI:10.1029/2005WR004387.

Borchers, J. W. 1996. Ground-water resources and water-supply alternatives in the Wawona area of Yosemite National Park, California. Water-Resources Investigations Report 95-4229. U.S. Geological Survey, Reston, Virginia, USA.

Burkett, V. R., D. A. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J. L. Nielsen, C. D. Allen, D. L. Peterson, G. Ruggerone, and T. Doyle. 2005. Nonlinear dynamics in ecosystem response to climatic change: Case studies and policy implications. Ecological Complexity 2:357–394.

Dettinger, M. D. 2005. From climate-change spaghetti to climate-change distributions for 21st century California. San Francisco Estuary and Watershed Science 3, 1 (March): Article 4. Available at http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art4.

Dettinger, M. D. 2006. A component-resampling approach for estimating probability distributions from small forecast ensembles. Climatic Change, DOI:10.1007/s10584-005-9001-6.

Hamlet, A. F., P. W Mote, M. P. Clark, and D. P. Lettenmaier. 2007a. 20th century trends in runoff, evapotranspiration, and soil moisture in the western U.S. Journal of Climate 20:1468–1486.

Hamlet, A. F., P. W. Mote, and D. P. Lettenmaier. 2007b. Implications of changing 20th century precipitation variability for water management in the western U.S. Proceedings of the 21st Conference on Hydrology, American Meteorological Society, January 2007. Abstract available at http://ams.confex.com/ams/87ANNUAL/techprogram/paper_120787.htm.

Intergovernmental Panel on Climate Change. 2007. Climate change 2007. IPCC Fourth Assessment Report (AR4). Available at http://www.ipcc.ch/.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States, Journal of Climate 19:4545–4559.

Loheide S. P., II, and S. M. Gorelick. 2007. Riparian hydroecology: A coupled model of the observed interactions between groundwater flow and meadow vegetation patterning. Water Resources Research 43, W07414, DOI:10.1029/2006WR005233.

Lundquist, J. D., and D. R. Cayan. 2007. Surface temperature patterns in complex terrain: Daily variations and long-term change in the central Sierra Nevada, California. Journal of Geophysical Research 112, D11124, DOI:10.1029/2006JD007561.

Lundquist, J. D., and A. Flint. 2006. Onset of snowmelt and streamflow in 2004 in the western United States: How shading may affect spring streamflow timing in a warmer world. Journal of Hydrometeorology 7:1199–1217.

Lundquist, J. D., P. J. Neiman, B. Martner, A. B. White, D. J. Gottas, and F. M. Ralph. 2008. Rain versus snow in the Sierra Nevada, California: Comparing radar and surface observations of melting level. Journal of Hydrometeorology 9:194–211.

Mote, P., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Myrna, H., P. Hall, and D. B. Fagre. 2003. Modeled climate-induced glacier change in Glacier National Park, 1850–2100. BioScience 53:131–140.

Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist, and M. D. Dettinger. 2008. Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. Journal of Hydrometeorology 9:22–47.

Pagano, T., P. Pasteris, M. Dettinger, D. Cayan, and K. Redmond. 2004. Water year 2004: Western water managers feel the heat. Eos, Transactions, American Geophysical Union 85:385–392.

Ralph, F. M., P. J. Neiman, and G. A. Wick. 2004. Satellite and CALJET aircraft observations of atmospheric rivers over the eastern North-Pacific Ocean during the winter of 1997/98. Monthly Weather Review 132:1721–1745.

Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, C. R. Cayan, and A. B. White. 2006. Flooding on California's Russian River: The role of atmospheric rivers. Geophysical Research Letters 33, L13801, DOI:10.1029/2006GL026689.

Stephenson, N., D. Peterson, D. Fagre, C. Allen, D. McKenzie, J. Baron, and K. O'Brian. 2006. Response of western mountain ecosystems to climate variability and change: The Western Mountain Initiative. Park Science 24(1):24–29.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes towards earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.

White, A. B., D. J. Gottas, E. T. Strem, F. M. Ralph, and P. J. Neiman. 2002. An automated brightband height detection algorithm for use with Doppler radar spectral moments. Journal of Atmospheric and Oceanic Technology 19:687–697.

About the authors

Jessica Lundquist *was a 2002 Canon Scholar from the University of California, San Diego. She completed her dissertation, "The pulse of the mountains: Diurnal cycles in western streamflow," in 2004. Dr. Lundquist is an assistant professor of hydrology and hydroclimatology in the Department of Civil and Environmental Engineering, University of Washington. She can be reached at jdlund@u.washington.edu.*

James Roche *is the park hydrologist in the Division of Resource Management and Science at Yosemite National Park. He can be reached at jim_roche@nps.gov.*

PS

Mercury in snow at Acadia National Park reveals watershed dynamics

By Sarah J. Nelson

Mercury at Acadia

AS A CLASS I AREA, ACADIA NATIONAL PARK (Maine) is afforded the highest level of air quality protection under the federal Clean Air Act Amendments (1990). Acadia hosts the highest peaks along the East Coast (~1,530 feet [466 m]), and its steep slopes and proximity to coastal fog create an environment conducive to intercepting polluted air masses (Weathers et al. 1986). Investigators have documented elevated deposition of contaminants, including mercury (Hg), at Acadia (Norton et al. 1997; Bank et al. 2007; Johnson et al. 2007; Kahl et al. 2007), which in certain areas of the park causes at least as much Hg contamination in tree swallow chicks and eggs as in birds living at a mercury-contaminated Superfund site in Massachusetts (Longcore et al. 2007).

PRIMENet, a long-term watershed research program at Acadia (Tonnessen and Manski 2007), has shown that the legacy of wildfire affects Hg in watersheds and biota for decades or longer (Bank et al. 2005; Johnson et al. 2007; Kahl et al. 2007). Because their needles have more surface area than deciduous leaves and they keep their foliage year-round, coniferous forests, like the spruce-fir forests of an unburned Acadia watershed, are more effective than postfire deciduous forests at canopy scavenging of atmospheric Hg (Grigal 2002; Johnson et al. 2007). That is, conifer forests collect more dust and dry particles on their foliage than deciduous trees. Dry-deposited Hg is washed to the forest floor in subsequent rain, fog, and snow events and collected as "throughfall" (Grigal 2002; Miller et al. 2005; Weathers et al. 2006; Johnson et al. 2007). Throughfall allows investigators to assess deposition across heterogeneous, forested areas by deploying a large number of samplers and comparing chemistry data with patterns in landscape features (Weathers et al. 2006).

Reports in the scientific literature suggested that Hg concentrations in snow throughfall might be low, though data were sparse (Nelson 2007). Therefore, the goal of this research was to collect winter throughfall Hg data and assess Hg mobility in forested research watersheds in Acadia to establish the importance of this Hg load to the terrestrial ecosystem (Nelson 2007).

Figure 1. Investigators used three methods to collect precipitation in the mercury deposition study at Acadia National Park. Here they deploy Teflon and plastic bags in snow tubes. Throughout the season they compared paired Teflon-lined tubes, collecting one bag and replacing it after each snow event while leaving the other bag deployed all winter. The third, plastic-lined tube (photo foreground) was used to collect other chemical data about snow at Acadia.

Methods

I measured snow throughfall deposition in Acadia at several sites in winter 2004–2005. Because few published papers described methodology for snow collection, I used three methods in this research: event sampling, cumulative sampling, and snowpack sampling. During event sampling, I deployed "snow bags" (i.e., Teflon liners in plastic tubes) to collect throughfall of large snowfall events (fig. 1). I deployed snow bags all winter for cumulative sampling and collected cores of intact snow on the ground for snowpack sampling. Detailed field methods and sample type descriptions are provided in Nelson (2007) and Nelson et al. (2008).

Key findings

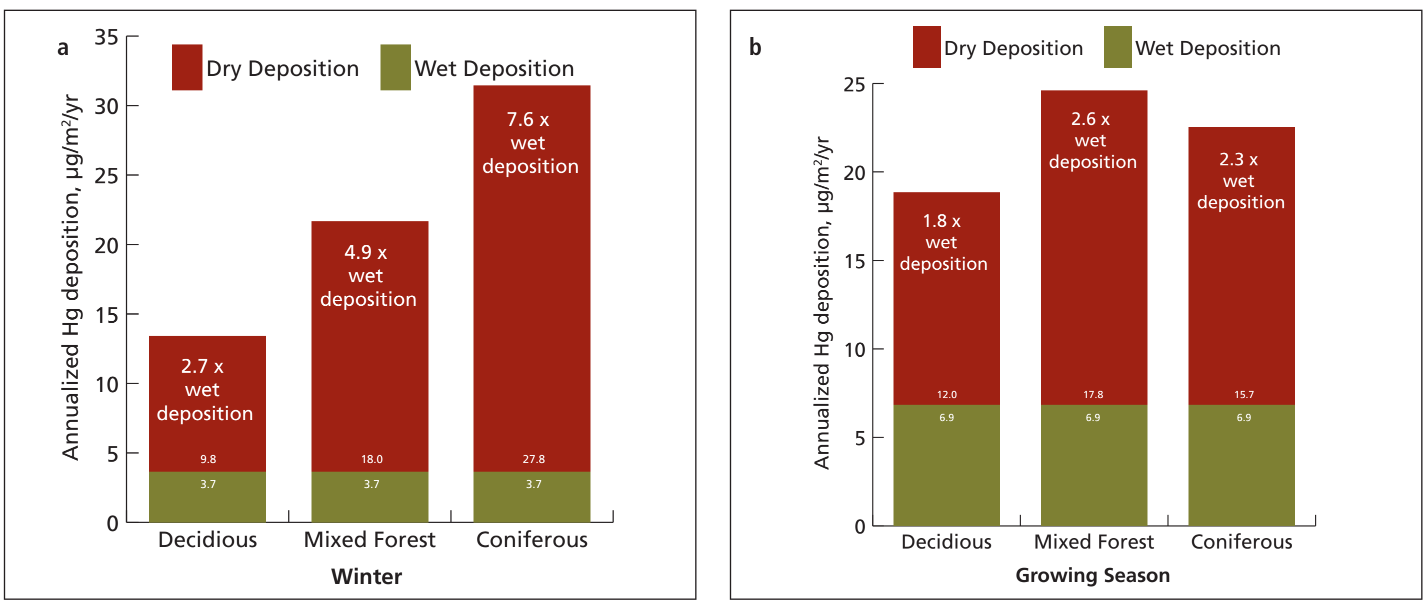
This study generated three major findings. First, the concentration of Hg under conifer forests after snowfall events in winter was similar to that found during the growing season in rain (fig. 2). As with rain throughfall, conifer forested sites had the greatest Hg concentration and deposition, followed by mixed sites, then deciduous sites, and finally nonvegetated sites. This finding differed from results of the few published studies from other sites, which suggested little Hg in snow (e.g., Mason et al. 2000).

Second, estimates of Hg in snow throughfall deposition varied by a factor of as much as three, depending on the collection method (fig. 3). When snow bags remained open to the atmosphere all winter, Hg could be emitted from the deposited snow back to the atmosphere. This method provided a low estimate of Hg deposition to watersheds. The closed snow bags collected after each event provided the greatest estimates of Hg flux to watersheds. Previous research at other sites (e.g., Mason et al. 2000) reported relatively low Hg burdens in snow, but their samples were left uncovered, allowing Hg to escape. This research demonstrates that closing collection devices after snowfall events effectively traps Hg.

Third, I documented that soils and leaf litter could contribute Hg to the overlying snowpack (fig. 3). I applied a labeled Hg tracer to soils and litter in late autumn. I then sampled the snowpack near the end of winter to determine whether any of the tracer moved vertically up into the snowpack. I recovered the labeled tracer in all the snowpack samples from sites that had been treated, and found greater amounts and percentages of total Hg of the tracer in the bottom portion of snowpack than in the top portion.

Acadia in context

Having identified snow throughfall deposition of Hg as a potentially important flux to forested watersheds, I synthesized published and unpublished snow Hg concentration and deposition data from temperate to subboreal North America to provide a broader context for the findings from Acadia, and to assess whether the controls on winter deposition at Acadia apply elsewhere. Studies that provided information on vegetation at collection sites reported Hg ratios in throughfall (wet + dry, under forests) to open (wet + dry, nonforested) deposition in snowpack as 2.1:1, and 3.8:1 for throughfall (wet + dry, forested) to wet-only (nonforested, no dry) deposition in snow events. These ratios are greater than the overall average growing season throughfall to wet deposition (1.8:1) (Grigal 2002). Across the broad geographic region and in discontinuous studies spanning 14 years, snow Hg concentration and deposition were consistently greatest in bulk



WET-ONLY DATA COURTESY OF THE MERCURY DEPOSITION NETWORK

Figure 2. This study measured throughfall of mercury (Hg) during winter (a) and the growing season (b) in Acadia National Park, Maine. Bars show the contribution of wet-only deposition, plus the amount of dry deposition inferred from throughfall measurements. The sampling period for winter throughfall was from 15 December 2004 to 16 March 2005 and from 28 May to 17 November 2004 for growing-season throughfall. The graph shows estimates from these measurements annualized to per-year rates for comparison. The overall average ratio reported for growing season throughfall (wet + dry) to wet deposition is 1.8:1 (Grigal 2002), whereas the ratio of throughfall to wet deposition averaged 3.1:1 during the growing season at forested sites at Acadia.

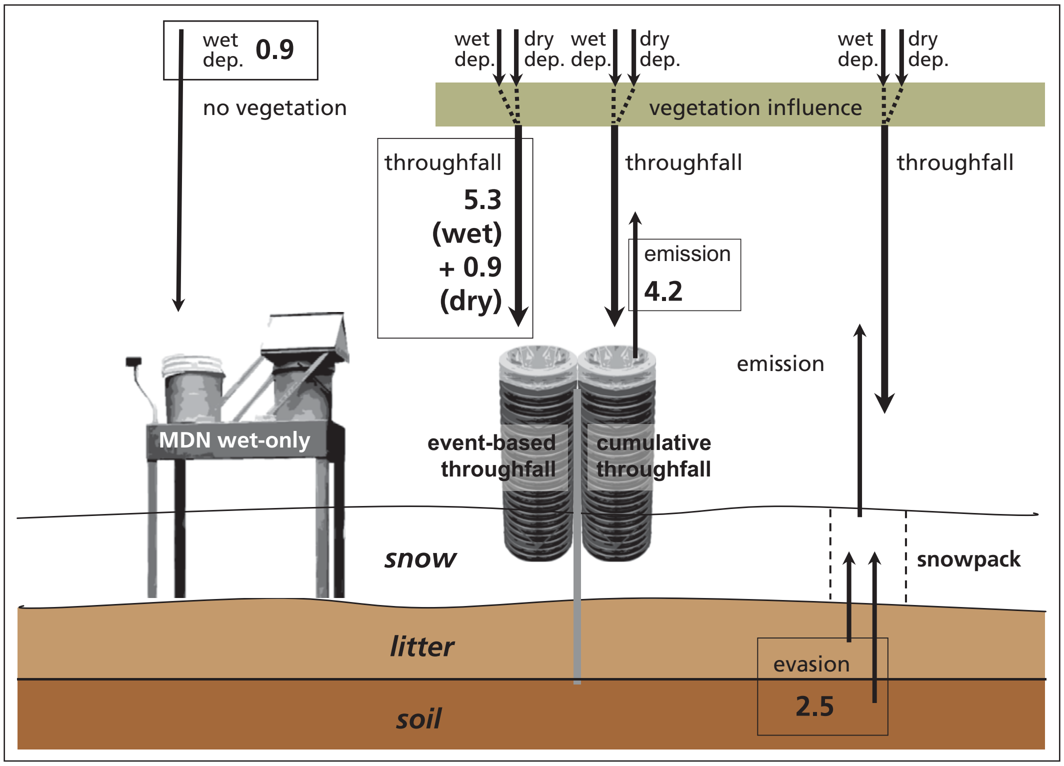


Figure 3. This study deployed three collection methods: event sampling, cumulative sampling, and snowpack sampling. This diagram also illustrates the Mercury Deposition Network (MDN) collection station (ME98) at McFarland Hill, which collected wet-only samples and provided the wet deposition "control" value for a landscape without vegetation. Re-emission of mercury (Hg) occurred in the cumulative throughfall and snowpack methods. Evidence from a mercury tracer study suggested that evasion of Hg from soil and leaf litter into snowpack also occurred. The fluxes of Hg shown in the figure are estimates (μg/m^2) during a 91-day period (December 2004–March 2005).

As with rain throughfall, conifer forested sites had the greatest Hg concentration and deposition, followed by mixed sites, then deciduous sites, and finally non-vegetated sites.

throughfall at conifer sites and lowest at open bulk sites without vegetation cover. This relationship held despite different field and laboratory methods. As with rain throughfall, this could be because of the greater scavenging efficiency of the coniferous canopy as compared to the deciduous canopy (largely bare twigs in winter). Another (yet unstudied and unpublished) mechanism for enhanced deposition in snow under coniferous canopies could be that dry particles could settle onto intercepted snow that sits on top of branches between storms.

Implications

This research provides new information regarding Hg inputs in winter. Although researchers have already identified winter processes such as snowmelt as important components of winter watershed chemical mass balances (Shanley et al. 2002), few published results document total atmospheric deposition in winter. The results of this study suggest that researchers can characterize the range of total deposition of Hg by focusing on two types of sites—those with year-round canopy and those without cover in winter. Hg inputs in sites with year-round canopies at Acadia were 3.8 times greater than in "open" sites.

In this study, three methods for measuring Hg in snow provided widely varying estimates of Hg inputs in winter (fig. 3). Collections after each major snowfall, particularly at conifer sites, contained the highest estimates of deposition (fig. 2); snow that was open to the atmosphere throughout the entire winter, allowing for volatilization and emission of deposited Hg, provided the lowest estimates of deposition. Snowpack sampling (of intact ground snow) provided an intermediate estimate of Hg. However, findings of this study indicate that soils and leaf litter could contribute Hg to the overlying snowpack; further research is necessary to determine the mechanisms that led to translocation of Hg. These findings can inform models that assess effects of changing Hg emissions. Furthermore, long-term monitoring to assess such changes would benefit from periodic snow-event throughfall sampling. At Acadia National Park, complementary research (Kahl et al. 2007) and ongoing monitoring continue to quantify the amount of mercury that falls onto the landscape and discrete studies track mercury as it moves through ecosystems and into living things.

Acknowledgments

The Canon National Parks Science Scholars Program, the National Park Service, Acadia Partners for Science and Learning, the University of Maine, and the Senator George J. Mitchell Center for Environmental and Watershed Research provided funding for this research. I thank advisory committee members J. S. Kahl, C. S. Loftin, I. J. Fernandez, K. C. Weathers, and K. E. Webster for their contributions. K. B. Johnson assisted with research implementation and data interpretation. I thank C. Devoy, T. Hyssong, J. Tillotson, and the USGS Toxics Program, particularly D. Krabbenhoft, for support. I also thank the Resource Management staff at Acadia National Park for logistical support. Field crews from the Mitchell Center were instrumental to this research project. Steve Little at Berghof America and the Advanced Manufacturing Center at the University of Maine assisted with design and manufacture of snow sampling equipment. Catherine Schmitt and others provided constructive comments that greatly improved this manuscript.

References

Bank, M. S., J. R. Burgess, D. C. Evers, and C. S. Loftin. 2007. Mercury contamination of biota from Acadia National Park, Maine: A review. Environmental Monitoring and Assessment 126:105–115.

Bank, M. S., C. S. Loftin, and R. E. Jung. 2005. Mercury bioaccumulation in northern two-lined salamanders from streams in the northeastern United States. Ecotoxicology 14:181–191.

Grigal, D. F. 2002. Inputs and outputs of mercury from terrestrial watersheds: A review. Environmental Reviews 10:1–39.

Johnson, K. B., T. A. Haines, J. S. Kahl, S. A. Norton, A. Amirbahman, and K. D. Sheehan. 2007. Controls on mercury and methylmercury deposition for two watersheds in Acadia National Park, Maine. Environmental Monitoring and Assessment 126:55–67.

Kahl, J. S., S. J. Nelson, I. Fernandez, T. Haines, S. Norton, G. B. Wiersma, G. Jacobson, A. Amirbahman, K. Johnson, M. Schauffler, L. Rustad, K. Tonnessen, R. Lent, M. Bank, J. Elvir, J. Eckhoff, H. Caron, P. Ruck, J. Parker, J. Campbell, D. Manski, R. Breen, K. Sheehan, and A. Grygo. 2007. Watershed nitrogen and mercury geochemical fluxes integrate landscape factors in long-term research watersheds at Acadia National Park, Maine, USA. Environmental Monitoring and Assessment 126:9–25.

Longcore, J. R., T. A. Haines, and W. A. Halteman. 2007. Mercury in tree swallow food, eggs, bodies, and feathers at Acadia National Park, Maine, and an EPA Superfund site, Ayer, Massachusetts. Environmental Monitoring and Assessment 126:129–143.

Mason, R. P., N. M. Lawson, and G. R. Sheu. 2000. Annual and seasonal trends in mercury deposition in Maryland. Atmospheric Environment 34:1691–1701.

Miller, E., A. Vanarsdale, G. Keeler, A. Chalmers, L. Poissant, N. Kamman, and R. Brulotte. 2005. Estimation and mapping of wet and dry mercury deposition across northeastern North America. Ecotoxicology 14:53–70.

Nelson, S. J. 2007. Winter contribution to annual throughfall inputs of mercury and tracer ions at Acadia National Park, Maine. Dissertation. University of Maine, Orono, Maine, USA.

Nelson, S. J., K. B. Johnson, K. C. Weathers, C. S. Loftin, I. J. Fernandez, J. S. Kahl, and D. P. Krabbenhoft. 2008. A comparison of winter mercury accumulation at forested and no-canopy sites measured with different snow sampling techniques. Applied Geochemistry 23(3):384–398.

Norton, S. A., G. C. Evans, and S. Kahl. 1997. Comparison of Hg and Pb fluxes to hummocks and hollows of ombrotrophic Big Heath Bog and to nearby Sargent Mt. Pond, Maine, USA. Water, Air, and Soil Pollution 100:271–286.

Shanley, J. B., P. F. Schuster, M. M. Reddy, D. A. Roth, H. E. Taylor, and G. R. Aiken. 2002. Mercury on the move during snowmelt in Vermont. EOS, Transactions, American Geophysical Union 83(5):45, 47–48.

Tonnessen, K., and D. Manski. 2007. The contribution of Acadia PRIMENet research to science and resource management in the National Park Service. Environmental Monitoring and Assessment 126:3–8.

Weathers, K. C., G. E. Likens, F. H. Bormann, J. S. Eaton, W. B. Bowden, J. L. Andersen, D. A. Cass, J. N. Galloway, W. C. Keene, K. D. Kimball, P. Huth, and D. Smiley. 1986. A regional acidic cloud/fog water event in the eastern United States. Nature 319:657–658.

Weathers, K. C., S. M. Simkin, G. M. Lovett, and S. E. Lindberg. 2006. Empirical modeling of atmospheric deposition in mountainous landscapes. Ecological Applications 16(4):1590–1607.

About the author

Sarah J. Nelson *was a 2003 Canon Scholar from the University of Maine, Orono. She completed her dissertation, "Winter contribution to annual throughfall inputs of mercury and tracer ions at Acadia National Park, Maine," in 2007. Dr. Nelson is an assistant research professor at the Senator George J. Mitchell Center for Environmental and Watershed Research, University of Maine, Orono, and can be reached at sarah.nelson@umit.maine.edu.*

Sarah Nelson and her team hiked more than 200 miles (322 km) (50 [80] of them on snowshoes) with packs full of rain, snow, and ice in carrying out her research on airborne mercury deposition at Acadia National Park.

PS

COURTESY OF HANG XIAO

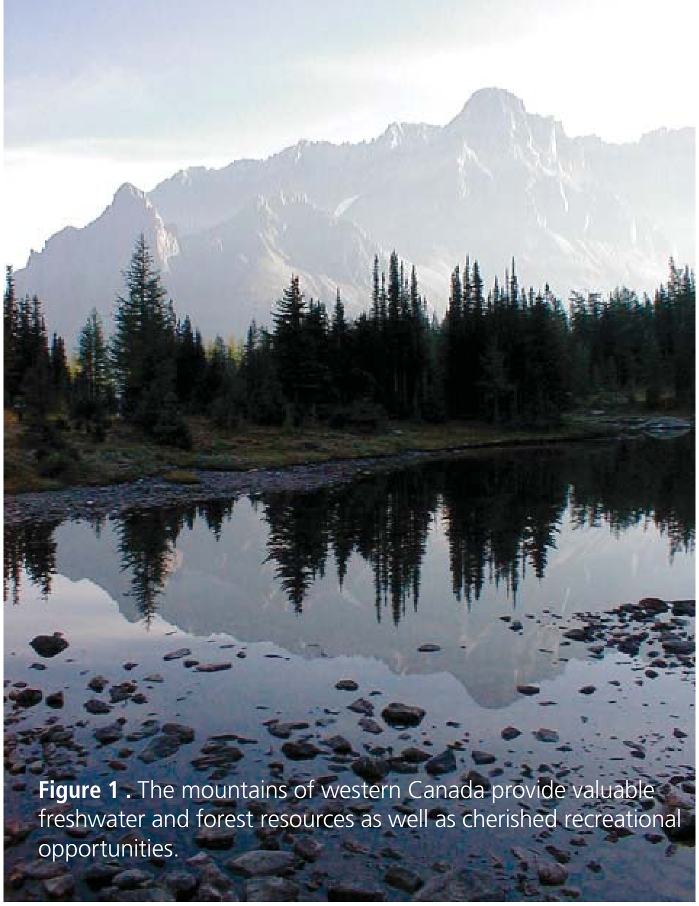


Figure 1 . The mountains of western Canada provide valuable freshwater and forest resources as well as cherished recreational opportunities.

Organic pollutant distribution in Canadian mountain parks

By Gillian Daly and Frank Wania

MOUNTAIN ENVIRONMENTS ARE IMPORTANT sources of freshwater and forest resources, contain areas of high biodiversity, and provide cherished recreational opportunities (fig. 1). Conservation of these resources and functions is the central objective of national parks in mountain regions. While some threats facing mountain environments, such as unsustainable use of natural resources and deforestation, can be avoided in national parks, other threats, such as climate change and chemical contamination, are more difficult to counter. Because of the large variability of environmental conditions in high-relief environments—caused by varying elevation and exposure—contaminant distribution within mountain regions is expected to be highly variable. Recent research in western Canadian mountain parks has provided new insight into the location of organic contaminant concentrations, and thus where exposure of organisms to those contaminants may be greatest. This insight can help park managers identify key hot spots—areas of elevated contaminant exposure—and communicate risks to the public (e.g., fish advisories). Identification of likely hot spots can also aid in the design of future research programs aimed at evaluating the ecotoxicological impact of elevated contaminant concentrations.

Contaminant hot spots

Hot spots develop when high contaminant input, for example through atmospheric deposition, combines with slow contaminant loss. Their location thus depends on source proximity, chemical properties (e.g., water solubility and degradability), and environmental conditions (e.g., temperature, precipitation, surface cover, and winds). Previous research efforts in Europe and western North America have shown that diurnal mountain winds, in conjunction with low temperatures and high precipitation rates that enhance deposition at higher elevations, can lead to the convergence of persistent organic chemicals at higher elevations of midlatitude mountains (Daly and Wania 2005).

Investigators measured air, soil, and lichen contaminant profiles along elevational gradients in three western Canadian mountain parks—Mount Revelstoke National Park (British Columbia), Yoho National Park (British Columbia), and Banff National Park (Alberta) (fig. 2, next page)—to determine the extent to which different mountains exhibit different contaminant accumulation patterns with elevation (Daly et al. 2007a). Analysis and aggregation of meteorological data revealed prevailing winds from the west and southwest in all three parks. This implies that pesticides in the parks are much more likely to originate in the agricultural regions of Washington State and southern British Columbia than in the prairies to the east. The Mount Revelstoke transect on the western side of the continental divide receives high winter precipitation and does not extend beyond the tree line. The Yoho transect, also on the western side of the continental divide, traverses the Trans-Canada Highway and extends beyond the tree line up to 2,561 meters (8,402 ft) above sea level. The transect along Observation Peak in Banff National Park lies on the eastern side of the continental divide and receives the least amount of precipitation; its three highest sampling sites are above the tree line at 2,370 meters (7,775 ft) above sea level.

Figure 2. Investigators sampled air, soils, and lichens for contaminants along three transects in Mount Revelstoke National Park, Yoho National Park, and on Observation Peak in Banff National Park (British Columbia and Alberta, Canada).

Concentrations of organochlorine pesticides in the air were fairly uniform across and between the three mountain transects, suggesting no significant local sources within the parks, and efficient atmospheric mixing on a regional scale (fig. 3). Revelstoke had consistently higher pesticide concentrations in soil than Yoho and Observation, likely driven by greater precipitation on the western side of the continental divide. In the Revelstoke transect, soil concentrations of the insecticides α-HCH, dieldrin, endosulfan-I, and endosulfan-II and the herbicide dacthal showed a statistically significant increase with elevation. Such increases in soil concentrations with elevation are likely a result of cold precipitation at higher elevation being more efficient in washing contaminants out of the atmosphere than warm precipitation occurring in the valley (Daly et al. 2007b). Investigators observed the highest pesticide concentrations in soil along the Yoho and Observation transects at intermediate elevations. Pesticide concentrations on these two transects were significantly correlated with the soil organic carbon (OC) content. Soil OC content showed greater variation in the Yoho and Observation transects than in Revelstoke; OC content dropped severely above the tree line. Overall, the findings suggest that contaminant concentrations in soil will increase along with precipitation up the mountain slope until the retentive capacity of the soil declines (i.e., when OC content drops off above tree line). Therefore, contaminant hot spots in mountain soils will likely be found where precipitation and contaminant retention are greatest (i.e., on the windward side of mountains and below tree line). Different patterns may be observed in vegetation, where contaminant uptake by gas absorption may be more important than wet deposition.

Whereas the above measured pesticides are not used within the parks, polycyclic aromatic hydrocarbons (PAHs) are emitted from cars, buses, and trucks traveling along traffic arteries in the mountain parks, and are also produced during forest fires. Investigators measured PAHs along the Observation, Yoho, and Revelstoke transects (Choi et al. in press). The air and soil concentrations were strongly correlated with proximity to traffic arteries. In particular, greatly elevated PAH levels were measured in air and soil sampled close to the Trans-Canada Highway in Yoho National Park. Concentrations along the Observation and Revelstoke transects decreased with elevation, which is also consistent with increasing distance from the roads at the bottom ends of the transects. The relative abundance of different PAHs changed with elevation, with heavier PAHs being more abundant in the valley. This again is consistent with a source location in the valley.

COURTESY OF HANG XIAO

Figure 3. Using passive air samplers, investigators found fairly uniform concentrations of pesticides in the mountains of western Canada.

Management implications and research opportunities

The implication for contaminant hot spots in mountain parks is the need to distinguish between contaminants from in-park sources and contaminants transported into the park over short or long range. Depending on the sources, contaminants are likely to display widely divergent distribution patterns with elevation. An understanding of prevailing winds and likely sources is vital in designing monitoring campaigns for specific chemicals within a park. In addition to field studies, model calculations can help explain how chemical properties and elevational gradients in temperature, precipitation, and soil organic matter influence contaminant exposure in mountains.

Research in the mountains of western Canada continues, along with large collaborative research efforts such as WACAP (http://www.nature.nps.gov/air/Studies/air_toxics/wacap.cfm) in the western United States and EMERGE (http://www.mountain-lakes.org/emerge/index.html) and MonarPOP (http://www.monarpop.at/) in Europe. These projects aim to provide decision makers with an overall understanding of contaminant fate in mountain environments so that appropriate policy and management measures can be taken at the level of the park manager, or on a regional, national, or larger (i.e., transboundary) scale. Research efforts can identify which contaminants are present in each park, where they are accumulating, and whether they pose an ecological threat (Daly et al. 2007b). Communication between researchers and park managers can create a better understanding of public-health and wildlife-health concerns in the parks and aid in the communication of potential risks to park users.

Acknowledgments

We would like to thank the Canon National Parks Science Scholars Program and the other members of the research team at the University of Toronto, Environment Canada, Mount Revelstoke National Park, Yoho National Park, and Banff National Park for supporting this work.

References

Choi, S. D., C. Shunthirasingham, G. L. Daly, H. Xiao, Y. L. Lei, and F. Wania. Levels of polycyclic aromatic hydrocarbons in Canadian mountain air and soil are controlled by proximity to roads. Environmental Pollution, in press.

Daly, G. L., Y. D. Lei, C. Teixeira, D. C. G. Muir, and F. Wania. 2007a. Pesticides in western Canadian mountain air and soil. Environmental Science and Technology 41:6020–6025.

Daly, G. L., Y. D. Lei, C. Teixeira, D. C. G. Muir, L. E. Castillo, and F. Wania. 2007b. Accumulation of current-use pesticides in neotropical montane forests. Environmental Science and Technology 41:1118–1123.

Daly, G. L., and F. Wania. 2005. Organic contaminants in mountains. Environmental Science and Technology 39:385–398.

About the authors

Gillian Daly *was a 2003 Canon Scholar from the University of Toronto, Ontario. She completed her dissertation, "Understanding the fate of persistent organic pollutants in temperate and tropical mountains," in 2007. Dr. Daly is currently a risk assessor for Golder Associates, Mississauga, Ontario, Canada, and can be reached at gdaly@golder.com.*

Frank Wania *is an associate professor in the Department of Physical and Environmental Sciences, University of Toronto Scarborough, Ontario, Canada, and can be reached at frank.wania@utoronto.ca.*

Social / Cultural Sciences

Building an NPS training program in interpretation through distance learning

DAVID SNYDER (BOTH)

By Elizabeth R. Barrie and Katie L. Bliss

Figure 1 (above right). Online courses are self-paced, with three levels of completion available: self study, basic certificate of completion, and advanced certificate of completion.

Figure 2 (above left). Interpretive coaches assess site-based activities before an advanced certificate of completion can be awarded.

A training chasm

"APPROXIMATELY 70,000 PRACTITIONERS work in partnership with the National Park Service to deliver interpretation and education services to the public," according to the *NPS Interpretation and Education Renaissance Action Plan* (National Park Service 2006). However, "only 3,000 of this workforce currently participate in interpretation and education training" (National Park Service 2006). A gap in training that encompasses 67,000 people creates vast challenges for maintaining and upholding professional standards. New tools—built on an interpretation and education training platform that has evolved over the years—are beginning to address this challenge.

As early as 1994, the NPS Division of Interpretation and Education defined competencies for interpretation in the parks. In 2004, using the Multipurpose Occupational Systems Analysis Inventory–Close-Ended (MOSAIC) methodology, the Office of Personnel Management (OPM) validated 13 competencies integral to the delivery of interpretation and education services:

A gap in training that encompasses 67,000 people creates vast challenges for maintaining and upholding professional standards.

- Knowledge of the Resource
- Knowledge of the Audience
- Knowledge of Appropriate Techniques
- Informal Visitor Contacts
- Interpretive Talk
- Conducted Activity
- Illustrated Program or Demonstration
- Interpretive Writing
- Curriculum-based Education Program
- Interpretive Planning
- Interpretive Media Development
- Interpretive Training and Coaching
- Interpretive Research

The MOSAIC process incorporated input from interpreters at multiple pay (i.e., GS or general schedule) levels who rated the competencies on several scales, including importance and requirement for entry. The rigor of this methodology ensures that the competencies can withstand legal challenges.

These competencies established professional standards for national park interpretation and education services, but did not provide the necessary training materials to reach all of the volunteers, concessioners, partners, and employees performing these services. Therefore, in 2005 the National Park Service partnered with Indiana University's Eppley Institute for Parks and Public Lands in order to revise the Interpretive Development Program curriculum and address this vast training gap. After a systematic review of the curriculum, the partners decided to create the Interpretation and Education Distance Learning and Credentialing Platform. This platform contains a blended curriculum based on the OPM-validated competencies.

The partners launched a pilot course in 2006, and courses on the Foundations of Interpretation (addressing the first three competencies listed above) and Informal Visitor Contacts rolled out in spring 2007. Subsequently the program has released courses on the interpretive talk, interpretive writing, conducted activities, and training and coaching. Courses on additional competencies will be released in late 2009.

The curriculum for each competency now includes (1) a competency narrative, (2) an online self-paced course, and (3) a classroom training packet. NPS partners and the public alike can access all materials at http://www.interptraining.org. Since the initial launch of the platform, people all over the world (e.g., China, New Zealand, the United Arab Emirates) have registered for more than 7,000 courses. Hence, the training gap is closing via a mechanism that provides park managers with flexible tools for upholding NPS interpretation and education standards, while also providing widespread access to NPS-sponsored training of OPM-certified competencies.

Flexible learning tools

The competency narrative addresses all the information an interpreter needs to know to meet the competency standard. As trainees complete each competency narrative (typically 40–50 pages long), it becomes available on the NPS Interpretive Development Program Web site (http://www.nps.gov/idp/interp). The narrative serves as the source document for the rest of the curriculum materials. For each competency David Larsen, training manager for Interpretation, Education, Recreation, and Conservation located at the Stephen T. Mather Training Center in Harpers Ferry, West Virginia, gathers a group of six to 10 interpreters from throughout the National Park Service to serve as subject-matter experts. Over the course of about six months, this group creates the competency narrative based entirely on the competency standard. An interpretation instructional designer at the Eppley Institute develops a draft of the online course when the competency narrative is complete. The subject-matter expert team then fine-tunes the course, conducting field tests to ensure learners can meet the competency-based course objectives.

Each online course contains (1) instructional content, (2) interactive practice sessions that provide immediate feedback, and (3) site-based activities through which participants develop an interpretive product or service. The courses are self-paced, with three levels of completion available: self study, basic certificate of completion, and advanced certificate of completion (fig. 1). Interpreters who complete the course via self study have access to all the instructional content and interactive practice sessions. They can also use the site-based activity rubrics to conduct a self-assessment of their own work. Participants must complete a knowledge assessment in order to receive a basic certificate of completion, and must have an interpretive coach (e.g., field supervisor, seasonal team leader, or concessions manager) assess their site-based activities to receive an advanced certificate of completion (fig. 2).

Staffs of the National Park Service and Eppley Institute designed the courses based on sound pedagogical principles to be used with an interpretive coach. These principles suggest that blending online with face-to-face instruction enhances learning. For instance, Brown and Corkill (2007) write, "appropriate online instruction should provide students with opportunities for active participation with the instructor." Similarly, blended learning courses that combine online learning and face-to-face instruction are equally or more effective than completely online or completely traditional learning. Students in a blended learning course achieved the same or better learning results and were highly satisfied with the combined process (Garrison and Kanuka 2004).

Park managers can use the coaching component of the curriculum to guide the creation of interpretive products and services while developing the knowledge, skills, and abilities of park staff. In field tests of the coaching system, supervisors found that the activities in the course provided a comprehensive, structured format for addressing previously overlooked issues (e.g., professional appearance and quality customer service). Coaches employ detailed rubrics to assess the site-based activities and provide helpful advice on improving interpretive skills and abilities (fig. 3). Coaches receive extensive training, including a minimum of 24 hours of classroom work conducted by regional training teams, before being permitted to award advanced certificates. To enhance the flexibility of the platform, participants at each site determine who should serve as a coach, though each coach must successfully complete the extensive blended learning training.

Each course contains a manual designed to assist coaches in using the online tools to meet their needs. This manual describes the spirit and intent of each activity, with tips for providing feedback. With this information interpretive coaches can ask staff to complete just one or two activities within a course; limiting the activities in this way focuses training and coaching on specific components of the competency, based on the needs of the interpreter.

In situations where individualized coaching is not feasible, peer coaching provided by site staff in a classroom setting is an option. The course materials include a classroom training packet, which provides classroom instructional content, hands-on activities, and training evaluation forms. Possible time frames are listed for each training segment, but adaptation of the materials to the specific group is encouraged.

Social scientific inquiry infused the entire curriculum revision. Katie Bliss, NPS curriculum revision coordinator, developed an online nominal group process to systematically develop the mate-

	Scoring		
Criteria	**Incomplete**	**Needs Revision**	**Fully Successful**
Checklist	The checklist fails to provide a realistic timeline for preparing to be on time and look professional during the talk.	The checklist contains a timeline that is incomplete or unrealistic for preparing to be on time and look professional when delivering a talk.	The checklist contains a complete and realistic timeline for preparing to be on time and look professional when delivering a talk.
Flexibility	The strategies for dealing with the potential challenges to delivering an effective talk are inadequate.	The strategies for dealing with the potential challenges to delivering an effective talk could be improved and/or they are lacking detail.	The strategies for dealing with the potential challenges to delivering a talk are well reasoned and would be effective.
Audience Comfort	The comfort of the audience has not been addressed.	An attempt was made to create plans for providing for the comfort of the audience, but important details are missing.	The comfort of the audience has been completely addressed.
Speaking Skills	A way to improve speaking skills has not been identified.	A plan for enhancing speaking skills has been developed, but essential elements are missing.	A detailed plan for enhancing speaking skills has been developed.
Responsiveness	The responsiveness strategy has not been identified and/or the strategy is not responsive.	The identified responsiveness strategy is incomplete and needs improvement.	The identified responsiveness strategy is complete and would be effective.

Figure 3. Coaches use detailed rubrics such as this example from the Interpretive Talk course to assess the site-based activities and provide helpful advice on improving interpretive skills and abilities.

Since the initial launch of the platform, people all over the world . . . have registered for more than 7,000 courses.

rials for the foundations course. We sent the call for participation in the process to 350 chiefs of interpretation, all seven regional chiefs of interpretation, and 226 past and present peer review certifiers. A total of 69 participants responded and contributed course content (Bliss 2006). Additionally, the instructional-design team incorporated Merrill's (2002) first principles of instruction, which developed from an analysis of instructional design theories in the field of instructional systems technology.

Fulfilling the mission

By meeting professional standards for interpretive services, interpreters enhance visitor experiences and inspire public support for park management in fulfilling the dual mandate of conservation and visitor enjoyment. With the creation of the Interpretation and Education Distance Learning and Credentialing Program, park managers have new, flexible tools to ensure that all park staff, volunteers, and concessioners who interact with the public are trained to NPS interpretation standards. NPS staff in operations as diverse as facility management, visitor services, and resource protection now have equal access to interpretation training, which will help them inspire visitors to learn about and, in turn, care for park resources. In addition, resource managers who participate in the courses gain a useful foundation for collaboration with interpreters and educators, specifically to engender public support for resource management initiatives through effective presentations, articles, press releases, and exhibits and to build powerful interpretation/education components into resource stewardship plans, initiatives, and funding requests (http://www.nps.gov/idp/interp/theprogram.htm#resmgt).

Acknowledgments

The primary author is deeply indebted to the Canon National Parks Science Scholars Program for validating the importance of research on interpretive experiences. Doors have been opened and pathways forged based on the author's status as a Canon Scholar. Both authors express thanks to the leadership of the National Park Service Interpretation and Education Division for their continued efforts to provide interpreters with essential tools for facilitating meaningful visitor experiences.

References

Bliss, K. 2006. Revising interpretive curriculum in the National Park Service: Fostering participant buy-in and assessing outcomes using a mixed method approach. Thesis. Stephen F. Austin State University, Nacogdoches, Texas, USA.

Brown, W., and P. Corkill. 2007. Mastering online education. American School Board Journal 194:40–42.

Garrison, D. R., and H. Kanuka. 2004. Blended learning: Uncovering its transformative potential in higher education. The Internet and Higher Education 7:95–105.

Merrill, M. D. 2002. First principles of instruction. Educational Technology Research and Development 50(3):43–59.

About the authors

Elizabeth R. Barrie *was a 1998 Canon Scholar from Indiana University. In 2001 she completed her dissertation, "Meaningful interpretive experiences from the participants' perspective." Dr. Barrie is an assistant research professor at the University of Nevada–Las Vegas and can be reached at elizabeth.barrie@unlv.edu.*

Katie L. Bliss *is the Interpretive Development Program curriculum revision coordinator, National Park Service, and can be reached at Katie_Bliss@nps.gov.*

Musical instruments in the pre-Hispanic Southwest


COURTESY OF EMILY BROWN

Figure 1. One of more than 1,250 musical objects studied, this decorated gourd rattle from Canyon de Chelly National Monument (Arizona) is 5.3 inches (13.5 cm) in diameter. Collection of the Western Archeology and Conservation Center, Tucson, Arizona, Catalog No. CACH 811.

By Emily Brown

STUDYING THE MUSIC OF PAST ERAS is challenging, even when written manuscripts are available. In archaeological contexts without written records, it becomes yet more difficult. However, a surprising amount can be learned by studying musical instruments from archaeological sites. Researchers studying the social and physical contexts in which music took place (Brown 2005) and the instruments themselves (Olsen 1990) have identified some roles music may have played in prehistoric societies. Music lends itself well to ritual; strategic use of ritual is one way Ancestral Puebloan leaders in the American Southwest established, validated, and maintained their social authority.

In the course of my research in nine museums, I studied more than 1,250 musical objects from the Four Corners area of New Mexico, Arizona, Colorado, and Utah, primarily from sites within 17 national parks, including Chaco Culture National Historical Park, Aztec Ruins National Monument, Bandelier National Monument, Pecos National Historical Park, Canyon de Chelly National Monument, Mesa Verde National Park, and Wupatki National Monument. The different instrument types included bone and wood flutes; bone, wood, and reed whistles; copper and clay bells; shell trumpets; shell, stone, hoof, and nut tinklers; gourd, tortoiseshell, hide, clay, and cocoon rattles (fig. 1); bone and wood rasps; stone kiva bells; and wooden bullroarers. Curiously, I found no evidence of prehistoric drums other than the controversial foot drums—stone vaults dug into the floors of subterranean ceremonial chambers known as kivas and covered with planks. Drums may be a relatively recent addition to Puebloan culture, perhaps during the late 1400s or early 1500s. They may have been introduced through trade with nomadic Plains groups or native Mexicans traveling with Spanish groups. Though some rock art images suggest flutes were present in the Archaic period, the earliest instruments I found in museum collections were from the Basketmaker II period (AD 200–500). Of course, music made by the human body leaves no trace in the archaeological record.

Basketmaker II (AD 200–500) and III (AD 500–700)

During this time, people lived part of the year in pithouse villages but were more mobile for the rest of the year. Instruments from this period were flutes and whistles of bone, reed, and wood. While instruments of perishable materials such as these rarely survive, some Basketmaker sites are in protected alcoves and caves where archaeologists have discovered well-preserved examples. One pair of wooden flutes found in a dry cave in northeastern Arizona was decorated with feathers that could still be identified as to species (Morris 1959). Some may have been used as animal calls for hunting. Others may have been used for shamanic ritual. Rock art images of flute players associated with birds (thought to symbolize a state of trance) may represent people with shamanic skill that held positions of religious and social authority.

Pueblo I (AD 700–900)

During this time, the reliance on agriculture grew, and habitation was changing from pithouses to communities with a mixture of above- and belowground architecture. These sites tend to be in more exposed locations and there are consequently far fewer examples of musical instruments from this time, but the use of bone whistles continued, and people began to use bone tinklers. Foot drums also appeared at this time. Many native groups in the Southwest believe they emerged into this place from a series of underworlds through a hole in the earth; if the vaults were used as instruments (foot drums), they may have been a way to communicate with ancestors in the underworld (Wilshusen 1988) as part of an ideology linking people to a place in the landscape they had chosen to settle more permanently (Bird-David 1990).

Pueblo II (AD 900–1150)

Chacoan society rose to its height in the Pueblo II period. While the degree and nature of the social and political hierarchy at the environmentally marginal sites in Chaco Canyon are subjects of ongoing research and debate, most researchers agree that religion played a large role. Some even believe a theocratic priesthood was present (see Lekson 1999). The elite at Chaco imported copper bells (Vargas 1995) and conch shell trumpets from Mexico. In addition to bone whistles, which continued from earlier periods, Chacoan people used large carved and painted wooden flutes, ideal for spectacle, and the first stone tinklers.

Pueblo III (AD 1150–1300)

Collapse of the Chaco system defines the Pueblo III period. This collapse and migration over much of the Southwest was due at least partially to severe drought and declining environmental conditions. Pueblos in the remaining inhabited areas were larger than in the past, and community-level social organization took precedence at this time. Few of the instruments found at Chaco persisted beyond its collapse. Wooden flutes disappeared and the first eagle bone flutes appeared (fig. 2). Possibly people were experimenting with different ceremonies and rejecting aspects of those used at Chaco because they failed to alleviate the drought. As time went on, members of lineages with greater ritual knowledge, valued by their communities, may have had access to better land and resources than those with less.

Pueblo IV (AD 1300–1540)

The large-scale migrations of the Pueblo III period culminated in aggregated communities of unprecedented size with enclosed central plazas and multistory room blocks. These communities required different levels of sociopolitical organization and community integration than had previously been used (Potter 1998). Most researchers agree that the kachina religion began in the early 1300s (Adams 1994; Schaafsma 1994). Kachinas are associated with ancestral spirits, clouds, and rain, and their visits are thought to ensure successful crops. This period of religious reinvention involved multiple new musical instruments in great numbers; archaeologists have found more instruments from the Pueblo IV period than any other period. New instrument types included clay bells made in imitation of their copper predeces-

Figure 2. Bone flutes such as these from San Lazaro Pueblo, Santa Fe, New Mexico, appeared during the Pueblo III period (AD 1150–1300). Private collection.

COURTESY OF EMILY BROWN

Spanish mission bells were systematically destroyed during the Puebloan revolt against the Spanish in 1680. … the silencing of the Spanish bells declared the Puebloan rejection of Spanish-imposed religion.

sors, leather rattles, bone rasps, kiva bells, and bone tinklers. The Spanish encountered this large and varied musical environment when they first came to the Southwest.

Spanish contact (AD 1540–1680)

Some of what we know about Pueblo music comes from the writings of Spanish explorers, though some accounts are not particularly complimentary or accurate (see Hammond and Rey 1940). The manuscripts do contain information on whether music was made by men, women, or both, and whether people played singly or in groups. The writings of Spanish officials say that music was one tool through which the Spanish missionaries drew Puebloans to church ceremonies. While my research did not focus on this period, I find it revealing that Spanish mission bells were systematically destroyed during the Puebloan revolt against the Spanish in 1680. Music clearly had a powerful association with ritual in Pueblo cultures; the silencing of the Spanish bells declared the Puebloan rejection of Spanish-imposed religion.

Conclusions

As Ancestral Puebloans first settled into an agricultural way of life, ritual played a role in establishing and maintaining systems of landownership and tenure. During the height of Chaco culture, leaders used religious spectacle complete with musical instruments, which were luxury trade items, to display social power and authority in the first example of a truly hierarchical Southwestern society. When Chacoan society collapsed, community leaders revised their ceremonies, seeking a more inclusive and less ostentatious system. The kachina ceremonies are community oriented, but in some cases they seem to be superimposed over an older socioreligious system (Ware 2002). One clue to the importance of the past role of music in Puebloan ritual is the destruction of Spanish mission bells during the Pueblo revolt against the Spanish.

Future research

The next step in researching precontact instruments from the Southwest is to incorporate the Native American voice. As rich as the ethnographic literature from the area is, much could be learned from people in native communities about aspects of their history and traditions of musical instruments. What would the drum-makers at Cochiti Pueblo say about why archaeologists have not found evidence of drums at precontact sites? Could flute players at Taos elucidate whether game calls are purely utilitarian or have a place in more formal musical forms? What insights would people at Hopi provide about clay bells made in imitation of those from copper? Such research will add a tremendous richness and depth to our understanding of the human cultures behind the objects.

Many of the objects most important to this research came from National Park Service collections, which is no coincidence. Sites become part of the National Park System because of their historical and natural significance and integrity; no research on Southwestern prehistory would be complete without data from these sites. Research in collections has the potential to inform park resource management and contribute to various academic disciplines. It also has the potential to greatly enrich regional interpretive programs because people today recognize and relate to musical instruments. Instruments provide park staff with a way to discuss subjects beyond survival and subsistence, presenting people in the past as creative and artistic and illustrating the continuity between past cultures and the modern Pueblos. In an era when the National Park Service is consolidating collections

Research in collections has the potential to inform park resource management and contribute to various academic disciplines.

and centralizing management, not losing sight of the value of collections to researchers is important. Collections should remain as well cared for and accessible as possible, if for no other reason than the study of musical instruments from archaeological sites is only possible using museum collections.

Acknowledgments

No collections research is possible without the assistance of museum curators; I am grateful for the assistance they provided me at the museums I visited. Canon U.S.A., Inc., has my deep appreciation for the generous funding provided by a Canon National Parks Science Scholars award. Thanks also to Dr. Nan Rothschild of Columbia University for her support of this somewhat unusual project, and to Polly Schaafsma, Charlotte Frisbie, Margaret Berrier, Dennis Gilpin, and Jane Kolber for sharing their own research.

References

Adams, E. C. 1994. The katsina cult: A western Pueblo perspective. Pages 35–46 *in* P. Schaafsma, editor. Kachinas in the Pueblo world. University of New Mexico Press, Albuquerque, New Mexico, USA.

Bird-David, N. 1990. The giving environment: Another perspective on the economic systems of gatherer-hunters. Current Anthropology 31(2):189–196.

Brown, E. J. 2005. Instruments of power: Musical performance in rituals of the Ancestral Puebloans of the American Southwest. Dissertation. Columbia University, New York, New York, USA.

Hammond, G. P., and A. Rey. 1940. Narratives of the Coronado Expedition 1540–1542. Coronado Cuarto Centennial Publications. University of New Mexico Press, Albuquerque, New Mexico, USA.

Lekson, S. H. 1999. The Chaco meridian: Centers of political power in the ancient Southwest. Alta Mira Press, Walnut Creek, California, USA.

Morris, E. A. 1959. Basketmaker flutes from the Prayer Rock District, Arizona. American Antiquity 24(2):406–411.

Olsen, D. A. 1990. The ethnomusicology of archaeology: A model for musical/cultural study of ancient material culture. Selected Reports in Ethnomusicology 8:175–197. University of California, Los Angeles, California, USA.

Potter, J. M. 1998. The structure of open space in Late Prehistoric settlements in the Southwest. Pages 137–163 *in* K. A. Spielman, editor. Migration and reorganization: The Pueblo IV period in the American Southwest. Anthropological Research Papers No. 51. Arizona State University, Tempe, Arizona, USA.

Schaafsma, P. 1994. The prehistoric kachina cult and its origins as suggested by Southwestern rock art. Pages 63–79 *in* P. Schaafsma, editor. Kachinas in the Pueblo world. University of New Mexico Press, Albuquerque, New Mexico, USA.

Vargas, V. D. 1995. Copper bell trade patterns in the prehispanic U.S. Southwest and northwest Mexico. Arizona State Museum Archaeological Series 187. University of Arizona Press, Tucson, Arizona, USA.

Ware, J. A. 2002. What is a kiva? The social organization of early Pueblo communities. Pages 79–88 *in* D. A. Phillips Jr. and J. A. Ware, editors. Culture and the environment in the American Southwest: Essays in honor of Robert C. Euler. SWCA Environmental Consultants, Phoenix, Arizona, USA.

Wilshusen, R. H. 1988. Sipapus, ceremonial vaults, and foot drums (or, a resounding argument for protokivas). Pages 649–671 *in* E. Blinman, C. Phagan, and R. Wilshusen, editors. Supporting studies: Additive and reductive technologies. Dolores Archaeological Program. Bureau of Reclamation, Engineering and Research Center, Denver, Colorado, USA.

About the author

Emily Brown *was a 2001 Canon Scholar from Columbia University in New York. She completed her dissertation, "Instruments of power: Musical performance in rituals of the Ancestral Puebloans of the American Southwest," in 2005. Dr. Brown is currently working as an archaeology consultant through her own business, Aspen CRM Solutions, and can be reached at emily@aspencrmsolutions.com.*

Societal dynamics in grizzly bear conservation:

Vulnerabilities of the ecosystem-based management approach

By Douglas Clark

CONSERVING GRIZZLY BEAR POPULATIONS is a significant challenge for wildlife managers throughout North America. Much fruitful research has been conducted on the biology of grizzlies, but how to craft policies that will suffice to conserve grizzlies at biologically meaningful spatial scales remains poorly understood. This task, which demands interjurisdictional cooperation in complex and varied social contexts (e.g., Herrero 1994; Herrero et al. 2001; Mattson et al. 1996), can create conflicts between management agencies and local residents that can jeopardize ecosystem management and planning programs—programs that often feature grizzlies as key components (Clark and Slocombe 2005; Primm and Murray 2005). Broadly, the goal of this study was to understand how and why such conflicts occur. I used qualitative data analysis and case study methods (Miles and Huberman 1994; Yin 2003) and the policy sciences' interdisciplinary problem analysis framework (Clark 2002) to analyze and compare four case studies of grizzly bear management in Canada (fig. 1, next page):

1. Foothills Model Forest (FMF), Alberta (including Jasper National Park)
2. Southwestern Yukon Territory (including Kluane National Park)
3. North slope of the Inuvialuit Settlement Region (ISR), Northwest Territories and Yukon Territory (including Ivvavik National Park)
4. Baker Lake, Nunavut (no park nearby)

Using established and culturally appropriate interview methods (Huntington 1998), I conducted 59 interviews with decision makers and stakeholders at these four sites from 2003 to 2005. Working with the Champagne and Aishihik First Nations in the southwestern Yukon, we held a series of focus groups to investigate bear management in detail. Using HyperResearch software (http://www.researchware.com), I transcribed and coded all recorded material for analysis. My interpretation of results was enriched by 12 years of experience working for Parks Canada, including two years of involvement with grizzly bear management in Kluane National Park. The views and conclusions expressed are my own and do not necessarily reflect the perspectives of the U.S. National Park Service, Parks Canada, or any other organization mentioned.

Results

The prevailing conservation paradigm for grizzlies is a coordinated regional ecosystem-scale approach to preserving habitat in large wilderness areas and limiting bear mortality (Herrero 1994; Paquet and Hackman 1995; Keiter and Locke 1996; Herrero 2005; Merrill 2005), which managers implemented in the Foothills Model Forest and Kluane National Park. Originating in the Greater Yellowstone Ecosystem (GYE) (Craighead 1977), this strategy appears vulnerable to profound failure when applied elsewhere, especially in the different social contexts I examined. Although the recovery of grizzlies in the Greater Yellowstone Ecosystem is considered a biological success story (Schwartz et al. 2006), some observers are seeing signs of emergent vulnerabilities from social causes there too (see, e.g., Primm and Murray 2005). In the FMF case, an ambitious, well-funded, and collaborative regional conservation program was unable to implement any of its research findings. The provincial government prematurely terminated the program in 2003 following a string of "bad news" findings and events. In the Yukon, recent settlement of Aboriginal land claims has created comanagement regimes for wildlife and national parks. There, comanagement partners, who had no faith in the park's extensive ecological research on grizzlies and felt that an inaccurate and inappropriate "solution" was being forced on them, effectively canceled an interjurisdictional conservation planning process for grizzly bears in the Kluane region in 2001.

Small-scale, community-based initiatives are often promoted as an alternative to such a traditional "top-down" approach to wildlife conservation (e.g., Adams and Hulme 2001; Berkes 2004), *Much fruitful research has been conducted on the biology of grizzlies, but how to craft policies that will suffice to conserve grizzlies at biologically meaningful spatial scales remains poorly understood.*

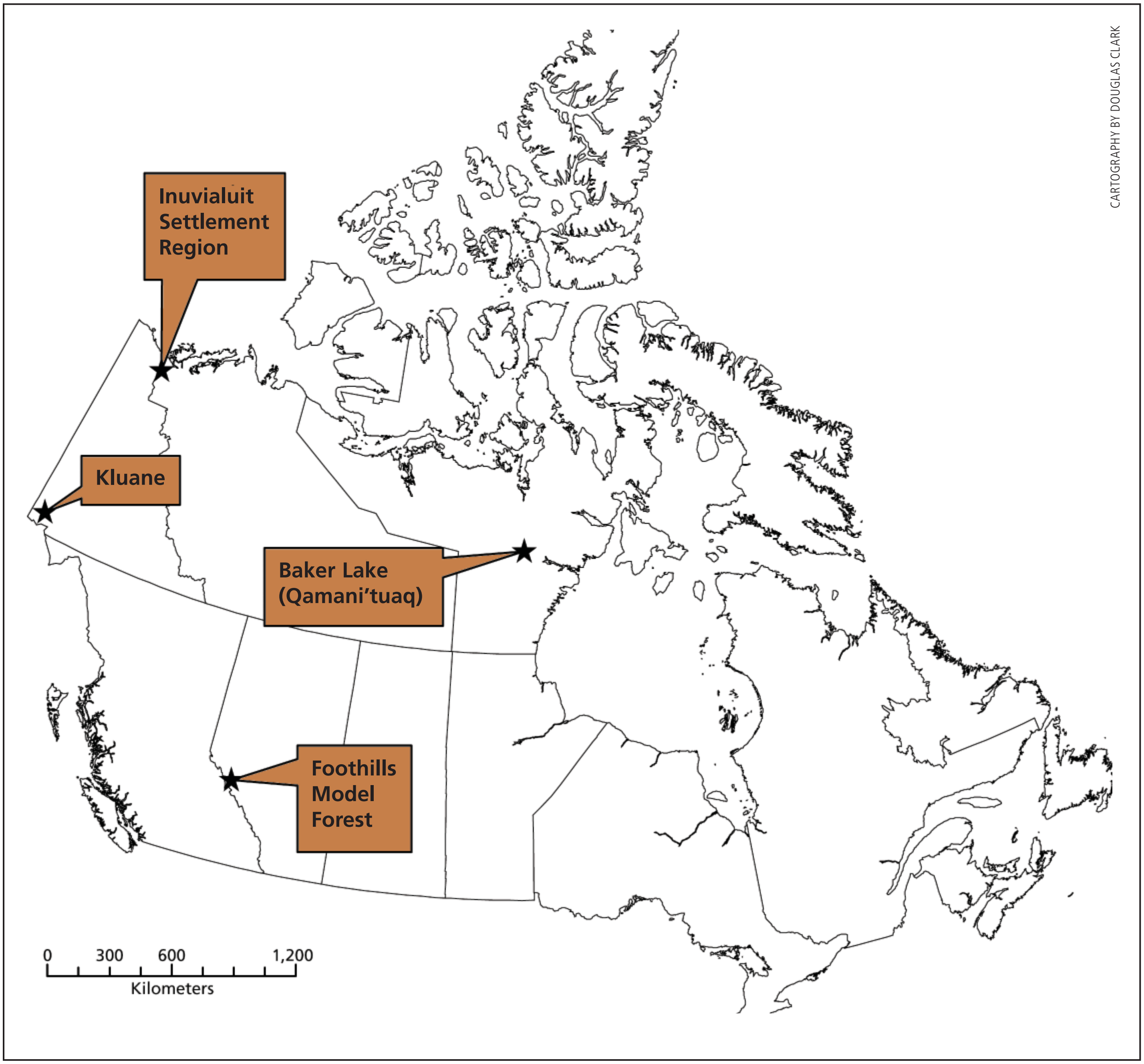


Figure 1. In order to understand conflicts that occur between management agencies and residents, this study analyzed and compared four case studies of grizzly bear management in Canada. The case study areas were (1) Foothills Model Forest, which includes Jasper National Park (Alberta); (2) southwestern Yukon Territory, which includes Kluane National Park; (3) the north slope of the Inuvialuit Settlement Region, which includes Ivvavik National Park (Northwest Territories and Yukon Territory); and (4) Baker Lake (Nunavut).

but these types of initiatives face many challenges and offer no guarantee of immediate success (Berkes 2007). For remote communities in particular, "horizontal" and "vertical" connections among institutions (Young 2002) are difficult to establish, yet are important for facilitating learning and integration of information. In Baker Lake, an abrupt increase in grizzly bear–human conflicts prompted the community's Hunters and Trappers Organization to begin a study of their traditional ecological knowledge of grizzlies (see e.g., Berkes 1999). In this way they could retain local control over responses to these conflicts, an undertaking they found challenging to complete. The Baker Lake example shows that without cross-scale connections, traditional ecological knowledge may not be effectively integrated into decision processes. In the Inuvialuit Settlement Region—where bear-human conflicts had also abruptly increased—comanagers successfully incorporated both science and traditional knowledge to reach a mutually satisfactory decision on harvest levels for grizzly bears. This outcome likely resulted largely because of their strong, cross-scale institutional network. The leadership provided by widely trusted individual champions (e.g., a biologist who had worked in the ISR since the 1970s) was also an important determinant of case study outcomes.

What do these findings mean for parks?

National parks have long had a prominent role in grizzly bear research and management in both the United States and Canada. Parks are often foci of conservation concern and grizzly bear research efforts, and as such have played an important role in their conservation. While parks have clearly functioned as refuges for grizzly populations in some areas of the lower 48 states (Mattson and Merrill 2002) and are likely to perform the same function in southern Canada given current land-use trends (Nielsen et al. 2006), the results of this study call into question aspects of the national-park approach to bear management.

At its most extreme the conventional narrative of grizzly conservation assumes all parks are protected core habitats for grizzlies, despite the fact that most western Canadian national parks inhabited by grizzlies contain little productive bear habitat and are mainly rock and ice (Banci 1991). Even in milder interpretations, though, this narrative casts national parks as privileged geographic entities (Zimmerer 2000; Hermer 2002). Park staff can unconsciously adopt this mindset and by so doing create considerable resentment among their neighbors. Outcomes in Kluane, where citizens demanded that the park withdraw from the regional grizzly conservation planning process, demonstrate the kind of negative effects such resentment can generate.

Quite a different approach was apparent in the FMF case, where Jasper National Park, a partner in the Regional Carnivore Management Group, heavily funded the model forest's bear research and invested considerable staff time and effort in negotiating a federal-provincial strategic framework for cooperation in grizzly conservation, a document unique in Canada. With the exception of the research, these programs have been terminated and the park's interests in regional grizzly bear conservation have been poorly served. Interestingly, Jasper's substantial regional grizzly conservation efforts were also quite distinct from its own internal bear management program. Operated by different staff, internal program units tended to function independently of one another. Greater integration of internal park operations and regional outreach initiatives would probably be beneficial.

Despite these discouraging outcomes, most Albertans appear to want Parks Canada to remain the primary participant in grizzly bear management (Stumpf-Allen et al. 2004). However, no mechanism exists to translate such public support into policy. Stumpf-Allen et al. (2004) conclude that "public involvement in grizzly bear management in the [Foothills Model Forest] should include processes that foster discussion and deliberation of values and preferences and that result in the public having a meaningful impact on decision-making." These results suggest the public would support Jasper National Park in taking a more aggressive favorable stance toward grizzly bear conservation efforts. Such a stance could include championing the development of some form of regional public involvement process.

In general, the most productive course probably lies somewhere between these observed extremes of pursuing park conservation goals without broader regional support and forming overly optimistic partnerships with institutions having very different goals and whose advantages are embedded in the very design of the collaborative processes. Nevertheless, constructive change is possible, even in seemingly intractable situations. For example, just as my data collection was ending in 2005, Parks Canada hired a new trainee superintendent from the Champagne and Aishihik First Nations and paired him with an experienced senior superintendent for a two-year training period. Under this new leadership, Kluane National Park has made significant advances in breaking down barriers and rebuilding institutional relationships. Tensions in the region's wildlife management system have eased enough that by late 2007 a careful dialogue about grizzly conservation had resumed.

References

Adams, W. A., and D. Hulme. 2001. Community conservation: From concept to practice. Pages 24–37 *in* D. Hulme and M. Murphree, editors. African wildlife and livelihoods: The promise and performance of community conservation. James Currey, Oxford, England, UK.

Banci, V. 1991. The status of the grizzly bear in Canada in 1990. COSEWIC, Ottawa, Ontario, Canada.

Berkes, F. 1999. Sacred ecology: Traditional ecological knowledge and resource management. Cambridge University Press, Cambridge, England, UK.

Berkes, F. 2004. Rethinking community-based conservation. Conservation Biology 18:621–630.

Berkes, F. 2007. Community-based conservation in a globalized world. Proceedings of the National Academy of Sciences 104(39):15,188–15,193.

Clark, D., and D. S. Slocombe. 2005. Re-negotiating science in protected areas: Grizzly bear conservation in the southwest Yukon. Pages 33–53 *in* G. Humphrys and M. Williams, editors. Presenting and representing environments. Springer, Dordrecht, the Netherlands.

Clark, T. W. 2002. The policy process: A practical guide for natural resource professionals. Yale University Press, New Haven, Connecticut, USA.

Craighead, J. J. 1977. A proposed delineation of critical grizzly bear habitat in the Yellowstone region: A monograph presented at the Fourth International Conference on Bear Research and Management held at Kalispell, Montana, USA, February 1977. Monograph Series 1. International Association for Bear Research and Management, Knoxville, Tennessee, USA.

Hermer, J. 2002. Regulating Eden: The nature of order in North American parks. University of Toronto Press, Toronto, Ontario, Canada.

Herrero, S. 1994. The Canadian national parks and grizzly bear ecosystems: The need for interagency management. International Conference on Bear Research and Management 9:7–21.

Herrero, S., J. Roulet, and M. Gibeau. 2001. Banff National Park: Science and policy in grizzly bear management. Ursus 12:161–168.

Huntington, H. 1998. Observations on the utility of the semidirective interview for documenting traditional ecological knowledge. Arctic 51(3):237–242.

Keiter, R. B., and H. Locke. 1996. Law and large carnivore conservation in the Rocky Mountains of the U.S. and Canada. Conservation Biology 10:1003–1012.

Mattson, D. J., S. Herrero, R. G. Wright, and C. M. Pease. 1996. 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.

Merrill, T. 2005. Grizzly bear conservation in the Yellowstone to Yukon region. Technical Report 6. Yellowstone to Yukon, Canmore, Alberta, Canada.

Miles, M. B., and A. M. Huberman. 1994. Qualitative data analysis: An expanded sourcebook. Second edition. Sage Publications, Thousand Oaks, California, USA.

Nielsen, S. E., G. B. Stenhouse, and M. S. Boyce. 2006. A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation 130(2):217–229.

Paquet, P., and A. Hackman. 1995. Large carnivore conservation in the Rocky Mountains. World Wildlife Fund Canada, Toronto, Ontario, Canada.

Primm, S., and K. Murray. 2005. Grizzly bear recovery: Living with success? Pages 99–137 *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.

Schwartz, C. C., M. A. Haroldson, G. C. White, R. B. Harris, S. Cherry, K. A. Keating, D. Moody, and C. Servheen. 2006. Temporal, spatial, and environmental influences on the demographics of grizzly bears in the Greater Yellowstone Ecosystem. Wildlife Monographs 161:1–68.

Stumpf-Allen, R. C. G., B. L. McFarlane, and D. O. Watson. 2004. Managing for grizzly bears in the Foothills Model Forest: A survey of local and Edmonton residents. Foothills Model Forest, Hinton, Alberta, Canada.

Yin, R. K. 2003. Case study research: Design and methods. Third edition. Sage Publications, Thousand Oaks, California, USA.

Young, O. 2002. The institutional dimensions of environmental change: Fit, interplay, and scale. MIT Press, Cambridge, Massachusetts, USA.

Zimmerer, K. S. 2000. The reworking of conservation geographies: Nonequilibrium landscapes and nature-society hybrids. Annals of the Association of American Geographers 90:356–369.

About the author

Douglas Clark *was a 2004 Canon Scholar from Wilfrid Laurier University in Ontario, Canada. He completed his dissertation, "Local and regional-scale societal dynamics in grizzly bear conservation," in 2007. Dr. Clark is a postdoctoral fellow in the Department of Renewable Resources, University of Alberta, Edmonton; a research affiliate with the Yale School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut; and the scholar-in-residence, Yukon College, Whitehorse, Yukon Territory. He can be reached at daclark@ualberta.ca.*

Technology Innovation

M. HEBBLEWHITE

L. NEUFELD

M. DIDKOWSKI

Linking wildlife populations with ecosystem change:

State-of-the-art satellite ecology for national park science

By Mark Hebblewhite

AS HUMAN IMPACTS INCREASE IN NATIONAL PARKS and the greater ecosystems surrounding them, the National Park Service faces the difficulty of monitoring ecosystem changes and responses of key wildlife indicator species within parks. Responses of bison to trail grooming in Yellowstone National Park (Wyoming, Montana , and Idaho) and control of the animals once they leave the park (Bruggeman et al. 2007), migration of wildlife across park boundaries (Griffith et al. 2002; Berger 2004), effects of restored wolves on vegetation communities through trophic cascades (Hebblewhite et al. 2005), and responses of wildlife to the use of prescribed fires all represent problems in understanding how the greater park ecosystem and wildlife populations change over time (Fagre et al. 2003). When you also consider ecosystem responses to climate change, the tasks facing national park scientists in the 21st century seem daunting.

Figure 1 (above). GPS collars (a) provide information that helps park managers determine wildlife-human relationships. GPS collars allow researchers to quantify and correct for habitat-induced GPS bias in a way never possible with VHF data (Hebblewhite et al. 2007). GPS collar studies of carnivores such as (b) wolves provide information on predator-prey relationships, wolf avoidance of human activity, and highway mitigation data (Hebblewhite and Merrill 2008). GPS-collared herbivores such as (c) elk allow park managers to understand links to climate drivers such as phenological changes, predator-prey dynamics, and human interactions (Hebblewhite et al. 2008).

New scientific tools based on satellite technology can provide some of the technical data needed to solve [park resource management] problems.

Remote sensing applications to national parks

Fortunately, new scientific tools based on satellite technology can provide some of the technical data needed to solve these problems. Satellite-based remote sensing of ecosystem dynamics is one of the fastest growing fields in global change research and should become a cornerstone of national park science in the 21st century (Turner et al. 2006). For instance, Pettorelli et al. (2005) provide a recent review of remote sensing tools for ecology that is relevant for park management. Remote sensing will not replace field data collection, but it offers several advantages, including easy implementation of consistent, large-scale, and quantifiable tools to monitor large-scale and long-term changes in park ecosystems (Kerr and Ostrovsky 2003; Zhao et al. 2005). Investigators have used remote sensing in large-scale vegetation–land cover mapping initiatives across park boundaries (Welch et al.1999; Franklin et al. 2005), change detection analysis of century-long trends in vegetation dynamics (Rhemtulla et al. 2002; Stephenson et al. 2006), fire severity mapping (Key and Benson 2003), shrub encroachment (Press et al. 1998), climate change detection (Running et al. 2004; Mildrexler et al. 2007), and glacial recession (Fagre et al. 2003).

But the real advances in understanding the consequences of ecosystem change for wildlife populations are just being realized. Recent studies confirm the importance of changes in remotely sensed measures of primary productivity, vegetation biomass, phytomass blooms in the ocean, snow cover dynamics, and climate to wildlife population dynamics (Huete et al. 2002; Pettorelli et al. 2005; Hebblewhite et al. 2008). The original Landsat satellite provided some of these products for scientists, but improved remote sensing platforms are slowly phasing out and replacing it. For example, the Moderate-resolution Imaging Spectroradiometer (MODIS) satellite circles the globe daily and provides composite images of primary productivity up to every eight days at 250-meter scale resolution (Huete et al. 2002). The main measure of primary productivity, the Normalized Difference Vegetation Index (NDVI), is especially relevant for terrestrial wildlife, although MODIS provides researchers with other useful indexes for measuring ecosystem change (Pettorelli et al. 2005). The NDVI records the reflectance of green plant biomass, including trees, shrubs, forbs, and graminoids, which will allow park scientists to understand the availability of important plant resources for wildlife. Recent technology includes higher-resolution Quickbird satellite imagery at 5-meter resolution for classifying vegetation communities and the astonishingly high resolution 1-meter hyperspectral sensor borne on helicopters, which scientists in Yellowstone National Park have already used (Mirik et al. 2005). Regardless of the new remote sensing tools, the next step will be to link bottom-up measures of primary productivity with wildlife populations. This link is now made easier through another set of technological advances made possible by satellites.

Harnessing knowledge of movement with GPS collar technology

Satellite technology has also brought about the Global Positioning System (GPS) collars that are revolutionizing the field of wildlife research (fig. 1). By locating the collars deployed on wildlife through the GPS system of satellites and either storing the locations onboard or transmitting them back to park scientists, biologists are now poised to understand how animals move in response to their environment. GPS collars are usually deployed for shorter time periods than VHF collars, and many systems have remote data collection technology to allow uploads without disturbing the animal from the ground, air, or satellites. Once the collar has run out of battery power, remote release or timer delay devices allow recovery of the collar without necessitating recapture (although as with any new technology, remote release devices sometimes fail). Remote collar release may also help assuage concerns regarding collaring wildlife in national parks—GPS collars are worn only for short time periods, ensuring collars are not deployed after their utility. Regardless, park managers will surely have to weigh the benefits of GPS collar technology with social perceptions of collars, though for some management questions, there really is no substitute for the data harnessed by this technology. In addition, GPS collars themselves permit researchers to quantify biases in location data for the first time (e.g., Hebblewhite et al. 2007), such as reduced location success under dense cover, improving wildlife habitat modeling for park management.

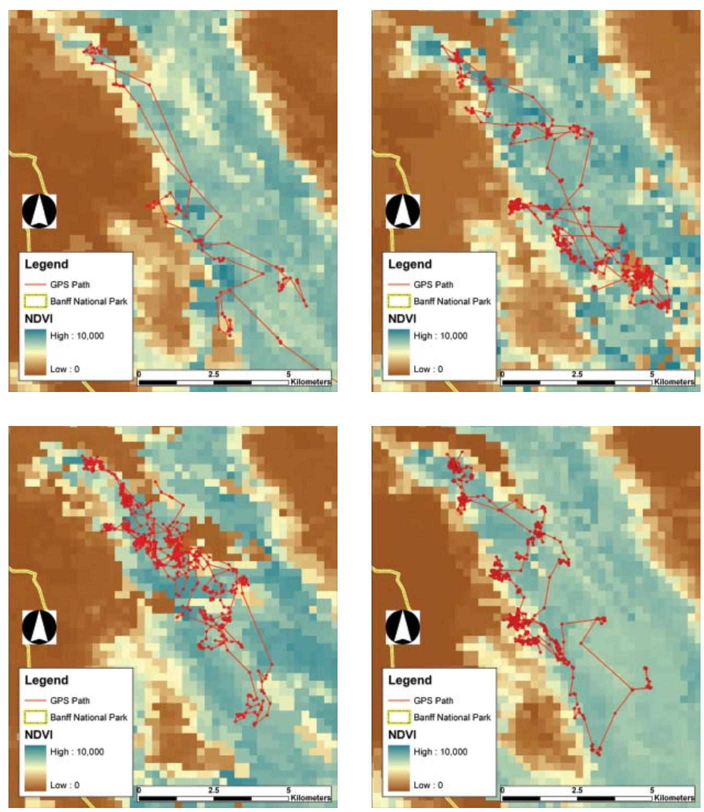
The real power of GPS collars lies in collection of consistent, fine-scale locations for wildlife ranging in size from elephants to migratory birds (e.g., Weimerskirch et al. 2007); such data collection has already changed how scientists think of park ecosystems.

The movements of a single GPS-collared wolverine as it roamed the entire Greater Yellowstone Ecosystem over a period of months (Inman et al. 2004), and the movements of GPS-collared caribou in the Arctic National Wildlife Refuge (Alaska), confirm key links across park and national boundaries, aiding in conservation (Griffith et al. 2002). The amazing 450-kilometer (280-mi) round-trip migrations of pronghorn in Grand Teton National Park (Wyoming) show that energy development hundreds of kilometers away could influence park wildlife (Berger 2004). In marine systems, GPS collars have tracked migratory albatrosses and sea turtles from marine protected areas throughout entire oceans (James et al. 2005; Weimerskirch et al. 2007). Joint collection of GPS data on predators and their prey is also improving our understanding of predator-prey dynamics and food webs in park ecosystems (Fortin et al. 2005; Forester et al. 2007). GPS locations are especially useful for addressing human-wildlife conflicts in national parks. For example, wolves' avoidance of human activity in daylight in Banff National Park (Alberta, Canada) (Preisler et al. 2006; Hebblewhite and Merrill 2008) was revealed only by GPS collar data. Such fine-scale avoidance of humans may have important implications for wolf-caused trophic cascades (Hebblewhite et al. 2005).

Linking wildlife and ecosystem responses

Significant advances in understanding wildlife responses to ecosystem changes will come from linking data provided by satellite technology with measurement made with GPS collars. For example, in Banff National Park, I developed a linked model of elk migration and vegetation dynamics using GPS-collared migratory elk and remotely sensed, MODIS-derived NDVI data. By working with remote sensing experts at the University of Calgary, our team developed statistical models relating elk migration to changes in biomass and to the quality of subalpine and alpine plant species (Hebblewhite et al. 2008) (fig. 2). These models confirmed that ungulate migration followed the "green" wave of newly emerging forage biomass driven by snowmelt patterns. This helped park managers understand the factors driving declines of migratory elk in this complex, transboundary migratory system (Hebblewhite et al. 2006). However, these kinds of linked wildlife-vegetation systems will also enable park managers to address future impacts of climate change on wildlife in a mechanistic way, improving on simple bioclimatic niche modeling approaches that often simply predict that wildlife will march north as it gets warmer (Post et al. 2009). Because recent studies confirm the critical importance of the spring green-up measured by NDVI to ungulate population dynamics (Pettorelli et al. 2007), understanding changes in the start or duration of the growing season will help clarify probable impacts of climate change on wildlife. Remote sensing provides the platform to collect long-term data to address such changes in key spring phenological parameters. By combining MODIS, Landsat, and earlier sensors, large parts of the world already have 20-year or longer time series of remote sensing data to address these critical questions (Running et al. 2004; Zhao et al. 2005). Furthermore, recent advances that link large-scale climatic indexes such as the North Atlantic Oscillation, Arctic Oscillation, and the El Niño Southern Oscillation with terrestrial primary productivity (Zhang et al. 2007) will help park scientists link wildlife populations to global changes (Hebblewhite 2005; Post et al. 2009).

By combining advances in remote sensing from satellites with satellite-based GPS collar technology, national park scientists will be well poised to understand complex ecosystem-wildlife interactions and apply science-based management in the 21st century.



COURTESY OF MARK HEBBLEWHITE

Figure 2 (clockwise from top left). A Global Positioning System tracks movements of a collared female elk following mountain snowmelt patterns in the Canadian Rocky Mountains. Data show movements following green-up of forage as indexed by the Normalized Difference Vegetation Index (NDVI) from the MODIS satellite in 16-day periods from 24 May to 27 July 2004.

The real power of GPS collars lies in collection of consistent, fine-scale locations for wildlife ranging in size from elephants to migratory birds . . .; such data collection has already changed how scientists think of park ecosystems.

Acknowledgments

I would like to sincerely thank the Canon National Parks Science Scholars Program for support during my dissertation research. Parks Canada, Alberta Sustainable Resource Development, Alberta Conservation Association, Rocky Mountain Elk Foundation, Mountain Equipment Co-op, Foundation for North American Wild Sheep, Sunpine, Weyerhaeuser Ltd., Alberta Cooperative Conservation Research Unit, National Science and Engineering Research Council (NSERC), and the National Science Foundation also provided key funding. I would also like to thank the numerous research assistants and technicians who helped with this study and the wolves and elk that wore the GPS collars.

References

Berger, J. 2004. The last mile: How to sustain long-distance migration in mammals. Conservation Biology 18:320–331.

Bruggeman, J. E., R. A. Garrott, P. J. White, F. G. R. Watson, and R. Wallen. 2007. Covariates affecting spatial variability in bison travel behavior in Yellowstone National Park. Ecological Applications,17:1411–1423.

Fagre, D. B., D. L. Peterson, and A. E. Hessl. 2003. Taking the pulse of mountains: Ecosystem responses to climatic variability. Climatic Change 59:263–282.

Forester, J. D., A. R. Ives, M. G. Turner, D. P. Anderson, D. Fortin, H. L. Beyer, D. W. Smith, and M. S. Boyce. 2007. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecological Monographs 77:285–299.

Fortin, D., H. Beyer, M. S. Boyce, D. W. Smith, T. Duchesne, and J. S. Mao. 2005. Wolves influence elk movements: Behaviour shapes a trophic cascade in Yellowstone National Park. Ecology 86:1320–1330.

Franklin, S. E., P. K. Montgomery, and G. B. Stenhouse. 2005. Interpretation of land cover changes using aerial photography and satellite imagery in the Foothills Model Forest of Alberta. Canadian Journal of Remote Sensing 31:304–313.

Griffith, B., D. C. Douglas, N. E. Walsh, D. D. Young, T. R. McCabe, D. E. Russell, R. G. White, R. D. Cameron, and R. Whitten. 2002. The Porcupine caribou herd. Pages 8–37 *in* D. C. Douglas, P. E. Reynolds, and E. B. Rhode, editors. Arctic Refuge coastal plain terrestrial wildlife research summaries. Biological Science Report USGS/BRD/BSR-2002-0001. U.S. Geological Survey, Washington, D.C., USA.

Hebblewhite, M. 2005. Predation interacts with the North Pacific Oscillation (NPO) to influence western North American elk population dynamics. Journal of Animal Ecology 74:226–233.

Hebblewhite, M., and E. H. Merrill. 2008. Modelling wildlife-human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology 45:834–844.

Hebblewhite, M., E. H. Merrill, and G. McDermid. 2008. A multi-scale test of the forage maturation hypothesis for a partially migratory montane elk population. Ecological Monographs 78:141–166.

Hebblewhite, M., E. H. Merrill, L. E. Morgantini, C. A. White, J. R. Allen, E. Bruns, L. Thurston, and T. E. Hurd. 2006. Is the migratory behaviour of montane elk herds in peril? The case of Alberta's Ya Ha Tinda elk herd. Wildlife Society Bulletin 34:1280–1295.

Hebblewhite, M., M. Percy, and E. H. Merrill. 2007. Are all GPS collars created equal? Correcting habitat-induced bias using three brands in the central Canadian Rockies. Journal of Wildlife Management 71:2026–2033.

Hebblewhite, M., C. A. White, C. Nietvelt, J. M. McKenzie, T. E. Hurd, J. M. Fryxell, S. Bayley, and P. C. Paquet. 2005. Human activity mediates a trophic cascade caused by wolves. Ecology 86:2135–2144.

Huete, A., K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment 83:195–213.

Inman, R. M., R. R. Wigglesworth, K. H. Inman, M. K. Schwartz, B. L. Brock, and J. D. Rieck. 2004. Wolverine makes extensive movements in the Greater Yellowstone Ecosystem 78:261–266.

James, M. C., R. A. Myers, and C. A. Ottensmeyer. 2005. Behaviour of leatherback sea turtles, *Dermochelys coriacea*, during the migratory cycle. Proceedings B (Biological Sciences) of the Royal Society 272:1547–1555.

Kerr, J. T., and M. Ostrovsky. 2003. From space to species: Ecological applications for remote sensing. Trends in Ecology and Evolution 18:299–305.

Key, C. H., and N. C. Benson. 2003. Remote sensing measures of fire severity: The normalized burn ratio. General Technical Report. U.S. Geological Survey, Rocky Mountain Research Station, Glacier, Montana, USA.

Mildrexler, D. J., M. S. Zhao, F. A. Heinsch, and S. W. Running. 2007. A new satellite-based methodology for continental-scale disturbance detection. Ecological Applications 17:235–250.

Mirik, M., J. E. Norland, R. L. Crabtree, and M. E. Biondini. 2005. Hyperspectral one-meter-resolution remote sensing in Yellowstone National Park, Wyoming: 1. Forage nutritional values. Rangeland Ecology and Management 58:452–458.

Pettorelli, N., F. Pelletier, A. von Hardenberg, M. Festa-Biachet, and S. D. Cote. 2007. Early onset of vegetation growth vs. rapid green-up: Impacts on juvenile mountain ungulates. Ecology 88:381–390.

Pettorelli, N., J. O. Vik, A. Mysterud, J. M. Gaillard, C. J. Tucker, and N. C. Stenseth. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20:503–510.

Post, E. S., J. Brodie, M. Hebblewhite, A. Anders, J. K. Maier, and C. C. Wilmers. 2009. Global population dynamics and hot spots of response to climate change. Bioscience 59:489–499.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2006. Statistical methods for analysing responses of wildlife to human disturbance. Journal of Applied Ecology 43:164–172.

Press, M. C., J. A. Potter, M. J. W. Burke, T. V. Callaghan, and J. A. Lee. 1998. Responses of a subarctic dwarf shrub heath community to simulated environmental change. Journal of Ecology 86:315–327.

Rhemtulla, J. M., R. J. Hall, E. S. Higgs, and S. E. Macdonald. 2002. Eight years of change: Vegetation in the montane ecoregion of Jasper National Park, Alberta, Canada. Canadian Journal of Forest Research 32:2010–2021.

Running, S. W., R. R. Nemani, F. A. Heinsch, M. S. Zhao, M. Reeves, and H. Hashimoto. 2004. A continuous satellite-derived measure of global terrestrial primary production. Bioscience 54:547–560.

Stephenson, T. R., V. Van Ballenberghe, J. M. Peek, and J. G. MacCracken. 2006. Spatio-temporal constraints on moose habitat and carrying capacity in coastal Alaska: Vegetation succession and climate. Rangeland Ecology and Management 59:359–372.

Turner, D. P., W. D. Ritts, W. B. Cohen, S. T. Gower, S. W. Running, M. S. Zhao, M. H. Costa, A. A. Kirschbaum, J. M. Ham, S. R. Saleska, and D. E. Ahl. 2006. Evaluation of MODIS NPP and BPP products across multiple biomes. Remote Sensing of Environment 102:282–292.

Weimerskirch, H., D. Pinaud, F. Pawlowski, and C. A. Bost. 2007. Does prey capture induce area-restricted search? A fine-scale study using GPS in a marine predator, the wandering albatross. American Naturalist 170:734–743.

Welch, R., M. Madden, and R. F. Doren. 1999. Mapping the Everglades. Photogrammetric Engineering and Remote Sensing 65:163–170.

Zhang, K., J. S. Kimball, K. C. McDonald, J. J. Cassano, and S. W. Running. 2007. Impacts of large-scale oscillations on pan-Arctic terrestrial net primary productivity. Geophysical Research Letters 34:1–5.

Zhao, M. S., F. A. Heinsch, R. R. Nemani, and S. W. Running. 2005. Improvements of the MODIS terrestrial gross and net primary production global data set. Remote Sensing of Environment 95:164–176.

About the author

***Mark Hebblewhite** was a 2002 Canon Scholar from the University of Alberta in Canada. He completed his dissertation, "Linking predation risk and forage to ungulate population dynamics," in 2006. Since then Dr. Hebblewhite has held the position of assistant professor and ungulate habitat ecologist in the Wildlife Biology Program at the University of Montana in Missoula, Montana, and can be reached at mark.hebblewhite@umontana.edu. Dr. Hebblewhite's current research includes endangered woodland caribou in the Canadian Rocky Mountains parks (Alberta and British Columbia), endangered Sierra Nevada bighorn sheep, Amur tigers and leopards in the Russian Far East, and developing approaches for understanding wildlife–climate change dynamics.*

PS

Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park

Using passive acoustic technology, researchers record the movements of whales, assess the impacts of noise from boat tours, and help refine tourism management

By Renata S. Sousa-Lima and Christopher W. Clark

COURTESY OF RENATA SOUSA-LIMA

Figure 1. A humpback whale (*Megaptera novaeangliae*) exposes its tail or fluke, a common occurrence while singing, in Abrolhos Marine National Park. Scientists use the unique black-and-white markings of the underside of the fluke to identify individuals. Brazilian Navy facilities are visible on Santa Bárbara Island in the background.

Editor's Note: You can hear whale song recordings and see a brief video clip showing the movements of two whales before, during, and after exposure to tourism boat noise, both products of this study, on the *Park Science* Web site (http://www.nature.nps.gov/ParkScience/index.cfm?ArticleID=270).

MALE HUMPBACK WHALES (*MEGAPTERA NOVAEANGLIAE*) (fig. 1) produce "songs"—long, patterned sequences of sounds—that are presumed to function as a reproductive display on the breeding grounds (Payne and McVay 1971; Winn and Winn 1978; Tyack 1981). Many preferred breeding areas are conservation hot spots protected by marine parks, and the whale-watching industry has flourished in those sites (Hoyt 2001). Noise generated from whale-watching boat traffic can mask important aspects of whale communication. This raises concerns about the potential influence of noise on reproductive success and population growth. Gray whales may temporarily or permanently abandon critical areas because of excessive exposure to boat noise (Bryant et al. 1984). Therefore, managers in parks created to protect and conserve whales are often faced with the task of managing noise-generating tourism activities, especially in breeding areas.

Because whales are acoustic specialists (Richardson et al. 1995), investigations can rely on listening to understand their social system. Recent advances in passive acoustic technology allow researchers to follow the movements of whales by locating and tracking vocalizing individuals. By continuously sampling and simultaneously following multiple whales, investigators can describe the movements of cohorts of individuals. By comparing whale tracks with the tracks and acoustic characteristics of human activities, investigators can measure whale responses to human-caused disturbance, such as an approaching vessel.

In this study, we used passive acoustic technology to evaluate the effects of boat traffic on the spatial-acoustic behavior of vocally active male humpback whales in the Abrolhos Marine National Park, Brazil (fig. 2); this park is situated in the main humpback whale breeding grounds in the southwestern Atlantic Ocean (Engel 1996). Our specific objectives were (1) to determine the types of singer responses to an approaching boat, and (2) to identify the "distance of disturbance"—the distances to which avoidance (i.e., movement away from boat) and behavioral disruption (i.e., cessation of singing) are observed.

Methods

We deployed an array of four "pop-ups" (fig. 3) programmed to record continuously from 5 July to 4 October 2005 inside the area of the Abrolhos Marine National Park in the northeastern part of the Abrolhos Bank (16°40'–19°30'S). The whale sounds were detected and located in the recordings using the software XBAT (http://www.xbat.org) written in MATLAB (the MathWorks computing language and interactive environment). We assigned each located whale sound to a particular individual singer based on (1) the unique repetition pattern of the sounds within the humpback whale song and (2) the location of the sound in relation to other located singers. We consolidated all located sounds from the same singer within 90 seconds into a single median point location and interpolated the sequences of such locations to yield an acoustic track using a custom programming routine (ISRAT_LT 1.3.2, Urazghildiiev unpublished) also written in MATLAB.

We gave Global Positioning System (GPS) units to tourism boats before they visited the park, and generated boat tracks from the GPS locations in ISRAT_LT 1.3.2. We used tracks of whales and boats to measure speed and boat-whale distances. We analyzed the spatiotemporal patterns of the movements of singers and boats to determine the orientation of each singer's movement in relation to a boat's movement. Possible orientations included away, toward, and neutral movement; neutral movement indicated that the boat track was parallel to the whale track after the closest point of approach between whale and boat.

We defined treatment periods (pre-exposure, exposure, and post-exposure) for each singer based on the distances between singer and vessel. Pre-exposure was defined as the period before the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers (2.5 mi). The period considered "exposure" occurred while the distances between whale and boat were less than 4.0 kilometers, which is a documented mean for whale-boat distance shown to have caused bowhead and humpback whales to respond to vessels (Richardson et al. 1985; Baker and Herman 1989). Post-exposure was

Figure 2. Investigators used passive acoustic technology to document and analyze the effects of boat traffic on the spatial-acoustic behavior of vocally active male humpback whales in Abrolhos National Marine Park. The polygons in the inset image define the park area.

COURTESY OF RENATA SOUSA-LIMA

Figure 3. "Pop-ups"—marine autonomous recording units developed by the Bioacoustics Research Program at Cornell University—are ready to be deployed at sea.

defined as the period after the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers.

Results

We analyzed four tracks of a single tourism boat and 11 acoustically tracked singers. Some singers moved away and stopped singing as the boat approached their location (four out of nine or 44.5%); others moved away but kept singing (five out of nine or 55.5%).

The predominant movement of singers relative to the boat's closest point of approach was "away" (77.8%). Six of the nine singers (66.7%) that moved away from the boat initiated movement before 4.0 kilometers (2.5 mi). The proportions of time devoted to movement away from, toward, and neutral to the boat were similar during pre-exposure. However, an increase in the proportion of time moving away occurred during the exposure, which continued to be disproportional during post-exposure (fig. 4). We identified two types of singer responses to the boat: (1) displacement followed by cessation of vocal activity (44.5%) and (2) displacement and continued vocal activity (55.5%). All located singers in the sampled area were displaced as the boat approached, and the ones that quit singing did not resume singing for at least 20 minutes.

Noise generated from whale-watching boat traffic can mask important aspects of whale communication. This raises concerns about the potential influence of noise on reproductive success and population growth.

Discussion

All whales moved from their original positions as the boat approached. Direct observations of singers being approached by boats in Abrolhos show that if they stopped singing, they invariably also left the area. Thus, we interpret cessation of singing as displacement.

Bejder et al. (2006) proposed that the individuals that are most sensitive to boat approaches would abandon preferred areas because of increased boat disturbance. Assuming this is true, only the individuals less sensitive to boat disturbances would remain in the area. The effect this selection for boat noise–habituated males could have on the population structure is unknown; it could affect

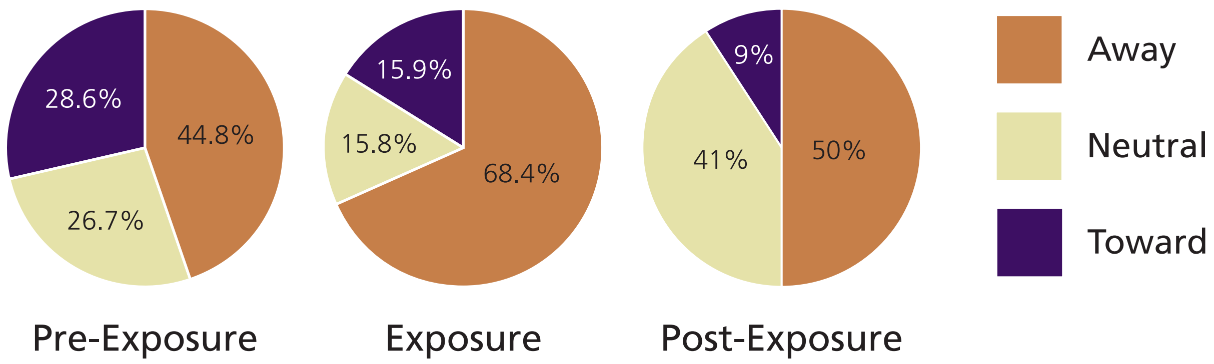


Figure 4. The pie graphs show the proportion of total time that the whales spent moving away from the boat (red), neutral or not moving (beige), or moving toward the boat (purple) during each treatment period. Pre-exposure was defined as the period before the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers (2.5 mi). The period considered "exposure" occurred while the distances between whale and boat were less than 4.0 kilometers. Post-exposure was defined as the period after the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers.

Our results should aid park managers in directing resources to keep noise disturbance at low levels in the park, perhaps through expansion and enforcement of regulatory measures such as the use of quieter engines, speed regulation, and boat quantity limitation.

female choice and consequently the distribution of breeding success among the males of this population. A primary management concern is that whale habituation to boats could increase the probability of fatal encounters with vessels.

The majority of the singers (77.8%) moved away from the boat at the boat's closest point of approach, suggesting avoidance, although the most compelling evidence that singers avoid boats was the direction of their movement. Almost 70% of singer movement was away from the boat when the singer-boat distance was less than 4.0 kilometers (2.5 mi). Vessel-singer distance also affected swimming direction of humpbacks off Hawai'i (Frankel and Clark 1988) and Alaska (Baker and Herman 1989): Whales moved away from approaching vessels. In our study, during the post-exposure period, singers were still moving away from the boat, which suggests a residual avoidance of the disturbance area.

Baker and Herman (1989) have observed boat avoidance orientation in humpback whales out to 8.0 kilometers (5.0 mi). The majority of singers in our study responded by swimming away from the boat at distances greater than 4.0 kilometers (mean distance of approximately 7.5 kilometers [4.7 mi]). Other studies from boats and land-based platforms found that whales were disturbed at closer ranges (<300 meters [984 ft]) (Watkins 1986; Corkeron 1995; Sousa-Lima et al. 2002; Morete 2007). While this could be a reflection of smaller sampling areas or specific close-range analytical designs, it could also be a bias toward less sensitive whales.

We have shown that the use of an acoustic array provides the acoustic equivalent of a bird's-eye view into cetacean behavior and can be a cost-effective monitoring tool to evaluate marine animal responses to human disturbances. Our results should aid park managers in directing resources to keep noise disturbance at low levels in the park, perhaps through expansion and enforcement of regulatory measures such as the use of quieter engines, speed regulation, and boat quantity limitation.

Park managers can use passive acoustic technology in a variety of wildlife management scenarios. This technology will help document and monitor wildlife distributions and responses to human activities, especially in areas of low visibility, difficult access, at night, or underwater. The U.S. National Park Service has begun to use acoustic monitoring of protected areas (e.g., Glacier Bay National Park), and its use as a diagnostic and regulatory tool for park rangers and managers may increase as its benefits become known.

Acknowledgments

We thank Stephen Morreale, Milo Richmond, and John Hermanson for their suggestions; Lucas Goulart Collares, Bruna Mazoni Guerra, and the *Piloto* crew for field assistance; Eric Shannon, Michelle Mathios, Jessica Musa, Caitlin Armstrong, and Roman Lesko for data processing. The Instituto Baleia Jubarte and its sponsor Petroleo Brasileiro S.A. (Petrobras), Abrolhos tourism operators and boat owners, the Brazilian government (CAPES, BEX 1523-01-5), Cornell Laboratory of Ornithology, and the Canon National Parks Science Scholars Program provided funding and support.

References

Baker, C. S., and L. M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. Final Report NPS-NR-TRS-89-01. U.S. Department of the Interior, National Park Service, Anchorage, Alaska, USA.

Bejder, L., A. Samuels, H. Whitehead, N. Gales, J. Mann, R. Connor, M. Heithaus, J. Watson-Capps, C. Flaherty, and M. Krutzen. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conservation Biology 20:1791–1798.

Bryant, P. J., C. M. Lafferty, and S. K. Lafferty. 1984. Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by gray whales. Pages 375–387 *in* M. L. Jones, S. L. Swartz, and S. Leartherwood, editors. The gray whale, *Eschrichtius robustus*. Academic Press, Orlando, Florida, USA.

Corkeron, P. J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: Behavior and responses to whale-watching vessels. Canadian Journal of Zoology 73:1290–1299.

Engel, M. H. 1996. Comportamento reprodutivo da baleia jubarte (*Megaptera novaeangliae*) em Abrolhos. Anais de Etologia 14:275–284.

Frankel, A. S., and C. W. Clark. 1988. Results of low-frequency playback of M-sequence noise to humpback whales, *Megaptera novaeangliae*, in Hawai'i. Canadian Journal of Zoology 76:521–535.

Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth Port, Massachusetts, USA.

Morete, M. E. 2007. Caracterização temporal da estructura de grupos e do comportamento de baleias jubarte (*Megaptera novaeangliae*) na área de reprodução dos Abrolhos (Bahia, Brasil). Dissertation. Instituto de Biociências da Universidade Federal de São Paulo, Brazil.

Payne, R. S., and S. McVay. 1971. Songs of humpback whales. Science 173(3997):585–597.

Richardson, W. J., M. A. Fraker, B. Wursig, and R. S. Wells. 1985. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: Reactions to industrial activities. Biological Conservation 32:195–230.

Sousa-Lima, R. S., M. E. Morete, R. C. Fortes, A. C. Freitas, and M. H. Engel. 2002. Impact of boats on the vocal behavior of humpback whales off Brazil. The Journal of the Acoustical Society of America 112(5):2430–2431.

Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecifics nearby. Behavioral Ecology and Sociobiology 8:105–116.

Watkins, W. A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammal Science 2(4):251–262.

Winn, H. E., and L. K. Winn. 1978. The song of the humpback whale, *Megaptera novaeangliae*, in the West Indies. Marine Biology 47:97–114.

About the authors

Renata S. Sousa-Lima *was a 2003 Canon Scholar from the Department of Natural Resources and Bioacoustics Research Program, Cornell University, and an associate researcher of the Instituto Baleia Jubarte (Humpback Whale Institute), Brazil. She completed her dissertation, "Acoustic ecology of humpback whales (*Megaptera novaeangliae*) in the Abrolhos Marine National Park, Brazil," in 2007. Dr. Sousa-Lima currently is an FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais) postdoctoral fellow at the Universidade Federal de Minas Gerais, Brazil, and can be reached at renata.sousalima@icb.ufmg.br or RSL32@cornell.edu.*

Christopher W. Clark *is the I. P. Johnson Director of the Bioacoustics Research Program, Cornell Laboratory of Ornithology, and a senior scientist of the Department of Neurobiology and Behavior, Cornell University.*

PARKScience
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

We hope you enjoy this issue of *Park Science*

There are four ways to

- **Subscribe**
- **Update your mailing address**
- **Submit manuscripts and letters**

1. Online
www.nature.nps.gov/ParkScience
Click "Subscribe."
Note: If the online edition of *Park Science* will meet your needs, select "e-mail notification."
You will then be alerted by e-mail when a new issue is published online in lieu of receiving a print edition.

2. E-mail
jeff_selleck@nps.gov
Include your unique, subscriber number, name, and address information.

3. Fax
303-987-6704
Use this page and make any necessary changes to your address information.

4. Mail
Send this page along with any updated address information to the editorial office address below.

Use your subscriber number below for easy subscription updates.

PARKScience
Natural Resource Program Center
Office of Education and Outreach
P.O. Box 25287
Denver, CO 80225–0287

FIRST-CLASS MAIL
POSTAGE & FEES PAID
National Park Service
Permit G-83